Connecting Models and Observations

CIRA ANNUAL REPORT FY 2017/2018

(Reporting Period April 1, 2017 – March 31, 2018)

COOPERATIVE INSTITUTE FOR RESEARCH IN THE ATMOSPHERE

DIRECTOR'S MESSAGE

The Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University (CSU) is one of a number of cooperative institutes (CIs) that support NOAA's mission. Although this mission continues to evolve, there continue to be strong reasons for partnering between NOAA and the fundamental research being done in the University environment and the students it entrains into NOAA's mission. Strengthening these ties in satellite remote sensing and regional/global weather prediction, as well as application development, education/training, data assimilation, and data distribution technology make CIRA a valuable asset to NOAA. As the Director of CIRA, I have tried to do everything possible to strengthen CIRA's ties not only among CSU's Department of Atmospheric Science, the College of Engineering, and the University but also the ties among the different groups within CIRA that now covers researchers in Fort Collins and College Park associated with NESDIS, researchers in Boulder working closely with OAR and researchers in Kansas City working with the National Weather Service. With a renewed emphasis on interactions and joint initiatives such as our Data Assimilation intern program, we are focusing on Connecting Models and Observations as the underlying principle that guides us in our daily decisions. With this, we hope to fulfill the promise of being the conduit for developing ground-breaking research to address socially-relevant problems that face NOAA and our society today as well as to help train a new workforce that has a broader perspective needed to continue developing decision support tools guided by scientific advances.

CIRA is fortunate in that its corporate culture and proximity to many of the Nation's top research institutions have allowed it to work with talented researchers and support staff who continue to perform at the highest possible level. There are many important accomplishments that are highlighted in this report and summarized in the executive summary. The new GOES-16 activities are certainly a great source of pride. Not as obvious, but equally important, are the activities that CIRA carries out with the National Park Service and the activities with NASA through the CloudSat data processing facility and OCO and GeoCarb algorithm development and data processing. While not funded by NOAA, these activities are highly synergistic in the areas of algorithm development, modeling and data distribution. They allow CIRA researchers working on exciting new satellite data to have access to other experts with whom they can consult as they develop their own projects. This progress report constitutes the fourth year of reporting under the second 5-year term of the Cooperative Agreement. With it, we again establish our commitment to the maintenance and growth of a strong collaborative relationship with NOAA, other National programs, the Department of Atmospheric Science at CSU, and the University as a whole.

Christian D. Kummerow

COOPERATIVE INSTITUTE FOR RESEARCH IN THE ATMOSPHERE

The Cooperative Institute for Research in the Atmosphere (CIRA) was established in 1980 at Colorado State University (CSU). CIRA serves as a mechanism to promote synergisms between University scientists and those in the National Oceanic and Atmospheric Administration (NOAA). Since its inception, CIRA has expanded and diversified its mission to coordinate with other Federal agencies, including the National Aeronautics and Space Administration (NASA), the National Park Service (NPS), the U.S. Forest Service, and the Department of Defense (DoD). CIRA is a multi-disciplinary research institute within the College of Engineering (CoE) and encompasses several cooperative agreements, as well as a substantial number of individual grants and contracts. The Institute's research for NOAA is concentrated in five theme areas and two cross-cutting research areas:

Satellite Algorithm Development, Training and Education - Research associated with development of satellite-based algorithms for weather forecasting, with emphasis on regional and mesoscale meteorological phenomenon. This work includes applications of basic satellite products such as feature track winds, thermodynamic retrievals, sea surface temperature, etc., in combination with model analyses and forecasts, as well as in situ and other remote sensing observations. Applications can be for current or future satellites. Also under this theme, satellite and related training material will be developed and delivered to a wide variety of users, with emphasis on operational forecasters. A variety of techniques can be used, including distance learning methods, web-based demonstration projects and instructor-led training.

Regional to Global Scale Modeling Systems - Research associated with the improvement of weather/climate models (minutes to months) that simulate and predict changes in the Earth system. Topics include atmospheric and ocean dynamics, radiative forcing, clouds and moist convection, land surface modeling, hydrology, and coupled modeling of the Earth system.

Data Assimilation - Research to develop and improve techniques to assimilate environmental observations, including satellite, terrestrial, oceanic, and biological observations, to produce the best estimate of the environmental state at the time of the observations for use in analysis, modeling, and prediction activities associated with weather/climate predictions (minutes to months) and analysis.

Climate-Weather Processes - Research focusing on using numerical models and environmental data, including satellite observations, to understand processes that are important to creating environmental changes on weather and short-term climate timescales (minutes to months) and the two-way interactions between weather systems and regional climate.

Data Distribution - Research focusing on identifying effective and efficient methods of quickly distributing and displaying very large sets of environmental and model data using data networks, using web map services, data compression algorithms, and other techniques.

Cross-Cutting Area 1: Assessing the Value of NOAA Research via Societal/Economic Impact Studies - Consideration for the direct and indirect impacts of weather and climate on society and infrastructure. Providing metrics for assessing the value of NOAA/CI research and tools for planners and decision makers. Achieving true 'end-to-end' systems through effective communication of information to policy makers and emergency managers.

Cross-Cutting Area 2: Promoting Education and Outreach on Behalf of NOAA and the University - Serving as a hub of environmental science excellence at CSU for networking resources and research activities that align with NOAA mission goals throughout the University and with its industrial partners. Engaging K-12 and the general public locally, regionally, nationally and internationally to promote both awareness and informed views on important topics in environmental science.

Annually, CIRA scientists produce over 200 scientific publications, 30% of which appear in peer-reviewed publications. Among the important research being performed at CIRA is its support of NESDIS' next-generation satellite programs: GOES-R and JPSS. These two multi-billion dollar environmental satellite programs will support weather forecasting and climate monitoring for the next 2-3 decades. They will include vastly improved sensors and will offer higher-frequency data collection. CIRA research is building prototype products and developing training, based on the new sensor technology, to assure maximum exploitation of these data when the sensors are launched.

CIRA EDUCATION, TRAINING AND OUTREACH ACTIVITIES: 2017-2018

From the CIRA Mission Statement: *"Important bridging elements of the CI include the communication of research findings to the international scientific community, transition of applications and capabilities to NOAA operational users, education and training programs for operational user proficiency, outreach programs to K-12 education and the general public for environmental literacy, and understanding and quantifying the societal impacts of NOAA research."*

Summary of CIRA Outreach

CIRA Outreach efforts during 2016 focused on identified needs facing the nation: Improved professional development for standards-based education, addressing community resilience in the face of natural disasters, including wildfires, floods, and droughts, and increasing the visibility of NOAA-generated products in the public eye. Along with these efforts, CIRA continued supporting pre-existing programs and collaborations; leveraging partnerships between CIRA's proven history with new opportunities will continue to define the direction of the E&O program for the next several years.

Teacher Professional Development

CIRA continues its commitment to professional development opportunities for fifth-grade teachers, especially with respect to meeting Next-Generation Science Standards (NGSS) and Colorado Department of Education requirements. As detailed previously, teachers are held to exacting standards and are required to provide students with sophisticated and detailed instruction regarding complex natural phenomena. An example of the standards to which teachers are held, taken from the State of Colorado fifth-grade standard, is provided as Figure 1.

Note the subtle complexity in the standard: Students are expected to master the concept that weather conditions change 'because of the uneven heating of Earth's surface by the Sun's energy.' Included in this concept are the rotation of the Earth and the complex interactions of fluid- and thermodynamics, resulting in weather systems. Students are then expected to demonstrate an understanding of these weather systems as made evident by direct observation of temperature, pressure, wind direction and speed, etc.

The formal preparation for fifth-grade science teachers rarely goes into these kinds of detail in the Earth sciences; teachers are left to fend for themselves in getting up-to-speed in the background needed to teach this element of the standards (and with many of the other intensive standards in which they also lack a formal education). NOAA Cooperative Institutes can offer a formidable resource to meet these needs. In this role, CIRA has developed and implemented a formal fifth-grade weather protocol training course, which has been presented and updated with four different course dates during the year to approximately seven local teachers.

Grade Level Expectation: Fifth Grade	
Concepts and skills students master: 3. Weather conditions change because of the uneven heating of Earth's surface by the Sun's energy. Weather changes are measured by differences in temperature, air pressure, wind and water in the atmosphere and type of precipitation	
Evidence Outcomes	**21st Century Skills and Readiness Competencies**
Students can: a. Develop and communicate an evidence-based scientific explanation for changes in weather conditions (DOK 1-3) b. Gather, analyze, and interpret data such as temperature, air pressure, wind, and humidity in relation to daily weather conditions (DOK 1-3) c. Describe weather conditions based on data collected using a variety of weather tools (DOK 1-2) d. Use data collection tools and measuring devices to gather, organize, and analyze data such as temperature, air pressure, wind, and humidity in relation to daily weather conditions (DOK 1-2)	**Inquiry Questions:** 1. Why does the Sun heat different surfaces at different rates? 2. Why does the weather change from day to day? **Relevance and Application:** 1. The Sun's energy helps change daily weather by influencing the water cycle, air movement, and temperature. 2. Gliders and birds exploit updrafts created by thermals. 3. Deicing airplanes in the winter is sometimes necessary so that they can fly. 4. Weather satellites generate data that measure and monitor changes in weather. **Nature of Science:** 1. Support explanations of weather using evidence. (DOK 2-3) 2. Understand how weather maps are utilized to predict the weather from day to day. (DOK 1-2) 3. Assess and provide feedback on other student's scientific explanations about weather, pushing for reasoning based on evidence and scientific principles. (DOK 2-3)

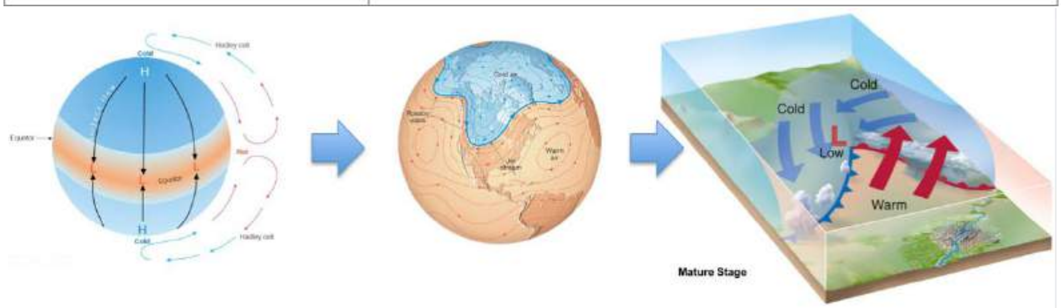


Figure 1. Fifth-grade weather standards and expectations, related through CIRA-developed professional development courses.

Resiliency Workshops

CIRA's new outreach development program is focused on the area of community resiliency, with a special intent to highlight mountain communities throughout the Colorado Rocky Mountains who are at enhanced risk of wildfire and flash flooding events. The new outreach program leverages significant real-time CIRA and NOAA observations, including the use of satellite observations from the Satellite Loop Interactive Data Explorer in Real-Time (SLIDER) tool, and model output from CIRA and NOAA fire-weather focused products. In concert with the Community Collaborative Rain, Hail and Snow (CoCoRaHS) Network and the Earth System Modeling and Education Institute (ESMEI) at CSU, CIRA is developing a summer workshop for teachers from rural mountain communities to learn how to diagnose and prepare for fire and flood weather events, as well as mitigation activities and other community projects to improve community resilience in the face of increasing fire and flood danger throughout the Rocky Mountains. Figure 2 shows a flyer for the course being offered this summer as a result of activities undertaken during the 2016-2017 year.

Figure 2. Course flyer for CIRA, ESMEI, and CoCoRaHS-developed fire, flood, and resilience workshop, designed in late 2017 and offered for the first time in the summer of 2018.

Social Media

CIRA continues to enjoy an enhanced online presence in the social media sphere, with satellite loop-of-the-day imagery and other opportunities to explore interesting geophysical and atmospheric phenomenon leveraging our social media platforms on Facebook, Twitter, and LinkedIn. Increased use of the SLIDER tool (online at: http:/rammb-slider.cira.colostate.edu) with special attention to the ability of SLIDER to create shareable URLs has led to a drastic increase of page views both on the CIRA Facebook page and on CIRA web servers. Facebook statistics reveal post public reach numbers in the 600-800 user range, with click-through and reaction statistics averaging around 8%, which is approximately four times than ratios for typical advertising-focused content. Moreover, the ability of news media to contact and/or publish PR pieces through or using CIRA social media increased during the year, especially during the 2017 hurricane season, which saw significant media presence of CIRA researchers online for interviews related to Hurricane Maria and Hurricane Harvey. Figure 3 shows a typical post from the season, featuring media work by CIRA researchers with a local news station.

Figure 3. Significant media interaction in the social media sphere during the 2017 hurricane season. Here, an interview with CIRA research scientist Dr. Kate Musgrave with 9News was shared to a larger audience over Facebook.

Collaborations

Little Shop of Physics

CIRA continued its long and prosperous partnership with the Little Shop of Physics in 2016. The Little Shop of Physics develops hands-on demonstrations of physical concepts for the K-12 audience and supports professional development and science education for K-12 teachers. Utilizing undergraduate and graduate student volunteers, the Little Shop of Physics tours nationally and internationally (including a trip to Africa this year), bringing science demonstrations to a large audience. Additionally, the Little Shop produces a cable-access TV program, also available online, and presents demonstrations at national conferences including the AMS and NSTA Annual Meetings, and hosts an annual Open House on the CSU Campus that draws nearly 10,000 participants.

Figure 4. Learning about electromagnetic fields and electricity at the 2018 Little Shop Open House

Community Outreach

CIRA Outreach continues to support the local chapter of the AMS, FORTCAST, and responded to several requests for school visits on behalf of FORTCAST, including to underprivileged communities in Loveland. CIRA also made several visits to local elementary schools in 2016, providing an annual presentation on fire, flood, and drought to Olander Elementary and a bilingual presentation on clouds, rainbows, and lightning formation to the English- and Spanish-speaking kindergarten classes at Harris Bilingual Elementary. Additionally, CIRA Outreach staff were asked to judge at the annual Longs Peak Science and Engineering fair held in Greeley, CO, adjudicating the award of NOAA- and NASA-sponsored awards.

Interaction with World Meteorological Organization Regional Training Centers through the WMO Virtual Laboratory

CIRA is an active member of the World Meteorological Organization (WMO) Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) and collaborates with WMO Regional Training Centers (RTC) in Costa Rica, Barbados, Argentina, and Brazil to promote satellite-focused training activities. One of our most productive activities with these RTCs continues to be providing support to monthly virtual weather/satellite briefings.

Our group is the WMO Focus Group of the Americas and the Caribbean, and we are a model group for other WMO countries. Participation in our monthly virtual satellite weather briefings is an easy and inexpensive way to simultaneously connect people from as many as 32 different countries, view imagery from Geostationary and polar orbiting satellites, and share information on global, regional, and local real time and climatic weather patterns, hurricanes, severe weather, flooding, and even volcanic eruptions. Forecasters and researchers are able to “build capacity” by being able to readily communicate with others in their discipline from different countries and discuss the impacts of their forecasts or impacts of broad reaching phenomena such as El Niño. Participants view the same imagery (geostationary and polar orbiting) available on the VISITview tool and the new SLIDER by connecting through GoToWebinar.

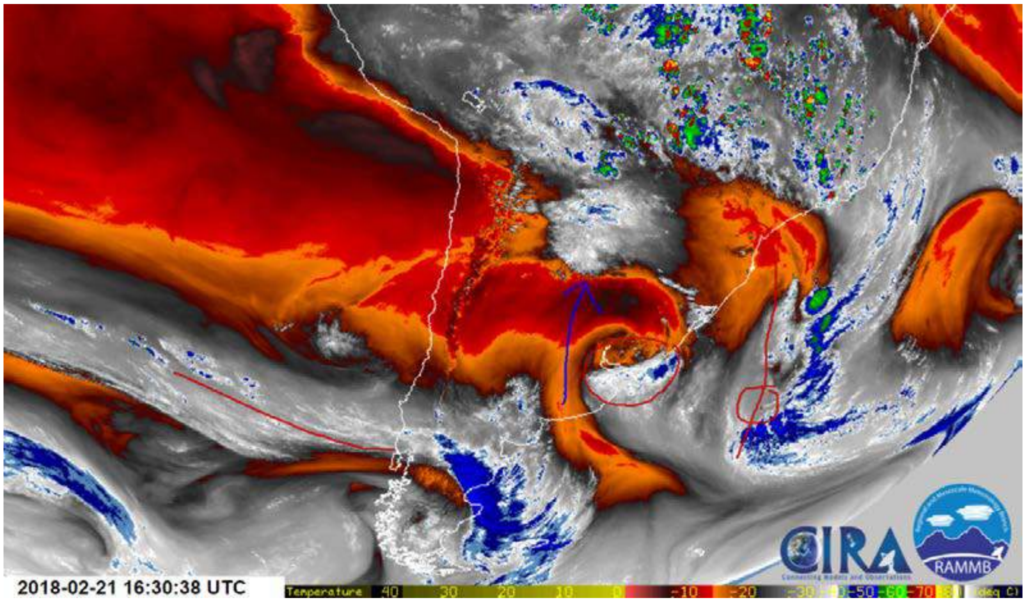


Figure 5. Synoptic flow analyzed on GOES-16 Water Vapor (6.2 µm) imagery from 21 February 2018 used by VLab training. GotoWebinar now allows easy real-time drawing and annotation of important weather features on the screen to assist student learning

For more information on various RTC activities and recording of the session ns, visit:

http://rammb.cira.colostate.edu/training/rmtc/focusgroup.asp

Science on a Sphere™ - K. Searight, S. Albers

During this reporting period, new SOS systems were installed at venues worldwide, including Liberty Science Center (Jersey City, New Jersey), NOAA Center for Weather and Climate Prediction (College Park, Maryland), Morristown-Beard School (Morristown, New Jersey), Srikrishna Science Centre (Patna, Bihar, India), The Regional Science Centre, (Guwahati, India), Raman Science Center (Nagpur, India), Biodiversity Museum (Kerala, India), Kaihua Meteorological Bureau (Kaihua, China), Xuchang Technology Activity Center (Xuchang, China), Zhejiang Shaoxing Meteorological Administration (Shaoxing, China), and University of South Australia (Adelaide, Australia). The total number of SOS systems installed worldwide now exceeds 150, with a total viewership estimated at over 37M people annually.

Additionally, the largest ever Science On a Sphere® (SOS) was set up as part of a temporary exhibit called Climate Planet in Aarhus, Denmark, which was designated the European Capital of Culture in 2017. The 4-meter diameter sphere was housed inside a temporary 24-meter spherical structure. A special SOS presentation about climate change was developed by the exhibit creators for the event.

The SOS team played a major role in 8th Science On a Sphere® Users Collaborative Network Workshop, held at the Detroit Zoo, with over 100 attendees. The Boulder staff gave presentations and demonstrations on SOS topics, including What's New in the SOS Product Suite, SOS: Global to Local, SOS Visual Playlist Editor Tutorial, and SOS Product Suite: Feedback and Future Direction.

SOS staff also led a Girls & Science program at Denver Museum of Nature and Science and facilitated webinars for the SOS community on scientific content and use of SOS software. In the SOS Planet Theater at the NOAA Skaggs building in Boulder, SOS educational shows were viewed by an average of 470 visitors per month, with SOS staff conducting some of the presentations or providing technical backup to presenters when needed.

Citizen Weather Observer Program (CWOP) - L. Cheatwood, R. Collander, T. Kent

There are currently 18935 active stations (citizen and ham radio operators) out of a total of 36973 stations in the CWOP database. CWOP members send their weather data via internet alone or internet-wireless combination to the findU (http://www.findu.com) server and then the data are sent from the findU server to the NOAA MADIS ingest server every five minutes. The data undergo quality checking and then are made available to users thru the MADIS distribution servers. CWOP is in the process of transitioning to operations within the NCO IDP MADIS system.

In 2017, there were approximately 1727 stations added to the database. Approximately 1100 revisions were made to site metadata. Adjustments include latitude, longitude and elevation changes in response to site moves, refinement of site location, and site status change (active to inactive, vice-versa).

Virtual Lab (VLab) - K. Sperow, M. Giebler, J. Burks

The NWS has created a service and IT framework that enables NOAA, in particular the NWS, and its partners to share ideas, collaborate, engage in software development, and conduct applied research from anywhere. VLab Development Services (VLDS) provides web-based services to help manage projects via issue tracking, source control sharing, code review, and continuous integration, VLDS has grown by over 100% again this year to support over 1170 projects and 3610 developers. Multiple demos and consultations were made to development and operations groups covering VLab's capabilities and how they can be leveraged to address the group's needs.

Ken Sperow is the VLab expert, which includes providing guidance on Gerrit, Jenkins, Liferay, and Redmine, but also git expertise. He worked with NCEP EMC to transition all of the numerical modeling code to VLab, switching from svn to git. Ken provided in depth training sessions to NCEP EMC on use of git and VLab services.

AWIPS II

Jason Burks developed an AWIPS II Developer Training Course and is currently delivering the course to approximately 26 developers. The rest of the course will be completed in early 2018. Recordings from the training will be available on VLab.

Autonowcaster (ANC) - J. Crockett

John Crockett again assisted Taiwan's Central Weather Bureau (CWB) with its understanding and use of ANC. As part of this work, John traveled to Taipei, Taiwan, where he reconfigured the CWB's MDL-ANC system to ingest six meteorological variables from the CWB's version of the STMAS-WRF model, after which he configured the data flows needed to produce eight model-based predictors that are used by ANC's "mixed" regime. He experimented successfully with using Himawari-8 data as input to the CWB's MDL-ANC's version of NRL Monterey's cloud classification algorithm, and he successfully translated the results to ANC's MDV format. He answered any and all questions as they arose, and provided to the CWB's ANC team a list of recommendations for them to consider with respect to their use of ANC. Upon his return, John investigated and fixed problems remotely as the need arose.

From mid-May through mid-August, John trained a visitor from the CWB at the MDL in order to transfer knowledge regarding the entire ANC system. Starting from how to build, (re)configure, and run ANC through the scientific underpinnings of some of ANC's intermediate products, e.g., the predictor of vertical instability. The exchange was fruitfully two-way, as the trainee often posed questions that caused John Crockett to delve more deeply into ANC's software, one result of which was to determine that one application that had been being used was, in fact, unnecessary.

Hydrologic Research and Water Resources Applications Outreach – L. Johnson

Hydrologic Research and Applications Development:
--Assisted in the design, coordination and development of hydrological modeling and water resources management applications for regional demonstrations with the Hydrometeorological Testbed (HMT) and NWS National Water Center (NWC).
--Provided guidance and leadership in carrying forward the hydrological research agenda defined by the HMA Team, including publication in technical reports, peer-reviewed journals, and conferences.
--Supported the HMA Team Leader in identifying and tracking candidate (and past) tools, techniques and knowledge transfers to NWS and key stakeholders.

Russian River Tributaries Water Budget Project:
--A web-based interface has been developed for the dissemination of information to project stakeholders.

Instructional Development for NOAA's OMAO- C. Kelly

One responsibility of Commerce Learning Center Administration is working with divisions/departments to build curriculum for ongoing and new hire training. We worked with the Marine Operation Engineering department (EEB) to build a curriculum for IT Training Requirements. This was a fairly straight-forward build because it contained all online courses. We are working on a more complex curriculum that contains ILT's and offsite courses. This project is ongoing.

The OMAO Learning Office CLO oversees learning, development, and training programs for OMAO employees. There are a variety of creative and administrative functions that the LMS Administrator executes to support the vision and mission of the Office. The CLO facilitates two, week-long, face-to-face leadership training sessions. Accordingly, Cari Kelly created graphical training materials for the Mid-grade Leadership course to develop standardized practices throughout NOAA leadership.

In collaboration with the Marine Operations and the Department of Census, the OMAO Learning Office is developing a training program for the newly developed ShipTA time management system for onboard personnel. Cari Kelly is building the online/onboard course using the adult learning principles of relevancy, practicality, and self-motivation. The course will respect the learners time by making the training to-the-point in a format that will be easy to navigate.

Rapid Update Cycle (RUC) Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR) Models Project, Data Distribution and Visualization - B. Jamison, E. Szoke

A dual-monitor hallway display on the second floor of the David Skaggs Research Center (DSRC) displays HRRR model graphics for public viewing. Currently, a montage loop of four output fields is regularly displayed and updated automatically.

A large touchscreen kiosk monitor in the second floor atrium area has been updated with added HRRR graphic loops of composite reflectivity, precipitation and precipitation type. New, larger, and more detailed images were created and are updated specifically for the kiosk.

CoCoRaHS

CoCoRaHS, the Community Collaborative Rain, Hail and Snow network (http://www.cocorahs.org/) was founded by the Colorado Climate Center at Colorado State University. This citizen-science project started in Fort Collins, Colorado after a devastating flash flood in 1997. The flood caused over $200 million in damages (including major damages to the CSU campus) and the loss of five lives and also pointed out the need for timely and localized precipitation data.

Precipitation is known to be extremely variable; and, with the help of volunteers who are trained and equipped, the gaps between official weather stations are being supplemented by volunteer data. The network quickly grew and now consists of over 20,000 volunteers in all 50 States, Canada and Puerto

Rico, U.S. Virgin Islands and The Bahamas with 10,000-12,000 reports submitted daily (Figure 6). One key to the project's success is that the data are used by the public as well as professionals including scientists and meteorologists at the National Weather Service.

CoCoRaHS has continued to produce new educational materials with respect to watershed education and awareness. CoCoRaHS released a new mapping product that produces accumulated precipitation amounts using watershed boundaries (Figure 7). This map provides uses with a visual representation of how much water will flow into streams and rivers in their own watershed, basin or sub-basin. The map is free and open to anyone: https://cocorahs.erams.com/

Since 2012, CoCoRaHS piloted an effort in to reach out to schools. Initially, Colorado recruited nearly 150 schools around the State. Many of them submitted data, and even more success was realized by holding two campaigns per year called 'Rain Gauge Week'. After the initial pilot and proven success, the model expanded to all of CoCoRaHS, and through 2017 there were still over 1000 schools registered in the database with almost 700 having entered data. The bi-annual 'Rain Gauge Week' occurs in May and September each year and has been a good way to keep enthusiasm high throughout the school year.

Over 1,110 students, teachers and members of the public were reached through 26 events and presentations throughout 2017. These include classroom presentations, professional development for teachers and public tours of the Fort Collins Weather Station.

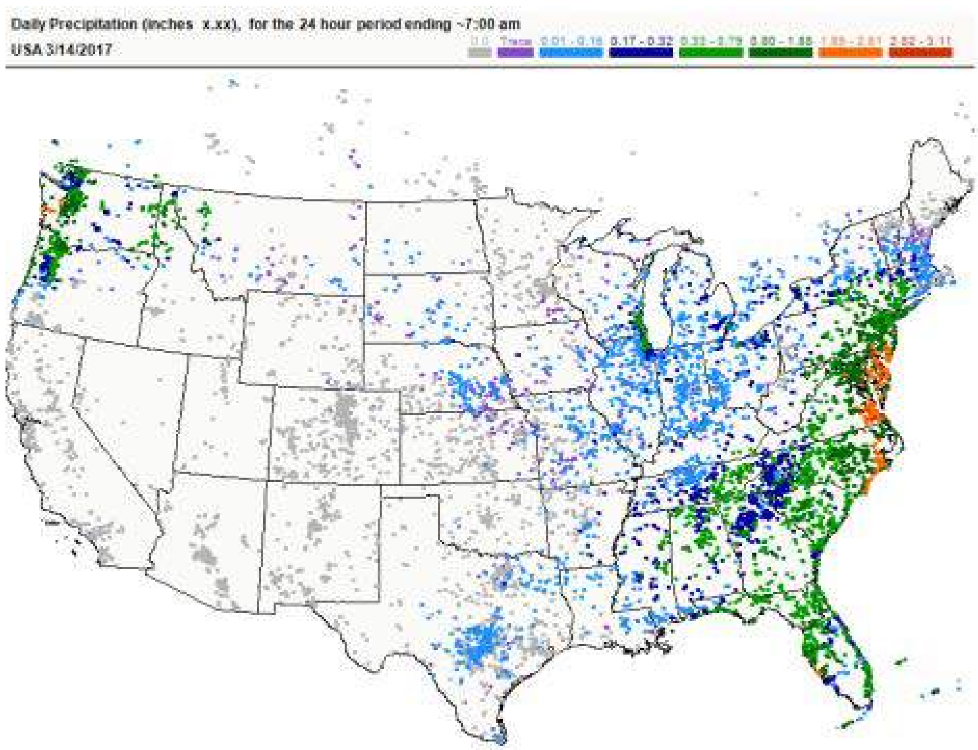


Figure 6. Current CoCoRaHS Station reporting for early 2017

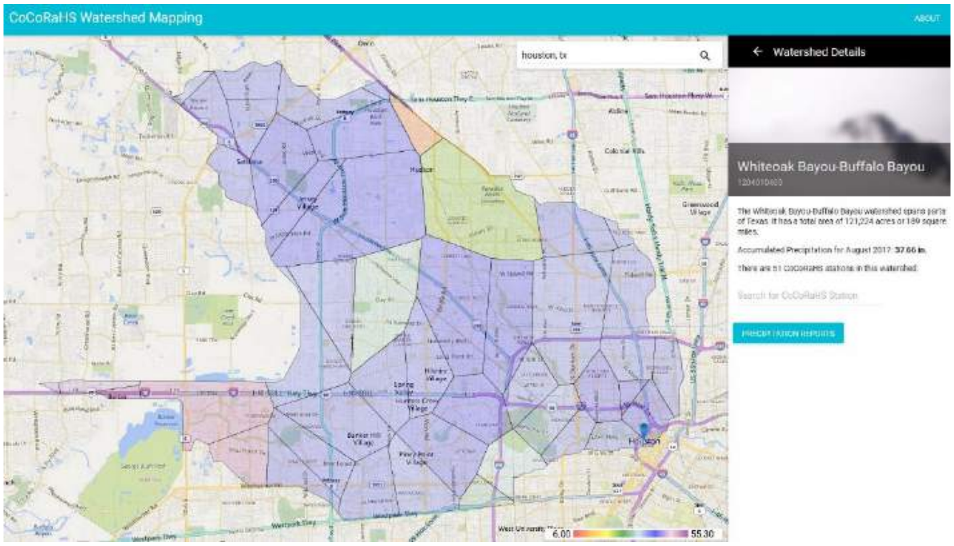


Figure 7. Watershed map of NW Houston, TX, August,2017 (Hurricane Harvey)
https://cocorahs.erams.com/reports?watershed=1204010403&reportType=monthly&date=2017-08-01

Summary

CIRA Education and Outreach initiatives continue to provide valuable education resources to the community and the nation, and will continue to develop new areas for education effort through 2017. CIRA has developed a program to continue education on resilience for local communities, and has applied for funding under the NOAA Office of Education to host workshops during 2018 and beyond to bring NOAA resources into the classroom. CIRA will continue to develop programs focusing on underrepresented minorities, and is looking at seeking funding for internships, pairing undergraduate students with CIRA researchers to showcase NOAA product development and operations. And as always, CIRA education efforts will continue to address evolving needs as they arise, helping to complete the goal of creating a truly weather-ready nation.

NOAA AWARD NUMBERS FOR CIRA

Award Number	Identifier	Project Title	Principal Investigators-Project Directors
NA14OAR4320125	Cooperative Agreement	A Cooperative Institute to Investigate Satellite Applications for Regional/global-scale Forecasts	Chris Kummerow
NA16OAR4590233	Competitive	Accounting for Non-Gaussianity in the Background Error Distributions Associated with Cloud-related Variables (microwave radiances and hydrometeors) in Hybrid Data Assimilation for Convection-scale Prediction	Karina Apodaca (Lead)
NA17OAR4310001	Competitive	Aerosol size distribution and composition evolution during FIREX activities: closure analyses and climate impacts	Jeffrey Pierce
NA16OAR4590237	Competitive	Assimilation of Lake and Reservoir Levels into the WRF-Hydro National Water Model to Improve Operational Hydrologic Predictions	Lynn Johnson (Lead)
NA16OAR4310094	Competitive	Collaborative Research: Assessing oceanic predictability sources for MJO propagation	Charlotte Demott
NA17OAR4590121	Competitive	Comparison of Model Versus Observationally-driven Water Vapor Profiles for Forecasting Heavy Precipitation Events	John Forsythe
NA15OAR4310099	Competitive	Development of a Framework for Process-oriented Diagnosis of Global Models	Eric Maloney
NA17OAR4590118	Competitive	Evaluating Stochastic Physics Approaches within Select Convection Allowing Model (CAM) Members Included in the Community Leveraged Unified Ensemble (CLUE) During the Hazardous Weather Testbed (HWT) Spring Experiment	Isidora Jankov
NA14OAR4310148	Competitive	Following Emissions from Non-traditional Oil and Gas Development through Their Impact on Tropospheric Ozone	Emily Fischer, Chris Kummerow
NA16OAR4310064	Competitive	Forecasting North Pacific Blocking and Atmospheric River Probabilities: Sensitivity to Model Physics and the MJO	Elizabeth Barnes (Lead)
NA16NWS4680012	Competitive	Implementation and Testing of lognormal Humidity and Cloud-related Control Variables for the NCEP GSI Hybrid EnVar Assimilation Scheme	Steven Fletcher (Lead)

NOAA AWARD NUMBERS FOR CIRA

NA15OAR4590202	Competitive	Improvement to the Tropical Cyclone Genesis Index (TCGI)	Andrea Schumacher
NA15OAR4590204	Competitive	Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models	Galina Chirokova, Andrea Schumacher
NA17OAR4590138	Competitive	Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models	Galina Chirokova
NA16OAR4590238	Competitive	Improving Probabilistic Forecasts of Extreme Rainfall through Intelligent Processing of High-resolution Ensemble Predictions	Russ Schumacher (Lead)
NA16OAR4590215	Competitive	Improving Understanding and Prediction of Concurrent Tornadoes and Flash Floods with Numerical Models and VORTEX-SE Observations	Russ Schumacher (Lead)
NA16OAR4310090	Competitive	Investigating the Underlying Mechanisms and Predictability of the MJO – NAM Linkage During Boreal Winter in the NMME Phase-2 Model Suite	Elizabeth Barnes (Lead)
NA17OAR4310003	Competitive	Modeling the Complex and Dynamic Evolution of Organic Aerosol in Biomass Burning Plumes	Shantanu Jathar
NA15OAR4590233	Competitive	Multi-disciplinary Investigation of Concurrent Tornadoes and Flash Floods in the Southeastern US	Russ Schumacher
NA17OAR4310010	Competitive	Near-field Characterization of Biomass Burning Plumes	Delphine Farmer
NA14OAR4830167	Competitive	NOAA's Observing System Experiments and Observing System Simulation Experiments in Support of the "Sensing Hazards with Operational Unmanned Technology (SHOUT) Program - Development and Testing of Sampling Strategies for Unmanned Aerial Systems	Chris Kummerow
NA14OAR4310141	Competitive	Observational Constraints on the Mechanisms that Control size- and Chemistry-resolved Aerosol Fluxes over a Colorado Forest	Delphine Farmer, Chris Kummerow
NA16OAR4590230	Competitive	Quantifying Stochastic Forcing at Convective Scales	David A. Randall (Lead)

NOAA AWARD NUMBERS FOR CIRA

NA13OAR4310103	Competitive	Research to Advance Climate and Earth System Models Collaborative Research: A CPT for Improving Turbulence and Cloud Processes in the NCEP Global Models	Chris Kummerow Dave Randall
NA14OAR4830166	Competitive	Sensing Hazards with Operational Unmanned Technology (SHOUT), Data Management and Visualization	Chris Kummerow
NA13OAR4310077	Competitive	Towards Assimilation of Satellite, Aircraft, and Other Upper-Air CO2 Data into CarbonTracker	David Baker, Chris Kummerow
NA17OAR4590181	Competitive	Use of the Stochastic-dynamic Approach in a Single Dynamic-Core Storm-Scale Ensemble for Improved Spread and Reliability of QPF and Surface Variables	Isidora Jankov

VISION AND MISSION

The overarching Vision for CIRA is:

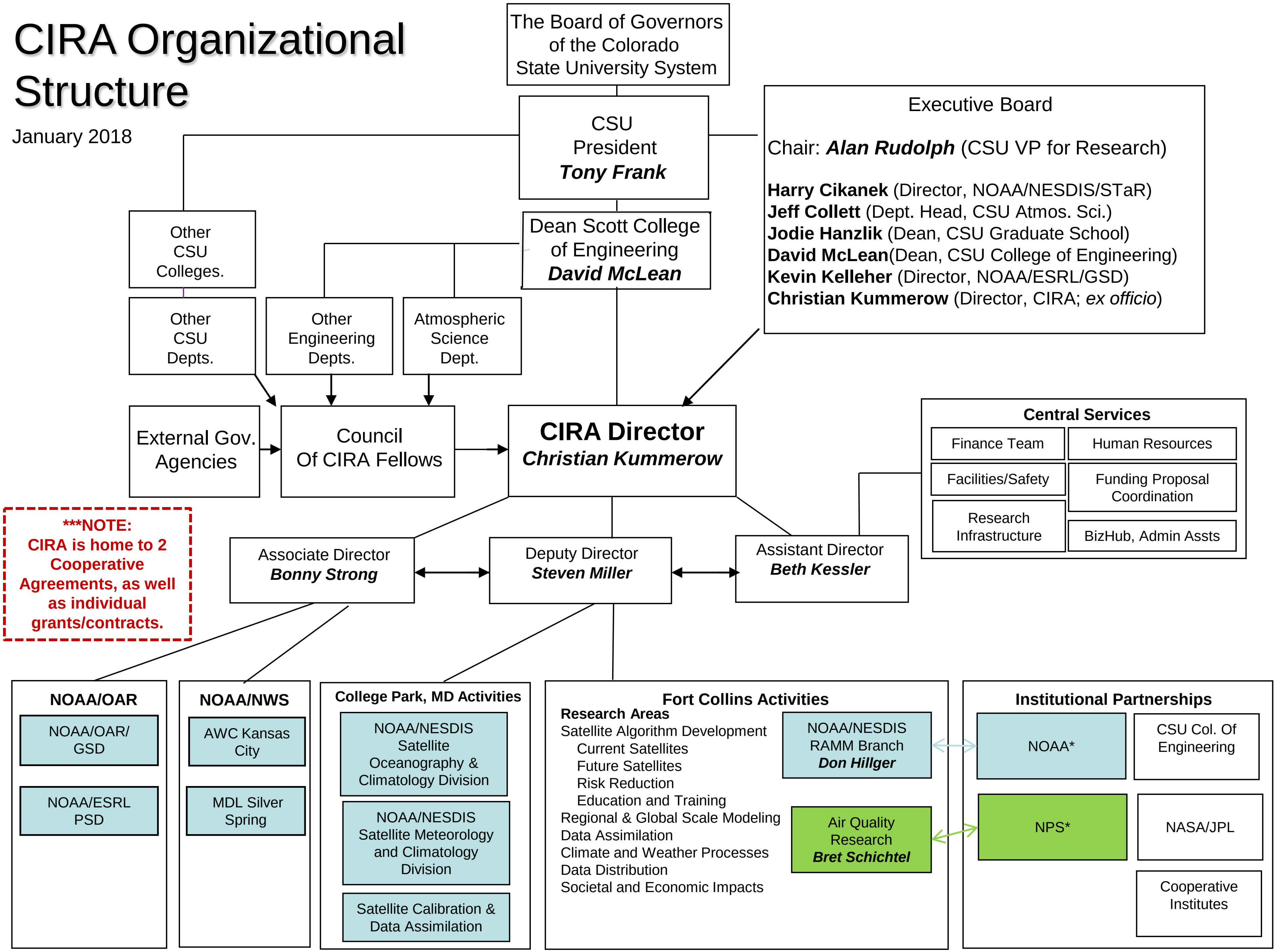
To conduct interdisciplinary research in the atmospheric sciences by entraining skills beyond the meteorological disciplines, exploiting advances in engineering and computer science, facilitating transitional activity between pure and applied research, leveraging both national and international resources and partnerships, and assisting NOAA, Colorado State University, the State of Colorado, and the Nation through the application of our research to areas of societal benefit.

Expanding on this Vision, our Mission is:

To serve as a nexus for multi-disciplinary cooperation among CI and NOAA research scientists, University faculty, staff and students in the context of NOAA-specified research theme areas in satellite applications for weather/climate forecasting. Important bridging elements of the Institute include the communication of research findings to the international scientific community, transition of applications and capabilities to NOAA operational users, education and training programs for operational user proficiency, outreach programs to K-12 education and the general public on environmental literacy, and understanding and quantifying the societal impacts of NOAA research.

CIRA Organizational Structure

January 2018



EXECUTIVE SUMMARY—Research Highlights

The Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University (CSU) serves as both an active collaborator and formal interface between academic expertise and multiple agencies holding both basic and applied research interests in atmospheric science. Under its capacity as NOAA's Cooperative Institute for exploiting satellite applications for improvements in regional and global-scale forecasting, CIRA provides an important and practical connection between two NOAA line offices—Oceanic and Atmospheric Research (OAR) and the National Environmental Satellite, Data and Information Service (NESDIS). Diverse expertise in satellite remote sensing, science algorithm and application development, education/training, regional/global weather and climate modeling, data assimilation, and data distribution technology make CIRA a valuable asset to NOAA in terms of transitioning research concepts to operational stakeholders. A good example of last year's contribution was the release of the true color GOES Imagery that was used throughout press releases for the satellite's launch.

Outside of the core group in Fort Collins, CIRA's collaborations with the Global Systems Division (GSD), the Physical Sciences Division (PSD), and the Global Monitoring Division (GMD) of the NOAA Earth System Research Lab (ESRL) in Boulder continue to be strong. Technical and scientific leadership is evident in work with the High Resolution Rapid Refresh Model HRRR and HRRR/Chem, as well as GSI Data Assimilation systems that provide the best possible model initialization fields. Likewise, CIRA research continues to expand in the areas of quality assessment of NWS and FAA products relevant to turbulence forecasting. Key research and development positions are held by CIRA researchers in programs that focus on the delivery and visualization of NOAA's data to research, operational and public users. Major projects include the NOAA Earth Information System (NEIS), the NWS AWIPS II Hazard Services, virtual client systems, the Meteorological Assimilation and Data Ingest System (MADIS), the NWS Virtual Laboratory (VLab), and the Integrated Dissemination Program (IDP). CIRA researchers are also leaders in the development of high-performance computing software and firmware (especially related to GPU processing).

The CIRA Annual Report provides summaries of the contributions emerging from our research partnership with NOAA, with more detail to be found in the peer-reviewed and technical conference publications cited within this report as appropriate. Highlighted below are accomplishments from the current reporting period and drawn from both the NOAA reports contained herein as well as from the broader palette of research conducted at CIRA. Organized by CIRA's research themes, these examples underscore intra- and inter-agency partnerships that present opportunities for leveraging activities of other agencies.

Satellite Algorithm Development, Training and Education

- With GOES-16 and JPSS now in orbit, much of the core focus in the satellite algorithm development and training work has focused on these two platforms. The GOES-16 risk reduction, in particular, has a number of elements designed to prepare the community for the new data products, improve the prediction of tropical cyclone genesis, understanding its structure and changes in structure leading to improved predictions of both track and intensity forecasts using the enhanced GOES-16 capabilities. Images using CIRA's true color image software was able to immediately release stunning imagery from GOES-16 that were used in nearly every first-light image shown by NASA and NOAA. This was followed by the release of the SLIDER software that allows the public to get an intimate look at the GOES imagery in near real-time through a web application. This however is simply a prelude to new multi-spectral products being developed at CIRA. An example of this is the detection of lofted dust in a visually-intuitive graphical display that bears direct relevance to the challenges of visibility hazards forecasting--a particular hazard for aviation weather and CIRA's work with the Aviation Weather Center. Another important aspect of this project is the synthetic imagery that uses cloud model output to extend the satellite radiances and thus provides an important tool for combining models and observations in a unique way that allows forecasters to assess forecast model quality by examining the continuity of the observed cloud fields as they loop from the present (observations) to the future (models).

- The imagery work related to GOES-16 also has a strong Tropical Cyclone component that seeks to aid forecasters with the interpretation of cloud-top microphysics from the imagery, improve the statistical inference of TC structures from Infrared Imagery and anticipate the TC eye formation. Using HWRF winds coupled with the synthetic imagery described above allowed the TC group to develop relationships between IR structures and TC winds. While not completed, early results are encouraging. These advances are further coupled to a strong program in education and training activities such as CIRA's participation in the Virtual Institute for Satellite Integration Training (VISIT), the Satellite Hydro-Meteorological training and education activity (SHyMET), and the International Virtual Laboratory (VLab)

- An area of great excitement continues to be the work being done with the Day/Night band of Suomi-NPP and now JPSS-1. Not only is detection of smoke, dust, and fog possible at night but these new results have generated a lot of excitement in the community. Much work was done in this previous year related to quantifying the arctic winter clouds that are often difficult to detect with infra-red methods alone. The VIIRS Sensor is also being used extensively to estimate tropical cyclone intensity and structure as well as for more-established applications related to Sea Surface Temperature and Ocean Color products produced by CIRA Research Scientists working directly with NOAA STAR employees in College Park, MD. Perhaps not evident when evaluating a single proposal, however, is the synergy that CIRA provides across projects through its internal communications and collaborations. A careful review of all the activities related to satellite algorithm development, training and education, however, clearly reveals these synergies and the benefits that these create on behalf of NOAA.

- A new area is the work being performed jointly by CIRA staff in Fort Collins with GSD staff in Boulder to connect GOES-16 with rapid-update numerical forecast models for advanced short-term prediction and data fusion capabilities. This effort hopes to exploit very-high resolution GOES-16 data to assimilate cloud location and latent heat release into GSD's HRRR model at 5- and possibility even 1 minute intervals over limited domains.

NOAA Regional to Global Scale Model Research

- CIRA researchers took the lead in several technical and modeling programs within the activities continuing within the Developmental Testbed Center (DTC), the Aviation Weather Testbed (AWT) and the Hydro Met Testbed (HMT). CIRA researchers have demonstrated the impact on stochastic parameter perturbations (SPP) to physics parameters within a regional (HRRR) ensemble and evaluated multiple ensemble convection-allowing ensemble configurations as part of HWT. CIRA researchers also contributed to development of ensemble-based hazard detection guidance tools for transition to NWS operations.

- CIRA researchers provided critical support for forecast model development with the development of new, innovative software tools to provide interactive model verification and model output visualizations for internet access.

- Project management, technical leadership and scientific research for the High Impact Weather Prediction Project (HIWPP), part of the Hurricane Sandy Supplemental funding work, concluded in 2017. Specifically projects in OSSEs, high performance computing, information systems, global models, and model verification submitted final reports to OAR. All nine of the GSD Sandy Supplemental projects have been completed.

- CIRA researchers continue to provide scientific and technical leadership to the Flow Following Finite Icosahedral Model (FIM) development program in order to evaluate physics suites and seasonal-to-subseasonal coupled model capabilities. Additionally, CIRA researchers supported efforts to begin migrating from the FIM model for global model research to the new FV3GFS model, which is the basis for the NOAA's new Unified Forecast System.

- CIRA researchers contributed to improvements in data assimilation (DA) used by forecast models. They prepared and tested the radiance assimilation package for the RAP Version 4 upgrade and have begun work to assimilate GOES-16 ABI radiance data into the RAP/HRRR modeling systems. An interface was developed in the GSI DA package to read all-sky camera cloud mask data. A website was created to compare camera images in Alaska to simulated images created from the HRRR model output in the same area.

- Following the implementation of the Graphical Turbulence Guidance (GTG), v3 into operations in November 2016, research has continued to enhance the calibration of the Global Ensemble Forecast System (GEFS) GTG product in order to improve the probabilistic Eddy Dissipation Rate (EDR).

Data Assimilation

- At the request of both EMC and ESRL, CIRA conducted a Data Assimilation Internship course again this year. This year's students are: Alex Libradoni (EMC), Matthew Brothers (EMC) and Amanda Back (GSD). These students all have advanced degrees in atmospheric science. They spend one year learning the basics of data assimilation along with practical applications that allow an immediate transition into the NOAA workforce upon graduation.

- Our Data Assimilation theme, of course, touches nearly every aspect of the HRRR data assimilation effort, including the high-resolution GOES data assimilation described in the Satellite section and the efforts related to the Aviation Weather's NextGen Weather Program.

Climate and Weather Processes

- Much of this effort centered on getting better soil moisture using precipitation data from CIRA's "Citizen Science" Project Enhancing NIDIS Drought Monitoring and Early Warning in the Upper Colorado River Basin as well as improving drought and precipitation recurrence intervals from models and observations.

NOAA Data Distribution Research

- Significant research and development work was conducted by CIRA researchers to continue the improvement and extension of the AWIPS II software suite. Systems developed and in the process of being transitioned to operations are: The Forecast Decision Support Environment (FDSE) tools, Hazard Services (aviation, winter weather, hurricane storm surge, severe weather forecast probabilities), and the FxCAVE thin client.

- As part of the NWS NextGen Aviation Weather Program, CIRA researchers at ESRL continued their research into the technology and science of populating a four-dimensional airspace with atmospheric data, extraction methodologies, distribution formats, and input mechanisms to be used by aviation decision support systems. Using real-time aviation weather forecast products and decision support tools that utilize verification information in real-time, a web-based tool (INSITE) is being developed for a transition to operations. Working with NOAA and CIRA Subject Matter Experts (SMEs) in the NWS Integrated Distribution Program, an automated process to create Product Description Documents (PDDs) is improving aviation weather data management and dissemination to the FAA, NWS and private enterprise partners. CIRA research efforts continue to provide OGC compliant weather and iWXXM observation data prototyping in the format required by the international aviation weather community, including the transition of software to NOAA data providers and aviation weather users.

- The MADIS (Meteorological Assimilation Data Ingest System) successfully upgraded the operational system in the NCEP Central Operations (NCO) with new Automated Surface Observing System (ASOS) and Integrated Ocean Observing System (IOOS) data. Significant development was continued on the NextGen IT Web Services (NGITWS) capability. The system has become an operational component of the NWS NCEP via the Integrated Dissemination Program (IDP).

- The on-going partnership with the NWS Meteorological Development Lab continued on several fronts. CIRA researcher's program and technical leadership to the Virtual Lab (VLab), the AutoNowCaster (ANC), Impacts Catalog, updating the Model Output Statistics (MOS) system, making updates to the MDL Map Viewer, and updates to the Local Climate Analysis Tool (LCAT). VLab is now a required component in the transition of research to operations for the NWS AWIPS II program. VLab Development Services (established, developed and maintained by the CIRA research team) has grown over 100% and now supports over 1700 projects and 3610 developers. The CIRA research team members lead the design and development of the new Project Registry used by VLab developers to improve AWIPS II software and develop decision support tools.

- CIRA researchers continued close collaborations with research and operations personnel at the Aviation Weather Testbed at the NWS Aviation Weather Center in Kansas City, MO. Primary goals of the partnership are to actively engage in the research-to-operations process and to develop, test, and evaluate new and emerging scientific techniques, products, and services in support of the aviation weather community. Aviation Weather Research Program (AWRP) research and development efforts have been centered in three research areas: 1) Aviation Impact Variables (AIVs) which are tested during the AWC Summer and Winter Aviation Weather Experiments and include the development of international global turbulence algorithm development, 2) NWS NextGen aviation weather data format prototyping for international standards and efficient data and product distribution via the Integrated Dissemination Program (IDP) and the web, and 3) AWIPS II decision support systems transition to operations.

- NextGen: CIRA researchers and software engineers at the AWC have led the effort to develop the data format standards and web services methods to disseminate forecast information and the web display capabilities required for visualization of distributed data.

Our Outreach Program

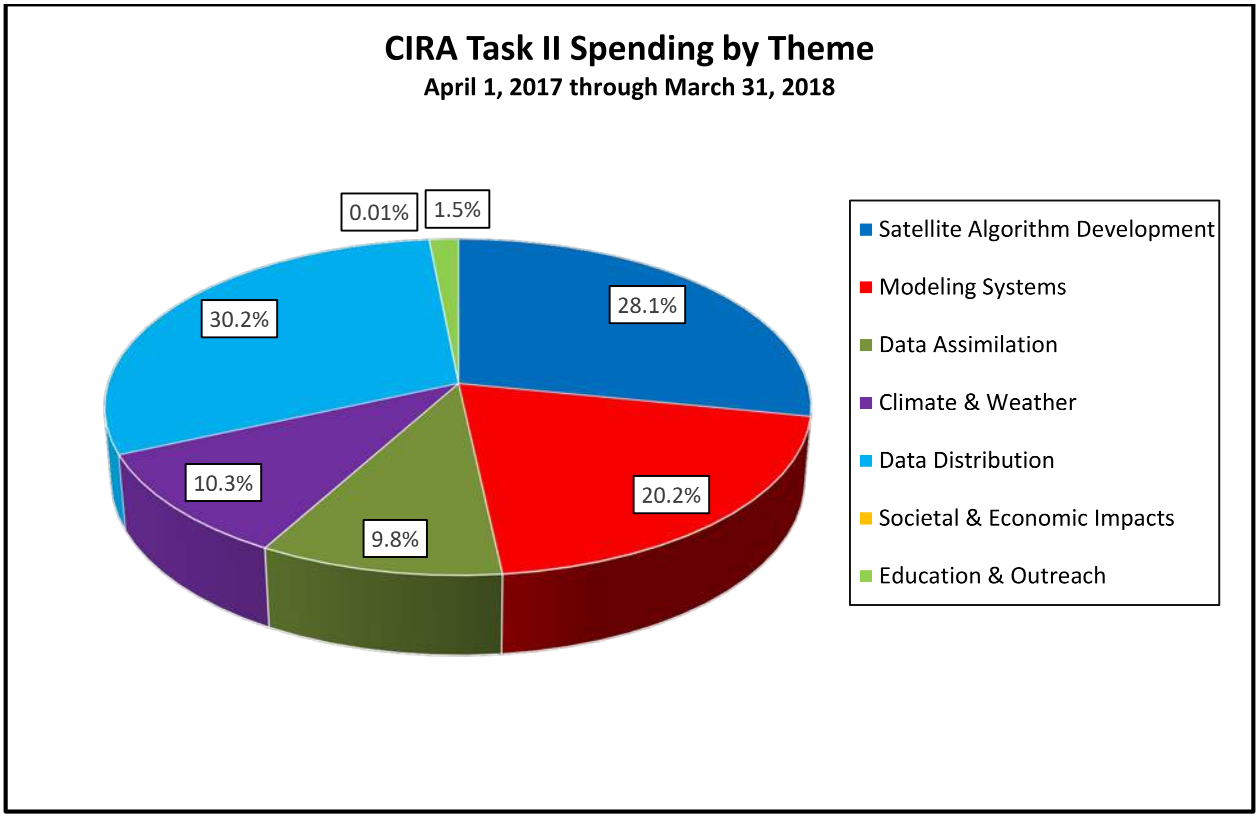
- Over the past year the CIRA group working with the National Park Service (NPS) continued its research on issues related to visibility and air quality at our Nation's National Parks. Their research, while focused on issues of importance to the National Park Service, overlaps considerably with a number of new CIRA initiatives related to pollutant transport such as those related to fires that are of great interest to the Park Service and NOAA and thus continues to be an integral partner in what we do as CIRA.

- The CloudSat Mission continues to enjoy strong support from NASA despite some anomalies with the spacecraft during the previous year. The CloudSat program, with its Data Processing Center running operationally at CIRA on behalf of NASA, has facilitated multiple research activities that are of benefit to NOAA. Chief among these is CIRA's ability to quickly make use of the CloudSat data to provide a unique validation for cloud base height retrievals produced by the VIIRS instrument on Suomi-NPP. A new effort to provide the algorithms and products for NASA's recently approved GeoCarb mission also offers the opportunity to more closely collaborate with GMD in its carbon tracking efforts.

- Interspersed among these major research themes are important contributions from CIRA's NESDIS postdoctoral and young researcher program in data distribution, assimilation, and satellite algorithm development. Located in College Park, MD, and integrated closely with NOAA technical contacts at StAR, these scientists are immersed in research ranging from refinements to the Community

Radiative Transfer Model (CRTM), data assimilation of cloudy radiances, satellite-based sea surface temperature (SST) algorithm development, techniques for monitoring and quality control of long-term SST records, and ocean color algorithm development for global climate and coastal/in-land water ecosystem monitoring. Some of the techniques and web interfaces being developed by this outstanding group of scientists is a constant reference source for other CIRA activities with similar objectives.

This Annual Report is the ninth in a series to be completed under CIRA's Cooperative Agreement established with NOAA. With this fourth report in the second 5-year lifecycle of the Cooperative Institute, we re-establish our commitment to the maintenance and growth of a strong collaborative relationship among NOAA, the Atmospheric Science Department at CSU, Departments of the University, and the other major programs within CIRA. As we pursue continued alignment with NOAA's Strategic Research Guidance Memorandum and NOAA's research themes, we look forward to the challenges and rewards for helping NOAA achieve its goals of understanding and predicting changes in climate, weather, oceans and coasts.


CIRA Task II Spending by Theme
April 1, 2017 through March 31, 2018
0.01%
1.5%
28.1%
30.2%
10.3%
9.8%
20.2%
Satellite Algorithm Development
Modeling Systems
Data Assimilation
Climate & Weather
Data Distribution
Societal & Economic Impacts
Education & Outreach

CIRA BOARD, COUNCIL, FELLOWS & BOARD MEETINGS

CIRA EXECUTIVE BOARD

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Jodie Hanzlik, Colorado State University
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John Schneider, NOAA
Chief, ESRL/GSD/Technology Outreach Branch
Pieter Tans, NOAA
Senior Scientist, Climate Monitoring and Diagnostics Lab
Fuzhong Weng, NOAA Retired

CIRA FELLOWS

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Andrew Jones, Senior Research Scientist, CIRA, CSU
Satya Kalluri, NOAA, Acting Chief SMCD, NOAA/STAR
Stanley Kidder, Senior Research Scientist, CIRA, CSU
Sonia Kreidenweis, Atmospheric Science Department & Associate Dean for Research, CSU
Christian Kummerow, CIRA Director, Atmospheric Science Department, CSU
Glen Liston, Senior Research Scientist, CIRA, CSU
Alexander "Sandy" MacDonald, NOAA
William Malm, Senior Research Scientist, CIRA; National Park Service (retired)
Steven Miller, CIRA Deputy Director, CSU
Anthony Mostek, Branch Chief, Forecast Decision Training Division, NOAA/NWS
Chris O'Dell, Senior Research Scientist, CIRA, CSU
Roger Pielke, Senior Research Scientist, CIRES, CU
James Purdom, Senior Research Scientist, CIRA, CSU
Robert Rabin, NOAA/National Severe Storms Laboratory
Steven Rutledge, Atmospheric Science Department, CSU
Joshua Scheck, Chief Aviation Support Branch, NOAA Aviation Weather Center
John Schneider, Chief, ESRL/GSD/Technology Outreach Branch
Tim Schneider, Office of Hydrologic Development NOAA/GSD
Pieter Tans, NOAA/CMDL
Thomas Vonder Haar, CIRA Director Emeritus and Atmospheric Science Department, CSU
Fuzhong Weng, NOAA Retired
Milija Zupanski, Senior Research Scientist, CIRA

Scheduled Meetings:
2017/18 Meeting of the CIRA Council – May 17, 2018
2017/18 Meeting of the CIRA Executive Board – June 15, 2018

TASK I – A COOPERATIVE INSTITUTE TO INVESTIGATE SATELLITE APPLICATIONS FOR REGIONAL/GLOBAL-SCALE FORECASTS

Task I activities are related to the administrative management of the CI. As reflected in the pie chart appearing earlier in this report, expenses covered by Task I are primarily salary and benefits, annual report production costs and some travel. This task also includes some support of postdoctoral and visiting scientists.

SEMINARS SUPPORTED BY TASK I

April 21, 2017, M. Berg (Kansas State University). Digital Holography of Aerosol Particles

April 28, 2017, T. Shaw (University of Chicago). Understanding Storm Track Shifts Across a Range of Timescales

May 2, 2017, R. Rios-Berrios (University at Albany, SUNY). Tropical Cyclone Intensification under Moderate Vertical Wind Shear

May 16, 2017, M. Surratt (U.S. Naval Research Laboratory Marine Meteorology Division), J. Solbrig (CIRA). The Geolocated Information Processing System (GeoIPS): A System for Processing Geoscience Data for Research and Operations

July 28, 2017, S. Miller (CIRA), C. Seaman (CIRA). A Sight for Sore Eyes: Bringing Back True Color Imagery for the New Generation Weather Satellites

August 10, 2017, K. Hageman (University of Otago, New Zealand). Predicting Pesticide Volatilization, Vapor Drift, and Impacts on Honey Bees

August 25, 2017, D. Lindsey (CIRA), S. Miller (CIRA). GOES-16: A New Era in Geostationary Satellite Observations

September 8, 2017, W. Lee (NCAR/EOL). Probing Precipitation, Cloud, and Clear Air Using EOL Remote Sensing Facilities

September 22, 2017, A. Russell (Georgia Institute of Technology). Air Pollution Accountability: Assessing Regulatory Impacts on Emissions and Air Quality

September 26, 2017, J. Kaplan (NOAA/AOML/Hurricane Research Division). Statistical Rapid Intensity Prediction: Implication of Recent Model Results

September 29, 2017, A. MacDonald (Spire Global, Inc.). The Global Energy-Carbon Dilemma is Solved!

October 6, 2017, S. Bililign (North Carolina A&T). Modeling Refractive Index of Biomass Burning Aerosols

October 12, 2017, C.J. Stubenrauch (LMD/IPSL, UPMC, Paris). The Role of Upper Tropospheric Cloud Systems in Climate: Building Observational Metrics for Process Evaluation Studies

October 13, 2017, H. Masunaga (Nagoya University, Japan). Radiative Regulation of Tropical Convection by Preceding Cirrus Clouds

October 20, 2017, J. Fleming (Colby College). Breaking Through the Clouds: Joanne Simpson and the Tropical Atmosphere

November 3, 2017, M. Parker (NC State University). How Well Can We Explain Why Some Supercells Make Tornadoes and Others Do Not?

November 10, 2017, W. Schubert (CSU). Bernhard Haurwitz Memorial Lecture (2017): Potential Vorticity Aspects of Tropical Dynamics

November 17, 2017, C. Williamson (NOAA ESRL, Boulder, CIRES). In-situ Measurements of the Global Distribution of Aerosol Particles

December 1, 2017, K. Armour (University of Washington). The Relative Roles of Radiative Feedbacks and Poleward Heat Transport in the Spatial Pattern of Climate Change

December 12, 2017, D. Jones (StormCenter Communications, Inc.). GeoCollaborate®: A Breakthrough Technology to Accelerate Data Sharing Across Multiple Platforms in a RT Collaborative Environment to Improve Research to Operations (R2O), Operations to Research (O2R), Situational Awareness and Decision Making

December 18, 2017, R. Ettema (CSU Dept. of Civil Engineering). Cold-weather Challenges for Water Infrastructure in the United States

January 23, 2018, A. P. Mizzi (CGD, NCAR). WRF-Chem/DART: Introduction, Application, Verification, and Compact Phase Space Retrievals (CPSRs)

January 26, 2018, B. Anderson (CSU). Assessing United States County-level Exposure to Tropical Storms and Investigating the Association between Tropical Storm Exposure and Community-wide Mortality Risks

February 2, 2018, D. Turner (NOAA). The Land-atmosphere Feedback Experiment

February 9, 2018, A. Heymsfield (NCAR) . A Comprehensive Observational Study of Graupel and Hail Properties

February 23, 2018, J. Bédard (Environment and Climate Change Canada). Background Error Covariances for Convective Scale 4D Ensemble-Variational Data Assimilation

February 23, 2018, M. Bell (CSU ATS). The 2017 Atlantic Hurricane Season

March 2, 2018, T.H. Vonder Haar (CSU ATS). History and Results from the Two Decade Quest to Measure the Earth's Radiation Budget

March 9, 2018, T. Weckwerth (NCAR Earth Observing Laboratory). Part I: Where, When and Why Did It Rain During PECAN? Part II: Overview of NCAR's Water Vapor DIAL

March 23, 2018, W. Ashley (Northern Illinois University). Hazardous Convective Weather in a Changing World.

March 30, 2018, I. Ebert-Uphoff (CSU Electrical and Computer Engineering). Casuality 101 for Geoscientists.

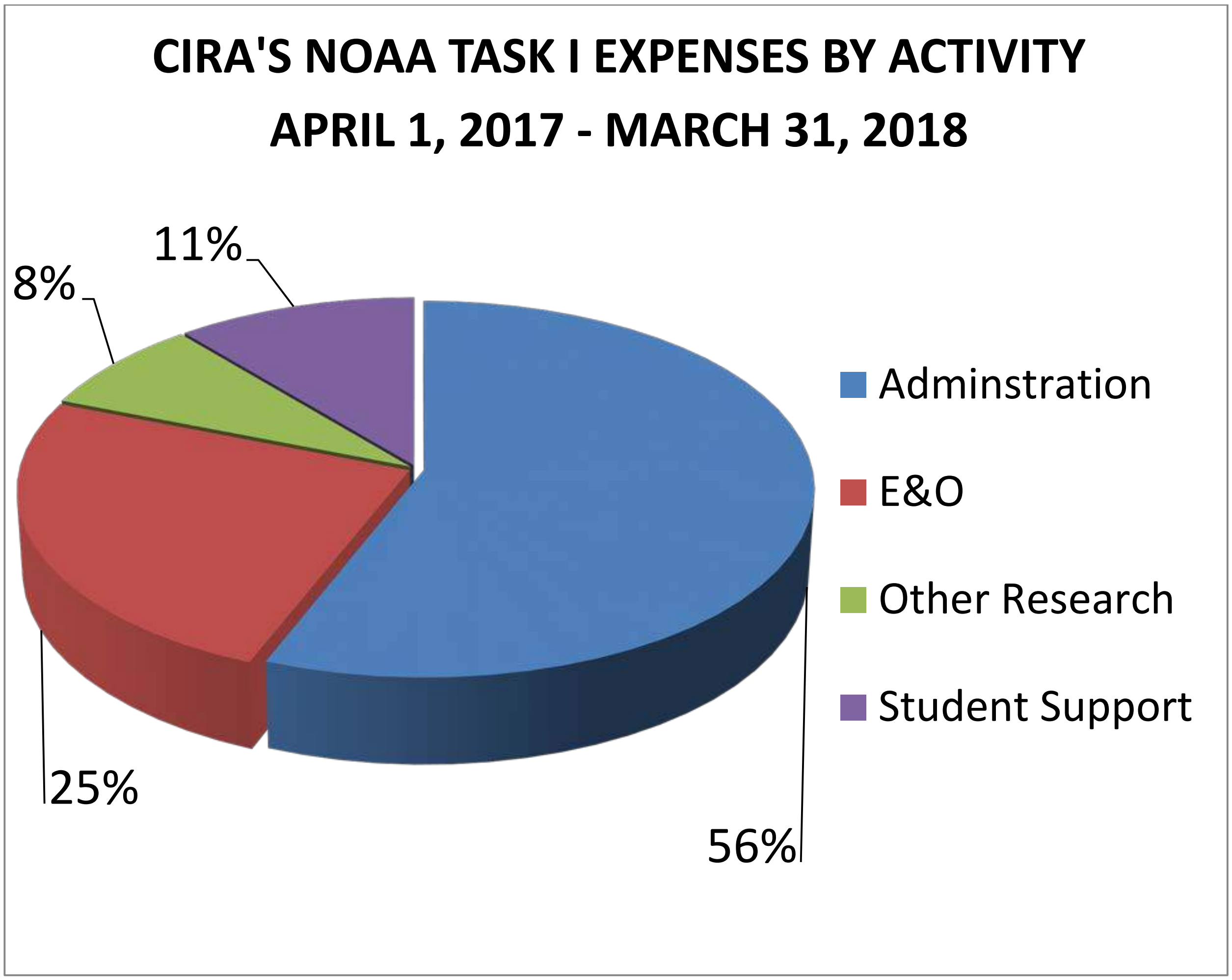
CIRA'S NOAA TASK I EXPENSES BY ACTIVITY
APRIL 1, 2017 - MARCH 31, 2018
11%
8%
25%
56%
Adminstration
E&O
Other Research
Student Support

TABLE OF CONTENTS

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Type	ID	Title	Status
Award Package	2478931	**A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts (NA14OAR4320125)**	Accepted
Special Award Condition Report	2478931	Special Award Condition Report	
Award File 0	2478815	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 1	2486219	Blended Hydrometeorological Products	Accepted
Award File 2	2487155	CIRA Support: Getting Ready for NOAA's Advanced Remote Sensing Programs	Accepted
		A Satellite Hydro-Meteorology (SHyMet) Education and Outreach Proposal	
Award File 3	2488641	CIRA Support for the JPSS Proving Ground and Risk Reduction Program: Application of JPSS Imagers and Sounders to Tropical Cyclone Track and Intensity Forecasting	Accepted
Award File 4	2491422	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 5	2489188	CIRA Support of NOAA's commitment to the Coordination Group for Meteorological Satellites: Enhancing the International Virtual Laboratory	Accepted
Award File 6	2495512	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 7	2488558	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Seeing the Light: Exploiting VIIRS Day/Night Band	Accepted
Award File 8	2489265	CIRA Support of the Virtual Institute for Satellite Integration Training (VISIT)	Accepted
Award File 9	2488553	SSMI and SSMIS Fundamental Climate Data Record Sustainment and Maintenance	Accepted
Award File 10	2489670	Algorithm development for AMSR-2	Accepted
Award File 11	2489691	Weather Satellite Data and Analysis Equipment and Support for Research Activities	Accepted
Award File 12	2489082	CIRA Support for Feature-Based Validation of MIRS Soundings for Tropical Cyclone Analysis and Forecasting	Accepted
Award File 13	2489686	Support for the 2015 JCSDA Summer Colloquium to be hosted by CIRA	Accepted
Award File 14	2489681	Applications of concurrent super rapid sampling from GOES-14 SRSOR, radar and lightning data	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 15	2486813	CIRA Support to a GOES-R Proving Ground for National Weather Service Forecaster Readiness	Accepted
Award File 16	2486808	CIRA Support for Tropical Cyclone Model Diagnostics and Product Development	Accepted
Award File 17	2488603	CIRA Support to the JPSS Science Program: S-NPP VIIRS EDR Imagery Algorithm and Validation Activities and S-NPP VIIRS Cloud Validation	Accepted
Award File 18	2489060	CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting	Accepted
Award File 19	2496525	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 20	2495520	CIRA Support to the NESDIS Cooperative Research Exchange Program	Accepted
Award File 21	2497195	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 22	2497181	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 23	2496807	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 24	2495693	EOY CIRA Support to RAMMB Infrastructure for GOES-R Rebroadcast Data Collection at CIRA/CSU	Accepted
Award File 25	2496490	NESDIS Environmental Applications Team (NEAT)	Accepted
Award File 26	2496040	Explicit Forecasts of Recurrence Intervals for Rainfall: Evaluation and Implementation Using Convection-allowing Models	Accepted
Award File 27	2495157	Building a "citizen science" soil moisture monitoring system utilizing the Community Collaborative Rain, Hail and Snow Network (CoCoRaHS)	Accepted
Award File 28	2496378	Estimating Peatland Fire Emissions Using Nighttime Satellite Data	Accepted
Award File 29	2496383	Integrating GPM and Orographic Lifting into NOAA???s QPE in Mountainous Terrain	Accepted
Award File 30	2495162	Instructional Development and Learning Support for NOAA's OMAO's Chief Learning Officer (CLO), OMAO Kansas City, Missouri	Accepted
Award File 31	2465060	CIRA Research Collaborations with the NWS Meteorological Development Lab on Virtual Laboratory, Innovation Web Portal, and AWIPS II Projects	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 32	2490588	CIRA Research Collaborations with the NWS Meteorological Development Lab on Virtual Laboratory, and AWIPS II Projects	Accepted
Award File 33	2491622	Environmental Applications Research (EAR)	Accepted
Award File 34	2491359	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program	Accepted
Award File 35	2496023	Hydrologic and Water Resources Research and Applications Outreach	Accepted
Award File 36	2501944	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 37	2514836	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program	Accepted
Award File 38	2513184	Environmental Applications Research (EAR)	Accepted
Award File 39	2515553	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 40	2522402	Environmental Applications Research (EAR)	Accepted
Award File 41	2523066	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program	Accepted
Award File 42	2524140	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 43	2526318	Environmental Applications Research (EAR)	Accepted
Award File 44	2534850	SSMI and SSMIS Fundamental Climate Data Record Sustainment and Maintenance	Accepted
Award File 45	2534835	Weather Satellite Data and Analysis Equipment and Support for Research Activities	Accepted
Award File 46	2527895	Hydrometeorological and Water Resources Research	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 47	2528844	CIRA Support to a GOES-R Proving Ground for National Weather Service Forecaster Readiness	Accepted
Award File 48	2537730	Environmental Applications Research (EAR)	Accepted
Award File 49	2529388	Blended Hydrometeorological Products	Accepted
Award File 50	2539333	Applications of Concurrent Super Rapid Sampling from GOES-14 SRSOR, Radar and Lightning Data	Accepted
Award File 51	2534840	CIRA Support to RAMMB Infrastructure for GOES-R Rebroadcast Data Collection at CIRA/CSU	Accepted
Award File 52	2537750	CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting	Accepted
Award File 53	2534845	CSU/CIRA support for ATMS SI traceable calibration effort	Accepted
Award File 54	2541040	Instructional Development and Learning Support for NOAA's OMAO's Chief Learning Officer (CLO), OMAO Kansas City, Missouri	Accepted
Award File 55	2545352	Environmental Applications Research (EAR)	Accepted
Award File 56	2544741	Environmental Applications Research (EAR)	Accepted
Award File 57	2537745	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Seeing the Light: Exploiting VIIRS Day/Night Band	Accepted
Award File 58	2543413	Expanding Precipitation Measurements in the Commonwealth Of The Bahamas through the CoCoRaHS (Community Collaborative Rain, Hail and Snow) Network	Accepted
Award File 59	2538448	JCSDA Observing System Assessment Standing Capability	Accepted
Award File 60	2539540	Enhancing NIDIS drought monitoring and early warning in the Upper Colorado River basin	Accepted
Award File 61	2540022	CIRA Support: Getting Ready for NOAA's Advanced Remote Sensing Programs. A Satellite Hydro-Meteorology (SHyMet)	Accepted
Award File 62	2543403	Tropical Cyclone Model Diagnostics and Product Development	Accepted
Award File 63	2547742	Hydrometeorological and Water Resources Research	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 64	2539141	CIRA Support to the JPSS STAR Science Program: S-NPP VIIRS EDR Imagery Algorithm and Validation Activities	Accepted
Award File 65	2546014	NESDIS Environmental Applications Team (NEAT)	Accepted
Award File 66	2543660	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Integration of JPSS Experimental Products in AWIPS II through EPDT Code Sprints	Accepted
Award File 67	2543675	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Improving NUCAPS Soundings for CONUS Severe Weather Applications via Data Fusion	Accepted
Award File 68	2543655	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Improving Tropical Cyclone Forecast Capabilities Using the JPSS Data Suite	Accepted
Award File 69	2543408	CIRA Support for Dynamical Core Selection for the Next Generation Global Prediction System (NGGPS)	Accepted
Award File 70	2543842	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: JPSS Satellite Training for NOAA Users	Accepted
Award File 71	2546556	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Addressing NWS Desires for a Cloud Cover Layers Product using Merged VIIRS and ATMS Products	Accepted
Award File 72	2542195	CIRA Support of Virtual Institute for Satellite Integration Training (VISIT)	Accepted
Award File 73	2543680	Using JPSS Retrievals to Implement a Multisensor, Synoptic, Layered Water Vapor Product for Forecasters	Accepted
Award File 74	2548421	CIRA Support to the NESDIS Cooperative Research Exchange Program	Accepted
Award File 75	2547800	CIRA Research Collaborations with the NWS Meteorological Development Lab on Virtual Laboratory, and AWIPS II Projects	Accepted
Award File 76	2551024	CIRA Research Collaborations with the NWS Meteorological Development Lab on Virtual Laboratory, and AWIPS II Projects	Accepted
Award File 77	2548825	CIRA Support for Feature-Based Validation of MIRS Soundings for Tropical Cyclone Analysis and Forecasting	Accepted
Award File 78	2549707	NESDIS Environmental Applications Team (NEAT)	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 79	2551561	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 80	2539242	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed	Accepted
Award File 81	2546546	EOY StAR Project: CIRA Support to RAMMB Infrastructure for GOES-R Rebroadcast Data Collection at CIRA/CSU	Accepted
Award File 82	2546551	CIRA Support of NOAA's commitment to the Coordination Group for Meteorological Satellites: Enhancing the International Virtual Laboratory	Accepted
Award File 83	2564667	Environmental Applications Research (EAR)	Accepted
Award File 84	2567423	Environmental Applications Research (EAR)	Accepted
Award File 85	2571981	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 86	2573606	Hydrometeorological and Water Resources Research	Accepted
Award File 87	2571970	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed	Accepted
Award File 88	2583141	Environmental Applications Research (EAR)	Accepted
Award File 89	2582313	Hydrometeorological and Water Resources Research	Accepted
Award File 90	2586202	Hydrologic and Water Resources Research and Applications Outreach	Accepted
Award File 91	2590615	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 92	2590552	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Cold Air Aloft Aviation Hazard Detection Using Observations from the JPSS Satellites and Application to the Visualization of Grid	Accepted
Award File 93	2590936	CIRA Support of NOAA's commitment to the Coordination Group for Meteorological Satellites: Enhancing the International Virtual Laboratory	Accepted
Award File 94	2590927	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 95	2590873	CIRA Support for the Organization of the 2016 Group for High Resolution Sea Surface Temperature Science Team Meeting	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 96	2590953	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 97	2596628	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 98	2590603	Using JPSS Retrievals to Implement a Multisensor, Synoptic, Layered Water Vapor Product for Forecasters	Accepted
Award File 99	2590917	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: JPSS Satellite Training for NOAA Users	Accepted
Award File 100	2596693	CIRA Research Collaborations with the NWS Meteorological Development Lab on Virtual Laboratory, and AWIPS II Projects	Accepted
Award File 101	2596624	Enhancing NIDIS Drought Monitoring and Early Warning in the Upper Colorado River Basin	Accepted
Award File 102	2591332	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Improving Tropical Cyclone Forecast Capabilities Using the JPSS Data Suite	Accepted
Award File 103	2599072	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 104	2599068	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Integration of JPSS Experimental Products in AWIPS II through EPDT Code Sprints	Accepted
Award File 105	2600008	Instructional Development and Learning Support for NOAA's OMAO's Chief Learning Officer (CLO), OMAO Kansas City, Missouri	Accepted
Award File 106	2600014	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 107	2591167	POES-GOES Blended Hydrometeorological Products	Accepted
Award File 108	2597117	CIRA Support to a GOES-R Proving Ground for National Weather Service Forecaster Readiness and Training	Accepted
Award File 109	2599057	MiRS High-Resolution Snow and Ice Products	Accepted
Award File 110	2597540	CSU/CIRA Support for ATMS SI Traceable Calibration Effort	Accepted
Award File 111	2590545	Weather Satellite Data and Analysis Equipment and Support for Research Activities	Accepted
Award File 112	2590540	CIRA Support to the JPSS STAR Science Program: S-NPP VIIRS EDR Imagery Algorithm and Validation Activities and S-NPP VIIRS Cloud Validation	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 113	2590530	CIRA Support to the JPSS Proving Ground and Risk Reduction Visiting Scientist Program	Accepted
Award File 114	2601311	Supplemental CIRA Support of the Virtual Institute for Satellite Integration Training (VISIT)	Accepted
Award File 115	2597127	ATMS Precipitable Water Algorithms and Products (MIRS)	Accepted
Award File 116	2599819	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Improving NUCAPS Soundings for CONUS Severe Weather Applications via Data Fusion	Accepted
Award File 117	2599824	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Addressing NWS Desires for a Cloud Cover Layers Product using Merged VIIRS and ATMS Products	Accepted
Award File 118	2599845	MiRS ATMS Rain-Rate and Total Precipitable Water Algorithm and Product Development	Accepted
Award File 119	2603556	Environmental Applications Research (EAR)	Accepted
Award File 120	2602575	CIRA Support to Connecting GOES-R with Rapid-Update Numerical Forecast Models for Advanced Short-Term Prediction and Data Fusion Capabilities	Accepted
Award File 121	2597513	Community Radiative Transfer Model Development and Maintenance	Accepted
Award File 122	2608626	Environmental Applications Research (EAR)	Accepted
Award File 123	2608669	Environmental Applications Research (EAR)	Accepted
Award File 124	2599838	CIRA Support for Development and Evaluation of JPSS-1 based Tropical Cyclone Intensity and Structure Estimates	Accepted
Award File 125	2601306	CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting and Training	Accepted
Award File 126	2610128	Applications of Concurrent Super Rapid Sampling from GOES-14 SRSOR, Radar and Lightning Data	Accepted
Award File 127	2608614	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program	Accepted
Award File 128	2612445	NESDIS Environmental Applications Team (NEAT)	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 129	2598905	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: In Pursuit of the Shadows: VIIRS Day/Night Band Research Enabling Scientific Advances and Expanded Operational Awareness of the Nocturnal Environment	Accepted
Award File 130	2614084	Hydrometeorological and Water Resources Research	Accepted
Award File 131	2609956	CIRA Research Collaborations with the NWS Meteorological Development Lab	Accepted
Award File 132	2601317	CIRA Support for Tropical Cyclone Model Diagnostics and Product Development	Accepted
Award File 133	2617473	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program	Accepted
Award File 134	2633736	Environmental Applications Research (EAR)	Accepted
Award File 135	2635566	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program	Accepted
Award File 136	2638062	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program	Accepted
Award File 137	2643676	Hydrometeorological and Water Resources Research	Accepted
Award File 138	2646779	Environmental Applications Research (EAR)	Accepted
Award File 139	2660722	Instructional Development and Learning Support for NOAA's OMAO's Chief Learning Officer (CLO), OMAO Kansas City, Missouri	Accepted
Award File 140	2652938	CIRA Support to the JPSS Proving Ground Risk Reduction Visiting Scientist Program	Accepted
Award File 141	2660837	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Cold Air Aloft Aviation Hazard Detection Using Observations from the JPSS Satellites and Application to the Visualization of Grid	Accepted
Award File 142	2660821	Using JPSS Retrievals to Implement a Multisensor, Synoptic, Layered Water Vapor Product for Forecasters	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 143	2660825	A Cooperative Institute to Investigate Satellite Applications for Regional/Global-Scale Forecasts	Accepted
Award File 144	2660833	CIRA Support of NOAA's commitment to the Coordination Group for Meteorological Satellites: Enhancing the International Virtual Laboratory	Accepted
Award File 145	2652928	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Improving NUCAPS Soundings for CONUS Severe Weather Applications via Data Fusion???	Accepted
Award File 146	2660817	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Improving Tropical Cyclone Forecast Capabilities Using the JPSS Data Suite	Accepted
Award File 147	2662401	Environmental Applications Research (EAR)	Accepted
Award File 148	2660829	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: JPSS Satellite Training for NOAA Users	Accepted
Award File 149	2652933	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: In Pursuit of the Shadows: VIIRS Day/Night Band Research Enabling Scientific Advances and Expanded Operational Awareness of the Noct	Accepted
Award File 150	2664181	Environmental Applications Research (EAR)	Accepted
Award File 151	2662915	CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Addressing NWS Desires for a Cloud Cover Layers Product using Merged VIIRS and ATMS Products	Accepted
Award File 152	2662910	CIRA Support for Tropical Cyclone Model Diagnostics and Product Development	Accepted
Award File 153	2664603	CIRA Research Collaborations with the NWS Meteorological Development Lab	Accepted
Award File 154	2660555	CIRA Support to a GOES-R Proving Ground for National Weather Service Forecaster Readiness and Training	Accepted
Award File 155	2665777	CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting and Training	Accepted
Award File 156	2669480	CIRA Support to Connecting GOES-R with Rapid-Update Numerical Forecast Models for Advanced Short-Term Prediction and Data Fusion Capabilities	Accepted
Award File 157	2667103	ATMS Precipitable Water Algorithms and Products (MIRS)	Accepted
Award File 158	2668358	Community Radiative Transfer Model Development and Maintenance	Accepted
Award File 159	2671304	Hydrometeorological and Water Resources Research	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 160	2669509	Joint Center for Satellite Data Assimilation (JCSDA)'s Summer Colloquium on Satellite Data Assimilation	Accepted
Award File 161	2664334	CIRA Support of Virtual Institute for Satellite Integration Training (VISIT)	Accepted
Award File 162	2671858	Environmental Applications Research (EAR)	Accepted
Award File 163	2666685	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program	Accepted
Award File 164	2671864	Environmental Applications Research (EAR)	Accepted
Award File 165	2670825	CIRA Support to the JPSS STAR Science Program: S-NPP/JPSS VIIRS EDR Imagery Algorithm and Validation Activities and S-NPP/JPSS VIIRS Cloud Validation	Accepted
Award File 166	2673925	CIRA Research Collaborations with the NWS Meteorological Development Lab	Accepted
Award File 167	2672943	CIRA Support for Development and Evaluation of JPSS-1 based Tropical Cyclone Intensity and Structure Estimates	Accepted
Award File 168	2672802	CIRA Support to RAMMB Infrastructure for GOES-S/GOES-17 Rebroadcast Data Collection at CIRA/CSU	Accepted
Award File 169	2676230	Hydrometeorological and Water Resources Research	Accepted
Award File 170	2676511	NESDIS Environmental Applications Team (NEAT)	Accepted
Award File 171	2671802	Satellite Loop Interactive Data Explorer in Real-time (SLIDER) Web Interface for the NESDIS/StAR webpage	Accepted
Award File 172	2673110	JPSS-1 Readiness for Blended Hydrometeorological Products	Accepted
Award File 173	2679026	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program	Accepted
Award File 174	2680178	Environmental Applications Research (EAR)	Accepted
Award File 175	2674682	CIRA Support to: Upgrade to the multiplatform satellite tropical cyclone surface wind analysis product	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 176	2678960	Enhancing NIDIS drought monitoring and early warning in the Intermountain West	Accepted
Award File 177	2678264	Development and Maintenance of MIRS	Accepted
Award File 178	2679761	CIRA Internship Program in Data Assimilation	Accepted
Award File 179	2678579	CSU/CIRA support for ATMS SI traceable calibration effort	Accepted
Award File 180	2678752	Weather Satellite Data and Analysis Equipment and Support for Research Activities	Accepted
Award File 181	2700764	Environmental Applications Research (EAR)	Accepted
Award File 182	2701788	Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program	Accepted
Award File 183	2707883	Hydrometeorological and Water Resources Research	Accepted
Award Package	2614337	**Accounting for Non-Gaussianity in the Background Error Distributions Associated with Cloud-related Variables (Microwave Radiances and Hydrometeors) in Hybrid Data Assimilation for Convective-scale Pre (NA16OAR4590233)**	Accepted
Special Award Condition Report	2614337	Special Award Condition Report	
Award File 0	2611931	Accounting for Non-Gaussianity in the Background Error Distributions Associated with Cloud-related Variables (Microwave Radiances and Hydrometeors) in Hybrid Data Assimilation for Convective-scale Pre (NA16OAR4590233)	Accepted
Award Package	2674460	**Aerosol Size Distribution and Composition Evolution during FIREX Activities: Closure Analyses and Climate Impacts (NA17OAR4310001)**	Accepted
Special Award Condition Report	2674460	Special Award Condition Report	
Award File 0	2585984	Aerosol size distribution and composition evolution during FIREX activities: closure analyses and climate impacts	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award Package	2614326	**Assimilation of Lake and Reservoir Levels into the WRF-Hydro National Water Model to Improve Operational Hydrologic Predictions (NA16OAR4590237)**	Accepted
Special Award Condition Report	2614326	Special Award Condition Report	
Award File 0	2611956	Assimilation of Lake and Reservoir Levels into the WRF-Hydro National Water Model to Improve Operational Hydrologic Predictions	Accepted
Award Package	2603839	**Collaborative Research: Assessing Oceanic Predictability Sources for MJO Propagation (NA16OAR4310094)**	Accepted
Special Award Condition Report	2603839	Special Award Condition Report	
Award File 0	2590660	Collaborative Research: Assessing Oceanic Predictability Sources for MJO Propagation	Accepted
Award File 1	2640935	Collaborative Research: Assessing Oceanic Predictability Sources for MJO Propagation	Accepted
Award File 2	2702630	Collaborative Research: Assessing Oceanic Predictability Sources for MJO Propagation	Accepted
Award Package	2667734	**Comparison of Model Versus Observationally-Driven Water Vapor Profiles for Forecasting Heavy Precipitation Events (NA17OAR4590121)**	Accepted
Special Award Condition Report	2667734	Special Award Condition Report	
Award File 0	2663774	Comparison of Model Versus Observationally-Driven Water Vapor Profiles for Forecasting Heavy Precipitation Events	Accepted
Award Package	2538850	**Development of a Framework for Process-Oriented Diagnosis of Global Models (NA15OAR4310099)**	Accepted
Special Award Condition Report	2538850	Special Award Condition Report	
Award File 0	2538327	Development of a Framework for Process-Oriented Diagnosis of Global Models	Accepted
Award File 1	2582795	Development of a Framework for Process-Oriented Diagnosis of Global Models	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award File 2	2640565	Development of a Framework for Process-Oriented Diagnosis of Global Models	Accepted
Award Package	2667760	**Evaluating Stochastic Physics Approaches Within Select Convection Allowing Model (CAM) Members Included in the Community Leveraged Unified Ensemble (CLUE) During the Hazardous Weather Testbed (HWT) (NA17OAR4590118)**	Accepted
Special Award Condition Report	2667760	Special Award Condition Report	
Award File 0	2664760	Evaluating stochastic physics approaches within select Convection Allowing Model (CAM) members included in the Community Leveraged Unified Ensemble (CLUE) during the Hazardous Weather Testbed (HWT)	Accepted
Award Package	2494494	**Following Emissions from Non-Traditional Oil and Gas Development Through their Impact on Tropospheric Ozone (NA14OAR4310148)**	Accepted
Special Award Condition Report	2494494	Special Award Condition Report	
Award File 0	2481822	Following Emissions from Non-Traditional Oil and Gas Development Through their Impact on Tropospheric Ozone	Accepted
Award File 1	2523977	Following Emissions from Non-Traditional Oil and Gas Development Through their Impact on Tropospheric Ozone	Accepted
Award File 2	2562067	Following Emissions from Non-Traditional Oil and Gas Development Through their Impact on Tropospheric Ozone	Accepted
Award Package	2603816	**Forecasting North Pacific Blocking and Atmospheric River Probabilities: Sensitivity to Model Physics and the MJO (NA16OAR4310064)**	Accepted
Special Award Condition Report	2603816	Special Award Condition Report	
Award File 0	2590675	Forecasting North Pacific Blocking and Atmospheric River Probabilities: Sensitivity to Model Physics and the MJO	Accepted
Award File 1	2640965	Forecasting North Pacific Blocking and Atmospheric River Probabilities: Sensitivity to Model Physics and the MJO	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award Package	2608726	**Implementation and Testing of Lognormal Humidity and Cloud-related Control Variables for the NCEP GSI Hybrid EnVar Assimilation Scheme (NA16NWS4680012)**	Accepted
Special Award Condition Report	2608726	Special Award Condition Report	
Award File 0	2600908	Implementation and testing of lognormal humidity and cloud-related control variables for the NCEP GSI hybrid EnVar assimilation scheme	Accepted
Award File 1	2632678	Implementation and testing of lognormal humidity and cloud-related control variables for the NCEP GSI hybrid EnVar assimilation scheme	Accepted
Award File 2	2640565	Development of a Framework for Process-Oriented Diagnosis of Global Models	Accepted
Award Package	2547895	**Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models (NA15OAR4310204)**	Accepted
Special Award Condition Report	2547895	Special Award Condition Report	
Award File 0	2545703	Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models	Accepted
Award File 1	2605978	Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models	Accepted
Award Package	2667738	**Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors (NA17OAR4590138)**	Accepted
Special Award Condition Report	2667738	Special Award Condition Report	
Award File 0	2665256	Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors	Accepted
Award File 1	2685530	Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors	Accepted
Award File 2	2686103	Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award Package	2548857	**Improvement to the Tropical Cyclone Genesis Index (TCGI) (NA15OAR4590202)**	Accepted
Special Award Condition Report	2548857	Special Award Condition Report	
Award File 0	2545733	Improvement to the Tropical Cyclone Genesis Index (TCGI)	Accepted
Award File 1	2606709	Improvement to the Tropical Cyclone Genesis Index (TCGI)	Accepted
Award Package	2614345	**Improving Probabilistic Forecasts of Extreme Rainfall through Intelligent Processing of High-resolution Ensemble Predictions (NA16OAR4590238)**	Accepted
Special Award Condition Report	2614345	Special Award Condition Report	
Award File 0	2611891	Improving probabilistic forecasts of extreme rainfall through intelligent processing of high-resolution ensemble predictions	Accepted
Award Package	2612424	**Improving Understanding and Prediction of Concurrent Tornadoes and Flash Floods with Numerical Models and VORTEX-SE Observations (NA16OAR4590215)**	Accepted
Special Award Condition Report	2612424	Special Award Condition Report	
Award File 0	2611614	Improving understanding and prediction of concurrent tornadoes and flash floods with numerical models and VORTEX-SE observations	Accepted
Award Package	2603828	**Investigating the Underlying Mechanisms and Predictability of the MJO ??? NAM Linkage in the NMME Phase-2 Models (NA16OAR4310090)**	Accepted
Special Award Condition Report	2603828	Special Award Condition Report	
Award File 0	2590690	Investigating the Underlying Mechanisms and Predictability of the MJO ??? NAM Linkage in the NMME Phase-2 Models	Accepted
Award File 1	2641219	Investigating the Underlying Mechanisms and Predictability of the MJO ??? NAM Linkage in the NMME Phase-2 Models	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award Package	2673817	**Modeling the Complex and Dynamic Evolution of Organic Aerosol in Biomass Burning Plumes (NA17OAR4310003)**	Accepted
Special Award Condition Report	2673817	Special Award Condition Report	
Award File 0	2586004	Modeling the complex and dynamic evolution of organic aerosol in biomass burning plumes	Accepted
Award File 1	2702579	Modeling the complex and dynamic evolution of organic aerosol in biomass burning plumes	Accepted
Award Package	2673800	**Near-field Characterization of Biomass Burning Plumes (NA17OAR4310010)**	Accepted
Special Award Condition Report	2673800	Special Award Condition Report	
Award File 0	2586069	Near-field characterization of biomass burning plumes	Accepted
Award Package	2495278	**Observational Constraints on the Mechanisms that Control size- and Chemistry-resolved Aerosol Fluxes Over a Colorado Forest (NA14OAR4310141)**	Accepted
Special Award Condition Report	2495278	Special Award Condition Report	
Award File 0	2481792	Observational constraints on the mechanisms that control size- and chemistry-resolved aerosol fluxes over a Colorado forest	Accepted
Award File 1	2523653	Observational constraints on the mechanisms that control size- and chemistry-resolved aerosol fluxes over a Colorado forest	Accepted
Award File 2	2562129	Observational constraints on the mechanisms that control size- and chemistry-resolved aerosol fluxes over a Colorado forest	Accepted
Award Package	2614341	**Quantifying Stochastic Forcing at Convective Scales (NA16OAR4590230)**	Accepted
Special Award Condition Report	2614341	Special Award Condition Report	
Award File 0	2611921	Quantifying Stochastic Forcing at Convective Scales	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award Package	2535274	**Reactive Nitrogen Biogeochemical Cycling in the GFDL Earth System Models: Advancing Understanding of Atmosphere-land Interactions Under Changing Climate and Land Use (NA15OAR4310066)**	Accepted
Special Award Condition Report	2535274	Special Award Condition Report	
Award File 0	2526272	Reactive Nitrogen Biogeochemical Cycling in the GFDL Earth System Models: Advancing Understanding of Atmosphere-land Interactions Under Changing Climate and Land Use	Accepted
Award File 1	2562039	Reactive Nitrogen Biogeochemical Cycling in the GFDL Earth System Models: Advancing Understanding of Atmosphere-land Interactions Under Changing Climate and Land Use	Accepted
Award File 2	2629033	Reactive Nitrogen Biogeochemical Cycling in the GFDL Earth System Models: Advancing Understanding of Atmosphere-land Interactions Under Changing Climate and Land Use	Accepted
Award Package	2437319	**Towards Assimilation of Satellite, Aircraft, and Other Upper-air CO2 Data into CarbonTracker (NA13OAR4310077)**	Accepted
Special Award Condition Report	2437319	Special Award Condition Report	
Award File 0	2428619	Towards Assimilation of Satellite, Aircraft, and Other Upper-air CO2 Data into CarbonTracker	Accepted
Award File 1	2464196	Towards Assimilation of Satellite, Aircraft, and Other Upper-air CO2 Data into CarbonTracker	Accepted
Award File 2	2526909	Towards Assimilation of Satellite, Aircraft, and Other Upper-air CO2 Data into CarbonTracker	Accepted
Award File 3	2641293	Towards Assimilation of Satellite, Aircraft, and Other Upper-air CO2 Data into CarbonTracker	Accepted
Award File 4	2677844	Towards Assimilation of Satellite, Aircraft, and Other Upper-air CO2 Data into CarbonTracker	Accepted

NOAA AWARD NUMBERS & AMENDMENTS FOR REPORT PROJECTS

Award Package	2671520	**Use of the Stochastic-dynamic Approach in a Single Dynamic-Core Storm-Scale Ensemble for Improved Spread and Reliability of QPF and Surface Variables (NA17OAR4590181)**	Accepted
Special Award Condition Report	2671520	Special Award Condition Report	
Award File 0	2669883	Use of the Stochastic-dynamic Approach in a Single Dynamic-Core Storm-Scale Ensemble for Improved Spread and Reliability of QPF and Surface Variables	Accepted

AWARDS ENDING PROJECT LIST

NA14OAR4830122	Competitive	Assimilation of Moisture and Precipitation Observations in Cloudy Regions of Hurricane Inner Core Environments to Improve Hurricane Intensity, Structure and Precipitation	Milija Zupanski
NA14OAR4830166	Competitive-Sandy	Sensing Hazards with Operational Unmanned Technology (SHOUT), Data Management and Visualization	Sher Schranz
NA14OAR4830167	Competitive-Sandy	NOAA's Observing System Experiments and Observing System Simulation Experiments in support of the SHOUT Program	Sher Schranz
NA13OAR4310163	Competitive	Use of the Ocean-Land-Atmosphere Model (OLAM) with Cloud System-Resolving Refined Local Mesh to Study MJO Initiation.	Eric Maloney
NA15OAR4590152	Competitive	Assessment of Gridded Hydrological Modeling for NWS Flash Flood Operations	Lynn Johnson
NA15OAR4590200	Competitive	Improvement and Implementation of the Probability-based Microwave Ring Rapid Intensification Index for NHC/JTWC Forecast Basins	Kate Musgrave
NA13OAR4310080	Competitive	Improving Carbon Tracker Flux Estimate for North	Ian Baker

RESEARCH THEME REPORTS

SATELLITE ALGORITHM DEVELOPMENT, TRAINING & EDUCATION

Research associated with development of satellite-based algorithms for weather forecasting, with emphasis on regional and mesoscale meteorological phenomenon. This work includes applications of basic satellite products such as feature track winds, thermodynamic retrievals, sea surface temperature, etc., in combination with model analyses and forecasts, as well as in situ and other remote sensing observations. Applications can be for current or future satellites. Also under this theme, satellite and related training material will be developed and delivered to a wide variety of users, with emphasis on operational forecasters. A variety of techniques can be used, including distance learning methods, web-based demonstration projects and instructor-led training.

PROJECT TITLE: ATMS Precipitable Water Algorithms and Products (MIRS) - Blended Hydrometeorology Products Validation

PRINCIPAL INVESTIGATOR: John Forsythe

RESEARCH TEAM: Stan Kidder, Andy Jones

NOAA TECHNICAL CONTACT: Limin Zhao (NOAA/NESDIS/OSPO)

NOAA RESEARCH TEAM: Limin Zhao (NOAA/NESDIS/OSPO), Ralph Ferraro (NOAA/NESDIS/STAR)

FISCAL YEAR FUNDING: $61,828

PROJECT OBJECTIVES:

This project began in October 2017 and has the goal of monitoring and validating the NESDIS operational blended hydrometeorology products. The three operational products are:

1--Blended Total Precipitable Water (TPW)
2--Blended TPW Anomaly (percent of normal)
3--Blended Rain Rate (RR)

In this year, the focus is on S-NPP and the recently available NOAA-20 products. Blended products use a wide variety of satellites including the NOAA, Metop, DMSP series of spacecraft along with the S-NPP, GCOM-W and GPM satellites. GOES-15 and surface-based GPS data are also used in the operational blended TPW product. The backbone retrieval system is the NOAA Microwave Integrated Retrieval System (MiRS).

The final blended products are monitored as a whole, as this is what forecasters see, as well as on a per sensor basis. Supporting NESDIS to ensure timely delivery of high-quality blended satellite hydrometeorology products to forecasters is the overall goal of the project. Toward this end, CIRA and NESDIS participate in biweekly teleconferences to discuss the project.

PROJECT ACCOMPLISHMENTS:

Continued maintenance of the near-realtime data ingest processes at CIRA is required to shadow the NOAA operational production and troubleshoot any anomalies. Processes to ingest polar satellite data at CIRA are being transitioned from the heritage DDS system to the PDA system. Near-realtime ingest of MiRS retrievals via PDA was completed in late February 2018.

Figure 1 shows a comparison of the blended TPW product created at CIRA using MiRS Version 07 (the current operational version) versus Version 11, which is likely to supersede V07 later in 2018. Improved performance of V11 is indicated versus the GPS surface data in the RMS and bias errors. GPS surface data is considered a high-quality validation source.

The effect of precipitation flagging on retrievals was investigated, both for V07 and V11 MiRS. Improperly screened retrievals can manifest themselves as erroneously high TPW values, which can mislead a forecaster. While rare, this can potentially impact high-impact weather forecasts such as for a cyclone off the east coast of the U.S. CIRA delivered a software module to NESDIS which can flag retrievals based on a user-specified rain rate threshold in addition to the quality flags provided in MiRS. Comparisons between V07 and V11 MiRS TPW retrievals indicate that V11 has improved rain rate flagging from the product quality control flags, and additional thresholding does not currently appear to be necessary.

The Algorithm Theoretical Basis Documents (ATBDs) for operational blended rain rate and blended TPW were updated by CIRA and delivered to OSPO. These updates were needed as the sensor constellation and retrieval package continues to evolve. The new ATBD's now reflect the state of the blended products as of February 2018.

Feb. 8, 2018 24 hourly TPW composites   MiRS V11 has less error

Sample	N	RMS V07 (mm)	RMS V11 (mm)	BIAS V07 (mm)	BIAS V11 (mm)
All Surfaces	2390	5.6	4.7	3.8	2.5
Ocean in MiRS	93	4.3	4.2	2.0	1.5
Land > 10 mm	1260	6.2	5.6	4.4	3.4

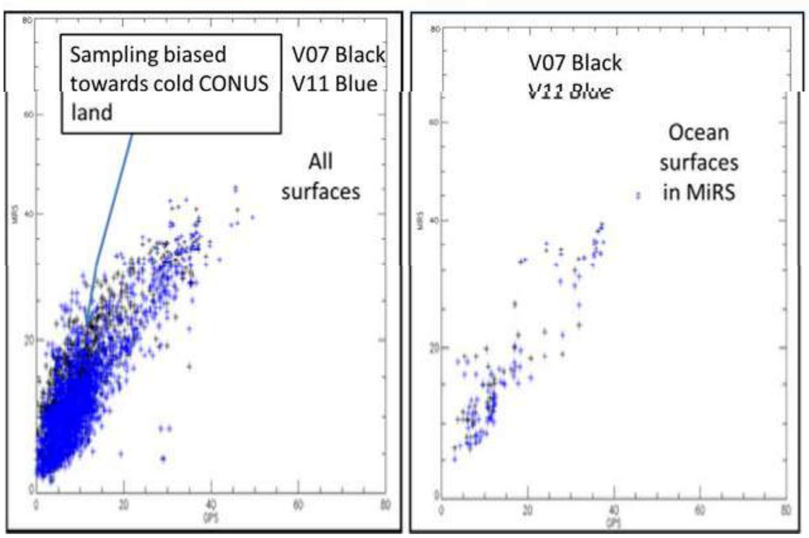

Figure 1. Comparison of MiRS Version 07 (current operational version) and MiRS Version 11 (future operational version) versus GPS TPW measurements in the CONUS region. All metrics for Version 11 show less error versus the gps validation.

Publications: None

Presentations: None

PROJECT TITLE: A GOES-R Proving Ground for National Weather Forecaster Readiness and Training

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Steve Miller, Dan Bikos, Rosemary Borger, Renate Brummer, Galina Chirokova, Bernadette Connell, Erin Dagg, Robert DeMaria, Kathy Fryer, Hiro Gosden, Lewis Grasso, Kevin Micke, Andrea Schumacher, Curtis Seaman, Stephanie Stevenson, Ed Szoke, Dave Watson

NOAA TECHNICAL CONTACT: Satya Kalluri/ Jeff Key (NOAA/NESDIS/StAR)
Steve Goodman/ Dan Lindsey (NOAA/NEDSIS/GOESR-Program Office)
Mark DeMaria (NOAA/NWS/NHC)

NOAA RESEARCH TEAM: Donald Hillger, John Knaff, Dan Lindsey, Deb Molenar (NOAA/NESDIS/StAR)
Tony Mostek and Brian Motta (NOAA/NWS)

FISCAL YEAR FUNDING: $709,667

PROJECT OBJECTIVES:

Since its inception in 2008, NOAA's GOES-R Proving Ground (PG) has played a central role in familiarizing forecasters and operational users of GOES-16 data with the new capabilities of the Advanced Baseline Imager (ABI) and the Geostationary Lightning Mapper (GLM). Traditionally, the most relevant forms of information used for PG demonstrations have been imagery from polar-orbiting satellites (e.g., the MODerate-resolution Imaging Spectroradiometer (MODIS) on Terra and Aqua, and the Visible/Infrared Imaging Radiometer Suite (VIIRS) on Suomi National Polar-orbiting Partnership), or else 'synthetic ABI imagery' based on Numerical Weather Prediction (NWP) models run through forward radiative transfer operators. While valuable in terms of illustrating information content and building training materials, the polar products provide limited temporal resolution. Similarly, while synthetic imagery enables replication of ABI space/time resolution, it is predicated on the NWP information and thus does not represent actual observation data that can be used to confront model forecasts. Despite these limitations, the PG has provided a powerful conduit for coupling NOAA's research and operational communities. In addition to establishing familiarity with GOES-R, PG has established a human interface and rapport that will serve the program for years.

CIRA's involvement in the NOAA GOES-R Proving Ground (PG) over the past year emphasized the demonstration of PG Baseline Products and CIRA-developed Display Aid products based on GOES-16 data. To do so, CIRA worked very closely with the Satellite PG Liaisons and continued to leverage existing capabilities within the organization to develop and demonstrate selected GOES-16 satellite applications (based in part on interactions with users who have articulated their operational needs) and to provide associated training (including SHyMet and VLAB training) and experience directly to NWS forecasters through ongoing support of the Proving Ground project. GOES-16 products were demonstrated at NWS Weather Forecast Offices (WFOs) and many different National Centers.

As part of a nationally distributed team of Proving Ground algorithm developers and subject matter experts, CIRA continued to work in collaboration with the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison, the NASA Short-term Prediction Research and Transition (SPoRT) Center located in Huntsville, Alabama, and various operational forecasting partners involved in Proving Ground product usage and evaluation. Emphasis was on 1) very close collaboration with the GOES-R Satellite Liaisons and 2) demonstrating all GOES-16 products within AWIPS II and, where appropriate, N-AWIPS.

Nearly all CIRA PG products are made available in real-time on the CIRA web page at http://rammb.cira.colostate.edu/ramsdis/online/goes-r_proving_ground.asp. The web page provides much information on each of the CIRA Proving Ground (PG) products, includes the developer and point of contact as well as a concise but informative "Product Description" that details how the product is made, why it is a PG product, and how it can be used in operations.   Real-time CIRA products are also available on CIRA's web application SLIDER at: http://rammb-slider.cira.colostate.edu/

This GOESR Proving Ground project supported the following NOAA mission goals: Weather and Water, Commerce and Transportation and Climate. Enhanced training also prepared the forecaster/manager on how to utilize imagery and products to provide services in these areas.

This annual GOES-R Proving Ground and Training report covers CIRA Proving Ground activities conducted in the following areas:

1-GOESR Proving Ground Activities -- CIRA Meteorological Satellite Application Group
2-GOESR Proving Ground Activities -- CIRA Tropical Cyclone Group
3-GOESR Proving Ground Activities -- CIRA Training Team
4-GOESR Proving Ground Activities -- NHC Liaison Activities
5-GOESR Proving Ground Activities – NHC Miami Liaison Activities
6-Satellite Hydro-Meteorology (SHyMet) Education and Outreach Activities
7-NOAA's GOES-R PG commitment to the Coordination Group for Meteorological Satellites: Enhancing the International Virtual Laboratory (VLaB)

Project 1—GOES-R Proving Ground Activities -- CIRA Meteorological Satellite Application Group

PROJECT OBJECTIVES:

As part of the GOES-R Proving Ground over the past years, CIRA has demonstrated many future capability and experimental products. Up to this point, the data for the products has involved proxy data from polar orbiting satellite instruments, model simulations, or through the use of the Himawari-8 Advanced Himawari Imager (AHI). During this reporting period we were in the position to use real GOES-16 ABI data in the production and demonstration of these various products to users. The GOESR Proving Ground gave us the opportunity to demonstrate and evaluate a variety of CIRA GOES-16 products. See the following section for which products were demonstrated.
Note – no product development was conducted under this project funding.

PROJECT ACCOMPLISHMENTS:

1--GOES-16 ABI True Color/GeoColor Evaluation and Demonstration
Under a GOESR Risk Reduction grant, CIRA/RAMMB scientists developed an algorithm that allows for the generation of ABI true color imagery in spite of the lack of a green band on ABI. An approach based on correlation between green and blue/red/near-IR (865-nm) bands, developed from AHI, produces a 'Synthetic' green band for GOES-R ABI, enabling true color imagery. An additional adjustment was necessary to its 510-nm band to provide more sensitivity to green vegetation. The novel 'Hybrid, Atmospherically Corrected' (HAC) adjustment to the native AHI green band provided an effective solution. The definition of the full Synthetic/Hybrid Atmospherically Corrected (SHAC) green band allowed for the generation of a GOES-R ABI true color imagery—the first of its kind since NASA's Applications Technology Satellite-3 in 1967. This true color algorithm was used to produce NOAA's GOES-16 First Light Imagery (released in late January 2017) and it received overwhelming praise. CIRA has been contacted by agencies throughout the international satellite community related to its processing of high-quality true color, which is widely regarded as the most 'user friendly' form of imagery which requires minimal training and high information content on myriad atmospheric and surface parameters for situational awareness. As an extension of true color (a daytime only product), GeoColor has emerged as a very popular Decision Aid product for operational forecasters. This blended multi-sensor value-added imagery product utilizes the Advanced Baseline Imager (ABI) sensor (VIS and IR) combined with complementary data from the Visible/Infrared Imager/Radiometer Suite (VIIRS). The GeoColor technique provides a simple yet visually powerful mechanism for transitioning seamlessly between multiple sources of information both in the vertical and horizontal dimensions. Under the hood of the GeoColor algorithm itself, dynamic scaling factors provide the flexibility to adjust the relative strength of transparency in both space and time dimensions (i.e., providing control over the amount of information retained/lost during the

blending operation). This technique results in dramatic improvement to the presentation quality of standard visible and infrared satellite imagery. CIRA's SHAC True color imagery described above is being used for the daytime portion of GeoColor, and the nighttime portion includes low cloud/fog detection and nocturnal city lights from the VIIRS Day/Night Band. The CIRA Proving Ground emphasis during this past year focused on the demonstration of the GOES-16 ABI GeoColor product. Developed under GOES-R Risk Reduction funding, the Proving Ground allowed for this very popular Decision Aid product to be converted to the appropriate formats for display in AWIPS-II and NAWIPS and to be demonstrated and evaluated by operational forecasters. Within this past year, the GOES-16 ABI GeoColor product quickly became very popular at NWS WFOs, NWS Regional Offices and National Centers. It can also be found frequently on the NESDIS/StAR home page, like on 28 August 2017 when Hurricane Harvey hit the Texas coast https://www.star.nesdis.noaa.gov/star/news2017_201708_HarveyGOES16.php
And is being used by NESDIS News & Articles, like in July 2017, when NESDIS chose to depict a GOES-16 GeoColor night imagery over Peru and Bolivia showing strong convection over those countries (http://campaign.r20.constantcontact.com/render?m=1120935055224&ca=20c24bba-5635-491e-84c5-b95a90511f79)

GeoColor mentioning can be found in AFDs, like for example:

```
Area Forecast Discussion
National Weather Service Denver/Boulder CO
934 AM MST Fri Feb 2 2018
.SHORT TERM...(Today and tonight)
Issued at 426 AM MST Fri Feb 2 2018

Areas of fog exist from the northern sections of Denver northward
to Fort Collins and Greeley area. Most of this so far has been
rather patchy, but also persistent over the northeastern sections
of Denver with the light wind regime. GOES Geocolor product also
showing this area of fog/stratus quite nicely with thin enough high clouds.
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The CIRA GeoColor gets frequently feedback from NWS WFO forecasters who think very highly of this product. On 14 September 2017, Bryan Ruby, Information Technology Officer at the NWS WFO Sioux Fall, South Dakota, summarized his experience with using GeoColor in the following tweet:
"@CIRA_CSU NOAA GOES-16 Geocolor (CIRA) in AWIPS II is freaking awesome"

David Zaff, WFO BUF commented on the GeoColor:
"Kudos to your staff on the GeoColor. It's an amazing product…"

On 6 February 2018, Michael Stroz (NWS/ WFO Satellite Focal Point) sent the following email to Satellite Liaison Chad Gravelle:
From: Michael Stroz - NOAA Federal <michael.stroz@noaa.gov>
Date: Tuesday, February 6, 2018 at 9:51 AM
To: Chad Gravelle <chad.gravelle@noaa.gov>
Since we installed the GEOcolor product in our office a few weeks ago it quickly became one of the most popular satellite products.

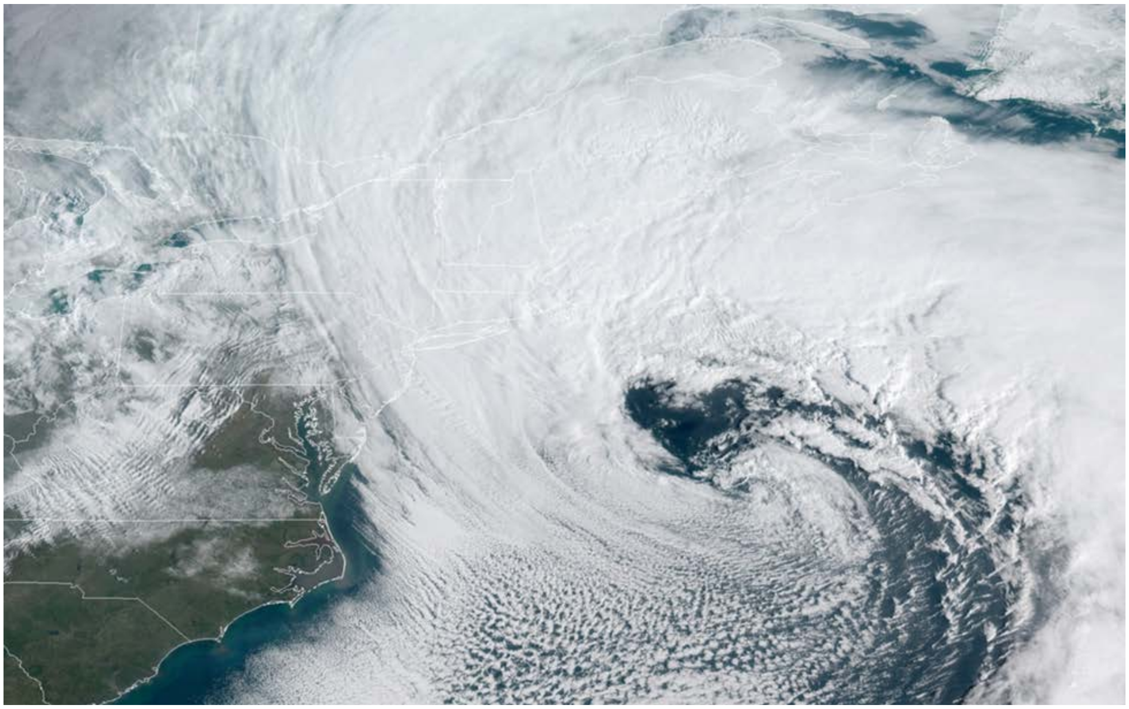


Figure 1. Example of the GOES-16 ABI GeoColor imagery (13:12 UTC on 13 March 2018): GeoColor depicting the third major winter storm hitting the North-Eastern United States within two weeks.

GOES-16 GeoColor imagery is also frequently used by NWS forecasters to highlight smoke events. During a heavy wildfire smoke event over the western part of the USA on 4 September 2017, NWS WFO Boulder forecaster David Barjenbruch generated a set of slides with GOES-16 GeoColor imagery clearly showing the smoke plumes over Colorado (see mentioning under the CIRA Training Proving Ground activities). David Barjenbruch sent CIRA an email stating:

From: David Barjenbruch - NOAA Federal <david.barjenbruch@noaa.gov>
Date: Wed, Sep 6, 2017 at 7:13 AM
"**The GeoColor has really been doing a great job with regard to visualizing the smoke! Really like that."**

GOES-16 GeoColor has proven to also be really great for dust detection over the Atlantic. On 17 October 2017, it depicted a big dust layer moving its way across the Atlantic today. Once GOES-16 moved to GOES-E the perspective got even much better.

As a result of CIRA's Proving Ground interaction with the NHC and AWC, the GeoColor color table was changed to represent the low clouds in blue instead of in pink. Mark DeMaria (NHC), Amenda Terborg and Chad Gravelle (both AWC) appreciated this change with positive feedback.

CIRA's close collaboration with Satellite Liaison Michael Folmer (NOAA/NWS WPC/OPC/TAFB and NOAA/NESDIS SAB) resulted in a fix to a GeoColor Center Point Error problem in December 2017.

The CIRA GeoColor team interacted with many WFO's regarding the product (too many to be listed here), answering questions about the algorithm, about City Lights, about resolutions. These interactions are the essence of our Proving Ground activities and help us to make the product even better.

The success of the GeoColor product resulted in a strong request for this product to be available for all WFOs. David B. Radell, Techniques Development Meteorologist, Scientific Services Division/STI at NOAA/NWS/Eastern Region Headquarters sent out an email in February 2018, informing Eastern Region

WFOs that: “We have the GOES-16 GeoColor data. Please contact me offline if you're interested in bringing it in locally. There will be a nationally led evaluation of this product to assess operational use starting very soon. Chad Gravelle of NWS/OPG is leading that effort. I expect offices that are pulling in the data to participate and provide feedback for this evaluation.”

2--Snow/Cloud Discrimination Product Evaluation and Demonstration

Under the GOESR Risk Reduction funding for the “DEAR-ABII Project”, two versions of the daytime VIIRS Cloud/Snow Discriminator algorithm have successfully been developed for GOES-16 ABI: a “binary” discriminator that highlights all clouds in yellow and snow and ice in white, and a “high/low” discriminator that colors clouds by height, with yellow low clouds, orange mid-level clouds, and magenta high clouds. The product is intended to augment the baseline RGB snow discrimination product by communicating the information at the native resolution of the sensor, and may be appealing to some forecasters for basic delineation between snow and cloud. This product complements the ABI Level 2 cloud products as it allows the human analyst to compare and contrast over complex scenes to complete the picture of when you're viewing, clouds, snow, or even clouds over snow in some cases. Forecasters at the WFO Cheyenne (CYS) have found the products to be useful (e.g., snow cover influences overnight low temperatures) as an evaluation tool. Coupled with other information, it can contribute toward a decision aid for locating regions of possible blowing snow across highways—a major forecasting challenge to WFO CYS during the winter season. As part of the CIRA Proving Ground activities, this product was moved over in March 2018 into CIRA’s SLIDER-demo webtool, where it is available in near-real-time. We are in the initial stages of adapting this protocol for porting the Cloud/Snow Discriminator product to AWIPS/NAWIPS which will allow for many more WFOs to test and evaluate this product during the next winter season, and –most importantly- to give feedback to the CIRA Proving Ground Team about the product.

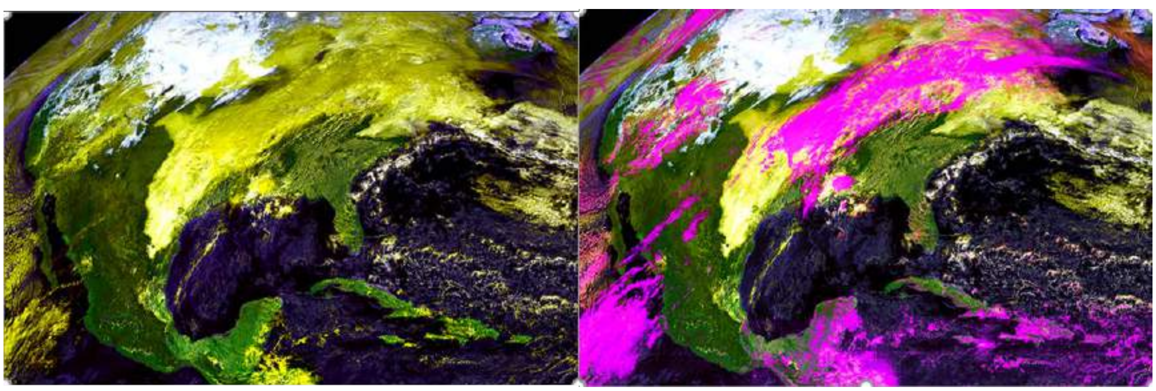


Figure 2. The Cloud/Snow Discriminator in “binary” (left) and “high/low” (right) versions for the GOES-16 CONUS domain (18:17 UTC 23 February 2018).

3--DEBRA Dust Product Evaluation and Demonstration

The Dynamic Enhancement Back-ground Reduction Algorithm (DEBRA) is a multispectral satellite imagery product designed to suppress false alarms in parameters of interest over land. Its primary application has been toward the detection of lofted dust. The algorithm works by comparing the current scene against a clear sky background reference to determine the likelihood that dust is present. The higher the confidence that dust is present, the stronger the DEBRA index. This index is used to modify conventional visible/infrared imagery to colorize regions of high confidence for the presence of dust. The algorithm utilizes physically-based dust detection tests bands based on 8.7, 10.8, and 12.0 μm spectral differences, and enlists additional bands for cloud masking and quality control. The brightness of DEBRA colorized pixels (e.g., yellow = dust) maps to its confidence factor [0-1]. The end-result is enhanced imagery at native sensor resolution which retains the meteorological context of the scene (oftentimes very important for understanding the nature of the lofting event and predicting its motion through complex terrain). The background subtraction minimizes false alarms, and the simplified display (only enhancing the parameter of interest) greatly simplifies training requirements. GOESR3 funding was used to adapt the DEBRA algorithm for GOES-16 ABI. Under the Proving Ground DEBA was made available to the

Aviation Weather Center(AWC) which is particularly interested in evaluating DEBRA in connection with strong dust events across the southwestern/central U.S. We are in the initial stages of getting this product into AWIPS/NAWIPS, which will then allow for testing and evaluation by operational forecasters, like the forecasters at the AWC.

4--GOES-16 Split Window Difference Product Evaluation and Demonstration
A newly funded CIRA GOES-R Risk Reduction proposal involves research into exploiting the GOES-16 ABI 10.4-12.3 µm "split window difference" to provide information about low-level water vapor convergence in the absence of clouds. This information provides focal points for monitoring the pre-convective environment. As part of our Proving Ground activities we created appropriate color tables for the GOES-R 10.35-12.3 µm ABI channel difference and made the product available in AWIPS-2. The AWIPS-2 information was distributed to the NWS Virtual Lab for inclusion in a subsequent Red Hat Package Manager (RPM). In addition, a training webinar has been developed on this subject under the VISIT program and delivered to NWS forecasters. The Split Window Difference Product will now be evaluated at several Central Region WFOs and at the Storm Prediction Center. The product will also be evaluated as part of SPC's HWT in spring of 2018.

5--GOES-16 Cloud Cover & Layers Product Evaluation and Demonstration
A newly funded GOES-R Risk Reduction proposal at CIRA involves improving Andy Heidinger's Future Capability Product Cloud Cover & Layers using a number of innovative techniques. Specifically, the layer of cloud below the topmost layer is often missed by the current version of the algorithm. When it is detectable, the geometric distance between the upper and lower layers is not known. The new techniques introduced by this research will attempt to provide new information in both circumstances, leading to improved geometric profile information useful for aviation. CIRA began converting this product to the necessary formats for evaluation at various NWS National Centers, including the AWC, and WFOs. This product is now being evaluated and demonstrated as part of our Proving Ground activities. It is also displayed in real-time within CIRA's SLIDER web application tool.

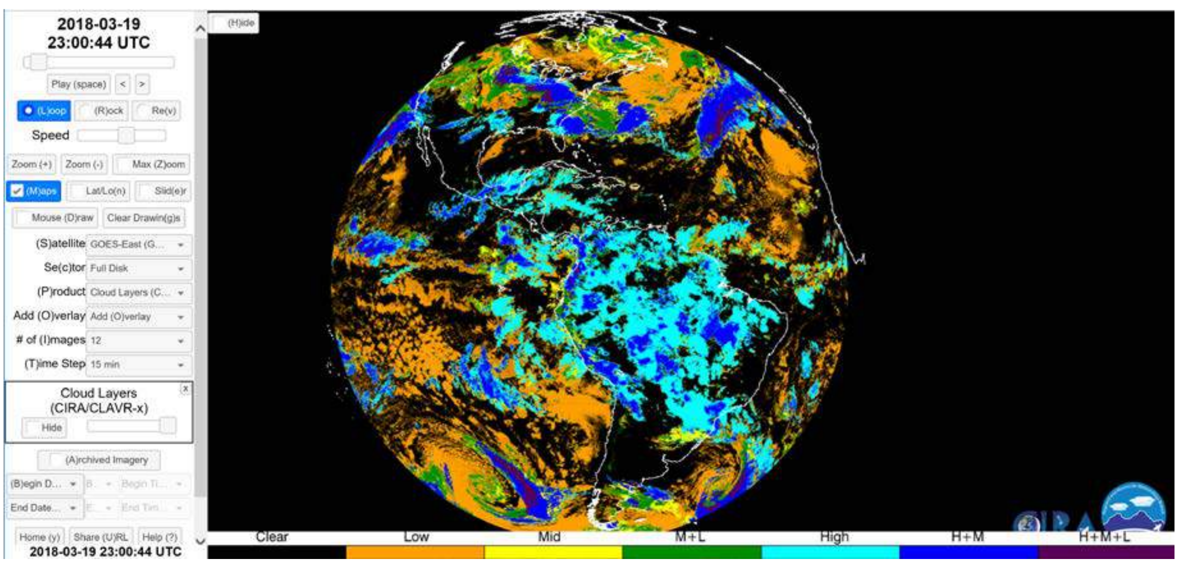


Figure 3. CIRA/CLAVR-x Cloud Layers product within SLIDER showing a GOES-16 ABI full disk image from 19 March 2018 23:00 UTC.

6--ABI-Infused Blended Total Precipitable Water Product Evaluation and Demonstration
This is another newly funded GOES-R Risk Reduction proposal at CIRA which involves incorporating GOES-16 information into the operational Blended Total Precipitable Water (TPW) product.
As reported under the GOESR Risk Reduction annual report, a near-real-time website, http://cat.cira.colostate.edu/ABI_TPW/ABI_TPW.htm, has been created using the CIRA ingest to animate the remapped CONUS sector TPW. The successful remapping of the GOES-16 TPW data with the CIRA Data Processing and Error Analysis (DPEAS) system, is a critical link to future R2O success as it is also

the operational system running at NESDIS OSPO which produces operational blended TPW. As soon as that newly improved product has reached sufficient maturity, the conversions will be made into the necessary AWIPS II and NAWIPS formats, and the CIRA Proving Ground will assist in the product's evaluation during spring of 2018 and in the following year.

7--Synthetic Satellite Imagery from NWP Evaluation and Demonstration
With the availability of real-time GOES-16 data, we no longer need to simulate the data for use as proxy data for algorithm development and forecaster training. However, the strength of the Synthetic Imagery created from real-time high resolution numerical models has proven to be the visualization of cloud/water vapor forecast imagery as depicted in the models vis-à-vis reality. Imagery animations that start out with real-time GOES-16 observation and morph into the synthetic forecast imagery allow the forecaster to judge the quality of the forecast as well. For this reason, CIRA is continuing to create synthetic imagery in real time and providing it to the NWS, as many offices have come to rely on it in their daily operations for model quality control. This demonstration falls under the CIRA Proving Ground activities.

<u>Project 2—GOES-R Proving Ground Activities -- CIRA Tropical Cyclone Group</u>

2.1--Tropical Cyclone Team - Tropical Contributions

PROJECT OBJECTIVES:

1--Continue to make lightning-based TC Rapid Intensification Index (RII) available for the 2016 NHC PG demonstration
2--Convert Simulated True Color Imagery to N-AWIPS format and deliver to NHC
3--Convert DEBRA-Dust product to N-AWIPS format and deliver to NHC
4--Convert proxy-visible imagery to N-AWIPS and AWIPS2 format and display in real-time at CIRA.
5--Provide proxy visible imagery in N-AWIPS format to NHC via LDM.
6--Create online training module for proxy-visible imagery, train NHC forecasters on use, and collect forecaster feedback.

PROJECT ACCOMPLISHMENTS:

1--CIRA has continued to run the experimental lightning-based TC RII year-round and display output text files on its public ftp site: ftp://rammftp.cira.colostate.edu/demaria/NHCPG. CIRA did experience a disruption in its WWLLN input data feed starting in July 2017, but has since resumed receiving near-real-time WWLLN data and has filled in all data gaps. As result of the data disruption, the lightning-based RII will be rerun for the Atlantic and N. E. Pacific basins for 2017 and updated output data will be posted by June 2018.

2--Simulated True Color Imagery (i.e., the CIRA Geocolor product) is now being routinely delivered in real-time to NHC in N-AWIPS format.

3--Scientists have begun work to convert DEBRA-Dust to N-AWIPS format. Once this is complete, this product will be provided to NHC via the LDM (similar to how the GeoColor product is being delivered).

4--Proxy visible imagery has been successfully converted to N-AWIPS format at CIRA. The AWIPS2 format is currently under development, and is expected to be completed by June 2018. Proxy visible imagery is being displayed in real-time on an internal CIRA website that will be made public in March 2018 (http://ramb-slider.cira.colostate.edu).

5--CIRA has been providing NHC with near-real-time proxy-visible imager in N-AWIPS format since December 2017. Since then, NHC has been using proxy-visible operationally as a replacement for the GOES-13 legacy Ch2-Ch4 difference.

6--Training slides on proxy-visible imagery have been provided to NHC. Further onsite training will be conducted via a presentation at the 2017 NHC Proving Ground Meeting on 7 March 2018. Feedback has been collected from NHC forecasters from both the Hurricane Specialist Unit and Tropical Analysis and Forecasting Branch. Feedback was positive, indicating that the proxy visible imagery will be of use in identifying low clouds, fog, and dust/smoke at night.

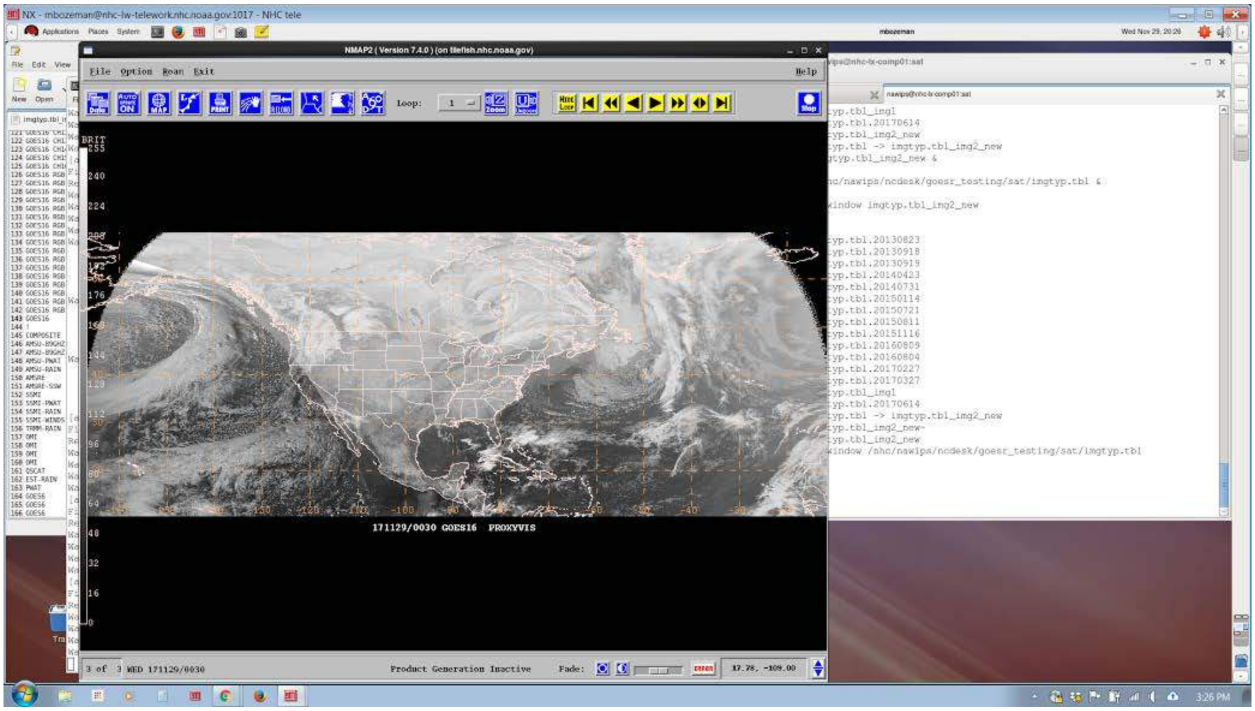


Figure 4. Proxy visible imagery, as displayed at the National Hurricane Center (N-AWIPS2).

2.2--Tropical Cyclone Team - Pacific Region Contributions

PROJECT OBJECTIVES:

1--Continue to make lightning-based TC Rapid Intensification Index (RII) available for the Pacific Regions
2--Convert proxy-visible imagery to N-AWIPS and AWIPS2 format and display in real-time at CIRA.
3--Provide N-AWIPS proxy visible imagery to Central Pacific Hurricane Center (CPHC) and AWIPS2 imagery to Pacific WFOs. Also, potentially provide AWIPS2 imagery to the Joint Typhoon Warning Center (JTWC).
4--Create online training module for proxy-visible imagery, train Pacific Region forecasters on use, and collect forecaster feedback.

PROJECT ACCOMPLISHMENTS:

1--CIRA has continued to run the experimental lightning-based TC RII year-round and display output text files on its public ftp site: ftp://rammftp.cira.colostate.edu/demaria/NHCPG. CIRA did experience a disruption in its WWLLN input data feed starting in July 2017, but has since resumed receiving near-real-time WWLLN data and has filled in all data gaps. As result of the data disruption, the lightning-based RII will be rerun for the N.W. Pacific basin for 2017 and updated output data will be posted by June 2018.

2--Proxy visible imagery has been successfully converted to N-AWIPS format at CIRA. The AWIPS2 format is currently under development, and is expected to be completed by June 2018. Proxy visible imagery is being displayed in real-time on an internal CIRA website that will be made public in March 2018 (http://ramb-slider.cira.colostate.edu).

3--As discussed above, proxy visible imagery has been converted in N-AWIPS format but has yet to be converted to AWIPS2 format. Work is underway to coordinate with the Central Pacific Hurricane Center to provide proxy-visible imagery in N-AWIPS format. Once proxy-visible imagery has been converted to AWIPS2 format, it will be provided to Pacific WFOs.

4--In October 2017 Kate Musgrave (CIRA) travelled to Honolulu, HI to conduct training and present CIRA products, including proxy-visible imagery, at the Joint Typhoon Warning Center (JTWC) and Central Pacific Hurricane Center (CPHC). Proxy visible imagery received most attention from forecasters. JTWC expressed interest in running proxy-visible on their system. Forecaster feedback will be collected once 3 is complete and forecasters have the opportunity to view the data on their operational workstations.

Project 3—GOES-R Proving Ground Activities -- CIRA Training Team

With GOES-R becoming operational as GOES-16 during the last fiscal year there was a large amount of Proving Ground demonstrations of new products while all the new imagery bands and baseline products were stabilized in AWIPS II. A great deal of new information was introduced to NWS forecasters and CIRA played an important role in this through their involvement in official training and ongoing updates to the initial training, planning and coordinating bi-weekly webinars and writing online blogs highlighting aspects of GOES-16 applications in various weather events.

PROJECT OBJECTIVES:

Distribute and improve (if requested) a suite of WFO PG Decision Aid products.

1--Continue close collaborations with local partner WFOs Boulder and Cheyenne
2--Continue general support of participating WFOs that receive CIRA PG products
3--Continue to collect and evaluate forecaster product feedback
4--Continue to refine and improve PG products as a result of forecaster feedback
5--Work closely with the GOES-R Satellite Liaisons to help establish product usage opportunities, collect formal feedback for products where appropriate, and to introduce and evaluate new products as they become available.

PROJECT ACCOMPLISHMENTS:

This specific project involves demonstrating potential new products and Decision Aids at WFOs through the Proving Ground. CIRA staff helped with the important activity of monitoring the flow of all the new satellite channels and baseline products into AWIPS II, particularly at our neighboring WFOs in Boulder and Cheyenne. Specifically, we evaluated forecaster use and understanding of baseline products and imagery, as well as any other issues and concerns from forecasters as they used the new data (for example, image quality, any issues with color tables, etc.). We also participated in WFO workshops at Cheyenne and Boulder where we could further learn of forecaster concerns while also introducing some of the new products that CIRA would be able to demonstrate in the future. CIRA's Proving Ground WFO Liaison Ed Szoke also worked occasional forecast shifts at the Boulder WFO in order to get a further appreciation for any issues with the new imagery and baseline products and using them in the forecast process. On a broader level we attended and presented at conferences that operational forecasters frequent, including the National Weather Association (NWA) Annual Meeting. These are invaluable for establishing new contacts and interest in potential products that CIRA can offer.

One of our original and popular CIRA Proving Ground products that we were able to demonstrate during the past year with GOES-16 is GeoColor imagery. Some of the WFOs that had been receiving this imagery as a demonstration product before GOES-16 were interested in having it in AWIPS II using GOES-16. We coordinated with NWS management to initially have a 15-minute updating version of the product in order to make sure it was stable in distribution and display on AWIPS II. After a period of testing the full 5-minute updating version was able to be distributed. A GOES-16 webinar presentation on GeoColor spurred interest in the product from a number of WFOs. Additional WFOs have become interested through contact with neighboring WFOs, or seeing it presented at conferences that we have attended. We continue to gather feedback on GeoColor via email, AFDs (Area Forecast Discussions), blogs, training, shift logs, and verbal feedback. Feedback has been overwhelmingly positive and the long term goal would be to have GeoColor become a baseline product.

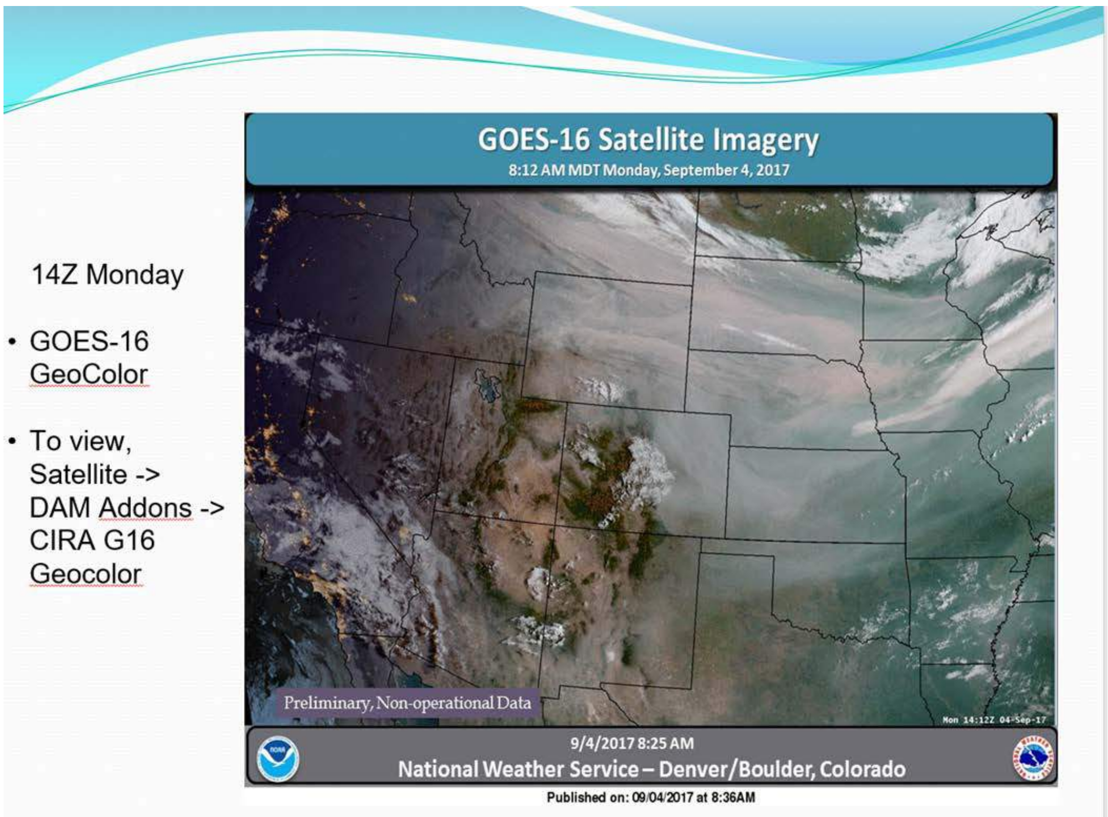


Figure 5. A power point slide showing CIRA/RAMMB's GOES-16 Geocolor product was composed and used by forecaster Dave Barjenbruch from the NWS WFO Boulder Office for a special WFO forecaster briefing on a strong wildfire smoke event over Colorado on 4 September 2017. Brown smoke plumes crossing a large part of the North-Western US are clearly depicted by the GeoColor imagery.

Other products that have been demonstrated in the past with MODIS and other data, specifically Snow/Cloud discrimination imagery and Blowing dust products will become available to WFOs using GOES-16 (and eventually GOES-17) over the coming year, with WFOs already identified for initial distribution.

In addition, we continued to distribute Synthetic Imagery (from the NSSL WRF-ARW and the CONUS NAM and Alaska Nests). Also Total Lightning pseudo-GLM products to the Boulder and Cheyenne WFOs using the Colorado LMA (in coordination with Steve Rutledge of CSU Atmospheric Science, and Geoffrey Stano of NASA/SPoRT).

During this reporting period CIRA's PG Team continued to coordinate our PG WFO activities with WFO Satellite Liaison Chad Gravelle. We participated in bi-monthly telecons with the Satellite Liaisons, and participated in Satellite Liaison meetings as scheduled.

Blogs supporting our CIRA Proving Ground Training Activities:
http://rammb.cira.colostate.edu/research/goes-r/proving_ground/blog/
http://rammb.cira.colostate.edu/training/visit/blog/

Project 4—GOES-R Proving Ground Activities -- NHC Liaison Activities

PROJECT OBJECTIVES:

1--Participate in PG-related meetings, workshops, conference calls, and training as required (Note: Required travel should not exceed 5 trips per year, with at least 3 of those trips being visits to NHC)

2--Coordinate with developers, training staff, NHC Satellite Focal Points, and other Satellite Liaisons to develop and deliver training on GOES-R demonstration products, as needed

3--Assist with development of annual NHC Proving Ground Demonstration Plan

4--Collect feedback from NHC and TAFB forecasters during the NHC Proving Ground Demonstration period (August - November)

5--Organize annual Proving Ground review (either remote or in-person)

6--Prepare annual NHC PG report

7--Approximately 20% of the NHC Satellite Liaison's time may be spent on GOES-R and/or JPSS-related research activities. This research time includes analyses, presenting results at scientific conferences, and preparing manuscripts for publication.

PROJECT ACCOMPLISHMENTS:

1--Participated actively in numerous PG-related calls, meetings, and workshops. Visited NHC 4 times during this period (in June, August, and November of 2017 and March 2018) to observe forecasters using GOES-16 products during hurricane operations and to obtain post-season feedback.

2--Taught the Tropical Applications segment of the COMET GOES-R Faculty Course on 6 September 2017. The course recording is available online at https://www.meted.ucar.edu/training_module.php?id=1311#.WnCuu6inF9N, and currently has a 5-star rating with 60 ratings. Also co-taught a session at the GOES-R Short Course at the 2018 AMS Annual Meeting.

3--The 2018 GOES-16 NHC PG Demonstration Plan was completed and turned into D. Lindsey on 2/22/18.

4--During this time period, feedback was collected mainly via an online form and during onsite visits to NHC. This feedback was used to develop several GOES-16 CMI Use Cases and will be documented in the 2017 NHC PG Final Report.

5--The 2017 NHC PG Review will be held on 7 March 2018 at NHC.

6--The 2017 NHC PG Final Report is currently being written and will be finalized shortly after the 2017 NHC PG Review on 7 March 2018.

7--Since this was the first year demonstrating actual GOES-16 data in operations, very little Liaison time was spent on research activities this year. Did attend the AMS Annual Meeting in Austin TX from 1/7-1/12 2018 and gave 3 separate presentations on GOES-16 NHC PG activities. Also gave an invited talk on GOES-R and the 2017 Hurricane Season at the Denver/Boulder Chapter of the AMS (12/7/17).

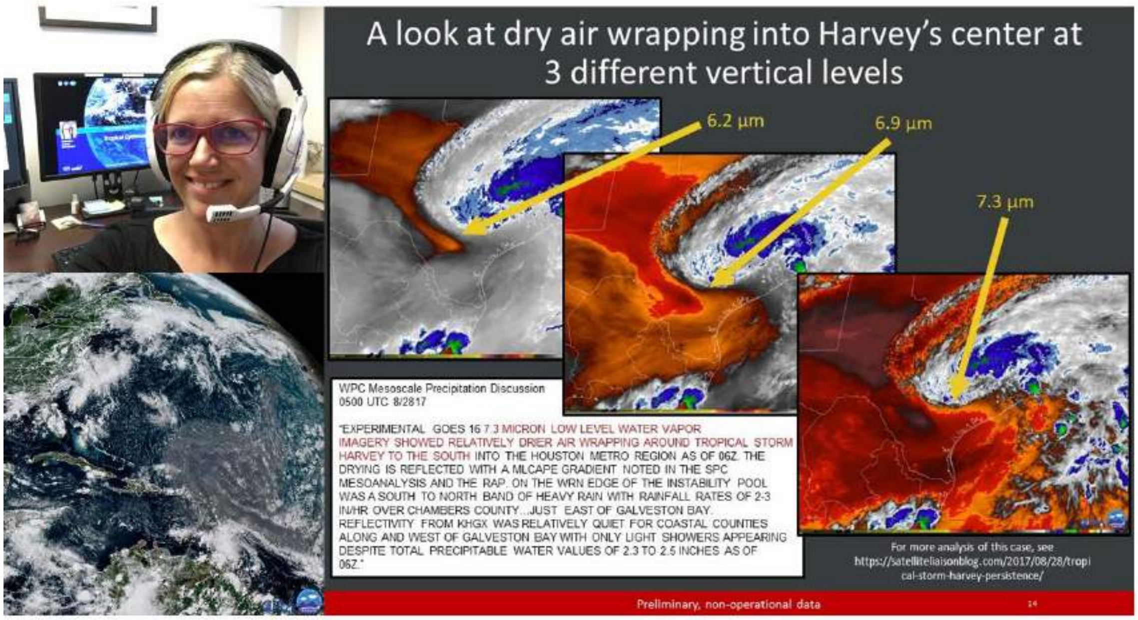


Figure 6. NHC Liaison A. Schumacher teaching on online COMET Faculty course on GOES-16 Tropical Capability (left top), CIRA GOES-16 GeoColor imagery during dusk outbreak over the Atlantic in June 2017 (left bottom), and imagery of 2017's Hurricane Harvey from the 3 GOES-16 water vapor channels.

Project 5—GOES-R Proving Ground Activities – NHC Miami Liaison Activities

PROJECT OBJECTIVES:

1--Work with the current CIRA-based NHC GOES-R Satellite Liaison to coordinate with NHC users, program managers, and product developers at NESDIS, CIRA, CIMSS, and NASA/SPoRT.

2--Work with NHC's TSB and researchers in the JHT and HFIP to improve existing multiplatform products through the incorporation of GOES-R data.

3--Work closely with HRD to develop and display tropical cyclone products that combine aircraft and satellite data.

4--Approximately 20% of researcher's time may be spent on GOES-R and/or JPSS-related research activities. This research time includes analyses, presenting results at scientific conferences, and preparing manuscripts for publication.

PROJECT ACCOMPLISHMENTS:

1--Worked with NESDIS/CIRA to develop a rectilinear McIDAS reader for GOES-16 ABI data. Also met with CIMSS colleagues during a Satellite Bootcamp in Madison, WI to discuss some of the product development they are interested in.

2--Modified the current Statistical Hurricane Intensity Prediction Scheme (SHIPS) code that runs on the NHC/NCEP operational system WCOSS to accommodate new GOES-16 ABI data, as well as fixed the IR computational errors from previous years. To accomplish this task, two GOES-16 IR channels (10.3 um and 11.2 um) were compared with GOES-13 IR channel (10.7 um) to find a suitable replacement.

3--Discussions on the data formats for ingesting NOAA WP-3D radar plan views and cross sections into AWIPS-2 have begun. Met with the data team at HRD and invited them to an AWIPS-2 training sessions in April to be help by NHC's TSB to facilitate a path forward on displaying HRD's aircraft data.

4--Active research on the GOES-16 GLM data in tropical cyclones is being conducted. Contributed to a manuscript written by Dr. Fierro (listed below) on GLM data use during the intensification of Hurricane Maria. Addition research is ongoing to test the impact of GLM vs. WWLLN data in the Rapid Intensification Index (RII).

Project 6--Satellite Hydro-Meteorology (SHyMet) Education and Outreach

The overall objective of the Satellite Hydrology and Meteorology (SHyMet) program is to develop and deliver comprehensive distance-learning courses on satellite hydrology and meteorology, in particular for the enhanced capabilities of the newly launched Geostationary Operational Environmental Satellites (GOES): GOES-R/16 (16 November 2016) and GOES-S/17 (1 March 2018). The development of training materials is an ongoing process that includes establishing foundational materials, providing applications training to ensure relevancy of products and usage in the forecast process, and encouraging continued use and deeper understanding of imagery and products over time. The Satellite Foundations Course for the GOES series (SatFC-G) was released in November of 2016. To follow on the foundational training of SatFC-G, efforts this past year included development of quick guides, quick briefs, webinars, and blogs highlighting applications of new imagery and products. This project leverages the structure of the Virtual Institute for Satellite Integration Training (VISIT) program but is distinct in that VISIT focuses on individual training modules, while SHyMet organizes modules into courses. This work was done in close collaboration with experts at CIRA, the Cooperative Institute for Meteorological Satellite Studies (CIMSS), the Short-term Prediction Research and Transition Center (SPoRT), the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), COMET, satellite liaisons, the NOAA Satellite Training Advisory Team (STAT), and the National Weather Service (NWS) Office of the Chief Learning Officer (OCLO) which includes the Training Center (NWSTC), the Warning Decision Training Division (WDTD), and the Forecast Decision Training Division (FDTD).

PROJECT OBJECTIVES:

1--Interact with CIMSS, NWS OCLO (FDTD, WDTD, and NWSTC), satellite liaisons, GOES-R and JPSS Satellite Proving Ground Partners and the Program Offices, COMET, SPoRT, CIMMS, and groups external to the US including the WMO VLab to meet high priority GOES-R training for user readiness. This includes participating in conference calls: STAT team (weekly), COMET (monthly), GOES-R/JPSS Proving Ground (quarterly)
2--Provide partial support for the creation of applications based content for the SatFC-G course; maintain the SHyMet Satellite Foundation Course for GOES-R/16 web pages for users external to NOAA; maintain and track metrics for the SatFC-G and the existing four SHyMet courses: Intern, Forecaster, Tropical, and Severe Thunderstorm.
3-- Contribute GOES and GOES-R content to blogs, to the VISIT Satellite Chat (interactive Webinar sessions), and monitor and respond to questions and comments proposed through the NWS VLab "satellite help desk" forum. The materials that are presented align with NWS Satellite Training plan to highlight use of new GOES-R/16 satellite imagery in recent significant weather events.
These activities were done in collaboration with the VISIT team.
4-- Attend meteorological and educational conferences and symposiums as the opportunities arise to present materials related to SHyMet/GOES-R and to actively solicit user needs from the community.

PROJECT ACCOMPLISHMENTS:

1--Interact with CIMSS, NWS OCLO (FDTD, WDTD, and NWSTC), satellite liaisons, GOES-R and JPSS Satellite Proving Ground Partners and the Program Offices, COMET, SPoRT, CIMMS, and groups external to the US including the WMO VLab to meet high priority GOES-R training for user readiness. This included participating in conference calls: STAT team (weekly), COMET (monthly), GOES-R/JPSS Proving Ground (quarterly)

-During the past year, high emphasis was put on developing content for the Level 2 applications aspects for the GOES-R series satellites. The organization of this required weekly participation in STAT calls to report on: 1) progress of obtaining and displaying Advanced Baseline Imagery (ABI), baseline products, and RGB composites correctly in AWIPS-II and the Weather Event Simulator (WES), 2) quick guide and quick brief creation, 3) subject matter expert review, 4) NWS Science and Operations Officer (SOO) review, 5) content revision, and 6) publishing the final version to the web page. The calls also served as a means to address related content and example availability issues that arose during the process. Both the SHyMet and VISIT programs were leveraged for this activity. The following objective provides more information on the content created.

2--Provide partial support for the creation of applications based content for the SatFC-G course; maintain the SHyMet Satellite Foundation Course for GOES-R/16 web pages for users external to NOAA; maintain and track metrics for the SatFC-G and the existing four SHyMet courses: Intern, Forecaster, Tropical, and Severe Thunderstorm. The VISIT program was leveraged for this activity.

- Applications based content developed at CIRA in collaboration with the VISIT project includes:

Quick Guides (2 page documents available for forecaster reference via a tool on their AWIPS II system) completed:
- Total Precipitable Water (TPW) Baseline Product
- Day Land Cloud Convection RGB
- Day Cloud Phase Distinction RGB

Quick Briefs (5 video highlighting image and product applications) completed:
- Creating new color enhancements in AWIPS
- Satellite Color Tables: Ranges
- Color table defaults in AWIPS
- Infrared satellite enhancement
- AWIPS remapping, scales, and spatial resolution
- Total Precipitable Water (TPW) Baseline Product

Quick Guides in Progress:
- Day Snow/Fog RGB
- SO_2 RGB
- Sea Surface Temperature Product

Content is available: http://rammb.cira.colostate.edu/training/visit/quick_reference.asp

The following five SHyMet courses continue to be administered:
-- The SHyMet NWS Satellite Foundational Course for GOES-R series (SatFC-G) contains 37 short training modules to bring forecasters, the scientific community, and others up-to-date on the capabilities of the GOES-R series satellites. This series of satellites introduces a variety of new and improved capabilities compared to previous GOES satellites. Topics include an introduction to the GOES-R series that highlights improved spatial and temporal resolution and additional new channels that will be available. This is followed by products and imagery that address a broad range of applications. This course was administered to NOAA through their Commerce Learn Center (CLC) Learning Management

System (LMS). Since the CLC LMS is not open to external users, the course was also made available through the SHyMet web pages http://rammb.cira.colostate.edu/training/shymet/satfc-g_intro.asp
-- The SHyMet *Intern* course touches on Geostationary and Polar orbiting satellite basics (areal coverage and image frequency), identification of atmospheric and surface phenomena, and provides examples of the integration of meteorological techniques with satellite observing capabilities. (http://rammb.cira.colostate.edu/training/shymet/intern_intro.asp).
This is the most popular of the older 4 courses.
-- The SHyMet for *Forecaster* course covers satellite imagery interpretation and feature identification, water vapor channels, remote sensing applications for hydrometeorology, aviation hazards, and what to expect on future satellites. http://rammb.cira.colostate.edu/training/shymet/forecaster_intro.asp
--The *Tropical* track http://rammb.cira.colostate.edu/training/shymet/tropical_intro.asp of the SHyMet Course covers satellite imagery interpretation and application of satellite derived products in the tropics as well as the models used at NHC for tropical cyclone forecasting.
-- The *Severe* Thunderstorm Forecasting Course
http://rammb.cira.colostate.edu/training/shymet/severe_intro.asp
covers how to integrate satellite imagery interpretation with other datasets in analyzing severe thunderstorm events.

Table 1 below reflects tracking *external* to the NOAA CLC LMS for the SatFC-G but includes both NOAA and external users for the Intern, Forecaster, Tropical, and Severe Courses. We know from previous experience with tracking metrics that not all users will register to take the course and of those that register, not all those that complete the course materials will let us know. The first 6 modules of the SatFC-G were used as background reading materials for 2 courses that were administered this past summer for the International community. For comparison of course completions, the NOAA CLC LMS recorded over 15,000 individual module completions representing more than 400 SatFC-G course completions during the same time period.

Table 1. Registrations and Completions for the newer SatFC-G and existing SHyMet Courses.

SHyMet Course	Total since debut		March 2017 - Feb 2018		Course Debut
	Registrations	Completions	Registrations	Completions	
SatFC-G (external to NOAA LMS)	128	19	20 US 40 International 7 unknown	3 US 14 International	December 2016
Intern	534	392	17	9	April 2006
Forecaster	74	46	1	0	January 2010
Tropical	46	22	1	0	August 2010
Severe	68	40	3	0	March 2011

3--Contribute GOES and GOES-R content to blogs, to the VISIT Satellite Chat (interactive Webinar sessions), and monitor and respond to questions and comments proposed through the NWS VLab "satellite help desk" forum. The materials that are presented align with NWS Satellite Training plan to highlight use of new GOES-R/16 satellite imagery in recent significant weather events. These activities were done in tandem with VISIT activities.

--The blog is intended to open the doors of communication between the Operational, Academic and Training Meteorology communities. The blog averages around 360 views per month and is located here: http://rammb.cira.colostate.edu/training/visit/blog/. There were 51 blog entries during the time period of interest with topics that focus on operational applications of GOES-16 and JPSS imagery and products.

In April 2017, the VISIT Satellite Chat sessions were renamed to "FDTD GOES-16 Applications Webinar" to shift the focus and increase their visibility. The webinars were coordinated with the Forecast Decision Training Division (FDTD) and were led by NOAA/NWS staff. This approach promotes peer to peer

(SOOs or forecasters training other SOOs or forecasters) learning. SHyMet/VISIT staff collaborated with CIMSS to develop a power point template and coordinated with presenters to focus on operational usage of GOES-16. Webinars were recorded and are available at http://rammb.cira.colostate.edu/training/visit/satellite_chat/

Webinar topics included GOES-16 operational applications for convective initiation, heavy snow events, wildfires, fog/low stratus, hail swaths, blowing dust and flooding. Imagery and products demonstrated from the ABI include single band, band difference products, RGB products, and lightning data from the GLM. In the past year, 19 webinars were delivered with a total of 332 office participations (average 17 offices per webinar).

Figure 7. Topics and presenters for the 7 March (left) and 7 February (right) 2018 FDTD GOES-6 Applications Webinars.

A satellite help desk exists in the NOAA Virtual Lab. So far the activity through the help desk has been light. We will continue to monitor it. http://rammb.cira.colostate.edu/training/visit/helpdesk.asp

4--Attend meteorological and educational conferences and symposiums as the opportunities arise to present materials related to SHyMet/GOES-R and to actively solicit user needs from the community.

--See the presentations listed below. The SatFC-G was actively promoted to the Academic and International communities in presentations at conferences and in two workshops.

<u>WORKSHOPS (Development and delivery of materials and presentations)</u>

AmeriGEOSS workshop "Training on Satellite Data: Access through GEONETCast Americas, Display, Interpretation, and Usage", 31 July - 4 August 2017, University of Costa Rica, San José, Costa Rica.

WMO/NOAA VLab Train the Trainer workshop on “Satellite Data Usage: Access through GEONETCast Americas, Display, Interpretation, and Usage in Training”, 15-16 July 2017, The City College of New York, New York, NY.

--Community Outreach at CIRA/Atmospheric Sciences/Colorado State University: B. Connell, E. Dagg, and A. Schumacher volunteered for the inaugural “Colorado Weatherfest” on Saturday, 24 June 2017. CIRA led a hands-on demonstration of how to interpret the red, green, and blue components of a camera picture and put them together to create a color image. The SLIDER software was used to show the near “true color” current images from GOES-16. The event was hosted by the Northern Colorado Chapter of the AMS (FORTCAST) and featured hands-on activities and demonstrations from the CSU Department of Atmospheric Sciences, the National Weather Service in Boulder, the CSU Little Shop of Physics, the Colorado Climate Center, Ball Aerospace, and others.

--Community Outreach at NOAA in Boulder: --E. Szoke gave a weather talk to 4 visiting classes during “8th Grade Science Days” on 17 and 19 October 2017. Another weather talk was given to a visiting 5th Grade class on 2 November 2017.

Project 7--NOAA's GOES-R PG commitment to the Coordination Group for Meteorological Satellites: Enhancing the International Virtual Laboratory (VLaB)

PROJECT OBJECTIVES:

The World Meteorological Organization (WMO) Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) is a collaborative effort joining major operational satellite operators across the globe with WMO regional training centers of excellence in satellite meteorology. Those regional training centers serve as the satellite-focused training resource for WMO Members. Through its cooperative institute for Research in the Atmosphere (CIRA) at Colorado State University (CSU), NOAA/NESDIS sponsors Regional Training Centers of Excellence (CoE) in Argentina, Barbados, Brazil, and Costa Rica.
The top-level objectives of the VLab are:

1--To provide high quality and up-to-date training and supporting resources on current and future meteorological and other environmental satellite systems, data, products and applications;
2--To enable the regional training centers to facilitate and foster research and the development of socio-economic applications at the local level through the National Meteorological and Hydrological Services.

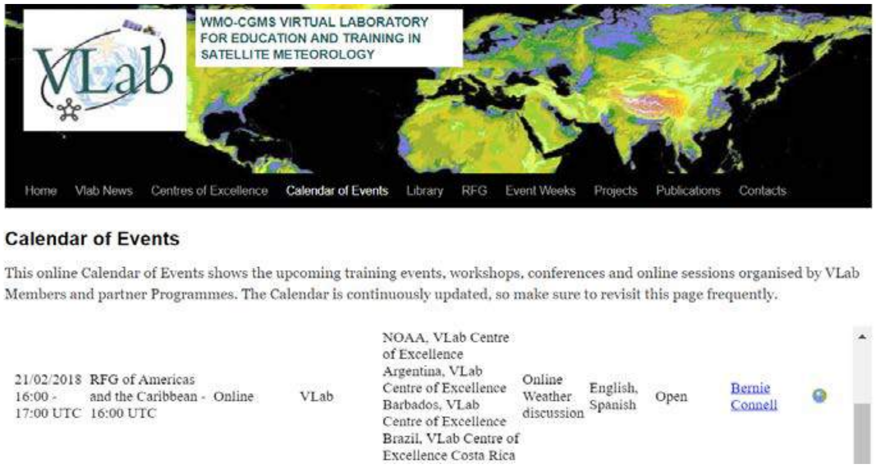
Enhanced training and coordination of training that is specifically targeted for the GOES-R series satellites and accomplished under this project will prepare forecasters, researchers, and managers on how to utilize imagery and products to provide services and training in these areas. Other CIRA RAMMB projects are leveraged to meet the VLab top level objectives.

Specific Objectives:
1--Provide partial support (2 months) for the WMO Technical Support Officer (TSO) position.
2--Provide GOES-R examples and partial support for monthly weather briefing sessions of the WMO VLab Regional Focus Group (RFG) of the Americas and the Caribbean.
3--Participate in virtual and in-person meetings of the WMO VLab Management Group, activities of the NOAA GEONETCast Americas (GNC-A) coordination group, and the WMO WMO Satellite Data Requirements (SDR) group.
4--Leverage NOAA and WMO VLab partners to organize and deliver virtual and in-person GOES-R training on data and product access, display, and interpretation.

PROJECT ACCOMPLISHMENTS:

1--This project provided partial monetary support (1.5 months) for a WMO VLab Technical Support Officer (TSO), Luciane Veeck. Her efforts provide a very important stabilizing factor for the global coordination of training efforts under the umbrella of the WMO VLab. Member countries have access to her resources through the entire year. Luciane was also supported through CIRA under a WMO grant and another CIRA project during the past year. Highlights of her work that benefit the WMO community and the US include:

-- Maintenance of the VLab central website and the VLab calendar of events http://vlab.wmo.int



--Support to VLab Management Group (VLMG) online meetings (4 and 5 April, 25 October, 28 November, 12 and 13 December, all in 2017, and 30-31 January 2018). Activities include the coordination and organization of meeting logistics and agenda, collection of Satellite Operator and Centre of Excellence Status reports, analysis of reports, and participation in the meetings.

-VLab global partners developed a survey on "What have we learned about training for use of RGBs" to assist in organizing a Global Train the Trainer event on RGBs. Select VLMG members met in November to have a focused discussion on a Global Train the Trainer event for either RGB or more broadly for image enhancement which includes RGB.

-VLMG met in October to review VLMG-8 action items and discuss global coordination efforts. Another VLMG meeting was held in December for select members to review the "Satellite Skills and Knowledge for Operational Meteorologists" document.

- The dates for the next face-to-face VLMG meeting were confirmed as 16 to 20 July 2018. WMO accepted NOAA's letter offering to host the meeting at CIRA in Fort Collins, Colorado, USA. Invitation letters were sent to VLMG members in February 2018. Preparations are underway.

--WMO Trainer Resources Portal – For four years now (including 2017), the TSO has been supporting the annual WMO Online Course for Trainers by writing training resources and helping with the facilitation of the course. To make the materials used in this course more accessible to all WMO Members, the VLab collaborated with the Global Campus initiative of the WMO- Education and Training (ETR) program to organize the resources in a Portal. The Trainer Resources Portal is now accessible at http://etrp.wmo.int/moodle/course/view.php?id=30 (no login required). Efforts will continue to make the Portal available in Spanish, French and Russian.

- VLab reports annually to the Inter-Programme Exert Team on Satellite Utilization and Products (IPET-SUP) and the Coordinating Group for Meteorological Satellites (CGMS). Reports and slides were prepared by the TSO and presented online by the VLab Co-Chair Kathy-Ann Caesar at both meetings:

IPET-SUP-3 (Geneva-Switzerland, 2-5 May 2017) and CGMS-45 (Jeju Island-Republic of Korea, 11-16 June 2017). The full reports can be downloaded from the VLab website listed above under Publications/Other reports.


- Best practices in implementing learning and development activities were both presented and gathered at the CALMet 2017 conference hosted by the Bureau of Meteorology in Melbourne, Australia in late August.

Figure 8. CALMet 2017 conference hosted by the Bureau of Meteorology in Melbourne, Australia in late August 2017.

2--Provide GOES-R examples and partial support for monthly weather briefing sessions of the WMO VLab Regional Focus Group (RFG) of the Americas and the Caribbean.

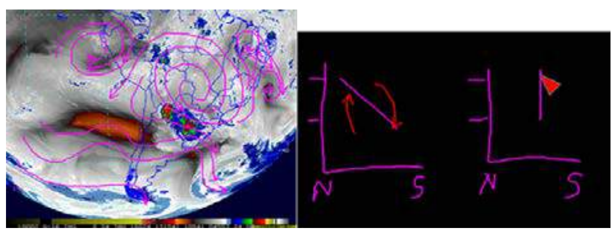


Figure 9. WMO VLab Regional Focus Group (RFG) of the Americas in the Caribbean in January 2018. Single channel water vapor imagery from GOES-16 (left) is used to show the upper level synoptic pattern over South America and (right) the “blackboard” is used to reinforce conceptual models.

During the January 2018 session, (left) single channel water vapor imagery from GOES-16 is used to show the upper level synoptic pattern over South America and (right) the “blackboard” is used to reinforce conceptual models.

- The WMO Virtual Laboratory Regional Focus Group of the Americas and Caribbean conducted 12 monthly bilingual (English/Spanish) weather briefings. The briefings made use of VISITview software to present GOES and POES satellite imagery from CIRA and GoToWebinar for voice communication over the Internet. Over the calendar year 2017, the participants from the U.S. included: CIRA, the NWS International Desk at NCEP/WPC, NWS/Office of the Chief Learning Officer (OCLO) Forecast Decision Training Division (FDTD), the UCAR/JOSS-NWS International Activities Office, NASA Short-term Prediction Research and Transition Center (SPoRT), and the Universal Weather and Aviation Private/Corporation. Thirty-one countries outside the US participated: Argentina, Antigua, Bahamas, Barbados, Belize, Bolivia, Brazil, Cayman Islands, Colombia, Costa Rica, Dominica, Ecuador, El Salvador, Germany, Grenada, Guatemala, Guyana, Haiti, Honduras, Italy, Jamaica, Mexico, Panamá, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Spain, Suriname, Trinidad and Tobago, and Uruguay. M. Davison and J. Galvez at the NCEP International Desks led the discussions (11 and 1 respectively). Participants offered comments and questions for their regions. The number of countries participating each month ranged between 9 and 22 (average 13); and the number of participants each month ranged between 13 and 48 (average 30).

The sessions were recorded and can be accessed here:
http://rammb.cira.colostate.edu/training/rmtc/fg_recording.asp

3--Participate in virtual and in-person meetings of the WMO VLab Management Group, activities of the NOAA GEONETCast Americas (GNC-A) coordination group, and the WMO Satellite Data Requirements (SDR) group.

Guidelines on Satellite Skills and Knowledge for Operational Meteorologists[1]

[1] Although there is no reference to the term "operational meteorologist" in the WMO Convention, for the purpose of this document, the term "operational meteorologist" includes one who performs the duties of analysis, diagnosis, prognosis, and forecasting of the weather.

CIRA participated in online meetings of the WMO VLab Management Group (VLMG-8) mentioned in accomplishment 1 above.
The main topics include
--Satellite skills and knowledge for operational meteorologists
--Language translation of training resources
--Evaluation of training impact
--User readiness (particularly relevant for GOES-R)
--Climate services
--Global training campus

The motivation behind VLab activities is to build a strong training foundation to make it is easier to get messages, information, and data to the user.

Back Row: Diego Souza, David Bradley, Michael Williams, James Parento, Dwayne Scott, Mitch Goldberg, Edison Cruz, Andre Joyeux, José Manuel Galvez, Bryan Thomas, Kathy-Ann Caesar, Glendell De Souza (hidden)
Third Row: Marcial Garbanzo, Jorge Chira, Estela Collini, Manuela Sanchez Marino, Diego Campos, Gregory Gibson, Bernie Connell, William Abarca, Hongming Qi, Stephan Bojinski
Second Row: Julian Baez Benitez, Vanessa Griffin, Rosario Alfaro, Rodolfo Sanchez Gonzales, Carlos Maldonado, Tom Renkevens, Wayne Mackenzie
Front Row: Luiz Machado, Natalia Donoho

GEONETCast-Americas (GNC-A) is a great way to provide instructional material to users as well as provide products. It is a low cost alternative to many users in countries that still do not have adequate internet access. It is also a good backup for emergency preparedness. GNC-A usage is strongly linked to training and aspects of this are covered in the next objective.
The WMO Satellite Data Requirements (SDR) Group for Regions III and IV was held in conjunction with the NOAA Satellite Conference.
http://www.wmo.int/pages/prog/sat/meetings/RA-3-4-SDR-3.php
CIRA participated in the meeting to listen to user feedback and address user needs where applicable and possible.

4--Leverage NOAA and WMO VLab partners to organize and deliver virtual and in-person GOES-R training on data and product access, display, and interpretation.

Figure 10. Left: Train the Trainer Workshop 15-16 July 2017 prior to the NOAA Satellite Conference; and right: GEONETCast Workshop at the Americas Global Earth Observation System of Systems (AmeriGEOSS) Meeting 31 July – 4 August 2017.

Exercises were developed for two workshops: the WMO/NOAA VLab Train the Trainer workshop on "Satellite Data Usage: Access through GEONETCast Americas, Display, Interpretation, and Usage in Training" occurring on 15-16 July 2017 in New York City, and the AmeriGEOSS "Training on Satellite Data: Access through GEONETCast Americas, Display, Interpretation, and Usage" occurring on 31 July - 4 August 2017, occurring in San José, Costa Rica. The agendas and two exercises reviewed at each workshop can be found on this web page:
http://rammb.cira.colostate.edu/training/rmtc/mcv_exercises.asp

Both workshops had a focus on display and interpretation of imagery from the next generation satellites which included both GOES-16 and JPSS. The exercises focused on linking information from online training modules with on hands-on data exploring activities. For participants that were not familiar with the new GOES-16 satellite or JPSS, online training modules were recommended for review prior to the workshops.

Publications:

Fierro, A. O., S. N. Stevenson, and B. Rabin, 2018: Variations of GLM-observed total lightning near maximum intensity in Hurricane Maria (2017). Mon. Wea. Rev., in revisions.

Miller, S. D., R. L. Bankert, J. E. Solbrig, J. M. Forsythe, and Y.-J. Noh, 2017: A Dynamic Enhancement with Background Reduction Algorithm: Overview and Application to Satellite-Based Dust Storm Detection. JGR-Atmospheres, 122(23), 12,938–12,959, doi.org/10.1002/2017JD027365.
Note: the DEBRA publication (Miller et al. 2017, listed above) was designated as a "Journal Highlight" by Zhanqing Li, the Editor of JGR: Atmospheres. JGR Highlight Title: "Addition by Subtraction: Raising the Bar for Satellite Imagery". Full JGR highlight text: https://eos.org/editor-highlights/addition-by-subtraction-raising-the-bar-for-satellite-imagery

Noh, Y.-J., J. M. Forsythe, S. D. Miller, C. J. Seaman, Y. Li, A. K. Heidinger, D. T. Lindsey, M. A. Rogers and P. T. Partain, 2017: Cloud Base Height Estimation from VIIRS, Part II: A Statistical Algorithm Based on A-Train Satellite Data. *J. Atmos. and Ocean. Tech.*, **34(**3), 585-598, doi: 10.1175/JTECH-D-16-0110.1.

Seaman, C. J., Y.-J. Noh, S. D. Miller, A. K. Heidinger and D. T. Lindsey, 2017: Cloud Base Height Estimation from VIIRS, Part I: Operational Algorithm Validation Against CloudSat. *J. Atmos. and Ocean. Tech.*, **34**(3), 567-583, doi: 10.1175/JTECH-D-16-0109.1.

Presentations:

Bikos, D., 2017. "Himawari-8 Using New Spectral Bands for Meteorological Applications", Invited lecture for a course at COMET in Boulder, CO for forecasters from the Korean Meteorological Agency, 6 December 2017.

Bikos, D., S. Lindstrom, S. Bachmeier, E. Szoke, B. Connell, C. Gravelle, D. Lindsey, C. Gitro, M. Jurewicz, 2017: VISIT / SHyMet Training on New Applications of GOES-16 Imagery. Poster, National Weather Association (NWA) Annual Meeting, 16-21 September, Garden Grove, California.

Connell, B., E. Dagg, K.-A. Caesar, M. Garbanzo, and D. Souza, 2018: Linking Data Access and Display, Hands on Exploratory Training, and Adaptations for Learners of Various Skill. 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Austin, TX, Amer. Meteor. Soc., 7-11 January 2018.

Connell, B., K.-A. Caesar, M. Garbanzo, D. Souza, N. Rudorff, and M. Campos 2018: 17 Years of Interactions between NOAA and the WMO VLab Members in Regions III and IV to Ensure Satellite Usage through Training. Third Symposium on Special Sessions on US-International Partnerships, Austin, TX, Amer. Meteor. Soc., 7-11 January 2018.

Connell, B., E. Dagg, A. Trotman, K.-A. Caesar, M. Garbanzo, and D. Souza, 2017: Linking Data Access and Display, Hands-on Exploratory Training, and Adaptations for Learners of Various Skills. 12th International Conference on Creating Activities for Learning Meteorology, Melbourne, Australia, 29 August – 1 September.

Connell, B., 2017: NOAA's contributions to International Activities for Training in Satellite Meteorology via the WMO VLab. NOAA Satellite Conference, 17-20 July, New York, NY.

Grasso, L., J. Dostalek, and D. T. Lindsey: GOES-16 ABI channel differencing used to reveal cloud-free zones of 'precursors of convective initiation' 22nd Conference on Satellite Meteorology and Oceanography, 98th AMS Annual Meeting, 7-11 January 2018, Austin Convention Center, 500 East Cesar Chavez, Austin, TX

Lindsey, D. T., S. D. Miller, C. J. Seaman, and S. J. Goodman, 2018: Highlights of the First Year of GOES-16 Imagery. AMS 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Development and Communication of Next-Generation Satellite Information for Forecasting Extreme Weather—Part II, 9 January, Austin, TX.

Lindsey, D. T., S. D. Miller, T. J. Schmit, S. Goodman, 2017: Operational Use of GOES-16 Imagery by the National Weather Service. *EUMETSAT* Meteorological *Satellite Conference*, 2-5 October, Rome, Italy.

Lindsey, D. T., 2017: GOES-16 GeoColor Product in real-time on Science on the Sphere (SoS). Invited Webinar, 21 September 2017.

Lindsey, D. T, and S. D. Miller, 2017: GOES-16: A New Era in Geostationary Satellite Observations, ATS/CIRA Colloquium, Colorado State University, Fort Collins, CO, 25 August 2017.

Miller, S.D. and C. J. Seaman, 2017: A Sight for Sore Eyes: Bringing Back True Color Imagery for the New Generation Weather Satellites, CIRA Research Initiative Award Ceremony, 28 July 2017, Fort Collins, CO.

Miller, S. D., 2017: Satellite Algorithm Development Research Theme -- The Return of True Color to Geostationary Satellites, CIRA Executive Board Meeting, 7 July 2017, Fort Collins, CO.

Miller, S. D., D. T. Lindsey, T. J. Schmit, C. J. Seaman, D. W. Hillger, R. L. Brummer, 2017: Where East Meets West: How Himawari-8 Enables True Color Capabilities for GOES-R ABI. *EUMETSAT Meteorological Satellite Conference,* 2-5 October, Rome, Italy. (presented by D. T. Lindsey)

Miller, S. D., D. T. Lindsey, C. J. Seaman, J. E. Solbrig, Y.-J. Noh, L. D. Grasso, and K. P. Micke, 2018: Advanced Imagery Applications Development for GOES-16 ABI. AMS 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Special Session on GOESR, 9 January, Austin, TX.

Miller, S., G. Chirokova, J. Knaff, and J. L. Beven, 2017: Proxy-visible Imagery. 98th AMS Annual Meeting, 22nd Conference on Satellite Meteorology and Oceanography, 7 - 11 January 2018, Austin Texas.

Miller, S. D., W. C. Straka, III, C. J. Seaman, C. L. Combs, A. K. Heidinger, A. Walther, and J. E. Solbrig, 2018: Chasing the Shadows with the VIIRS Day/Night Band. AMS 8th Conference on Transition of Research to Operations, Advances in Satellite Observations for Earth Science and Observing Technologies—Part I, 8 January, Austin, TX.

Parrish, P., B. Muller, and L. Veeck, 2017: The WMO Global Campus has arrived. 12th International Conference on Creating Activities for Learning Meteorology, Melbourne, Australia, 29 August – 1 September.

Parrish, P., and L. Veeck, 2017: The WMO Trainer Resources Portal. 12th International Conference on Creating Activities for Learning Meteorology, Melbourne, Australia, 29 August – 1 September. Presentation.

Rogers, M., S. D. Miller, L. Grasso, J. Haynes, Y-J. Noh, J. Forsythe, M. Zupanski, and D. Lindsey: New GOES-R Risk Reduction Activities at CIRA. Poster. AGU Fall Meeting 2017, New Orleans, LA, 11-15 December 2017.

Schmit, T. J., M. Gunshor**,** D. T. Lindsey, S. D. Miller**,** K. Bah, J. Daniels, S. Goodman, 2017: An Early Look at the Imagery from the Advanced Baseline Imager (ABI) on GOES-16. *EUMETSAT* Meteorological Satellite Conference, 2-5 October, Rome, Italy. (presented by D. T. Lindsey)

Schumacher, A.B. and M. Folmer, 2018: AMS Short Course: GOES-R Series: Products and User Applications – Tropical Cyclones, 98th AMS Annual Meeting, Austin, TX, 7-11 January 2018.

Schumacher, A.B., 2018: Development and Communication of Next-Generation Satellite Information for Forecasting Extreme Weather—Part I (Panel Member), 98th AMS Annual Meeting, Austin, TX, 7-11 January 2018.

Schumacher, A.B., 2017: GOES-16 Capabilities & the 2017 Hurricane Season. Denver/Boulder Chapter of the American Meteorological Society Seminar, NCAR Mesa Lab, Boulder, CO, 7 December 2017.

Schumacher, A.B., 2017: GOES-16 Tropical Applications. GOES-R Series Faculty Virtual Course: Tropical Cyclones, 6 September 2017, Online presentation (https://www.meted.ucar.edu/training_module.php?id=1311#.WnCuu6inF9N)

Schumacher, A.B., 2017 (Recorded): GOES-16 Applications for Hurricane Forecasting. WMO RA-IV Hurricane Committee - 39 Meeting, San Jose, Costa Rica, 23 March 2017.

Seaman, C., S. Miller, D. Lindsey and D. Hillger: Multispectral imagery applications for the new generation of geostationary satellites. Oral presentation. EUMETSAT Meteorological Satellite Conference, Rome, Italy, 2-6 October 2017.

Seaman, C., and Coauthors: Connecting with operational forecasters in the GOES-16 era via the NOAA Satellite Proving Ground program. Poster presentation. EUMETSAT Meteorological Satellite Conference, Rome, Italy, 2-6 October 2017.

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Torres and C. Seaman, 2018: Advancing potential new satellite products into operations: CIRA's NWS Proving Ground plans. Poster, 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, 98th Amer. Meteor. Soc. Annual Meeting, Austin, TX, 7-11 January 2018.

Szoke, E, 2017. GOES-R Proving Ground and HRRR talks at the Boulder NWS WFO Winter Workshop, 2 and 5 October 2017.

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Torres and C. Seaman, 2017: Future directions for CIRA's NWS Proving Ground activities now that GOES-16 is operational. Poster, National Weather Association (NWA) 42nd Annual Meeting, 18-21 September, Garden Grove, California.

Szoke, E.J.**,** and D. Bikos, 2017: GOES-R training seminar at the NWS WFO in Cheyenne, WY, 25 April 2017.

Szoke, E, 2017: GOES-R Proving Ground and HRRR talks at the Boulder NWS WFO Spring Workshop, 6 and 10 April.

Thomas, J. R., S. Goodman, E. Madsen, J. Peronto, B. Connell, A. Stevermer, K. Mozer, and M. Seybold, 2018: GOES-R Series International Training Working Group. 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Austin, TX, Amer. Meteor. Soc., 7-11 January 2018. Presentation.

Veeck, L., 2017: Embracing the Translation Challenge. 12th International Conference on Creating Activities for Learning Meteorology, Melbourne, Australia, 29 August – 1 September. Presentation.

PROJECT TITLE: CIRA Support to Connecting with Rapid-Update Numerical Forecast Models for Advanced Short-term Prediction and Data Fusion Capabilities

PRINCIPAL INVESTIGATOR(S): Chris Kummerow

RESEARCH TEAM: Kyle Hilburn, Max Marchand, Steven D. Miller and Chris Slocum

NOAA TECHNICAL CONTACT: Satya Kalluri (NOAA/NESDIS) and Steve Goodman (NOAA/NESDIS/GOESR Program)

NOAA RESEARCH TEAM: Dan Lindsey (NOAA/NESDIS/STAR/RAMMB), Stephen Weygandt and Curtis Alexander (NOAA/OAR/ESRL)

FISCAL YEAR FUNDING: $193,798

PROJECT OBJECTIVE:

The main objective of our project is to be able to initialize convection in the High Resolution Rapid Refresh model when and where it is observed by GOES-16. After gaining experience with the components of the RAP/HRRR system (described in the last progress report), we identified the existing radar initialization pathway as the most direct route to get GOES-16 information in HRRR. Making use of this pathway requires the development of an observation operator to transform GOES-16 information (ABI reflectances and brightness temperatures and GLM lightning observations) into three-dimensional (3D) radar reflectivity fields. Thus, during the latest period, our work has focused heavily on analysis of the newly available GOES-16 data. At this point we are developing a large set of cases including phenomenon observed during the 2017 severe weather season over the Great Plains and the 2017 Atlantic hurricane season. We also have a long enough period of data to perform statistical analysis on GLM and ABI properties relative to other datasets.

PROJECT ACCOMPLISHMENTS:

1--Geostationary Lightning Mapper (GLM)

1a--GLM Geolocation

The first issue we encountered in working with the newly available GLM data was artificial displacements in the flash locations. The problem became evident when overlaying GLM data on ABI images. Since

ABI locations have their own location uncertainty due to the parallax effect, we also overlaid GLM on the Multi-Radar Multi-Sensor (MRMS) national radar mosaic and found a similar problem. The offsets were large enough in some cases (8-16 km), that when clusters of storms occurred in close proximity, it was difficult to tell which storm the GLM flashes were associated with.

Evaluating potential geolocation displacements requires a dataset that provides an estimate of the truth. We used Earth Networks Total Lightning Network (ENTLN) observations because they provide a record that is both continuous in time and covers the contiguous United States. Max Marchand has access to these data through his connection with the Fuelberg Research Group at FSU. No dataset is perfect, and ENTLN is known to be less reliable in the western United States and in the offshore waters around the United States. However, ENTLN does match physical expectations very well, providing dense clusters of flashes co-located with areas of MRMS composite reflectivity exceeding 35 dBZ. We note that the time/space parameters used to define a flash in ENTLN are different than GLM. Re-grouping ENTLN flashes using GLM parameters (330 msec, 16.5 km) results in about a 20% reduction in the total number of flashes compared with the standard ENTLN product. However, this produces only about a 2% increase in the detection efficiency because when comparing GLM with ENTLN, regrouping ENTLN reduces the GLM misses a few percent more than the GLM hits. We note that the spatial patterns of re-grouped ENTLN flashes are not substantially different from the standard product; the re-grouping has the effect of thinning the ENTLN flashes.

The top panels of Figure 1 show estimates of the GLM geolocation offset relative to ENTLN. These statistics have been calculated using the Version 1 GLM data and were accumulated over the 65-day period 1-May to 4-July. During this period GOES-16 was located at the 89.5W test slot longitude. The statistics were calculated using a space/time matching methodology that required the GLM and ENTLN flashes to be within 20 km and 0.6 s to be considered a match. The sign of the difference is such that over Fort Collins, CO, GLM is displaced 3-6 km west and 6-9 km south of ENTLN. The southern displacement is inconsistent with an error due to the parallax effect. Note that the offsets have a strong spatial pattern with near zero offsets in both directions on the East Coast, and the largest offsets in both directions along the West Coast.

The GLM Science Team has been very active in assessing and addressing the causes of geolocation offsets. The bottom two panels in Figure 1 show the improvement in the geolocation error going from GLM Version 1 to Version 2. These statistics were calculated over a five-hour period during a severe weather event (8-May) over northeast Colorado for which we had both the original GLM data and a reprocessed version (which we are calling Version 2 herein) prepared by Doug Mach. The figures show the correlation coefficient (R^2) between ENTLN and GLM flash centroid density maps as a function of varying X and Y (longitude and latitude) offsets. It shows that in Version 1, GLM has offsets 9 km west and 6 km south of the ENTLN location. These results are consistent with the match-up analysis within the sampling uncertainty. The Version 2 GLM data have the highest correlation for a 3 km west and 0 km north offset of ENTLN, but zero offsets have nearly the same level of correlation. It is also worth noting that the correlation between GLM and ENTLN spatial patterns has increased from Version 1 to Version 2. We are very happy to see the big improvement in GLM locations.

1b--GLM Detection Efficiency and False Alarms

Having assessed the location accuracy of GLM observations, the next question becomes how to interpret the presence of or lack of GLM-observed lightning flashes. In other words, to use GLM for data assimilation applications, we need a characterization of the GLM detection efficiency (DE) and false alarm ratio (FAR).

GLM is an optical sensor, observing at 0.777 micron with a 2 ms frame rate. The GLM charge-coupled device (CCD) readout is from top-to-bottom north of the Equator (approximately) and bottom-to-top south of the Equator. The real time event processor (RTEP) settings control the detection of events from the background, and the coherency filter settings do most of the work in suppressing false alarms. Events are detected at 8 km (at nadir) resolution. GLM provides estimates of the latitude, longitude, and energy. Groups are composed of simultaneous adjoining events (equivalent to lightning pulses/strokes). The latitude and longitude is an energy-weighted average of events. Flashes are composed of groups occurring within 330 ms and 16.5 km. GLM corrects for the parallax effect using a latitude dependent height.

Since GLM is an optical sensor, there are two primary reasons why it would fail to detect a flash observed by a ground-based radio direction-finding system. First, if the flash has low power and/or is of small size (a compact flash) it will be more difficult to detect using a space-borne optical sensor. Second, the light from the flash will undergo extinction as it passes through the ice water path (IWP) located above the flash. This can be a significant issue with Great Plains thunderstorms that produce large amounts of cloud ice above the source regions of lightning flashes.

There are two primary reasons why GLM can produce false alarms: a coherent bright foreground signal or corruption of the background. Examples of foreground signals are sun glint over water surfaces at sunrise/sunset that can appear as lightning, and stray light around the edge of the Earth disk that can appear as lightning at midnight. For a trained meteorologist, these types of false alarms are relatively easy to distinguish from real lightning. The false alarms arising from corruption of the background are more difficult to identify. This type of false alarm is more likely in dark areas near contrast boundaries. For the northern hemisphere this is along the south edge of clouds/coasts due to the direction of the CCD readout. The co-occurrence of these false alarms with cloud edges makes them more difficult to distinguish from real lightning. There are other less common sources of false alarms, but this is beyond the scope of this report.

Our comparison dataset, ENTLN, has sensors located across the globe. It detects lightning using wider frequencies than NLDN (1 Hz – 12 MHz versus 1 - 350 kHz), resulting in better detection of intra-cloud flashes. ENTLN has an estimated > 90% DE in areas of high density of sensors. For cloud-to-ground strokes the DE is thought to be around 95%, while for intra-cloud strokes the DE is thought to be around 75%. This is based on analysis over the eastern United States. The location accuracy is < 1 km.

Figure 2 provides the results of the matchup analysis described in the previous section applied to the time period 1-May to 7-Aug. Note that the GLM data changed versions 5-July. Analysis of the two difference data versions showed about a 5% increase in the number of GLM flashes in the latest dataset. The spatial offset changes were described in Section 1a. The top, left panel of Fig. 2 shows that 60-75% of ENTLN flashes are detected by GLM over most of the country outside of the Great Plains where the percentage falls to 30-50%. The top, right panel shows a map of the percentage of GLM flashes detected by ENTLN. We see that ENTLN detects 70-80% of GLM observed flashes over the portion of the United States with the highest density of ENTLN sensors. If ENTLN were perfect, this would give a FAR of 20-30% for GLM. However, given the estimated ENTLN DE of 90%, this results in a 10-20% FAR for GLM.

The lower, left panel of Fig. 2 shows how the DE varies with ENTLN peak current. For peak currents less than 2 kA, the DE drops as low as 20%. For higher peak currents, the DE is about 50% when averaged over all of CONUS. Note an asymmetry where negative polarity flashes have about a 5% lower DE. The lower, right panel of Fig. 2 shows how DE varies with ENTLN multiplicity, showing that for multiplicities above 10, the GLM DE is 70% and it falls off for lower multiplicities. We hypothesize that the inverse relationship between DE and multiplicity results from a direct relationship between multiplicity and the size of the flash. However, we have so far found no clear relationship between GLM DE and the GLM flash area.

To understand the physical and meteorological processes that affect GLM DE, Fig. 3 presents results from a detailed storm-scale analysis of GLM data for the 8-May storm event over Colorado. The storms that day produced hail ranging from 1.00-2.75 inches [*SPC storm reports*], and it produced $1.4B in insured loses [*Denver Post*], making it the most expensive catastrophe in Colorado history. The convection was multi-cellular in nature, and the three largest thunderstorms in Northern Colorado that day are distinguished by the city they affected: Denver, Fort Morgan, and Greeley. Despite their close proximity in time and space, we found that different physical factors are required explain the DE of GLM for the different storms. To produce the time series, GLM and ENTLN flashes were accumulated over 30, 35, and 55 km radii for the Denver, Fort Morgan, and Greeley storms following the motion of the storm. The accumulations were over 5-minute time windows matching the ABI RadC sampling. Details of the storm tracking are provided in [*1*]. Note that for all storms, GLM observes fewer flashes than ENTLN, with the largest negative differences for the Fort Morgan storm.

For the Denver storm (Figure 3, top panel), the highest correlation with GLM DE is with the absolute peak current from ENTLN (R^2=0.43). During the early stages of the Denver storm, GLM DE was particularly low, and this appears due to the weak nature of the flashes at that time. For the Fort Morgan storm (Fig. 3, middle panel), the highest correlation with GLM DE is with the intra-cloud fraction (R^2=0.38). The IC Fraction is defined using ENTLN as the ratio of IC flashes to all flashes. Fig. 3 shows that the Fort Morgan storm had consistently high IC ratios, and the GLM DE was lower when the IC ratio is lower. This may indicate that normal polarity IC flashes are easier for GLM to detect than CG flashes, or it may arise from correlations among variables. For the Greeley storm (Fig. 3, bottom panel), the highest correlation with GLM DE was with ice water path (IWP, R^2=0.44). Note that we have calculated IWP above the flash source using 3D radar reflectivity fields from MRMS and the flash heights from ENTLN. The flash height matters, because assuming a constant height produced decidedly poorer results. There is a negative correlation in time where higher IWPs are associated with lower DE. It is not surprising that the inverted polarity storm (Greeley) had the strongest relationship with IWP. We have also compared GLM against COLMA data for these cases and find qualitatively similar results.

Figure 4 provides an evaluation of GLM for areas outside of CONUS. Note that the extent of the GLM field-of-view is evident. This is because there are GLM flash detections in every latitude/longitude box, despite that ocean locations under the subtropical ridges are unlikely to have lightning flashes. Thus false alarms produce a flash density floor for GLM over the ocean. The features with flash densities above that floor may be real lighting, because they seem to correspond with features in ENTLN, however ENTLN has lower flash densities, which could be a sampling artifact in ENTLN. Over CONUS, GLM flash density is generally lower than ENTLN. GLM has higher flash density than ENTLN over Columbia and Venezuela, especially near Lake Maracaibo. GLM is also higher than ENTLN along Mexico's Sierra Madre Occidental Mountains. GLM is also somewhat higher than ENTLN over the Amazon basin and over the humid subtropical portions of northeastern Argentina and eastern Paraguay. Keep in mind that this comparison is over the southern hemisphere winter, otherwise much higher flash densities would be observed over South America.

Regional differences in flash characteristics also correspond to differences in the GLM DE relative to ENTLN (top, left panel of Fig. 2). We identified a region of poor GLM DE in the Northern Plains (from 104.5 to 93.5 W, and 37.5 to 49.5 N), and of good GLM DE in the Southeast United States (from 93.5 to 79.5W, and 23 to 35.5N). Figure 5 shows histograms of peak current from ENTLN flashes in these regions (only using flashes over land in the southeast). As a percentage of total flashes, the Southeast has many more flashes with peak current less than -15 kA. These are typically negative cloud-to-ground (CG) lightning flashes that are considered normal polarity CG flashes. The Southeast also has weaker positive flashes (between 0 and 15 kA) that are typically intra-cloud (IC) flashes, and considered of normal polarity IC flashes. The Northern Plains has more weakly negative flashes (between -15 kA and 0 kA), which are typically considered inverse polarity (or anomalous) IC flashes. Less difficult to see in Fig. 5 are the greater number of strong positive flashes (e.g., greater than 60 kA) in the Northern Plains compared to the Southeast, which are often considered anomalous CG flashes. Using these characteristics, we construct what we define as the normal index, which is the count of flashes of peak current < -15 kA, plus the count of IC flashes with peak current > 0 kA, minus the count of flashes with peak current between 0 and 15 kA, minus the count of flashes with peak current > 50 kA, all divided by the total number of flashes. The resulting product mapped out using a Gaussian spatial filter of 25 km (Fig. 5), shows strong negative values in the Northern Plains and positive values in the Southeast. Also notable are minima areas of negative values in the Snake River valley in Idaho, southwestern Arizona, eastern Pennsylvania, and other areas east of the Appalachian Mountains in the Carolinas and Virginia. These correspond to minima of GLM DE in the top, left panel of Fig. 2. Because anomalous IC flashes tend to be low in altitude, GLM has more difficulty optically detecting these flashes relative to normal IC flashes that tend to be high in altitude. Another possible explanation is that storms producing many anomalous flashes tend to have more ice and possibly smaller ice crystals that can shield the GLM optical sensor, or reduce its sensitivity, to the lightning produced by these strong storms.

We tested the storm intensity relationship to GLM DE using the MRMS vertically integrated ice (VII) metric. We computed the average VII within 5 km of each ENTLN flash during 70 days from late June through September 2017. Plotting GLM DE relative to ENTLN as a function of VII indicates that the GLM DE does decrease as the VII increases for both the Southeast (left panel of Fig. 6) and Northern Plains (right panel of Fig. 6). However, this correspondence is much stronger for the Northern Plains, which has a decrease in DE from ~40% for VII of 0-2 mm to less than 20% at VII > 60 mm. The Southeast GLM DE decreases from ~60% to ~54% for VII 12-14 mm. Very few storms have VII > 14 mm in the Southeast (much less than 1% of flashes as apparent by the histogram bars). Storm intensity and flash polarity appear to explain a lot of the variance in the GLM DE in the Northern Plains, but other unknown large factors appear to explain why GLM detects some flashes and not others in the Southeast.

1c--GLM CONUS Examples

We have been monitoring GLM data and comparing with other available datasets (ENTLN and COLMA) for storms occurring over northeast Colorado. This area in particular represents one of the most challenging regimes for space-borne optical remote sensing of lightning due to the large ice water paths produced thunderstorms. Figure 7 provides time series for four different storms. For all these cases, we used MRMS reflectivity object centroids to define a moving area over which to accumulate lightning statistics. For all of these examples, lightning flashes have been accumulated over a 5-minute period, and we used a tracking radius of 25 km (1963 km^2 area), except for the 6/21 case which used a 50 km radius (7854 km^2 area). We obtained the real-time, decimated COLMA data for these cases from Brody Fuchs, a PhD student in the Rutledge Research Group at CSU.

The first example from 5/15 (Fig. 7 top, left panel) was a relatively weak storm that occurred after sunset in southwesterly flow aloft. GLM reaches a peak of 15 flashes, while ENTLN peaks near 29 flashes and COLMA peaks near 38 flashes. Given that COLMA coverage is superior to ENTLN over northeast Colorado, it makes sense that COLMA would detect more flashes. The time variability is very well correlated among the three datasets. The second example from 6/12 (Fig. 7, top, right panel) involved a tornadic thunderstorm that formed in the late afternoon with southwesterly flow aloft. Note that the flash counts are much higher, on the order of 1000. They can be expected to be 4x higher than the other examples because of the larger tracking radius, but taking this into account, the flash density is still 10x higher than the weak storm case. Curiously, for this storm, GLM and ENTLN both show a peak around 23Z, while COLMA has a peak around 21Z. The COLMA data become noisy after 22Z. For this case, ENTLN peaks at more than 1000 flashes, while GLM peaks around 250 flashes. The third example from 8/2 (Fig. 7 bottom, left panel) was an isolated thunderstorm in northwesterly flow aloft. For this example, ENTLN has three bursts of flashes that are well correlated with bursts of higher MRMS composite reflectivity. GLM only captured the last of the three bursts, which was followed by rapid decay of the thunderstorm. For the last burst, ENTLN peaked near 175 flashes, while GLM peaked near 90 flashes. The fourth example from 8/10 (Fig. 7 bottom, right panel) was an isolated thunderstorm in northwesterly flow aloft. Both GLM and COLMA observed a drop-off in lightning activity near 21:30Z, which was followed by a lightning jump around 22:00Z. Note that with the real-time COLMA data, a drop-off in activity can also indicate missing data. At its peak, COLMA saw 800 flashes and GLM saw 200 flashes.

Considering these examples together, we see that GLM generally has good correlation in time with ground-based lightning observations. There are cases where GLM can miss bursts of activity, which based on the analysis of the 5/8 case (Fig. 3), can be caused by too much ice water path above the flash source height and by too weak (or too small) flashes, especially near the beginning of a storm event. For these cases over northeast Colorado, GLM detection generally ranges from 2x-4x lower than ENTLN or COLMA. These cases can be considered a worst-case scenario for space-borne optical detection of lightning.

It is helpful to consider cases from other regions. Over the southeast United States, GLM DE is at its highest (Fig. 2), and Fig. 8 shows an intermediate case over the south-central United States. This is an example of a squall line covering six states from Minnesota to Texas. At the time of this example, it is nighttime and a large stratiform area can be observed in MRMS (the areas of 35 dBZ behind the squall line). This example shows extremely good correlation between a high density of GLM flash observations and composite reflectivity values of 50 dBZ or higher. Along the edge of the squall line, the lightning observations are very coherent in time – the image at this time very closely resembles the image 5 minutes before and after but with a shift in the direction of the flow aloft. The lightning observations in the stratiform area, on the other hand, have a much lower density and are less coherent in time – they tend to flicker and move about throughout the stratiform areas. This example suggests there is value in using GLM flash data at multiple time scales. The 5-minute accumulations can help pinpoint the convective cores, while 15-minute accumulations can delineate the stratiform areas.

1d--GLM Hurricane Examples

Hurricane Harvey was the first major hurricane to make landfall in the United States since Wilma in 2005, and is tied with Hurricane Katrina as the costliest on record [*Wikipedia*]. Figure 9 provides lightning time series for Harvey for the inner core (< 100 km), outer core (100-300 km), and the outer rainband (300-600 km) areas of the storm. The first thing to note is that GLM and ENTLN have roughly similar temporal variability, which gives greater confidence that the relationships shown between lightning and intensification in Fig. 9 have a physical basis and are not the result of sampling or detection efficiency artifacts. While Harvey was still a tropical depression, there was a large increase in inner core lightning, and the intensity remained steady. Once the inner core lighting leveled-off, the outer core lightning began to increase. At this point (on the 24th) Harvey began to rapidly strengthening to Category 1. The intensity levels-off late on the 24th and the outer core lightning began to drop. Then on the 25th, the outer rainband lightning began increasing rapidly, at which point the intensity rapidly increased from Category 1 to Category 4. Hours after reaching peak intensity, around 3Z on the 26th, Harvey made landfall on San Jose Island, Texas. Thus, Hurricane Harvey provides evidence that tracking lightning activity and its time change at different radii can provide clues for intensification.

Figure 10 shows a frame from a GLM/ABI loop near the time of landfall. As Maria was approaching the U.S. Virgin Islands around 3Z, Maria was at peak intensity, Category 5, and there was very little lighting observed by GLM. Then around 6Z, as Maria was undergoing an eyewall replacement cycle, there was a dramatic increase in inner core and outer rainband lightning. Figure 10 shows Maria at 9Z when three arc-like bands of lightning activity are located in the southeast/northeast quadrants. This lasted for about 2 hours after landfall, which occurred at 10:15Z, when the inner core lightning shut-off and copious amounts of lightning flashes were observed by GLM in the outer rainbands. At this point Maria had dropped to a Category 4 storm, and was rapidly weakening. This example illustrates the potential usage of GLM to identify and monitor eyewall replacement cycles.

2--Advanced Baseline Imager (ABI)

2a--ABI Spectral Information Content

GOES-16 provides a wealth of spectral information with its 16 bands. To make sure we do not leave valuable information unused, we carried-out a statistical analysis of GOES-16 information content relative to MRMS composite reflectivity for the 2017 spring-summer convective season over CONUS. Figure 11 shows where in GOES-16 spectral space MRMS composite reflectivities exceeding three different thresholds are located. This is based on six months (April-September 2017) of daytime-only observations from GOES-16. Both GOES and MRMS have been resampled to the 3 km HRRR grid for this analysis. Figure 11 shows four different precipitation signatures. The first, present in Bands 1-4, is a cloud optical depth signal that results in brighter reflectances. While the precipitation observations are fairly spread out in reflectance-space, notice that the total fraction of all observations is fairly low for reflectances above 0.6. This results in fairly high hit rates, around 60%, using the optical depth signal to delineate precipitation areas. For bands 1-3, the blue, green, and red curves are overlapping, meaning that these bands do not offer the ability to reliably distinguish light from heavy precipitation. Band 4, which has strong water vapor absorption, does offer some ability to distinguish the strongest 50-dBZ cores from weaker reflectivity areas. Bands 5-7 provide two different precipitation signatures. The first is a cloud particle phase signature, which is a dark signature where clouds have glaciated. The only difficulty using this signature comes because the peak for all observations occurs near the same reflectances as the glaciation signal. In this regard, band 6 is the best choice of the three because the peak for all observations is shifted darker. These bands also offer a cloud particle size signature, which is a bright signature from small ice particles produced by convective updrafts. This leads to the 50-dBZ line (red) to be shifted brighter than the other curves. Note that Band 7 is tricky to use because it contains both solar reflective and thermal emission signals. Finally, Bands 8-16 provide a cloud top temperature signature. This is a cold signature, and the separation between the curves shows that it provides good discriminating power between light echoes and strong echoes. The low fraction of all observations at colder temperatures provides high hit rates, similar to the visible and vegetation bands, but with different spatial structure. There is additional information that can be captured using channel differences, which we have begun to investigate.

Thus, based on this statistical analysis, the essential channels for daytime precipitation detection would take advantage of the cloud optical depth, cloud particle size, and cloud top temperature signatures. However, Fig. 11 does not provide information about how the information is correlated across channels. To better understand the information content in channel combinations, we used the six-month dataset to analyze all 816 unique combinations of 1, 2, and 3 channels. We ranked those combinations in terms of the critical success index (CSI), which accounts for both misses and false alarms, based on MRMS composite reflectivity. We found the most skillful combination was 2-6-13, which had a hit rate of 0.47, a false alarm ratio of 0.53, and a CSI of 0.31; using the 20-dBZ threshold as an example. Note that this combination contains one channel to capture each of the signatures, and all of the top-ranking combinations had similar combinations. To put these values in context, note that HRRR 1-hour forecast of simulated reflectivity has a CSI of 0.22 with a hit rate of 0.53 and false alarm ratio of 0.73. Thus, HRRR has somewhat higher hit rates than GOES-16 ABI, but a higher false alarm ratio due to the fact that HRRR simulated reflectivity tends to be too high and too spatially extensive. HRRR skill decreases with forecast length, and for HRRR 6-hour forecasts, the hit rate drops to 0.41, and the false alarm ratio increases to 0.81. For ABI, there is an inverse relationship between skill and reflectivity threshold, with CSI values around 0.6 for 5 dBZ, around 0.3 for 20 dBZ, around 0.2 for 35 dBZ, and around 0.1 for 50 dBZ. The precise CSI values depend on regime, with lower values occurring for convection that produces large amounts of ice water path, such as thunderstorms in Colorado. This is because the optical depth signal saturates near the low end of radar reflectivity, around 20 dBZ; while the cloud top temperature signal saturates near the middle, around 35 dBZ, but large thunderstorm anvils cause the saturation to occur at lower reflectivity values. Other high-ranking combinations with slightly lower skill involved replacing channel 2 with 1 or 3, replacing channel 6 with 5 or 7, and replacing channel 13 with 8-16. The two-channel combinations ranked much lower, with hit rates of 0.42, false alarm rates of 0.57, and CSI of 0.27. Thus, two-channels are about 5% less skillful than three-channels. Finally, the one-channel combinations ranked the lowest with hit rates of 0.35, false alarm ratios of 0.65, and CSI of 0.21. Thus, using just one-channel is about 7% less skillful than two-channels.

2b--ABI High-Resolution Spatial and Temporal Information

In addition to the new spectral information provided by GOES-16 ABI, the sensor also offers higher spatial and temporal resolution. The nominal spatial resolution of ABI channels ranges from 0.5 km to 2 km, which are all at a finer resolution than the 3 km HRRR grid. So, ABI data are already at a higher resolution than can be used by HRRR, however the question becomes whether spatial filtering of the high resolution ABI data can provide useful information? We found the answer is yes, and this section will demonstrate the connection between texture in Band 2 (the highest resolution band) and convective cores.

ABI also provides higher temporal resolution, with 15-minute sampling of the Full Disk sector, 5-minute sampling of the CONUS sector, and 1-minute sampling of a movable Mesoscale sector. The cadence for bringing radar data into HRRR is 15 minutes, and experiments at NSSL have found that using a cadence faster than 10 minutes generally produces poorer results because the model does not have enough time to readjust back into mass-wind balance [*Thomas Jones, personal communication*]. Thus it appears that ABI sampling at faster than 15-minute time-scales cannot currently be used for data assimilation purposes. However, one can ask a similar question for temporal resolution as for spatial resolution; namely, whether temporal filtering of the ABI data can provide useful information? We find that areas of high temporal variability correspond very closely with areas of high spatial variability, thus time and space derivatives on these small/short scales highlight the same information. Note that our context is using ABI for initializing precipitation, and that if ABI is used for wind vectors or storm tracking, the higher temporal resolution is likely to be critical for those applications.

Figure 12 provides an example of using the higher resolution ABI information to derive lower resolution information about the locations of convective cores. The cyan line encloses the areas identified by ABI as being overshooting tops (OTs). It can be seen that these areas agree very well with areas of active lightning flashes. They also agree very well with the 35 dBZ composite reflectivity contour. To derive OTs, the first step is to identify the thunderstorm anvils (dark blue line) within which the OTs can be found. This was performed using histogram-based image segmentation, which works very well because the visible reflectance histogram becomes strongly bimodal at the time of convective initiation. This method results in a reflectance threshold value for each image, which is helpful to account for changing solar illumination. Binary dilation is used to fill in the holes resulting from shadows cast on the anvils by overshooting tops. Then the visible texture is calculated as the absolute value of the gradient magnitude, where the gradient was calculated with the Sobel filter. For Fig. 12, OT areas are where the gradient magnitude exceeds a value of a constant times the image segmentation threshold. For Fig. 12, a constant of 0.5 produced good agreement with radar reflectivity and lightning areas. However, we note that the area of the OTs is very sensitive to the threshold. This is because the histogram for texture is approximately exponential, so that small changes to the threshold produce large changes in the OT area. This has made it difficult to apply this technique to other storms, because each case requires a different threshold to achieve similarly good agreement with radar and lightning. This can be particularly problematic when the convective cores are located near the edge of the anvil, because cloud edges also produce large gradients in visible reflectance. While use of texture seems very promising, we have not had enough time to further develop techniques for its usage. Instead, we have collaborated with Yoonjin Lee, a PhD student in Chris Kummerow's Research Group, to investigate use of texture for identifying convective cores. Note that we have only examined gradient magnitude information, but the texture also contains information about the orientation. The properties of texture objects, such as aspect ratio and area, contain information about modes of convective organization. We also note that texture works well as the solar illumination becomes lower, and generally is helpful in situations where the VIS signal by itself is marginal due to a large solar zenith angle.

2c--Observation Operator for Radar Reflectivity

To make use of GOES information in data assimilation and model initialization, the key required component is an observation operator that can transform the GOES information into the variables recognized by the modeling system. For the radar initialization pathway, these are three-dimensional fields of radar reflectivity. It must be understood that the information provided by GOES is primarily useful in identifying when and where convective precipitation areas are located. GOES imager does not provide information about the vertical profile of reflectivity, so the observation operator must make assumptions about the vertical profile. Thus, the observation operator we developed has two major sub-systems. The first part is to derive the spatial information, given by the composite reflectivity – which is the vertical maximum value of reflectivity. The second part then associates the composite reflectivity with a vertical profile, based on height information provided by RAP/HRRR forecasts.

To derive the spatial information, Fig. 13 shows an example to illustrate our object-based methodology. We use MRMS composite reflectivity to create a set of objects using component labeling at a variety of thresholds. In Fig. 13, the black line gives the MRMS 20 dBZ object, and in general, we use 12 thresholds, ranging from 5 dBZ to 60 dBZ in steps of 5 dBZ. We found that reflectivities exceeding 60 dBZ are uncommon and cover very little area after MRMS has been resampled to a 3 km grid. Precipitation is less common below reflectivities of 20 dBZ, but drizzle can be observed at reflectivities down to 5 dBZ. After creating the MRMS objects, then GOES ABI is used to create objects from an ensemble of binary masks, using different channels and thresholds. As described in Section 2c, the channel combination of 2-6-13 was found to be most skillful, and the object-based analysis that varied channels also found the same conclusion. The binary masks are created from thresholds using a "greater than" comparison for the cloud optical depth and cloud particle size signatures, and a "less than" operator for cloud top phase and cloud top temperature signatures. The masks are combined using a Boolean "and" operation. The best matching GOES object is then selected based on the CSI relative to MRMS. Figure 13 shows the GOES object enclosed with a red contour, and the legend shows that this was composed of the combination of C02 > 0.70, C06 > 0.40, and C13 < -10°C. The advantage of this method is that it provides an upper-bound on the GOES-16 skill. The threshold tuple that generates the object is the best possible result achievable using GOES-16. The threshold tuples derived using this method then become the training input to construct the observation operator.

Following the presentation prepared for AMS [*2*], we will provide case studies for two different convective events representing distinct regimes. The first is a Southeast United States convective initiation example from 21-March. On this day there was MUCAPE of 1500-2000 J/kg over the area and the shear was not particularly strong [*SPC MD 0302*]. The storms produced wind and hail hazards with 1 injury and 1 fatality in Georgia [*SPC storm reports*]. The second example is the multi-cellular convection example over the Great Plains (northeast Colorado) on 8-May. For this case there was MLCAPE of 1000-1500 J/kg and deep-layer shear of 30-40 kts [*SPC MD 0664*]. As noted in Section 1b, the hail damage from this day was the most expensive catastrophe in Colorado history.

Figure 14 shows the observation operator results for composite reflectivity. The filled circles in this figure are the data – an average over the objects in the region of interest from 20-21Z. Note that we have parallax corrected the ABI data using a 10 km height. This approach has a small error, but avoids the large error of doing nothing. Also note that we use reflectance that has been scaled by the inverse of the cosine of the solar zenith angle to avoid a late afternoon drop-off in the reflectance. The lines are an analytical fit using the Gompertz function, which is an S-shaped function. To perform the fit, the data are scaled by the minimum and maximum to go from 0 to 1, so that the asymptote of the Gompertz function is fixed at 1. We found the best results using a fixed growth rate of 3 because higher growth rates produce sharper transitions, which tend to amplify noise in the GOES ABI data. The MRMS reflectivities are scaled to go from -1 to 1 in the direction matching the sense of the threshold comparison. In other words, the channels 2 and 6 increase from left-to-right in Fig. 14, while channel 13 increases from right-to-left. This gives one free parameter, the displacement parameter, which gives the reflectivity midpoint. For the Southeast case, channel 2 transitions at 22 dBZ, while channels 6 and 13 transition at 36 and 34 dBZ. For the Great Plains case, channel 2 transitions at 20 dBZ, as does channel 13, and channel 6 transitions at 28 dBZ. The skill of the method in reconstructing the spatial field of composite reflectivity depends on the range of reflectivity midpoints covered by the different channels. For the Southeast case, there is a good spread, and we will show this results in great agreement between GOES-derived reflectivity and MRMS. For the Great Plains case, the range is much lower, and without channel 6, it would be difficult to identify the convective cores. The reason for the lower spread is that the convection in the Great Plains case produced large anvils with abundant ice water path. This means that both the visible and long-wave infrared saturate at low reflectivity values, and reconstructing the higher end of the reflectivity distribution, where the convective cores are located, is challenging. Note that in these cases, texture information can be extremely helpful.

Once the horizontal distribution of composite reflectivity is established, a parametric model is used to specify the vertical profile of reflectivity. Figure 15 compares the observed MRMS vertical structure (filled circles) with the parametric model (solid lines). This model specifies the vertical profile as a function of composite reflectivity, with critical inflection points occurring at HRRR specified heights (lifting condensation level LCL, -20°C level, and the equilibrium level EL). This model was specifically formulated for convective precipitation. The model is a piecewise linear fit with nothing below the LCL plus an offset that depends on composite reflectivity and may be positive or negative. This is needed to reproduce profiles beginning above the LCL at lower reflectivities, and extending below the LCL for higher reflectivities. The model has a constant value, given by the composite reflectivity, up to the -20°C level. Above that level, there is a linear decrease to the EL plus an offset to account for the behavior of profiles that stop short of the EL at lower reflectivities and extend well above it for very high reflectivities. In the model, the slope of the decrease above the -20°C level is a function of composite reflectivity. The same model was used to derive profiles in both the Southeast and Great Plains. The model also uses topography to convert between height above the ground and height above mean sea level.

Figure 16 provides results applying the observation operator to the Southeast case. The composite reflectivity shows that GOES does a good job locating the eight centers of convective initiation. The weak reflectivity (< 20 dBZ) tends to be over-estimated by the technique. Mid-range reflectivity (~35 dBZ) tends to be displaced downwind. Strong reflectivity (> 50 dBZ) has great location agreement. The cross-sections show that GOES does a good job capturing the vertical towers of strong reflectivity. To first order, the parametric vertical profile model captures the vertical extent and shape of the reflectivity profile.

Figure 17 gives the results applying the observation operator to the Great Plains case. GOES-derived composite reflectivity does a good job locating the three storms. As in the Southeast case, the operator tends to over-estimate the weak reflectivity (< 25 dBZ), and note that it also tends to be displaced downwind. The mid-range reflectivity (~35 dBZ) is in very good agreement. The strong reflectivity areas (> 50 dBZ) are too small and have false alarms. GOES does a reasonable job capturing the locations of the strong reflectivity towers, however MRMS cores are narrower than GOES. For both cases, the differences between MRMS and GOES-derived reflectivity are due to the fact that GOES primarily provides information about cloud top. These differences can also be seen in the details of the vertical development of convective cores and their time evolution.

3--Tropical Cyclone Intensification Work

While this aspect of the project has just begun with the arrival of Chris Slocum as a post-doctoral fellow, the presence of convective hot towers in tropical convection are indicative of formation and intensity change in tropical cyclones. With the preliminary data collected with GOES-R during the 2017 Atlantic hurricane season, case studies with GOES-R convective parameters are being conducted. As suspected prior to the launch of GOES-R, and confirmed in section 1 of this report, existing convective parameters such as tropical overshooting tops and lightning from ground-based detection networks, are not always spatially collocated during the 2017 season. However, given the increased temporal resolution of ABI scans during tropical storms, tracking the duration of overshooting tops may prove more useful and help unravel the observed spatial discrepancies. Figure 19 shows filtered flashes from preliminary GLM data and regions identified as convectively vigorous and unique using a combination of brightness temperatures – a pseudo-TOTS product is used (see Griffen, S. M., 2017: Climatology of tropical overshooting tops in North Atlantic tropical cyclones. *J. Appl. Meteor. Climatol.,* **56,** 1783-1796.) – and reflectance from Hurricane Harvey at 18:04 UTC on 24 Aug 2017 during the system's rapidly intensification. These features are being examined for incorporation into the SHIPS Rapid Intensification Index as a predictor and evaluated as a candidate to improving TC vortex initialization into numerical models.

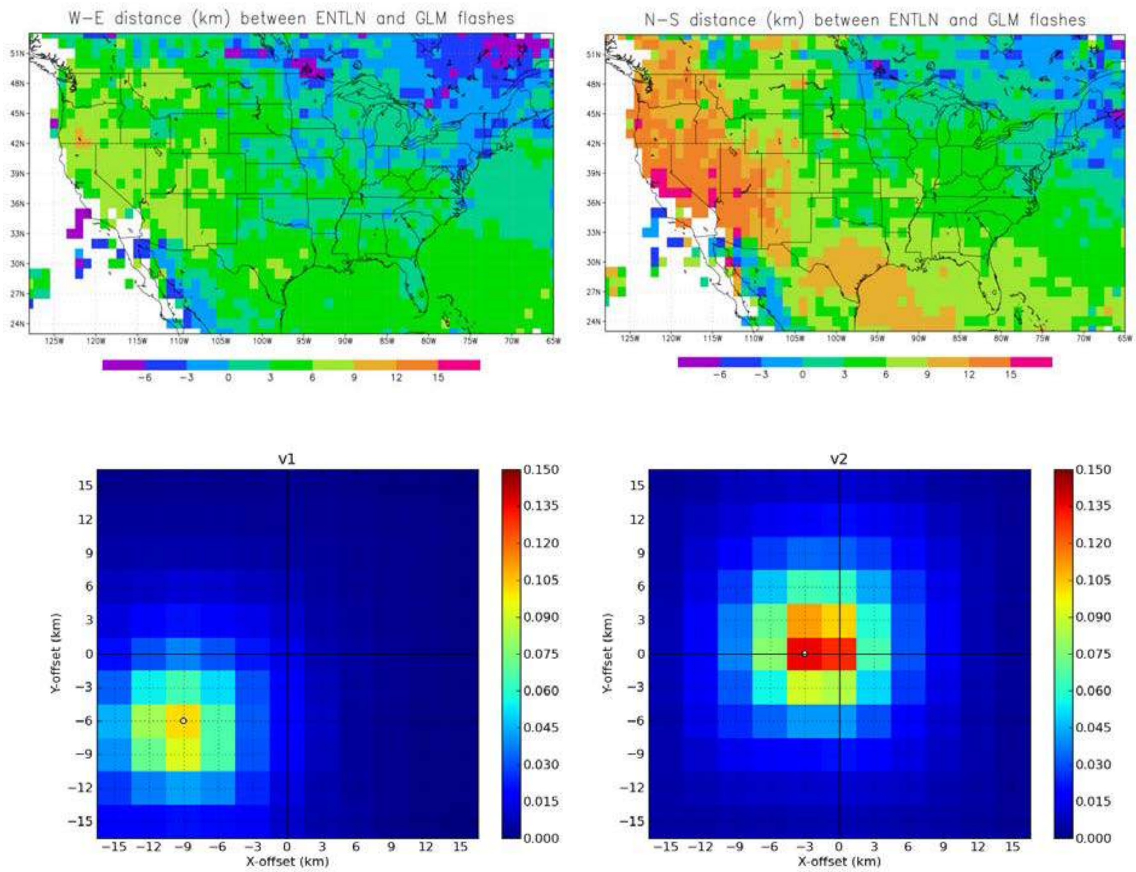


Figure 1. GLM geolocation results. Top, left: west-east displacement between ENTLN and GLM flashes. Top, right: north-south displacement between ENTLN and GLM flashes. Bottom, left: GLM Version 1 displacement correlation analysis. Bottom, right: GLM Version 2 displacement correlation analysis.

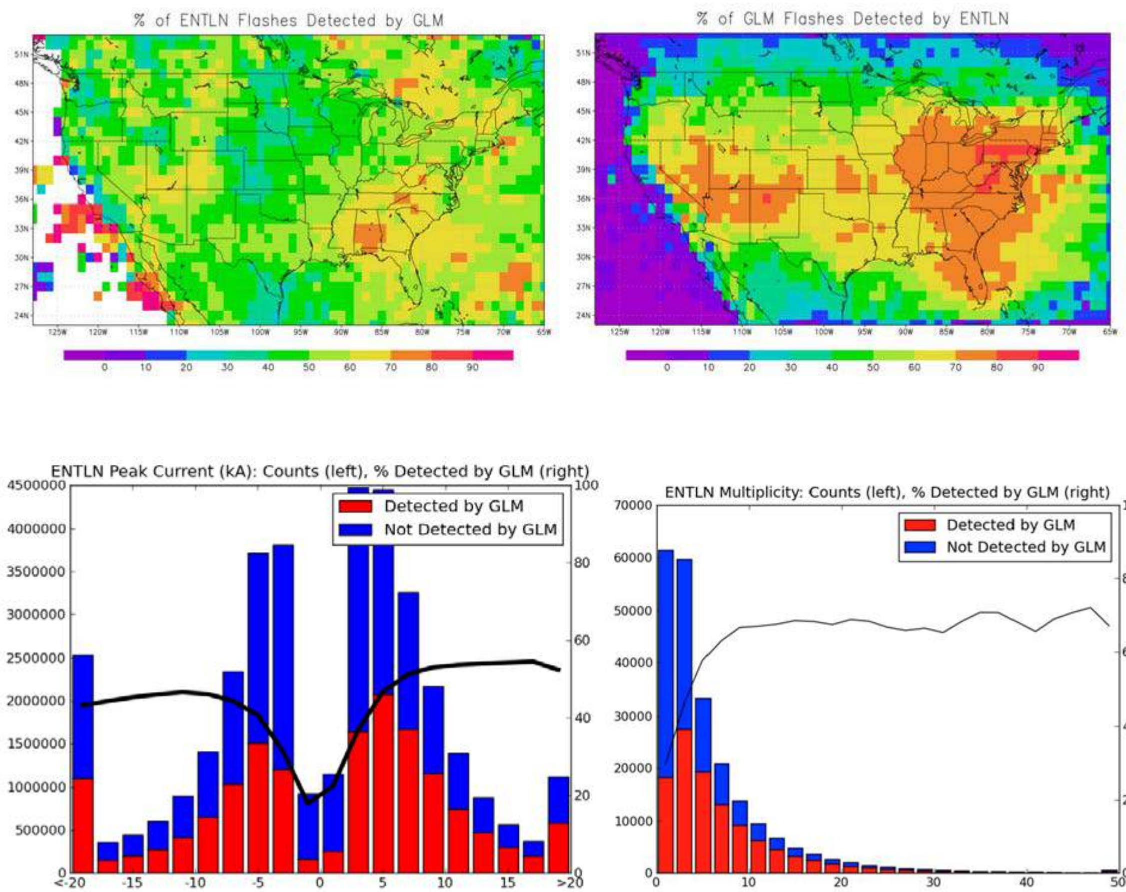


Figure 2**.** GLM detection efficiency and false alarm results. Top, left: percent of ENTLN flashes detected by GLM. Top, right: percent of GLM flashes detected by ENTLN. Bottom, left: ENTLN lightning detected by GLM (red bar) and not detected (blue bar) with percent detected (black line) as a function of the ENTLN peak current. Bottom, right: as in bottom, left panel but as a function of ENTLN multiplicity.

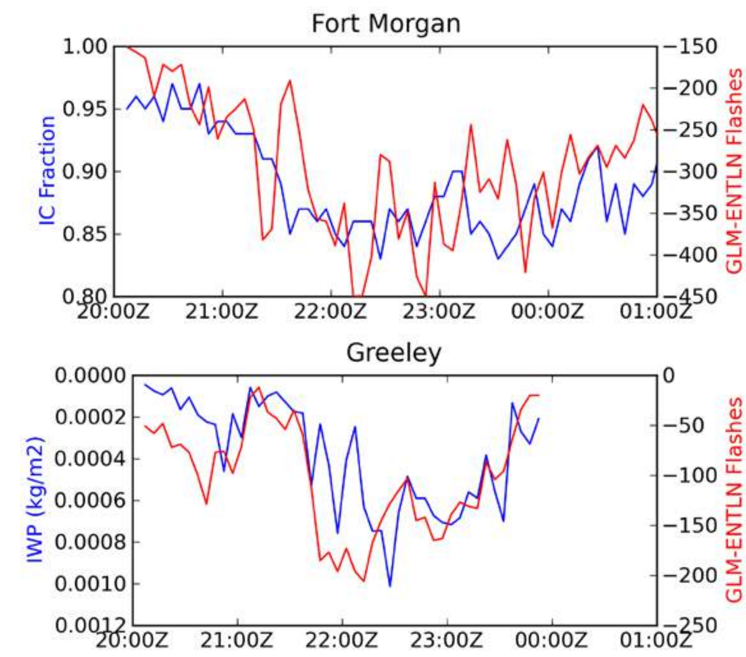


Figure 3. GLM-ENTLN flash density time series (red line) and time series of ENTLN peak current (top panel), intra-cloud fraction (middle panel), and ice water path (bottom panel) in blue line.

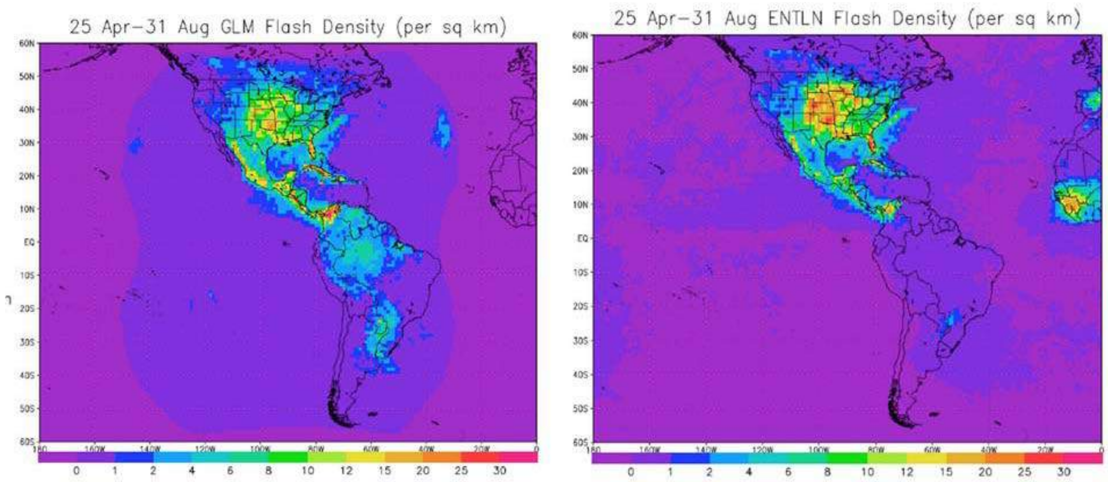


Figure 4. GLM flash density (left) and ENTLN flash density (right).

Southeast

Northern Plains

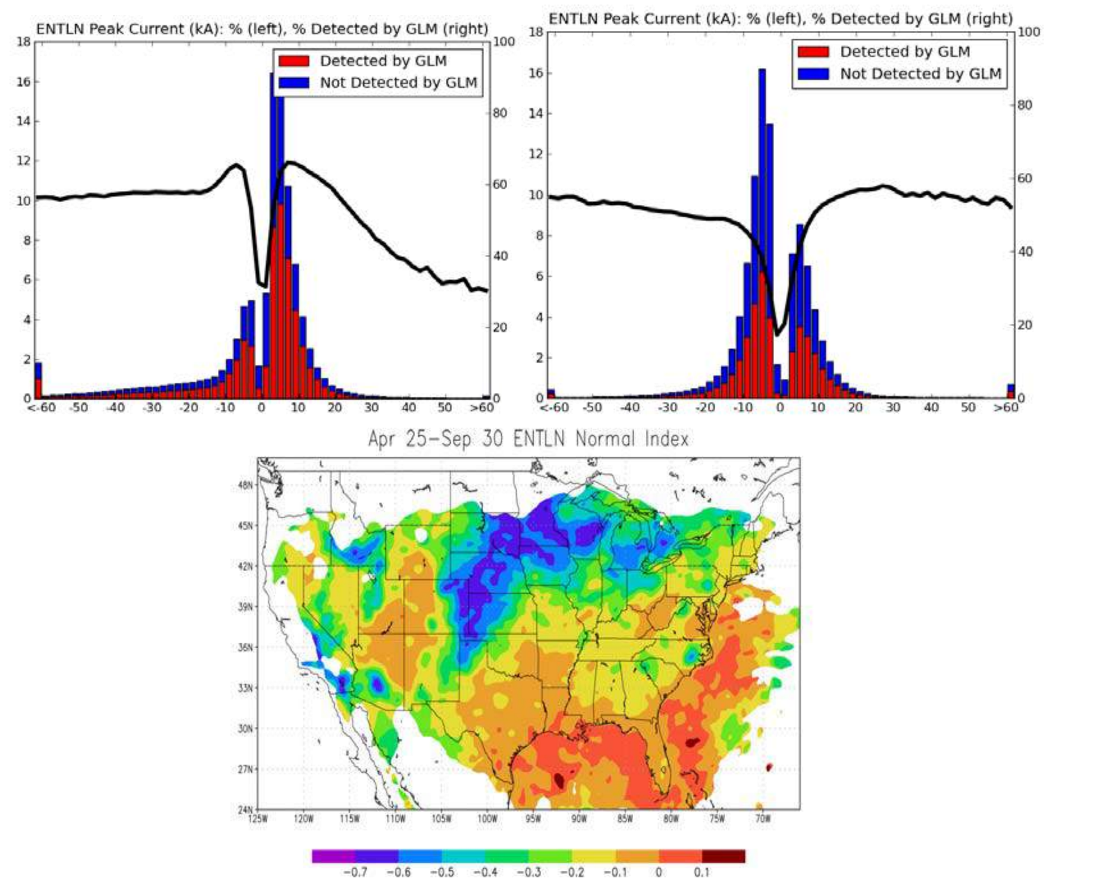


Figure 5. Bar histogram indicating the percent of ENTLN flashes (LHS of y-axis) with the corresponding ENTLN peak current (kA; x-axis) in the southeast (top, left) and northern plains (top, right). Also shown by the solid line is the GLM DE (%; RHS of y-axis) for the corresponding peak current. Flashes were binned for every 2 kA of peak current over the time period of 25 April to 30 September 2017. Bottom: Normal index (defined in text) for 25 April to 30 September 2017 with a 25 km Gaussian spatial filter applied. Areas with flash density less than 1 flash km^{-2} or ENTLN DE relative to GLM less than 50% are masked out in white.

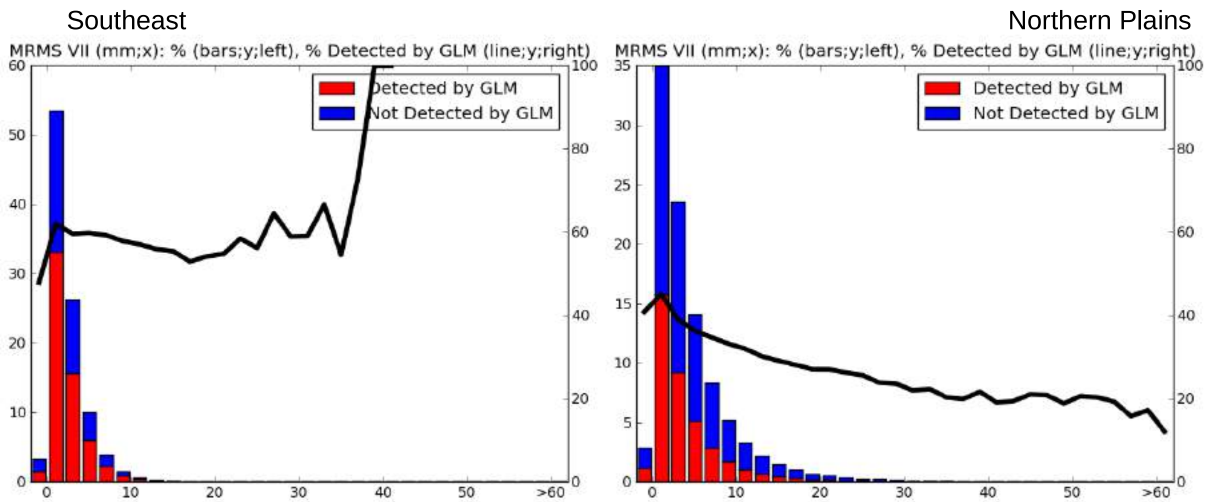


Figure 6. Bar histogram indicating the percent of ENTLN flashes (LHS of y-axis) with the corresponding average vertically integrated ice (VII; in mm; x-axis) in the southeast (left panel) and northern plains (right panel). Also shown by the solid line is the GLM DE (%; RHS of y-axis) for the corresponding VII. Flashes were binned for every 2 mm of VII over 70 days in 2017.

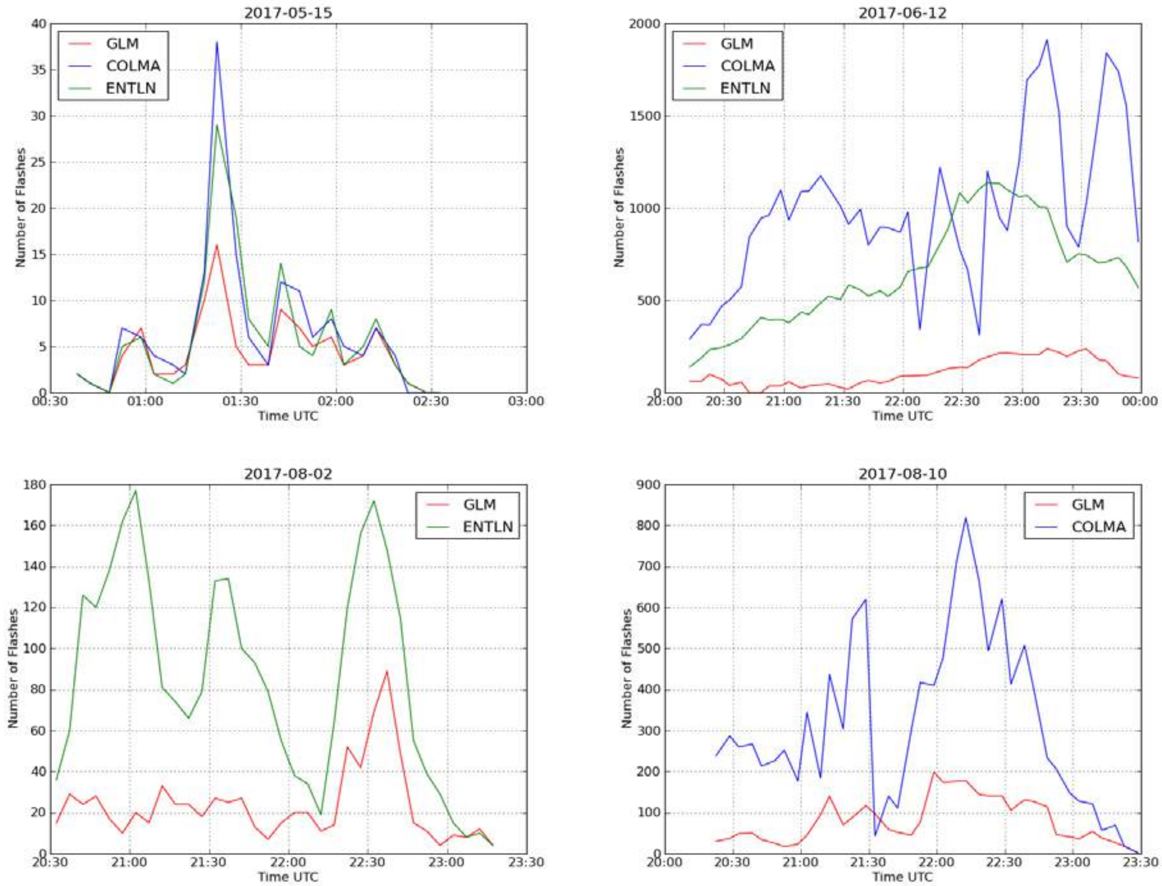


Figure 7. Storm examples over northeast Colorado occurring on 5/15 (top, left), 6/12 (top, right), 8/2 (bottom, left), and 8/10 (bottom, right).

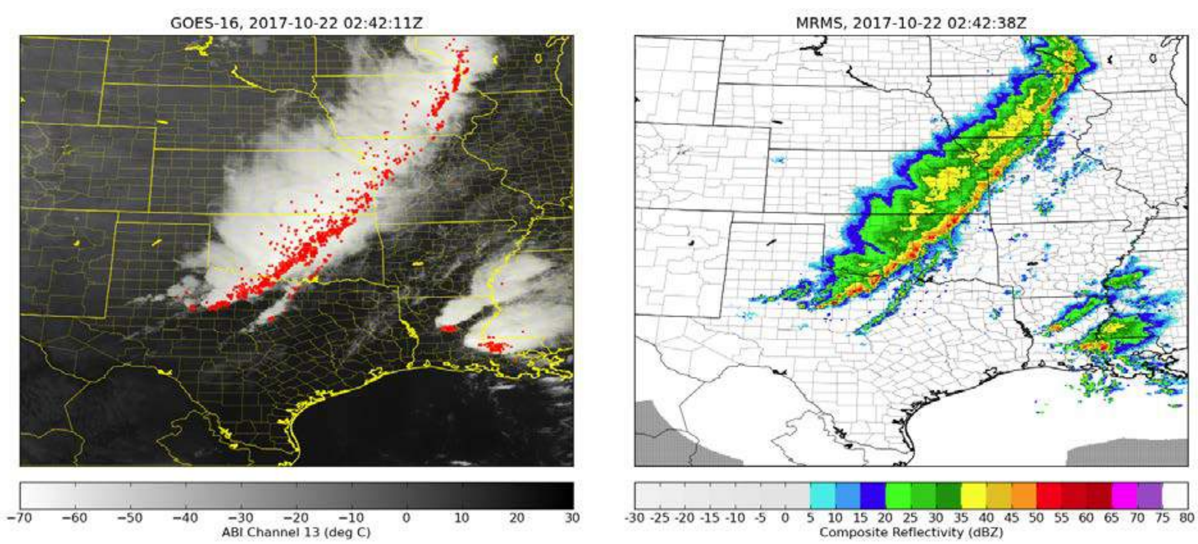


Figure 8. Storm example over the southern Great Plains on 10/22 showing ABI and GLM (left) and MRMS (right). GLM has been accumulated over a 5-minute period.

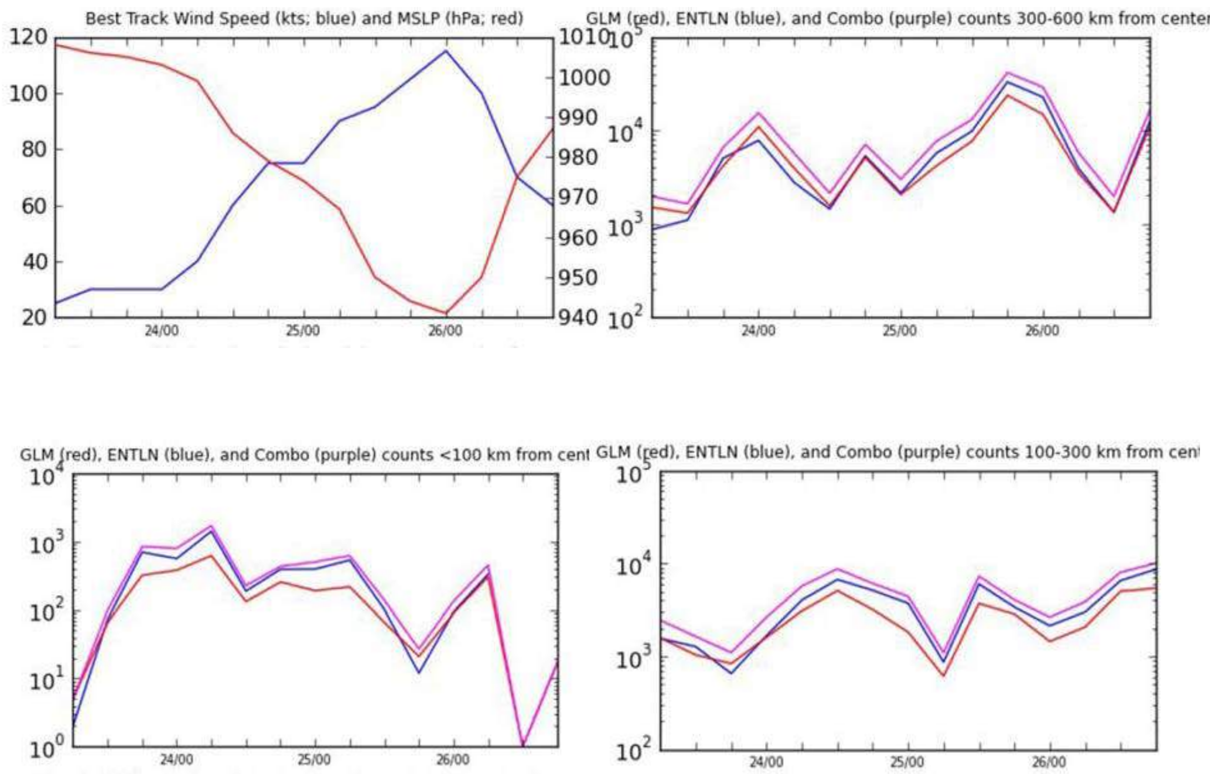


Figure 9. Harvey time series showing wind speed (top, left; blue line), inner core lightning (bottom, left), outer core lightning (bottom, right), and outer rainband lightning (top, right). In the lightning panels, GLM is the red line and ENTLN is the blue line.

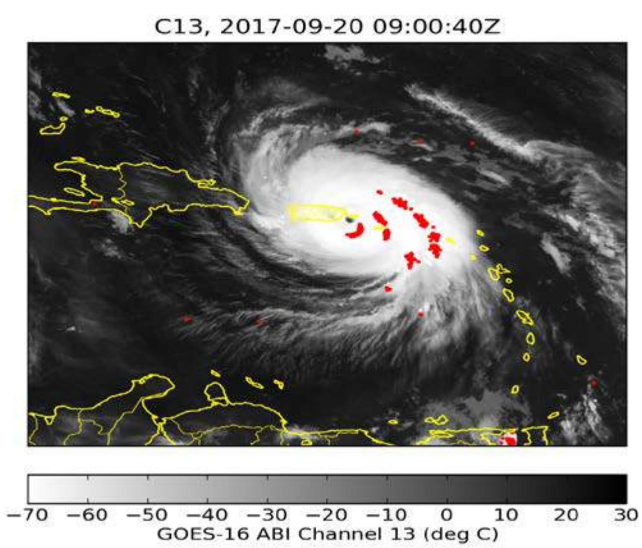


Figure 10. GLM (red points) overlaid on ABI Channel 13 for Hurricane Maria near the time of landfall.

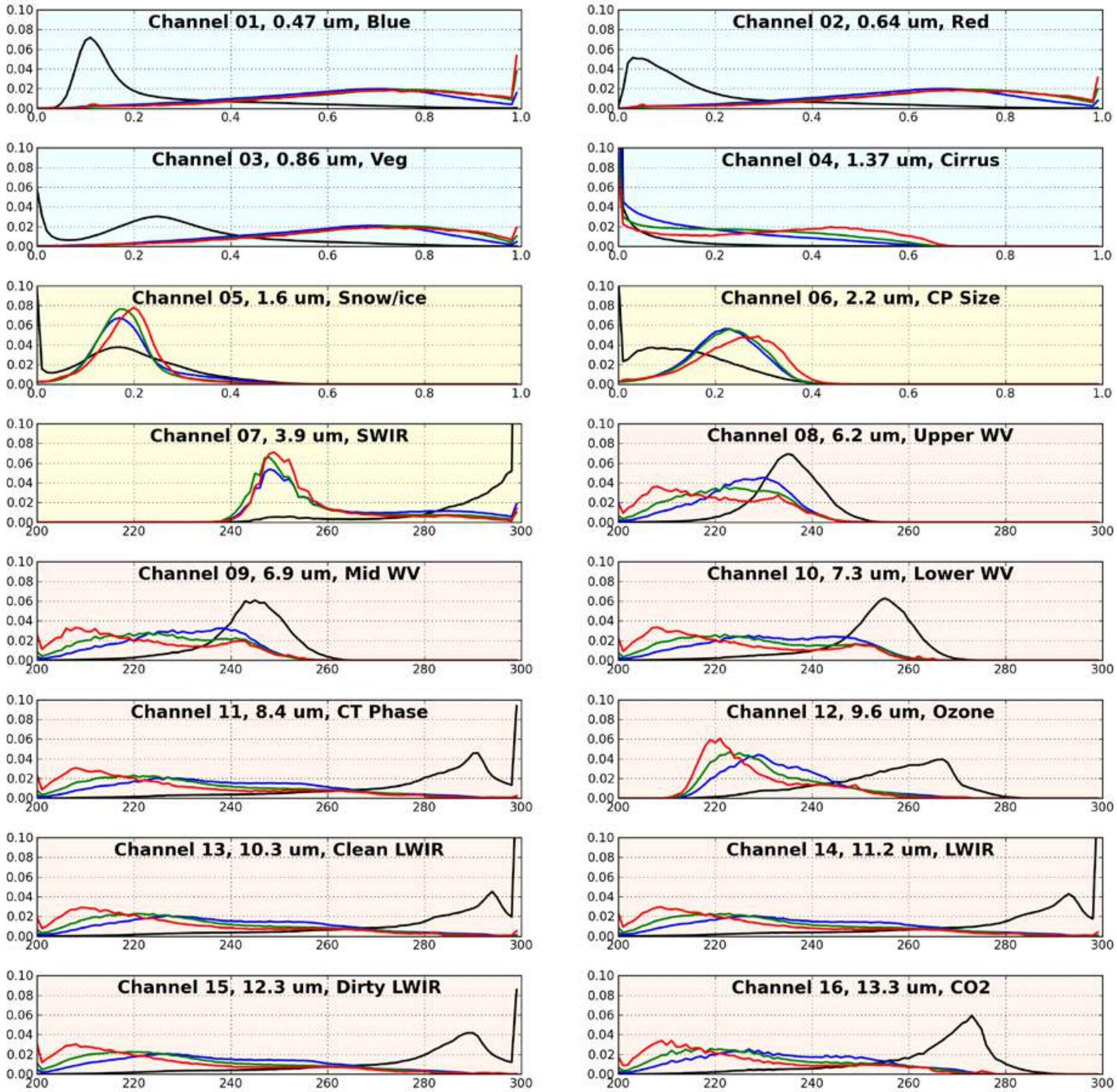


Figure 11. Histograms showing fraction of GOES-16 observations with MRMS composite reflectivity exceeding the threshold 20 dBZ (blue), 35 dBZ (green), 50 dBZ (red), and all observations (black). The horizontal axis for Bands 1-6 is reflectance (0-1) and for Bands 7-16 it is brightness temperature (200-300K).

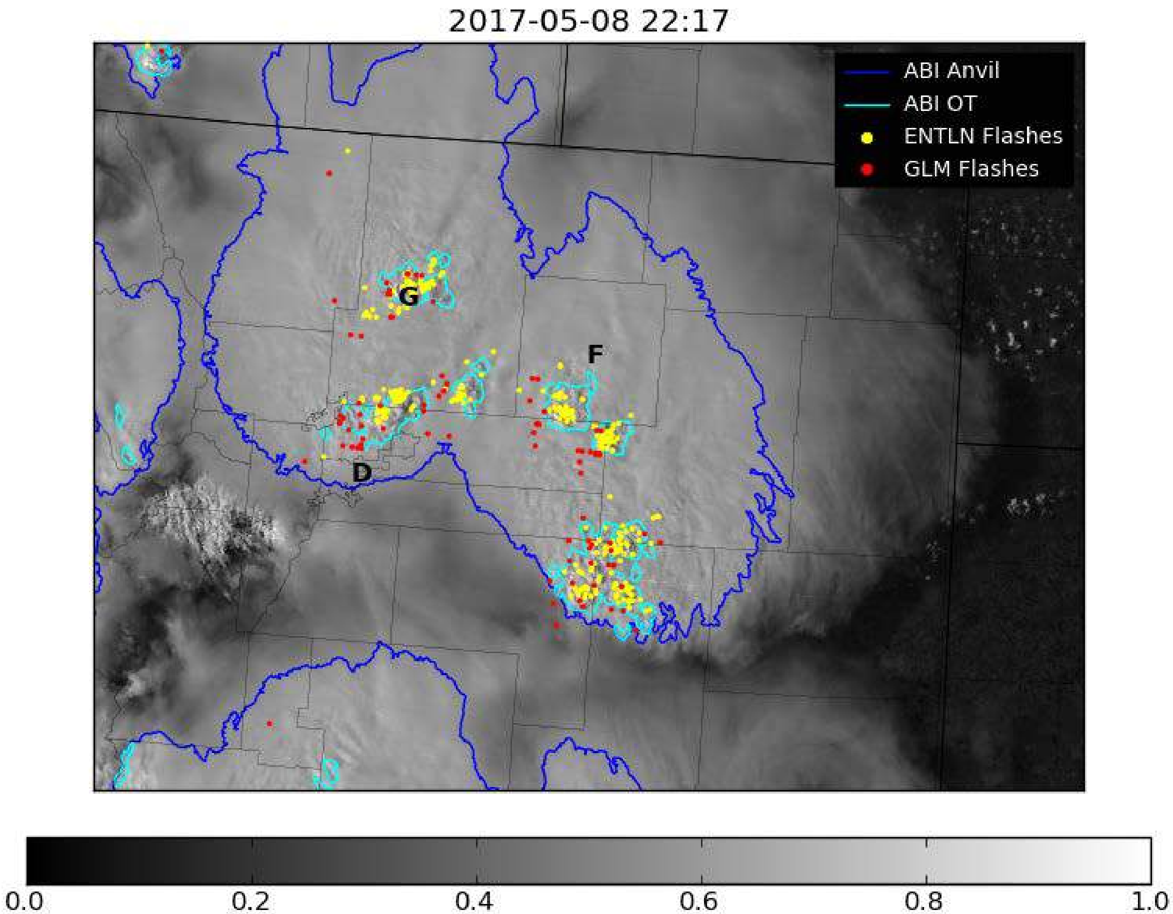


Figure 12. Snapshot from the 8-May case at 22:17Z when there were thunderstorms located just north of Denver (D), over Greeley (G), and approaching Fort Morgan (F). The image is ABI channel 2 reflectance and has been corrected for parallax assuming a cloud height of 15 km, the dark blue line encloses the ABI identified anvil areas, the cyan line encloses the ABI identified overshooting tops, the yellow dots are ENTLN lightning flashes, and the red dots are GLM lightning flashes. Note that this uses the older version of GLM data, which have a clear location shift relative to ENTLN.

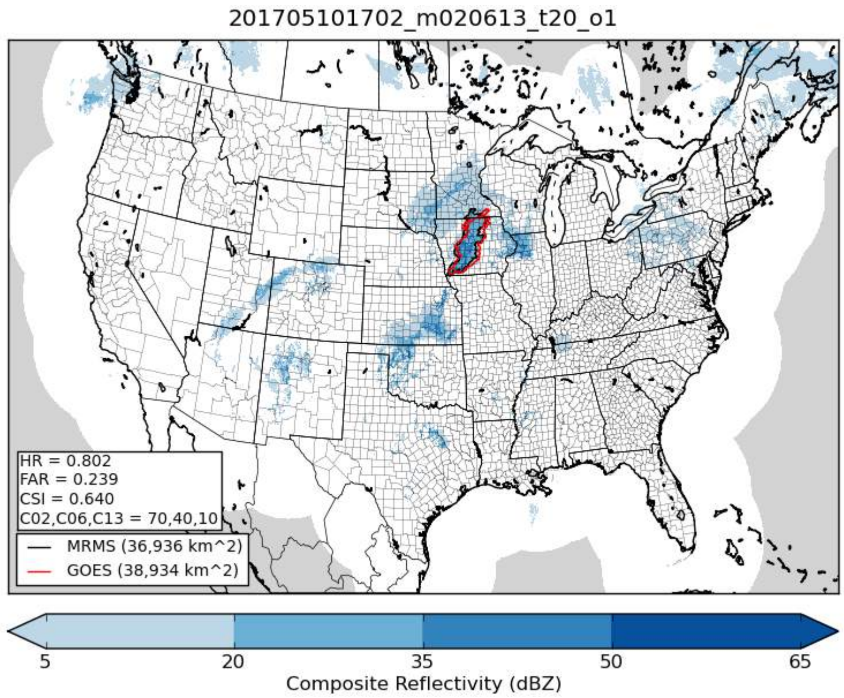


Figure 13. Object-based methodology example image. This example is representative of the mode skill, which is a hit rate of 80% and false alarm ratio of 30%.

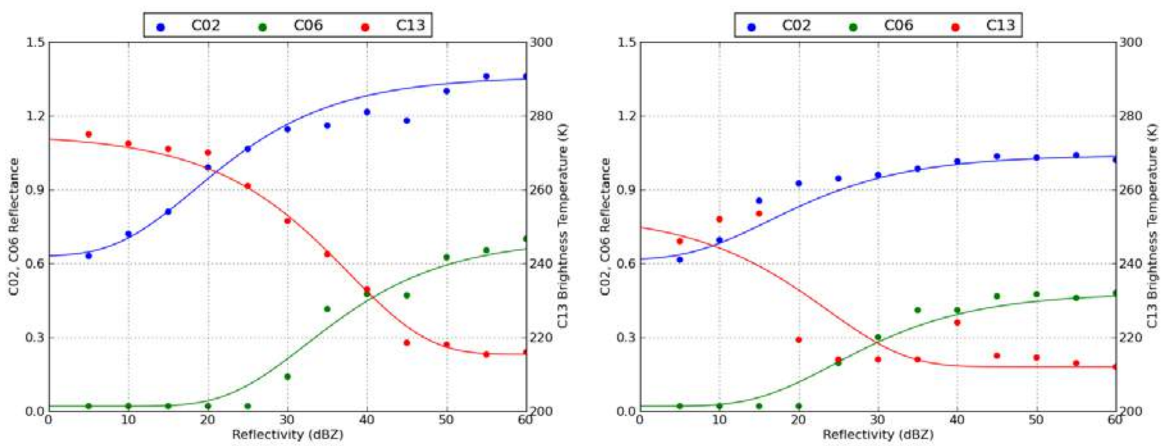


Figure 14. Observation operator for composite reflectivity for the Southeast (left) and Great Plains (right).

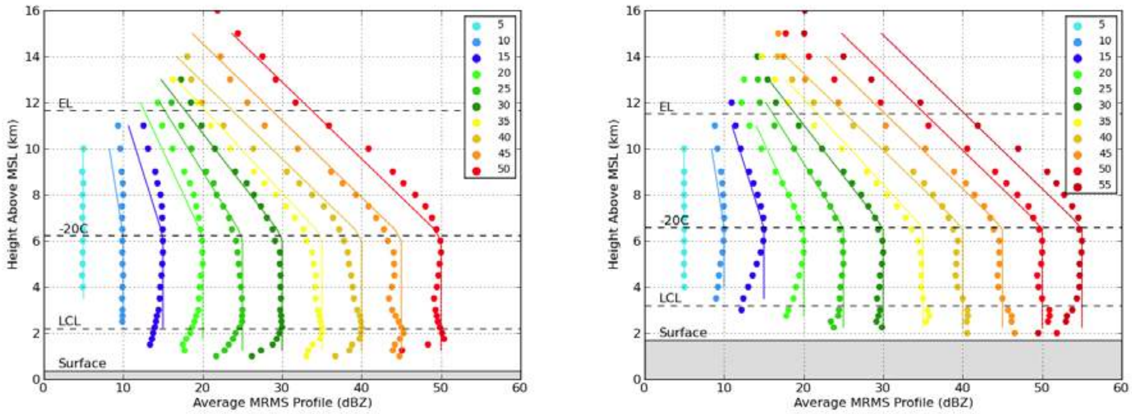


Figure 15. Observation operator for reflectivity vertical profile for the Southeast (left) and Great Plains (right).

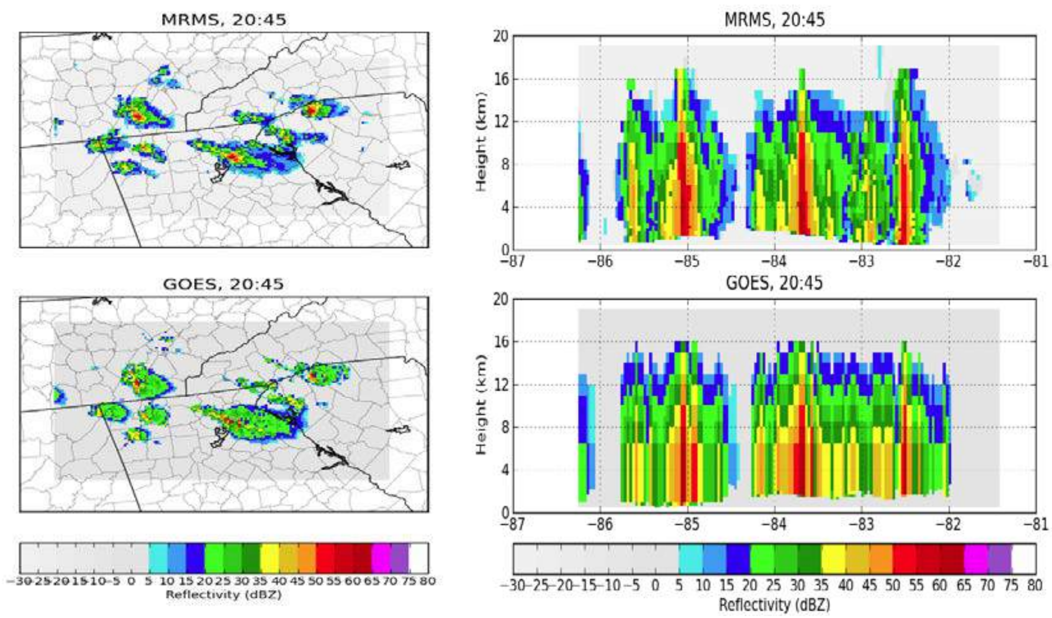


Figure 16. Composite reflectivity maps (left) and vertical cross-sections (right) for Southeast case comparing MRMS (top) with GOES (bottom). The cross-section gives the latitude-maximum value as a function of longitude and height.

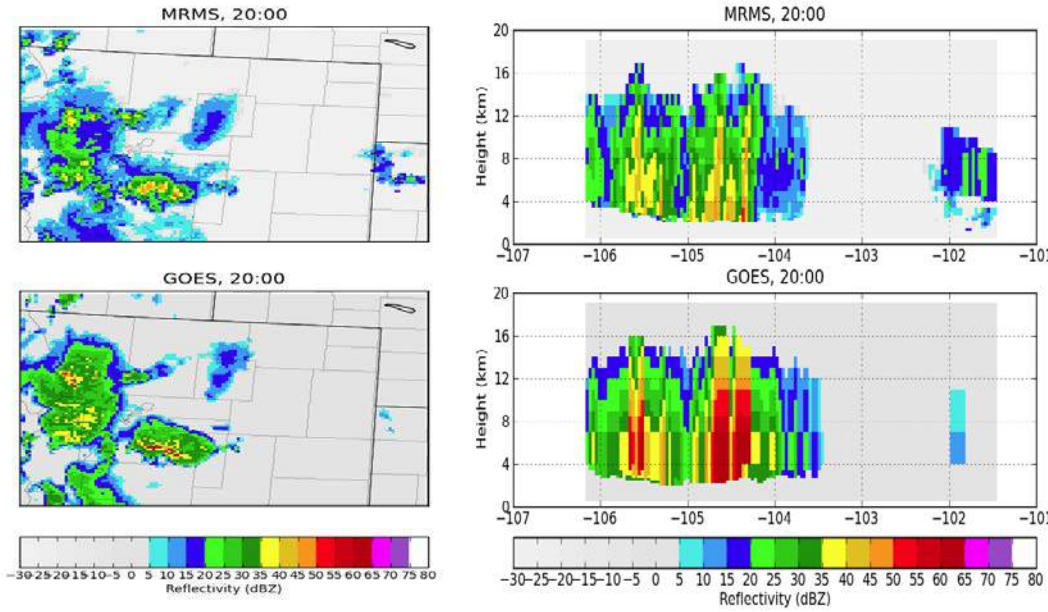


Figure 17. Composite reflectivity maps (left) and vertical cross-sections (right) for the Great Plains case comparing MRMS (top) with GOES (bottom). The cross-section gives the latitude-maximum value as a function of longitude and height.

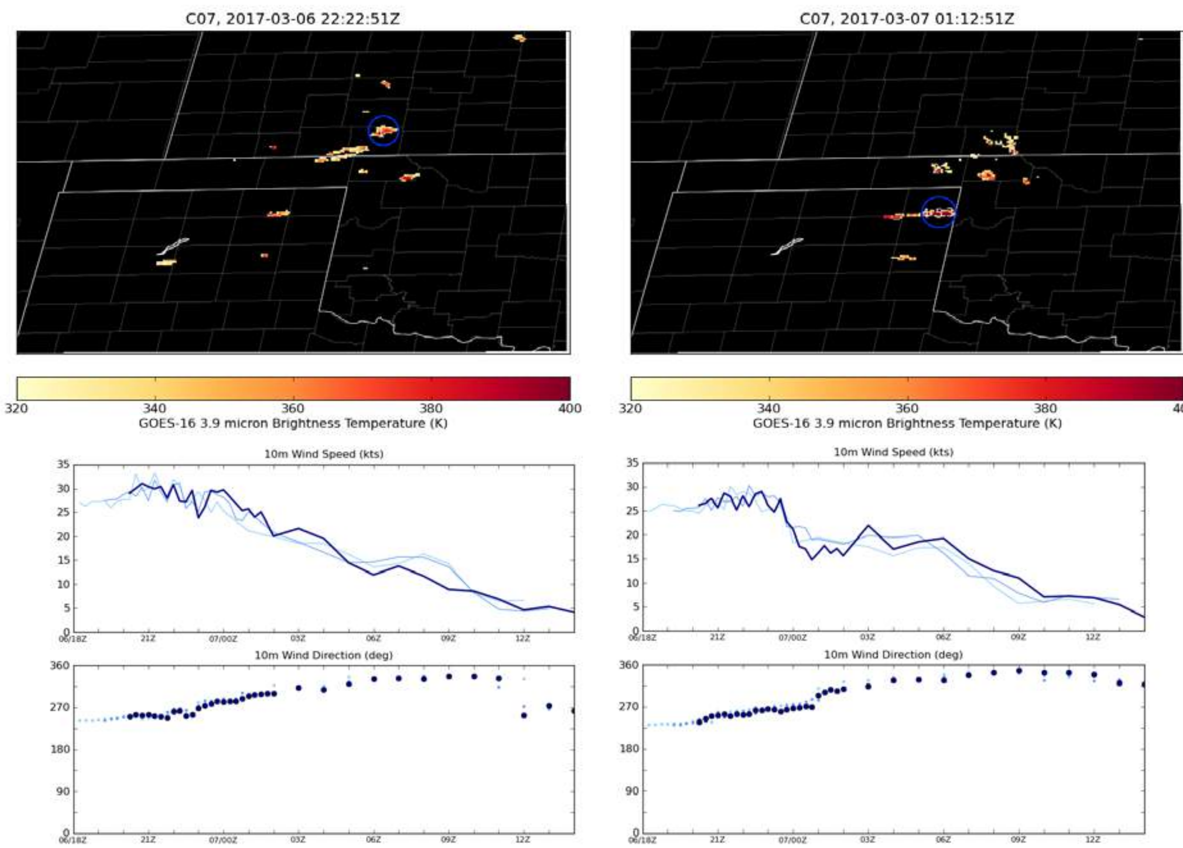


Figure 18. March 6 wildfire example. Top, left panel shows Channel 7 (short-wave infrared) just before the front turned the fire propagation direction to the south (22:22Z). Top, right panel shows about three hours later (01:12Z) just before the front reached the fires in Texas. The bottom, left panel shows the wind speed and direction at the Oklahoma fire location. The bottom, right panel shows the wind speed and direction at the Texas fire location.

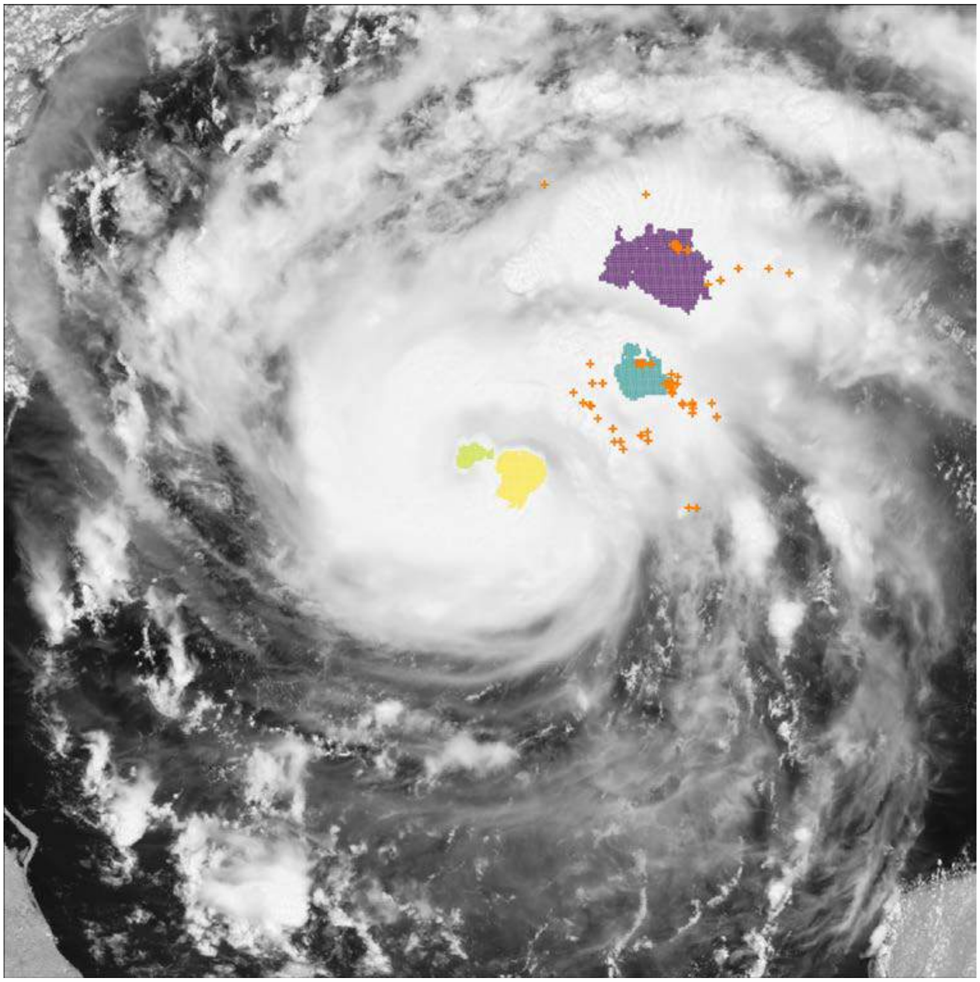


Figure 19. Filtered, preliminary GLM flash data (orange) and unique, vigorous convective labeled features (yellow to blue shading) containing tropical overshooting tops overlaid on 0.64 µm GOES-16 imagery from Hurricane Harvey at 18:04 UTC on 24 Aug 2017.

Publications: None

Presentations:

Hilburn, K., 2017: GLM Assessment During ER-2 Campaign over Colorado. *GLM Annual Science Team Meeting*, Huntsville, AL, 14-Sep.

Hilburn, K., M. Marchand, Y. Lee, C. Kummerow, and C. Alexander, 2018: Using GOES-16 to Improve Short Term Forecasts. *AMS 98th Annual Meeting*, Austin, TX, 11-Jan.

PROJECT TITLE: CIRA Support for Development and Evaluation of JPSS-1 Based Tropical Cyclone Intensity and Structure Estimates - Application of JPSS Imagers and Sounders to Tropical Cyclone Track and Intensity Forecasting

PRINCIPAL INVESTIGATOR**:** Galina Chirokova

RESEARCH TEAM**:** Robert DeMaria, Jack Dostalek, Andrea Schumacher

NOAA TECHNICAL CONTACT**:** Satya Kalluri (NOAA/NESDIS) and Candice Jongsma (NOAA/OAR)

NOAA RESEARCH TEAM**:** John Knaff (NOAA/NESDIS/STAR)

FISCAL YEAR FUNDING: $111,600

PROJECT OBJECTIVES:

The ability to forecast tropical cyclone (TC) intensity changes has improved much more slowly than the ability to forecast TC tracks. An especially difficult but very important forecast problem is predicting rapid increases in TC intensity, that is Rapid Intensification (RI). Improving RI forecasts is one of the highest priorities within NOAA. The time scale of TCs' track and intensity changes is on the order of 12 hours, which makes the JPSS instruments well suited for the forecasting of these parameters. Several TC applications of JPSS data using S-NPP ATMS, CrIS, and VIIRS data are being developed. The first group of applications uses ATMS-MIRS and NUCAPS retrievals to improve the Rapid Intensification Index (RII). JPSS data are used to develop new predictors for the RII as well as to improve existing predictors. As part of the development of the new predictors for the RII, two additional end user applications were developed: (1) the moisture flux application that allows for the detection of dry air intrusions that are an important factor for forecasting intensity (the Moisture In Flux Storm Tool, MIST); and (2) the improved eye-detection application (the Satellite Eye Detection Routine, SEDR). The objective automated eye-detection algorithm was enhanced by using VIIRS data and ancillary data, and will be adapted to be used as an additional predictor in SHIPS, LGEM, and RII. The newly developed and improved predictors developed here will be incorporated into the NHC's operational RII to improve its performance. The second group of applications developed tools to better utilize VIIRS imagery, especially VIIRS DNB imagery, for TC forecasting, and includes a proxy-visible imagery application and improved TC VIIRS DNB imagery.

The newly developed products were made available via the satellite Proving Ground to operational forecasters at the National Hurricane Center (NHC) and the Joint Typhoon Warning Center (JTWC) for evaluation and feedback. If the evaluation is positive, the products can be transitioned to NHC and JTWC operations.

PROJECT ACCOMPLISHMENTS:

1--Estimate the Utility of ATMS-MIRS/NUCAPS Data for Detecting Warm Core Changes Prior to RI

The analysis of the changes in the warm core structure during the RI has been completed for Hurricane Edouard, al062014. Changes in the ATMS temperature fields were evaluated to test the hypothesis that RI is associated with a better vortex alignment. It was found that the ATMS temperature fields capture the warm core titled downshear prior to the RI. Figure 1 shows the vertical cross-section of the ATMS-MIRS temperature profile for Edouard on September 13, 2014, at 17:13 UTC.

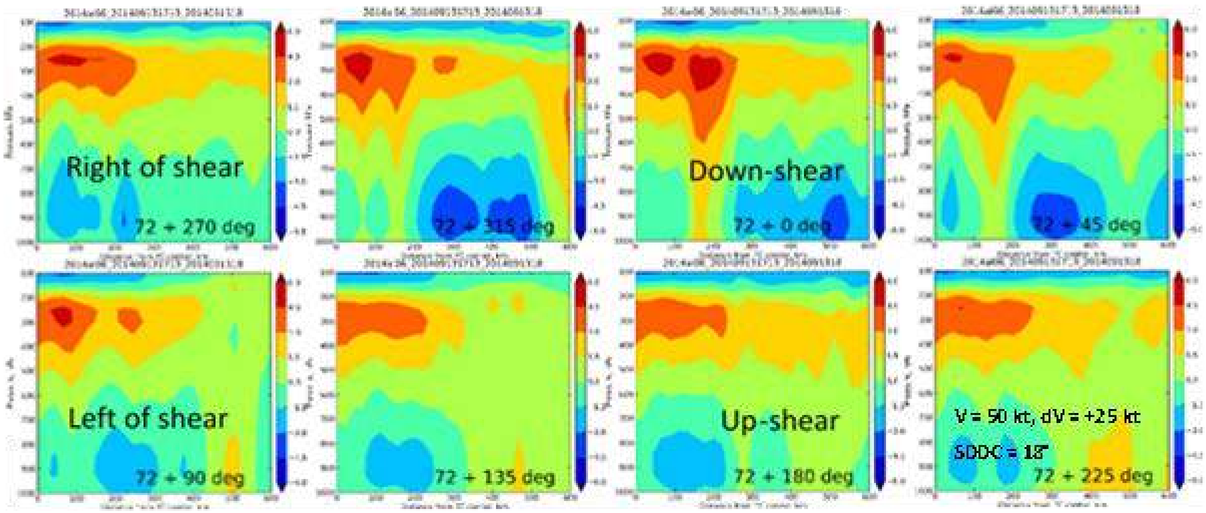


Figure 1. The ATMS-MIRS vertical temperature cross-sections for al062014, Edouard, on Sep 13, 2014 at 17:13 UTC. The current intensity is 50 kt, and the storm went through 25 kt RI in next 24 hours. The GFS shear (SDDC) heading is 18°. Images are created for every 45° relative to the direction of shear, starting at -90° upshear right at the top left image.

2--Generalize Eye-detection Algorithm to be an Iterative Algorithm

A correction algorithm to the "first pass" GOES-VIIRS algorithm was developed to better utilize the higher spatial resolution provided by VIIRS imagery. The correction algorithm uses two inputs as predictors in a “second pass” machine learning algorithm. The first input is the eye presence probability generated by the “first pass” GOES-VIIRS algorithm. The second input is a temperature difference parameter (TDP) determined from the VIIRS imagery. Figure 2 shows an example of how the TDP is calculated. The TDP is defined as the temperature difference between the warmest center pixel and the coldest concentric ring. The coldest concentric ring is shown as the large red circle in Figure 1. The TDP is large when there is a warm pixel near the center surrounded by a symmetric cold ring, which is a basic characteristic of tropical cyclone eyes. After the TDP is determined, it is used together with the eye probability from the combined GOES-VIIRS algorithm as input to a two-parameter machine learning algorithm to provide a revised eye probability estimate. The comparison of the new iterative algorithm with the previous version demonstrated that the iterative algorithm increases the probabilities of eye cases and reduced the probability of non-eye cases for a sample of Atlantic TCs.

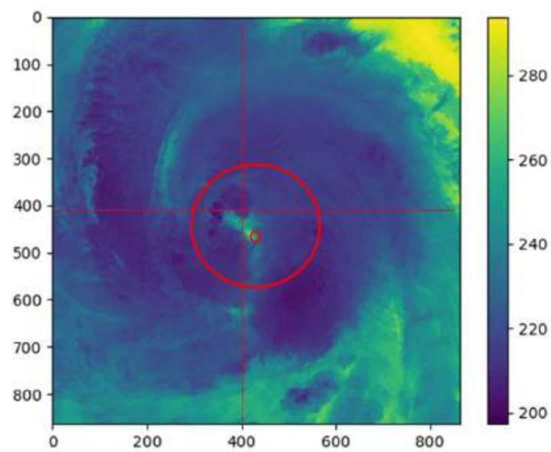


Figure 2. The temperature difference parameter (TDP) calculation illustrated on al062014, Edouard, Sep 15 2014 at 05:21 UTC.

3--Test “Proxy Visible" Algorithm on VIIRS and GOES 2012 - 2014 Data

The proxy-visible algorithm was tested on approximately 20 VIIRS scenes from 2015-2016, which is a very large sample size since values at each pixel are used as independent variables. The stretched VIIRS I04 band was used as a baseline to evaluate the performance of the proxy-visible algorithm. The testing cases were selected to include different types of clouds to represent a wide range of conditions. Figure 3 shows the comparison of the I04 band with fixed stretching and the proxy-visible image. This image is for the case that works best for the static algorithm applied to 3.9 μm band. The proxy-visible image shows a better contrast, and both images depict similarly well the low-level clouds. The proxy-visible image is slightly over-saturated for the high clouds. A larger sample will be used to further investigate whether the over-saturation can be reduced or eliminated. It is very important to point out that forecasters who will be using this product are most interested in low-level cloud motions and that other GOES IR channels are better suited for observing the upper-level/cold cloud evolution.

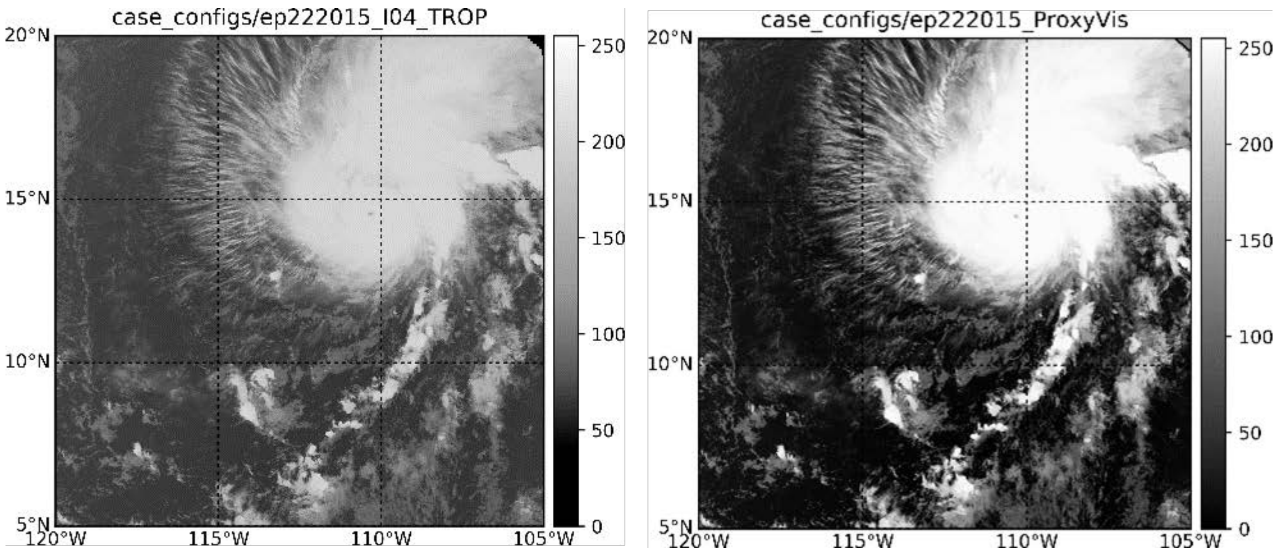


Figure 3. VIIRS Band I04 statically stretched to highlight low-level clouds (left) and proxy-visible image (right) for Major Hurricane Sandra, ep222015, on November 26, 2015 at 08:53UTC. This image is for the case that works best for the static algorithm applied to 3.9 μm band. The proxy-visible image shows a better contrast, and both images depict similarly well the low-level clouds.

4--Develop Improved Algorithm for Displaying VIIRS TC DNB Imagery

The development of the tropical scaling for DNB images has been completed and the development of the updated software for processing VIIRS TC-centered imagery has continued. The final version of the scaling algorithm was tested on a limited number of TC images, and showed very good performance for both day- and nighttime images for a wide range of conditions. The new method was compared with error function scaling developed by Seaman and Miller (2015), and showed either similar or better performance for several tested cases. Figure 4 shows the scene for TC Carlos, sh042017, on 2017 02/05 20:48 UTC. That image is at 06 AM local time, and shows the scene across the terminator scaled using the error function (left) and the new tropical scaling (right). The new tropical scaling will be used to create TC-centered DNB imagery for NHC during the 2017 Atlantic and east Pacific Hurricane seasons, and will also be used to produce VIIRS TC-centered imagery on RAMMB-CIRA’s TC Real-Time page, http://rammb.cira.colostate.edu/products/tc_realtime/

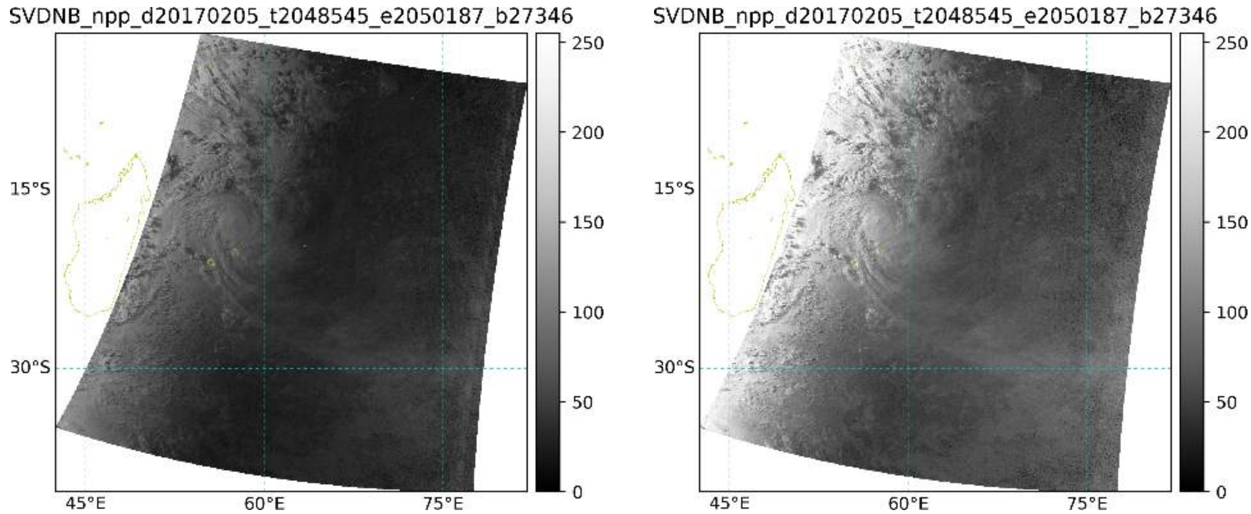


Figure 4. TC Carlos, sh042017, on February 05, 2017 at 20:48 UTC, 06:00 AM local solar time. The scene contains the terminator. Left: image created using error function scaling (Seaman and Miller, 2015). Right: image created using the new tropical scaling.

5--Evaluate the Use of Combined ATMS-MIRS and NUCAPS Data for Improving RII Predictors

Overall, ATMS-MiRS moisture data are better suited for estimating horizontal moisture flux into tropical cyclones than NUCAPS. The main advantage of ATMS-MiRS retrievals is that they tend to provide more accurate estimates of atmospheric variables in cloudy and rainy conditions that normally occur in the TC environment. However, NUCAPS is outperforming ATMS-MiRS soundings in clear or partly-cloudy conditions. Thus, combining available NUCAPS soundings over clear areas with ATMS-MiRS soundings has a potential for providing more accurate moisture flux (MIST, Moisture In-Flux Tool) estimates. A comparison of moisture flux estimated at different distances from the TC center from ATMS-MiRS and NUCAPS data has been performed for several cases. Figure 5 shows MIST calculated from a) ATMS-MiRS, b) NUCAPS, and c) NUCAPS microwave-only retrievals (NUCAPS-MW) for Hurricane Danny (2015) at R = 510 km from the storm center. MIST calculated using ATMS-MiRS is similar to MIST calculated using NUCAPS, however, they are not identical. For example, both NUCAPS and NUCAPS-MW tend to have much larger flux values at the lower levels compared to ATMS-MiRS estimates. Provided that MIST estimates are similar when calculated from both ATMS-MiRS and NUCAPS, and that NUCAPS was not designed to be used in the presence of heavy rain and ice that are common in TC environment, the statistical development of rapid intensification predictors based on MIST will be continued using only ATMS-MiRS data.

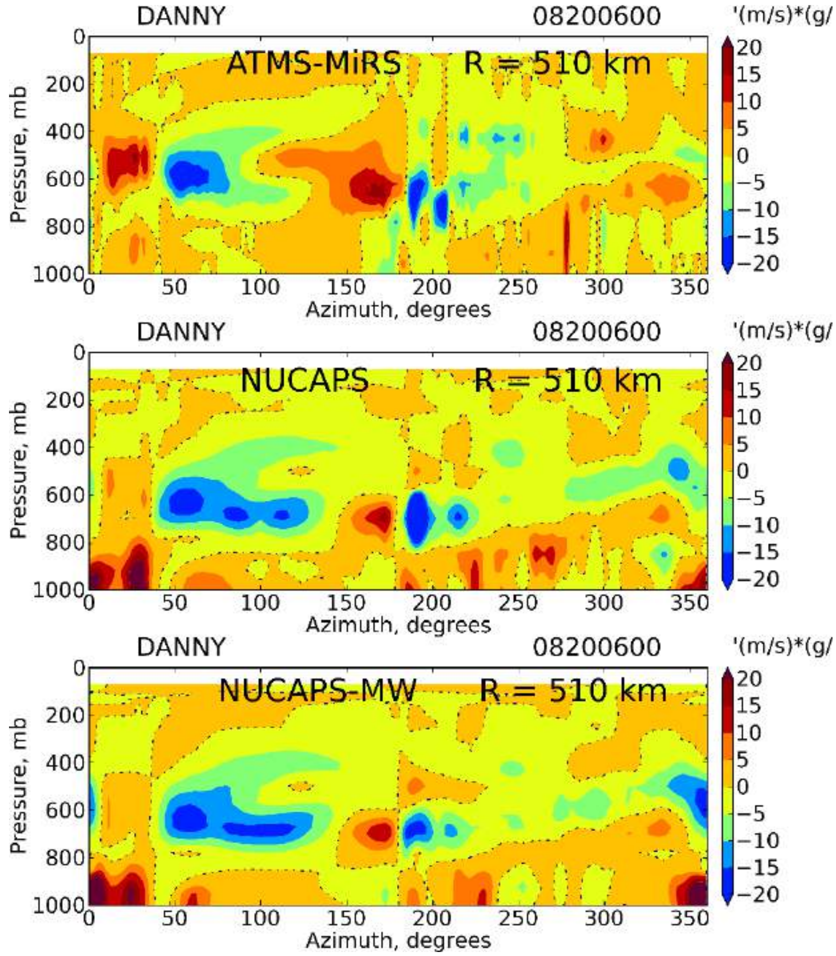


Figure 5. MIST for Hurricane Danny (2015) on 08/20/2015 06UTC. Shown are MIST estimates using ATMS-MiRS (upper), NUCAPS (middle), and NUCAPS microwave-only retrievals (lower).

6--Create and Incorporate into the RII New Predictors Based on the Probabilistic Eye-detection Algorithm, Moisture Flux, and/or Warm Core Structure

The new potential RII predictors based on MIST and SEDR have been developed and the RII predictors based on SERD were tested for 2017 cases. Missing ATMS data were filled with GFS data to provide database that can be used to continuously run statistical models, including cases when ATMS overpass is not available at the time the model is run. The developed predictors are listed in Table 1. MIST predictors include the total horizontal moisture flux averaged between 900 - 700 hPa, 700 - 400 hPa, 500 - 200 hPa, and 100 - 300 hPa. Each of these predictors will be estimated at several radii from the storm center, between 100 and 500 km.

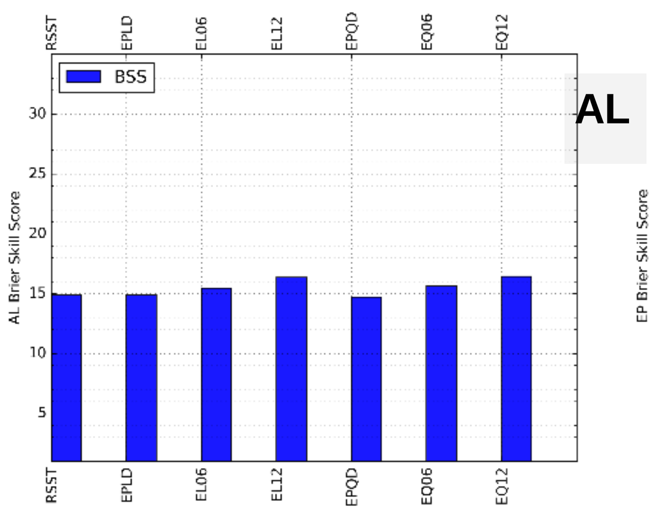
MIST	
M900	Total horizontal moisture flux averaged between 900 - 700 hPa
M700	Total horizontal moisture flux averaged between 700 - 400 hPa
M500	Total horizontal moisture flux averaged between 500 - 200 hPa
M300	Total horizontal moisture flux averaged between 300 - 100 hPa

Table 1. Possible RII predictors based on MIST and changes to warm core structure

In addition, predictors based on SEDR have been developed from both Linear Discriminant Analysis (LDA) and Quadratic Discriminant Analysis (QDA) versions of SEDR and tested in the RII for the sample that included 2017 data. The predictors included are listed in Table 4. Figure 2 shows the Brier Skill Score (BSS) for including the new predictors into the RII for Atlantic and east Pacific basins. For both Atlantic and east Pacific, the biggest improvement is obtained by adding the predictor based on the probability of the eye-existence 12 hours prior to the forecast time, EQ12.

EPQD	QDA probability of the eye existence at t = 0 hours
EPLD	LDA probability of the eye existence at t = 0 hours
EP06	QDA probability of the eye existence at t = -6 hours
EL06	LDA probability of the eye existence at t = -6 hours
EP12	QDA probability of the eye existence at t = -12 hours
EL12	LDA probability of the eye existence at t = -12 hours

Table 2. RII predictors based on the probability of the eye existence



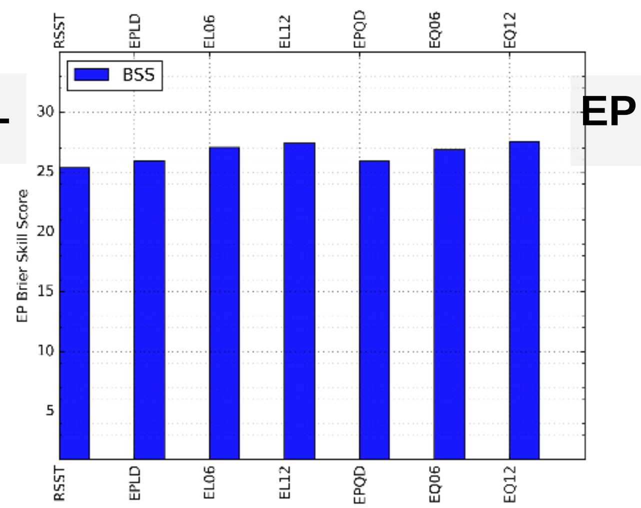


Figure 6. Brier Skill Score (BSS) for the control run (RSST) and for runs with additional *predictors based on the probability of eye-existence for the Atlantic (left) and east Pacific (right).*

7--Set Up Real-time Demonstration of Improved TC VIIRS DNB Imagery

The software for displaying real-time TC-Centered DNB imagery was upgraded to include an improved algorithm for scaling TC-centered DNB imagery as well as number of upgrades to make the processing more stable and portable. The updated version of VIIRS TC-Centered DNB imagery is available on CIRA/RAMMB TC Real-Time page, http://rammb.cira.colostate.edu/ products/tc_realtime/.

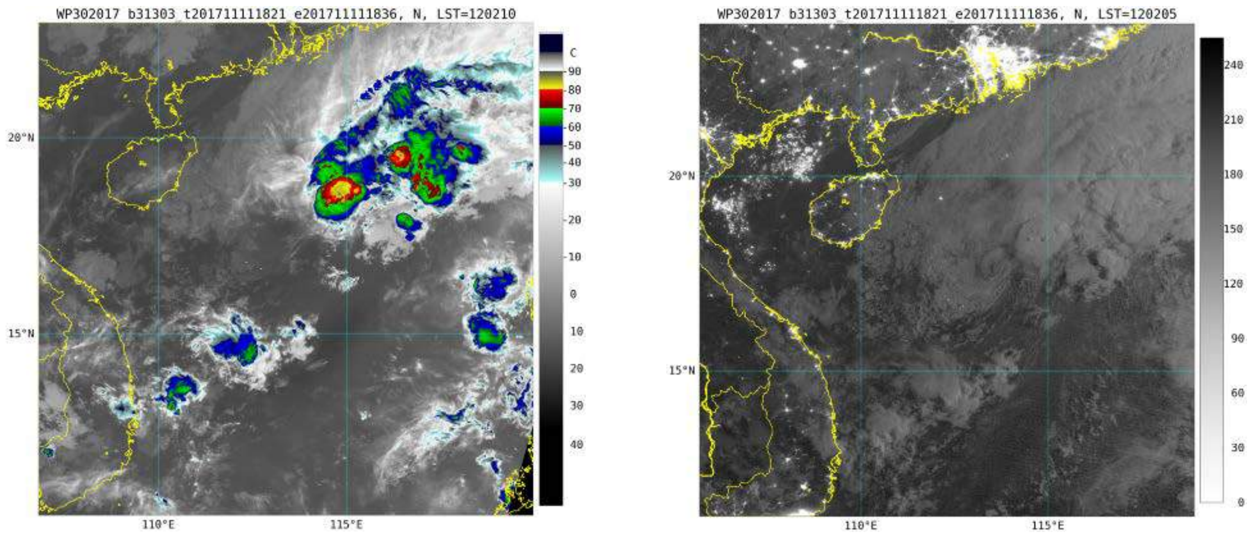


Figure 7. Storm-centered VIIRS DNB (left) and high-resolution IR (band I05, 375 m, left) and VIIRS DNB (right) of the Tropical Storm HAIKUI (wp30 2017) on 11 November 2017 at 1836 UTC. Notice that a standard IR enhancement does not show the warmer low-level clouds indicated by the exposed low-level center depicted in the DNB image.

8--Set up Near Real-time Online Demonstration of the Eye-detection Algorithm

A near real-time online demonstration of the eye-detection algorithm has been setup and placed on the RAMMB TC Real-time page. The real-time demonstration produces plots of eye probabilities over the lifetime of each storm. Testing of VIIRS-based probabilities in real-time was complicated by the data flow changes related to NOAA-20 data, thus the algorithm was tested on past data. The monitoring of the real-time eye-detection algorithm with VIIRS input revealed, a number of bugs in the real-time code that are currently being fixed.

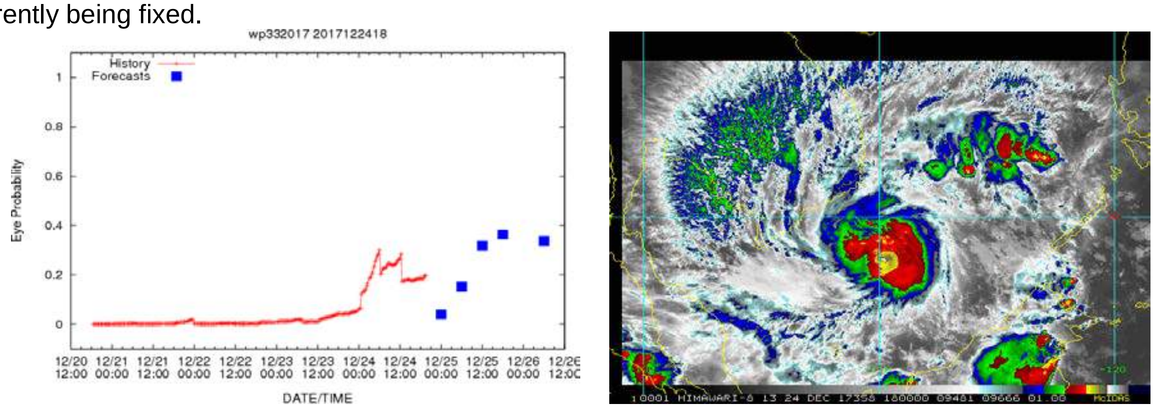


Figure 8. The probability of eye-existence as determined by SEDR as displayed on CIRA/RAMMB TC Real Time page. Left plot: The red-line shows GOES-based probability and the blue squares show the forecast of the eye-formation probability. The forecast of the eye-formation probability has been developed as part of GOES-R Project Right Plot: corresponding GOES IR image on Dec 24th.

9--Begin Setting Up Near Real-time Online Demonstration of the Proxy-visible Imagery

Work on setting up the real-time online demonstration of the proxy-visible imagery has begun. The original version of the proxy-visible imagery for producing full-disc GOES-16 image was taking about 30 minutes to complete. The code was optimized to ensure the processing of each image takes less than 15 minutes, which ensures that 15-minutes full disk images can be processed in real-time. In addition, a new re-gridding subroutine has been added to the code to re-grid proxy-visible imagery to 0.5 degree resolution of visible imagery. That will allow displaying a combined visible and proxy visible imagery without degrading the quality of the visible part. The real-time demonstration of proxy-visible imagery is currently tested on the internal version of CIRA SLIDER. In addition, the NAWIPS version of proxy-visible imagery has been provided to NHC via LDM as part of GOES-R PG project.

Figure 9. GOES-16 proxy-visible imagery for the Atlantic on 08/02/2017. TC Emily can be seen to the east of Georgia.

10--Training

1--Introductory training slides on proxy-visible imagery were provided to NHC in December, 2017

2--Applications developed for this project, including MIST, SEDR, VIIRS TC-Centered Imagery, and the proxy-visible imagery were presented to NHC forecasters at the NHC PG Review on March 7, 2018.

3--G. Chirokova provided slides on DNB TC-Centered Imagery and Proxy Visible imagery to M. Folmer who discussed these applications in his lecture at the JPSS Short Course at the 98th AMS Annual meeting

4--A. Schumacher and G. Chirokova discussed with NHC forecasters the applications that are available at NHC in real-time, VIIRS TC-Centered Imagery and proxy-visible imagery and received feedback and provided one-to-one training.

Publications:

Knaff, J.A. and R.T. DeMaria, 2017: Forecasting tropical cyclone eye formation and dissipation in infrared imagery. Wea. Forecasting, 32, 2103–2116, https://doi.org/10.1175/WAF-D-17-0037.1

Presentations:

Chirokova, G., M. DeMaria, J. Knaff, S. Longmore, and J. L. Beven, 2017: ATMS-MiRS: Tropical Cyclone Applications. STAR JPSS 2017 Annual Science Team Meeting 14-18 August 2016 College Park, MD

Chirokova, G., J. Knaff, R. DeMaria, and J. L. Beven, 2017: Proxy-visible Imagery. STAR JPSS 2017 Annual Science Team Meeting 14-18 August 2016 College Park, MD

Chirokova, G., 2017: Improving tropical cyclone forecast capabilities using the JPSS data suite. JPSS Proving Ground/Risk Reduction Review May 23-25, 2017

Chirokova, G., 2018: Outlook for JPSS DATA and products for Tropical Cyclone Analysis and forecasting. March 13-15, 2018, TCORF/72nd IHC, Miami, Florida.

DeMaria, M. and G. Chirokova, 2017: TROPICS applications for the National Hurricane Center. TROPICS Science Meeting May 10, 2017 AOML Miami, FL

DeMaria M., A. Schumacher, and G. Chirokova, 2018: JPSS Tropical Cyclone Applications. March 7, 2018, NHC, Miami, Florida.

Miller, S., G. Chirokova, J. Knaff, and J. L. Beven, 2017: Proxy-visible Imagery. 98th AMS Annual Meeting/22nd Conference on Satellite Meteorology and Oceanography, 7 - 11 January 2018, Austin Texas.

PROJECT TITLE: CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Addressing NWS Desires for a Cloud Cover Layers Product Using Merged VIIRS and ATMS Products

PRINCIPAL INVESTIGATOR**:** Steve Miller

RESEARCH TEAM: Yoo-Jeong Noh, Curtis Seaman, John Forsythe, Steve Finley, Renate Brummer

NOAA TECHNICAL CONTACT: Satya Kalluri (NOAA/NESDIS) and Andy Heidinger (NOAA/NESDIS)

NOAA RESEARCH TEAM: Dan Lindsey (NOAA/NESDIS/STAR/RAMMB)

FISCAL YEAR FUNDING: $60,000

PROJECT OBJECTIVES:

This project is collaboration with Andrew Heidinger of NOAA/NESDIS/STAR/ASPB and his colleagues at the Cooperative Institute for Meteorological Satellite Studies (CIMSS). The ultimate goal is to address key challenges articulated by the National Weather Service (NWS) with regard to Cloud Cover and Layers (CCL). The requirement was for improved plan-view imagery at 2 km spatial resolution reporting the presence of cloud, its classification, and an estimation of its phase at selected flight levels.

The CIRA team assisted CIMSS in the exploitation of Day/Night Band by supplying an updated version of our lunar irradiance model for use in CLAVR-x cloud retrievals. Retrieval of cloud optical depth at night is enabled by the high sensitivity of visible light reflectance (in this case, moonlight), which requires the assistance of the lunar model. In order to calculate the cloud geometric thickness (CGT) the CIRA team derived the cloud optical depth, particle size, and the cloud water path. The cloud water path was used to estimate cloud geometric thickness—a key parameter for an augmented CCL application.

PROJECT OBJECTIVES:

1--Continue validation of CGT retrieval algorithm against CloudSat

2--Implementation and demonstration of the CCL application for AWC (Alaska and Hawaii). Work directly with respective points of contact and use feedback to improve CCL

3--Assist in the inclusion of additional parameters for supercooled and convective cloud types to the baseline CCL cloud fraction

4--Develop extension of CCL to Nighttime VIIRS Data

PROJECT ACCOMPLISHMENTS:

1--The statistical CBH/CGT algorithm using A-Train satellite data has been implemented successfully in the Clouds from AVHRR Extended (CLAVR-x) processing system into the NOAA operational system in collaboration with CIMSS and the NESDIS/STAR Algorithm Scientific Software Integration and System Transition Team (ASSISTT). We provide the evaluation results of the operational output against CloudSat as requested by ASSISTT and support monitoring the algorithm updates at every operational code delivery.

2--The current CCL algorithm employs the cloud base information which enhances lower cloud layer fractions often obscured under cloud top. Figure 1 shows examples the improved VIIRS layer cloud fractions over Alaska and Hawaii being produced at CIRA in near-real time. We are working on the product demonstration and will continue to get users' feedback (AWC) on the product.

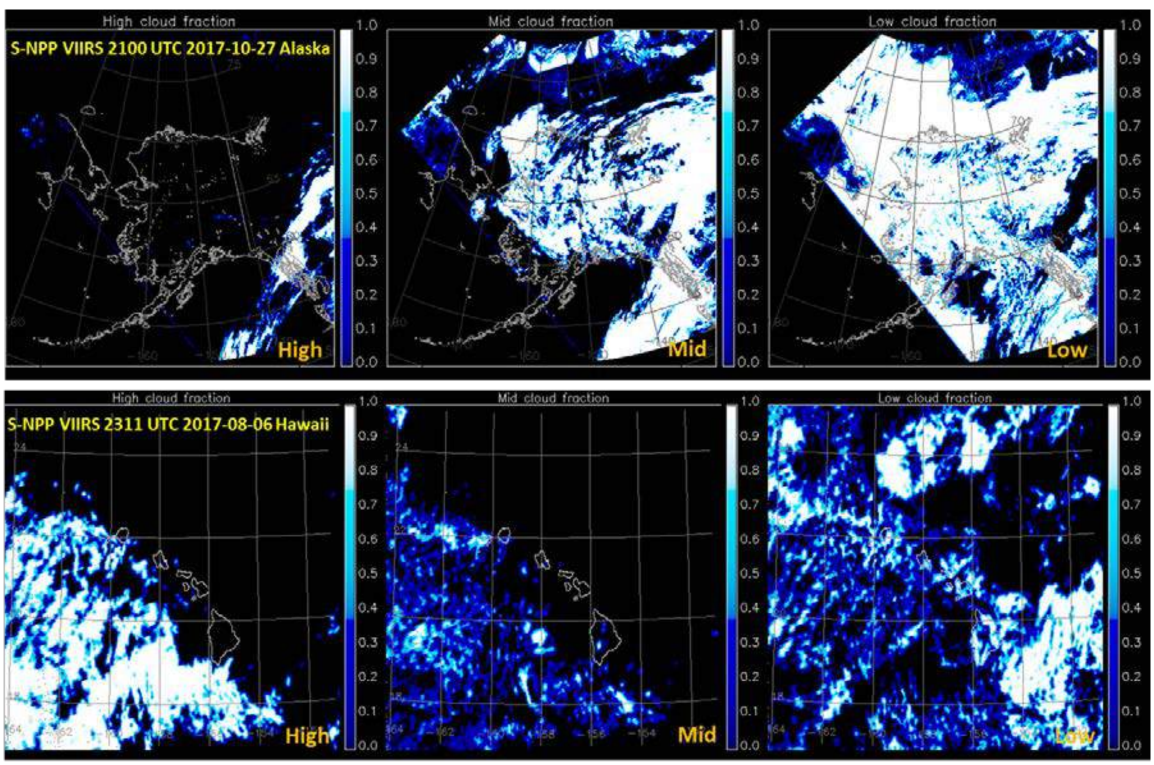


Figure 1. VIIRS Cloud Cover Layers products being produced at CIRA in near-real time over Alaska (top) and Hawaii (bottom).

3—CIMSS collaborators (led by Andrew Heidinger) are working on development of additional parameters for supercooled and convective cloud probabilities. We will support the product evaluation using CloudSat and CALIPSO. We will attempt to extend the approach to sub-layers by using a multi-spectral approach for detection of supercooled topped mixed-phase clouds (Noh and Miller 2017) for selected cases.

4--We utilize VIIRS DNB data for CGT and CCL at night. Nighttime cloud optical properties for CWP to retrieve CGT and CCL are retrieved using lunar reflectances from VIIRS DNB data. When moonlight is not sufficient, NWP-based CWP (currently GFS) is used as supplementary data. Figure 2 shows samples of CGT and CCL over Alaska from DNB lunar reflectance (left). We continue to evaluate the nighttime products using ground-based measurements at ARM sites. CIRA currently runs a data ingest system for the operational MiRS (Microwave Integrated Retrieval System) products produced at the NOAA/NESDIS Office of Satellite and Product Operations (OSPO). The MiRS/ATMS will be also used together with NWP data to overcome the nighttime CWP retrieval limitations.

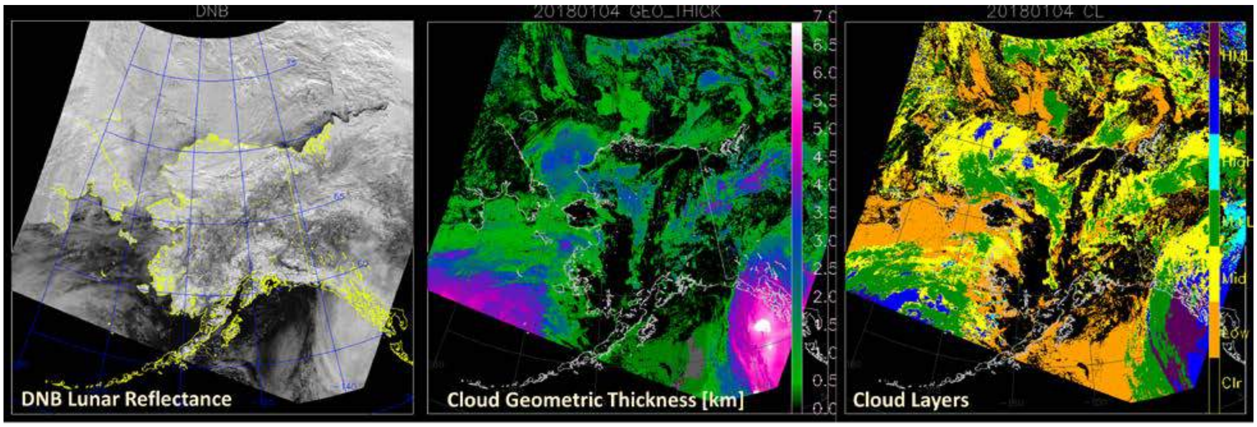


Figure 2. Nighttime cloud geometric thickness and layer products utilizing lunar reflectance from VIIRS DNB (with supplementary NWP data) over Alaska on 4 January 2018 (1254 – 1301 UTC).

Publications:

Noh, Y. J. and S. M. Miller, 2017: Detection of mixed-phase clouds from shortwave and thermal infrared satellite observations. In C. Andronache (Ed.), Mixed-phase Clouds: Observations and Modeling (Chapter 3, p. 43-67). ISBN: 978-0-12-810549-8, Elsevier, 288 pp.

Seaman, C. J., Y.-J. Noh, S. D. Miller, A. K. Heidinger and D. T. Lindsey, 2017: Cloud Base Height Estimation from VIIRS, Part I: Operational Algorithm Validation Against CloudSat. J. Atmos. and Ocean. Tech., 34(3), 567-583, doi: 10.1175/JTECH-D-16-0109.1.

Noh, Y.-J., J. M. Forsythe, S. D. Miller, C. J. Seaman, Y. Li, A. K. Heidinger, D. T. Lindsey, M. A. Rogers and P. T. Partain, 2017: Cloud Base Height Estimation from VIIRS, Part II: A Statistical Algorithm Based on A-Train Satellite Data. J. Atmos. and Ocean. Tech., 34(3), 585-598, doi: 10.1175/JTECH-D-16-0110.1.

Presentations:

Haynes, J. M., Y. J. Noh, S. D. Miller, D., D. T. Lindsey, A. K. Heidinger, 2018: Improving cloud layer boundaries from GOES-16. 2018 AMS Joint Satellite Conference, 7-11 January, Austin, TX.

Noh, Y. J., S. D. Miller, J. Forsythe, C. J. Seaman, J. Haynes, A. K. Heidinger, D. T. Lindsey, and Y. Li, and S. Wanzong, 2017: The Newly Operational VIIRS Cloud Cover/Layers and Base. STAR JPSS Annual Science Team Meeting, 14-18 August 2017, College Park, MD.

Noh, Y. J., 2017: Satellite Cloud Detection and Height Estimation. An invited talk, Department of Astronomy and Atmospheric Sciences/Kyungpook National University, 20 March 2017, Daegu, South Korea.

PROJECT TITLE: CIRA Support to the JPSS Proving Ground and Risk Reduction Program: The Cold Air Aloft Aviation Hazard: Detection Using Observations from the JPSS Satellites and Application to the Visualization of Gridded Soundings in AWIPS II

PRINCIPAL INVESTIGATOR**:** Jack Dostalek

RESEARCH TEAM: Kevin Micke

NOAA TECHNICAL CONTACT: Satya Kalluri, Jeff Key (NOAA/NESDIS), Mitch Goldberg (NOAA/NESDIS/JPSS Program)

NOAA RESEARCH TEAM: Carrie Haisley, Gail Weaver, and Kris White (NOAA/NWS)

FISCAL YEAR FUNDING: $25,000

PROJECT OBJECTIVES:

At high latitudes during the winter months, the air at altitudes used by passenger and cargo aircraft can reach temperatures cold enough (-65°C) such that the jet fuel used by the aircraft can begin to freeze. Currently, aviation forecasters rely on a combination of isolated aircraft reports, a sparse network of radiosondes, and global model fields for identifying and characterizing these cold air hazards. They have expressed a need for additional data that can be used to fill in observational data gaps and/or confirm information that is seen in models. To that end, a collaboration among SPoRT, CIMSS, CIRA, GINA, and the NWS has been developed to provide forecasters access to retrievals generated from the NUCAPS algorithm. CIRA's primary role in this effort is to maintain a web site displaying information from the NUCAPS retrievals in a manner useful to the detection of cold air aloft. The web display allows for quick implementation of new ideas, and is useful to users who do not have AWIPS II.

Research conducted during the third year:
1--Review the performance of the NUCAPS products during the 2016-2017 season in collaboration with the NWS forecasters at the Anchorage Center Weather Service Unit (CWSU).
2--Prepare the website (http://rammb.cira.colostate.edu/ramsdis/online/cold_air_aloft.asp) for the 2017-2018 cold air aloft season and maintain its operation during the season.

1--The performance of the NUCAPS products during the 2016-2017 season was discussed via emails and teleconferences. Perhaps the most significant request from the Anchorage CWSU was to provide the option to display the gridded NUCAPS product on flight levels instead of pressure levels in AWIPS II. The upgrade was made for the 2017-2018 season. Flight level information is already available on the web loops.

2--The web loops available to the forecasters during the 2016-2017 season were again available during the 2017-2018 season. The software that constructs the images and places them on the web was modified to operate on NUCAPS retrievals received from a different source than last year. An example image from the web is given below.

In March 2018, this work was featured by Debra Werner in the magazine Aerospace America in an article entitled "Danger in the Air" (https://aerospaceamerica.aiaa.org/features/danger-in-the-air/).

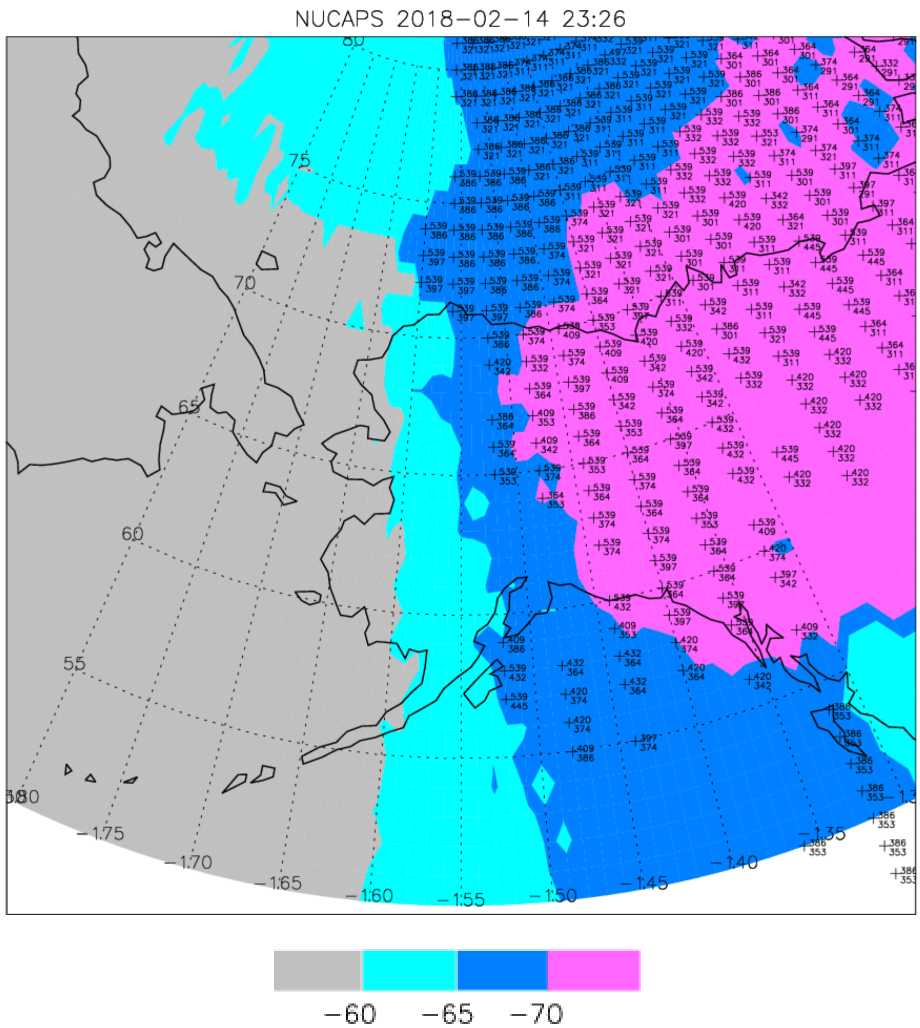


Figure 1. Image from web page showing cold air aloft over Alaska and Canada on 14 February 2018. Shading denotes coldest air temperature (°C) from the surface to 100 hPa and numbers indicate the vertical bounds of air with a temperature below -65°C. The units of the bounds are in flight level (hundreds of feet).

Publications: None

Presentations:

Dostalek, J., 2017: NUCAPS Data Fusion and Cold Air Aloft. JPSS-Satellite Training Advisory Team (STAT) meeting, 10 August 2017, Fort Collins, CO.

Weaver, G., 2018: Results from an Operational Demonstration of a Gridded CrIS/ATMS Product for Cold Air Aloft. 2018 AMS Joint Satellite Conference, 7-11 January, Austin, TX.

Zavodsky, B., 2017: Gridded NUCAPS for Cold Air Aloft. STAR JPSS Annual Science Team Meeting, 14-18 August 2017, College Park, MD.

PROJECT TITLE: CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Improving NUCAPS Soundings for CONUS Severe Weather Applications via Data Fusion

PRINCIPAL INVESTIGATOR: Jack Dostalek

RESEARCH TEAM: John Haynes

NOAA TECHNICAL CONTACT: Satya Kalluri, Jeff Key (NOAA/NESDIS), Mitch Goldberg (NOAA/NESDIS/JPSS Program)

NOAA RESEARCH TEAM: Dan Lindsey (NOAA/NESDIS/StAR), Daniel Nietfeld (NOAA/OAR/ESRL)

FISCAL YEAR FUNDING: $103,200

PROJECT OBJECTIVES:

In the final year of this three-year project, the work performed revolved around the 2017 HWT Spring Experiment, where the product was available on AWIPS II for evaluation. The algorithm applies a near surface layer correction to NUCAPS retrievals based on RTMA and GOES data, employing a simple boundary layer height model found in Stull (1994):

$$z_{i+1} = \left[z_i^2 + \frac{2}{\gamma} C_H |V| (\theta_{skin} - \theta_{air}) \Delta t\right]^{\frac{1}{2}}.$$

Research conducted during the third year:
1--Work with the Proving Ground to have the modified soundings evaluated at the 2017 HWT Spring Experiment, as well as by individual NWS forecast offices.
2--Update code to incorporate changes suggested at the HWT Spring Experiment and by individual forecast offices, including changes to both the algorithm itself as well as to the AWIPS II display.
3--Make preparations for including updated code in the 2018 HWT Spring Experiment, as well as for distribution to individual NWS forecast offices

1--The modified soundings were available for evaluation by the forecasters during the 2017 HWT Spring Experiment. Typically, forecasters would manually adjust the low levels of the NUCAPS retrievals to better match surface observations. This algorithm automates the procedure, saving time for the forecasters. The reception of the modified NUCAPS was positive overall, and can be reviewed in the blogs posted during the four weeks of the Spring Experiment at http://goesrhwt.blogspot.com/ . The figures below present an example of a NUCAPS retrieval and its modified counterpart taken over southwestern Kansas at 1900 UTC on 20 June 2017.

2--One of the limitations of the algorithm is that it always produces a boundary layer that is well mixed in mixing ratio and potential temperature. This assumption is quite accurate for a sunny day over the Plains, but is not broadly applicable. The algorithm is in the process of being updated to allow for differing boundary layer temperature and dewpoint temperature lapse rates. The lapse rate used will be dependent on the difference in the surface air temperature and surface skin temperature during the course of the day leading up to the time of the retrieval.

3--The updating of the algorithm is currently underway and will be ready for demonstration at the 2018 HWT Spring Experiment. Yet to be determined is to what extent the algorithm will be made available to individual forecast offices.

References:
Stull, R. B., 2001: An Introduction to Boundary Layer Meteorology, Kluwer Academic Publishers, 670 pp.

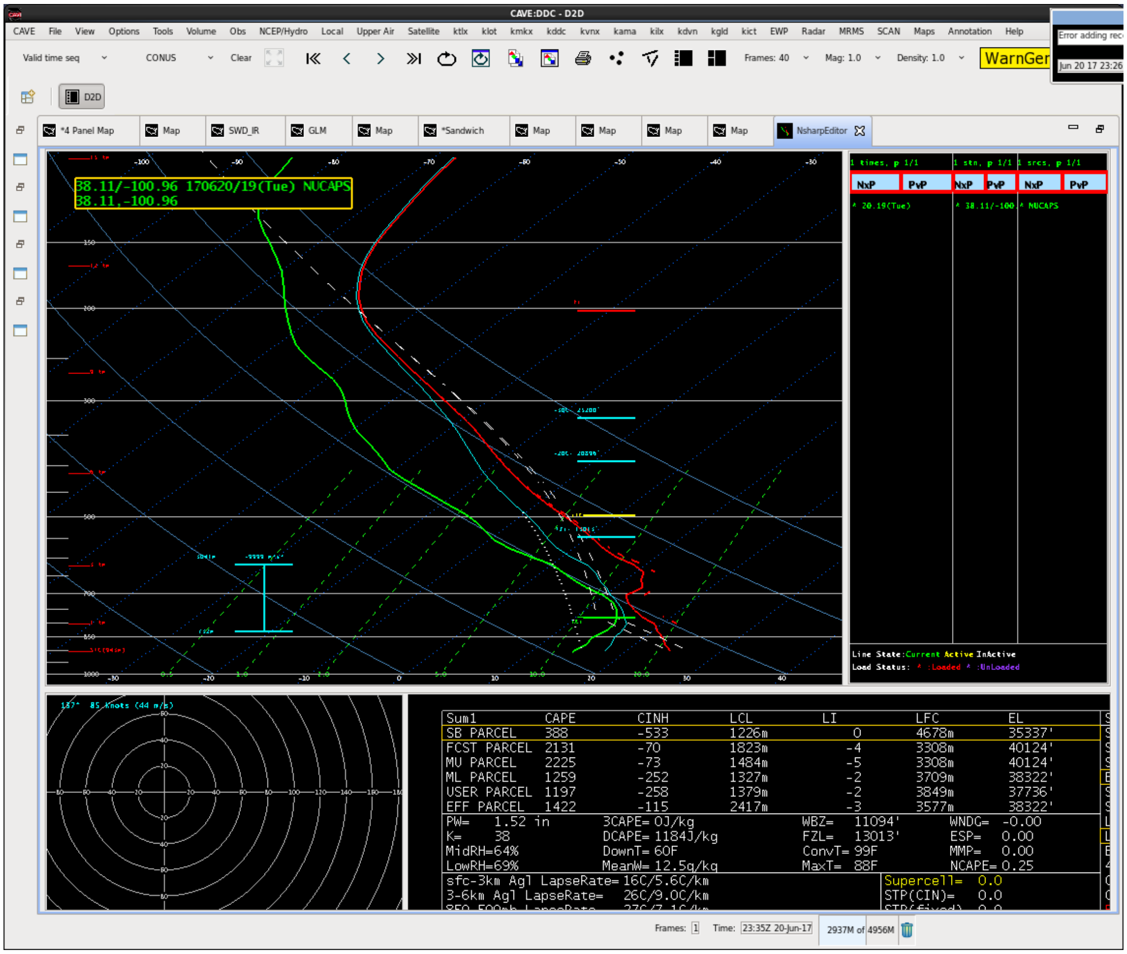


Figure 1. Unmodified NUCAPS retrieval as see on AWIPS II display. The retrieval is over southwestern Kansas at 1900 UTC 20 June 2017.

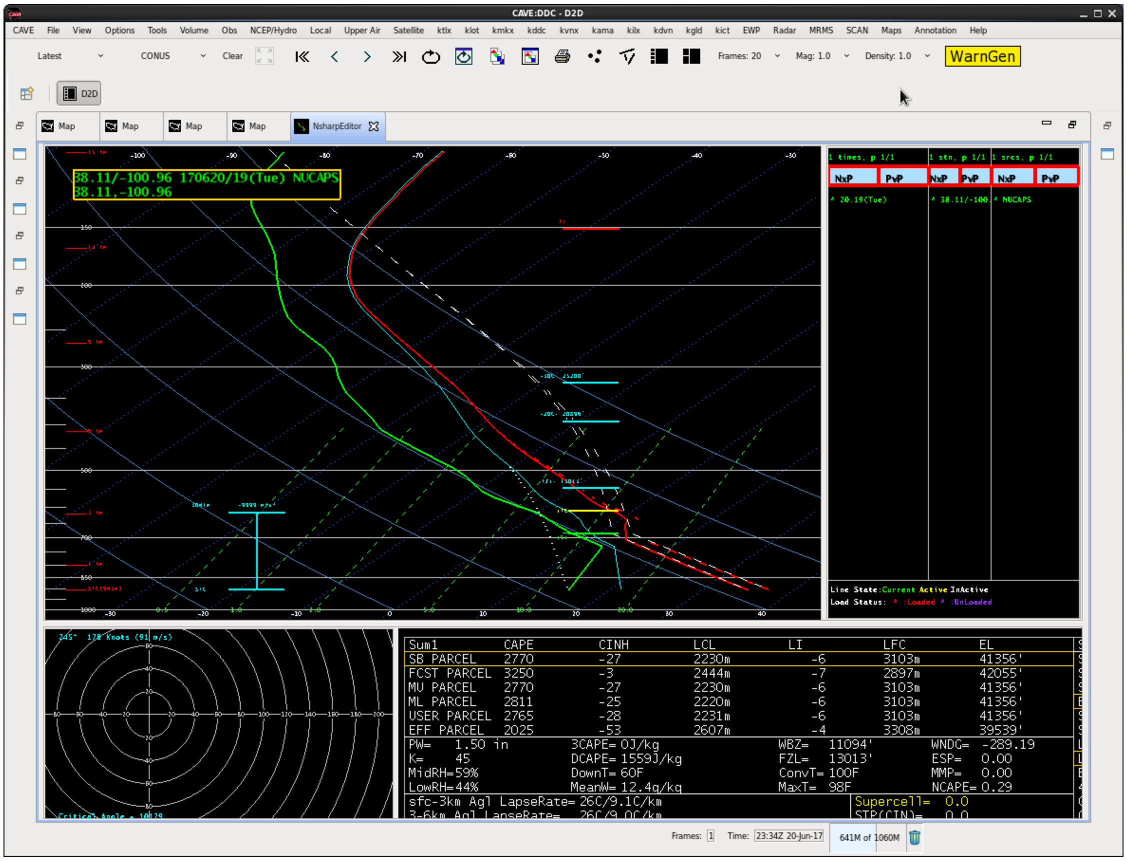


Figure 2: NUCAPS retrieval from previous figure with boundary layer modified according to the algorithm demonstrated at the 2017 HWT Spring Experiment.

Publications: None

Presentations

Dostalek, J., 2017: Improving NUCAPS Soundings for CONUS Severe Weather Applications via Data Fusion. Remote Presentation for 2017 JPSS PGRR Program Review. 23-25 May 2017.

Dostalek, J., 2017: NUCAPS Data Fusion and Cold Air Aloft. JPSS-Satellite Training Advisory Team (STAT) meeting, 10 August 2017, Fort Collins, CO.

Dostalek, J., 2017: NUCAPS Boundary Layer Corrections in Pre-Convective Environments. STAR JPSS Annual Science Team Meeting, 14-18 August 2017, College Park, MD.

Lindsey, D., 2018: Automated Modifications to SNPP NUCAPS Soundings Using Surface Data for Severe Weather Analysis. 2018 AMS Joint Satellite Conference, 7-11 January, Austin, TX.

PROJECT TITLE: CIRA Support to the JPSS Proving Ground and Risk Reduction Program: In Pursuit of Shadows: VIIRS Day/Night Band Research Enabling Scientific Advances and Expanded Operational Awareness of the Nocturnal Environment

PRINCIPAL INVESTIGATOR**:** Steve Miller

RESEARCH TEAM: Curtis Seaman, Yoo-Jeong Noh, Louie Grasso, Scott Longmore, Cindy Combs

NOAA TECHNICAL CONTACT: Mitch Goldberg (NOAA/NESDIS/JPSS),

NOAA RESEARCH TEAM: Don Hillger and Dan Lindsey (NOAA/NESDIS/STAR/RAMMB)

FISCAL YEAR FUNDING: $158,025

PROJECT OBJECTIVES:

The overarching goal of this project is to integrate 'low-light visible thinking' into the minds of the operational forecaster, providing familiarity with the new technology, and a new empowerment to forecasters as they contend with longstanding challenges of nocturnal environmental characterization. This research spans essential DNB tool development, novel user applications, instrument stewardship, and foundational research. This is a collaborative project with the Cooperative Institute for Meteorological Satellite Studies (CIMSS) at the University of Wisconsin-Madison which receives 12.5% of the CIRA grant. The CIMSS Team regularly contributes special DNB imagery to this project covering events like tropical cyclones, volcanic eruptions, wildfires, power outages, and aurora events.

This project directly addresses NOAA's Weather Ready Nation objectives. The project also fits under the Satellite Algorithm Development, Training and Education theme of CIRA's current Cooperative Agreement with NOAA.

Research Conducted during the reporting period:

1--Lunar irradiance modeling
2--Nocturnal imagery application development
3--Sensor performance assessment and preparations for JPSS-1
4--Exploratory studies
5--Training opportunities

PROJECT ACCOMPLISHMENTS:

Noteworthy Special Achievements During this Period:

On 21 August 2017, both the CIRA and CIMSS DNB teams provided images of the total solar eclipse to the JPSS Program Office. The CIRA-produced images were included as part of the STAR JPSS website on the eclipse: https://www.star.nesdis.noaa.gov/jpss/eclipse.php These images show the DNB was sensitive over the entire range of radiances from typical early afternoon solar illumination to the low levels of radiance observed within the path of totality (Figure 1).

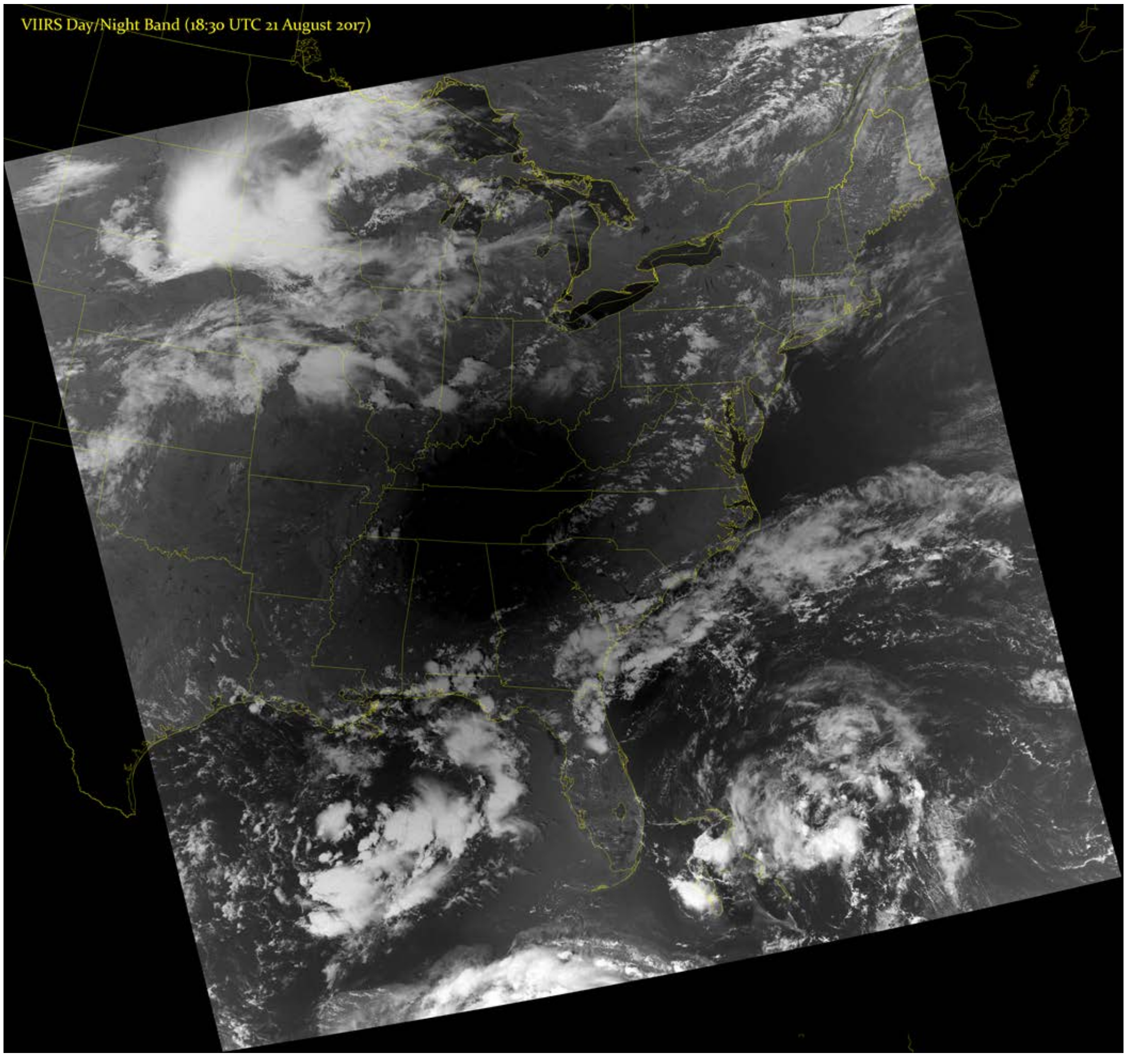


Figure 1. VIIRS Day/Night Band image of the total solar eclipse (18:30 UTC 21 August 2017) as the path of totality passed through Tennessee.

As soon as the JPSS-1 VIIRS nadir doors were opened, and DNB Night Data became available to the cal/val team on 13 December 2017 (around 1645 UTC), a set of first-light JPSS-1 DNB Night Time imagery was produced by several members the *Pursuit of Shadows* Team. Our Team found some problems with the fill values and stray light which affected the generation of JPSS-1 DNB imagery. Using the "ellipsoid" geolocation information, which has not been corrected for the parallax-effects of terrain, eliminated this issue and allowed the Team to generate the first nighttime JPSS-1 DNB imagery. A CONUS composite of this imagery was posted on the NESDIS Facebook page on December 15th: https://www.facebook.com/NOAASatellites/. Figure 2 below shows a screen capture of the NESDIS Facebook posting.

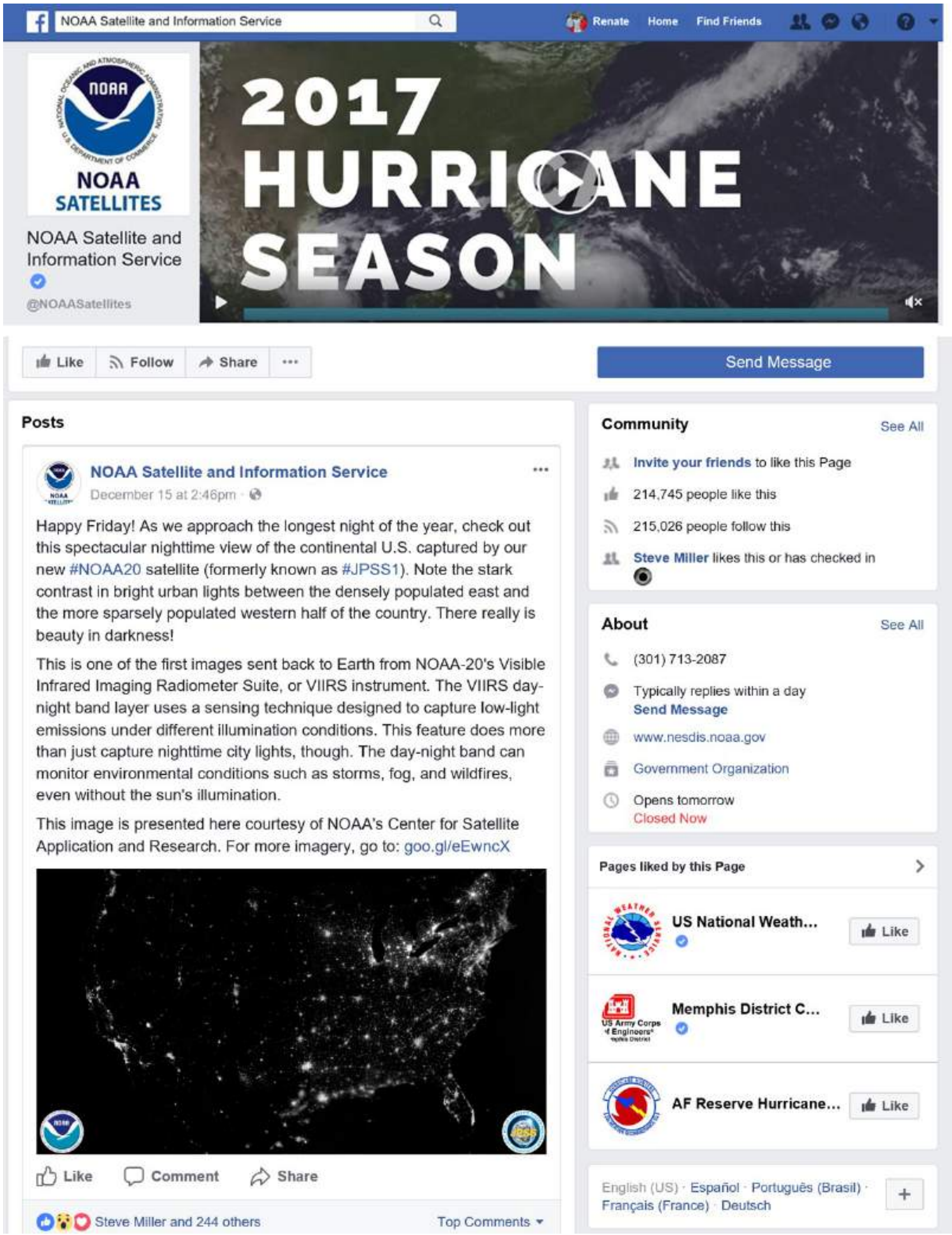


Figure 2. On December 15th at 2:46pm the NESDIS Facebook posted the first nighttime JPPS-1 DNB CONUS composite imagery with JPSS-1 data from 14 December 2017 14 Dec 2017 (0714 UTC to 1035 UTC).

Several special hazard event DNB imagery examples were generated by the CIRA and CIMSS *Pursuit of Shadows* Team. Imagery of the December 2017 Southern California fires were produced daily by William Straka (CIMSS) for 2 weeks in a row. See details under Milestone 1.

A manuscript titled “The Dark Side of Hurricane Matthew—Unique Perspectives from the Day/Night Band” was submitted to the Bulletin of the American Meteorological Society on 15 December 2017. Co-authors are: S. D. Miller, W. C. Straka, III, J. Yue, C. J. Seaman, S. Xu, C. D. Elvidge, L. Hoffman, S. I. Azeem. This is an important paper illustrating the expanded utility of the DNB for moonless nights, combines surface and satellite-based perspectives, and presents examples of power outage detection and display capabilities.

CIRA and GINA have been collaborating on the production of several Quick Guides for forecasters. These include: Daytime Land Cloud RGB (a.k.a. Natural Color), Fire Temperature RGB, Day Land Cloud Fire RGB (a.k.a. Natural Fire Color) and the DNB Snow/Cloud Discriminator product. These quick guides are expected to be in final form and submitted to the TOWR-S team in January 2018.

Accomplishments by Milestones:

1--We continue to evaluate the lunar irradiance model that was developed under prior research projects. The lunar irradiance model is used to calculate quantitative DNB reflectance values under moonlit conditions. These reflectance values open the door for quantitative nighttime DNB applications, much like traditional visible satellite channels during the daytime. A manuscript on our model evaluation is currently in preparation at the time of this report, and is expected to be submitted to the Journal of Atmospheric and Oceanic Technology shortly. The lunar irradiance model was used in the development of a new NASA “Black Marble” standardized data product suite - a global 500m-resolution composite of nighttime lights and their variability. A manuscript discussing the development of the “Black Marble” product suite, led by Miguel Roman (NASA) and co-authored by S. Miller and others, was submitted to Remote Sensing of the Environment.

2--DNB images of high-impact weather events are regularly provided to the JPSS Program office. These images are used in public relations materials and shared with both conventional media and social media. DNB imagery for this reporting period included: the total solar eclipse in August 2017; Hurricanes Harvey, Irma and Maria; the large wildfires that destroyed the Pedrógão Grande community of Portugal (June 2017); the destructive wildfires in the Napa Valley region of California (September 2017); vivid imagery of the aurora borealis and aurora australis, and others. These cases have been used to further develop and improve RGB imagery applications utilizing the DNB, including the Power Outage RGB, as well as applications for fire detection and monitoring (Figure 3).

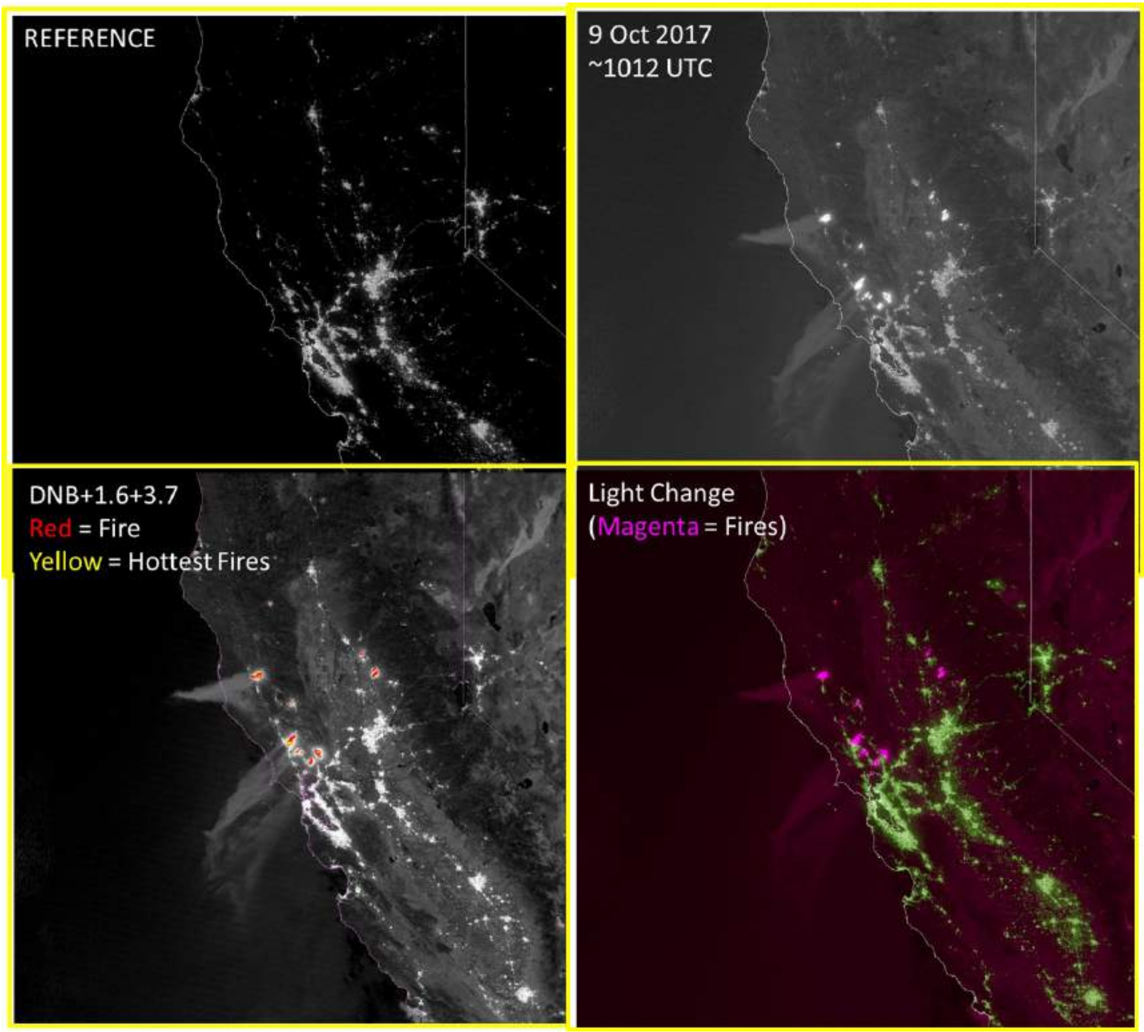


Figure 3. CIRA Day/Night Band RGB enhancements for the 9 October 2017 SNPP pass over the fires in California. Upper left: DNB Reference Imagery. Upper right: DNB Imagery depicting many fires and smoke plumes in the Napa, Sonoma, and Santa Rosa area. Lower left: DNB imagery with the additional enhancements of 3.7 um (red) and 1.6 um (yellow) to indicate where thresholds for fire detection is exceeded. Note that the yellow 1.6 signal means the fires are extremely hot. Lower right: Light changes vs. the reference mask (magenta are the fires).

A DNB version of CIRA's multispectral Snow/Cloud Discriminator product has been developed that extends the utility of this product to nighttime scenes (Fig. 4). Through a collaboration with the University of Alaska-Fairbanks Geographic Information Network of Alaska (GINA), this product is now being delivered to forecasters throughout the Alaska Region. We are working with the JPSS Satellite Liaison (J. Torres) and the Alaska Region Satellite Liaison (E. Stevens) to evaluate product performance and identify areas for improvement.

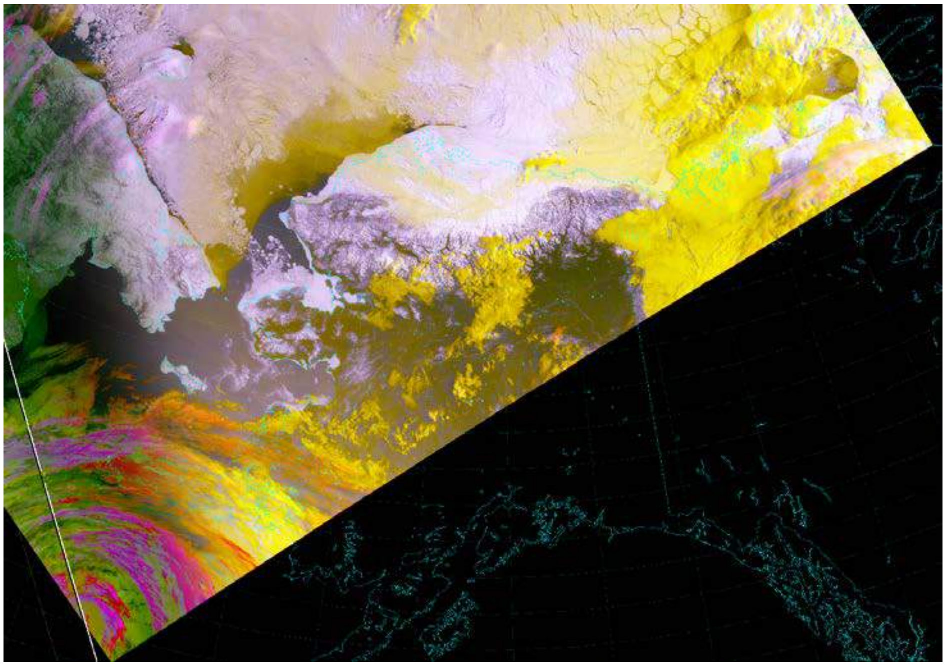


Figure 4. The first nighttime Snow/Cloud Discriminator image produced using the CIRA DNB algorithm at GINA for the Alaska Region NWS.

3--S. Miller and C. Seaman have been involved with JPSS Imagery Team activities and participated in discussions with the VIIRS SDR team related to non-linearity of response in the JPSS-1 DNB near the edge of scan. We have coordinated with these groups to evaluate JPSS-1 (now NOAA-20) DNB imagery during the initial post launch testing and evaluation period. Figure 5 shows the first NOAA-20 DNB composite of nighttime lights across CONUS, utilizing dark offsets developed by S. Miller.

Figure 5. First Light JPSS-1/NOAA-20 VIIRS DNB imagery for a 3-orbit CONUS composite at 14 Dec 2017 (0714 UTC to 1035 UTC), produced using CIRA's dark-offset adjustment.

4--We continue to develop an archive of mesospheric gravity wave images provided by the S-NPP DNB and have begun to look for similar images from NOAA-20. A paper on DNB mesospheric gravity wave detection by the DNB has been published in Advances in Space Research. The search for images of “milky seas” in the DNB is ongoing.

5--A Quick Guide has been developed on the Snow/Cloud Discriminator product and has been made available for forecasters. We continue to collaborate with satellite liaisons, E. Stevens (Alaska Region), J. Torres (JPSS), and M. Folmer (OPC/WPC) on DNB applications. Informal training is provided through blogs, including the “Seeing the Light: VIIRS in the Arctic” Blog (http://rammb.cira.colostate.edu/projects/alaska/blog/).

Interactions with Operational and Other Partners:

Interaction with University of Alaska, Fairbanks, GINA:
The CIRA DNB Team continues to be in very close contact with the GINA Team in Alaska, Fairbanks. Eric Stevens is our primary POC at GINA. Eric references CIRA’s VIIRS Imagery blogs frequently on the GINA homepage. See also Milestone 1.

Interaction with NWS/WFOs:
The CIRA Team provides frequently example DNB imagery and demonstrations of the use of DNB to WFO forecast offices. CIRA’s JPSS Satellite Liaison Jorel Torres and CIRA’s WFO Liaison Ed Szoke participate in WFO workshops and demonstrate DNB imagery to operational forecasters.

Interaction with National Hurricane Center (NHC):
CIRA displays DNB imagery of tropical storms on its TC Real-Time webpage (near real time and archive available) at http://rammb.cira.colostate.edu/products/tc_realtime/
NHC forecasters are very interested in this product.

Interaction with NOAA/NWS WPC/OPC/TAFB and NOAA/NESDIS SAB:
The CIRA DNB Team is in close contact with Satellite Liaison Michael Folmer, who frequently uses DNB and other CIRA imagery for his presentations, blogs, and research studies.

<u>Interaction with AWC</u>
The CIRA Team interacts closely with Amanda Terborg. AWC does use the CIRA GeoColor product (uses DNB city lights as an information layer) and expressed interest in using CIRA’s Snow/Cloud Discrimination product

<u>Interaction with the JPSS Satellite Training Advisory Team (STAT)</u>
The Satellite Training Advisory Team (STAT) for JPSS met with CIRA researchers and faculty on 10 August 2017. Several CIRA researchers presented on a variety of JPSS projects that are underway to the STAT team, with follow-up questions and discussions. C. Seaman gave a presentation which focused on VIIRS application especially DNB. The STAT team involves members from the National Weather Service (NWS), Office of the Chief Learning Officer (OCLO), NWS Operational Advisory Team (NOAT), and a few cooperative institutes: CIRA, COMET, NASA-SPoRT, CIMSS and GINA. The team focuses on the development of training, specifically, the foundational course, product and application training for JPSS. The STAT team also participated in a tour of the CIRA facility after presentations and discussions were complete.

Education / Outreach Materials / Blogs:

VIIRS DNB Imagery Blog Posts
The DNB blogs written by Curtis Seaman and JPSS Satellite Liaison Jorel Torres serve as excellent education material for VIIRS DNB and NCC applications:
http://rammb.cira.colostate.edu/projects/alaska/blog/
http://rammb.cira.colostate.edu/projects/npp/blog
http://rammb.cira.colostate.edu/training/visit/blog/

VISIT blogs which include DNB imagery

NCC, GOES-16, and the Pacific Northwest:

Alamo Fires, CA
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2017/07/11/california-alamo-fire/

Tropical Activity in the East Pacific
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2017/07/26/tropical-activity-in-the-east-pacific/

Fires in the Pacific Northwest
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2017/08/04/fires-in-pacific-northwest/

Hurricane Harvey
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2017/08/28/hurricane-harvey/

California Wildfires
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2017/10/10/california-wildfires/

Hurricane Ophelia and Wildfires in Spain and Portugal
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2017/10/17/hurricane-ophelia-and-wildfires-in-spain-and-portugal/

Early morning fog in Colorado
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2017/11/03/early-morning-fog-in-colorado/

Tropical Storm Rina
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2017/11/07/tropical-storm-rina/

December Wildfires in California
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2017/12/06/december-wildfires-in-california/

Thomas Fire, California
http://rammb.cira.colostate.edu/training/visit/blog/index.php/2017/12/11/thomas-fire/

CIRA NCC Imagery produced for the California wildfires was put on the NOAA Satellites Twitter/Facebook pages on 7 December 2017:

Twitter Link
https://twitter.com/NOAASatellites/status/938771876683317254

Facebook Link
https://www.facebook.com/NOAASatellites/videos/1891803114193290/

Publications:

Hawkins, J., S. D. Miller, J. E. Solbrig, R. L. Bankert, M. Surrat, K. A. Richardson, 2017: Tropical Cyclone Characterization via Nocturnal Low-Light Visible Illumination. Bull. Amer. Meteor. Soc., In press.

Lai, C., J. Yue; J. Xu; W. Straka III; S. D. Miller; X. Liu, 2017: Suomi NPP VIIRS/DNB imagery of nightglow gravity waves from various sources over China. Advances in Space Research, 59(8), 1951-1961, doi.org/10.1016/j.asr.2017.01.041, Manuscript Number: ASR-D-16-00683R1; Section: EM -Earth Magnetosphere/Upper Atmosphere.

Miller, S. D., W. C. Straka, III, J. Yue, C. J. Seaman, S. Xu, C. D. Elvidge, L. Hoffman, S. I. Azeem, 2018: The Dark Side of Hurricane Matthew—Unique Perspectives from the Day/Night Band. Submitted to Bull. Amer. Meteor. Soc.

Roman, M., Z. Wang; Q. Sun, V. Kalb, S. D. Miller, A. L. Molthan, L. A. Schultz, J. R. Bell, E. Stokes, K. Seto, B. Pandey, D. K. Hall, T. Oda, R. E. Wolfe, G. Lin, N. Golpayegani, S. Devadiga, C. C. Davidson, S. Sarkar, C. Praderas, J. Schmaltz, R. A. Boller, J. Stevens, O. M. Ramos Gonzalez, E. Padilla, J. Alonso, Y. Detres, R. Armstrong, I. Miranda, Y. Conte, N. Marrero, K. MacManus, T. Esch, E. J. Masuoka, 2018: NASA's Black Marble Standard Product Suite. Submitted to Remote Sensing of the Environment.

Presentations:

Hillger, D. W., T. J. Kopp, C. J. Seaman, S. D. Miller, D. T. Lindsey and J. Torres, 2018: First VIIRS Imagery from JPSS-1. *AMS 14th Annual Symposium on New Generation Operational Environmental Satellite Systems,* 8 January, Austin, TX.

Miller, S. D, 2018: *Bridging the Nocturnal Gap:* Capabilities and Revelations from the VIIRS Day/Night Band. Invited oral presentation with WebEx service. NASA Headquarters, Washington, DC, 8 March 2018.

Miller, S. D., W. C. Straka, III, C. J. Seaman, C. L. Combs, A. K. Heidinger, A. Walther, and J. E. Solbrig, 2018: Chasing the Shadows with the VIIRS Day/Night Band. *AMS 8th Conference on Transition of Research to Operations, Advances in Satellite Observations for Earth Science and Observing Technologies—Part I,* 8 January, Austin, TX.

Miller, S. D., W. C. Straka, III, C. J. Seaman, C. L. Combs, J. E. Solbrig, A. Walther, and A. K. Heidinger, 2017: Seeing the Night in a New Light—VIIRS Day/Night Band Capabilities and Prospects for a Joint Suomi/JPSS-1 Observing System. 2017 AGU Annual Meeting, New Orleans, LA 11-15 December 2017

Miller, S. D., W. C. Straka III, C. J. Seaman, R. L. Brummer, 2017: Double-Take: Possibilities for Improved Nocturnal Environment using VIIRS Day/Night Band sensors on Suomi NPP and JPSS-1. *EUMETSAT Satellite Conference*, 2-5 October, Rome, Italy.

Miller, S. D. and D. T. Lindsey, 2017: GOES-16: A New Era in Geostationary Satellite Observations, ATS/CIRA Colloquium, Colorado State University, 25 August 2017, Fort Collins, CO.

Miller, S. D., 2017: Satellite Algorithm Development at CIRA, CIRA Council & Fellows Meeting, 9 May 2017, Fort Collins, CO.

Seaman, C. J., S. D. Miller, D. T. Lindsey, D. W. Hillger, 2017: Multispectral Imagery Applications for the New Generation Weather Satellites. *EUMETSAT Satellite Conference*, 2-5 October, Rome, Italy

Seaman, C., S. Miller, W. Straka III, D. Lindsey and J. Torres: Night Vision: Illuminating the Capabilities of the VIIRS Day/Night Band. STAR JPSS Annual Science Team Meeting, College Park, MD, 14-17 August 2017. (invited keynote talk)

Seaman, S., S. Miller, J. Torres, C. Dierking, J. Cable, E. Stevens, K. Strabala, D. Hillger, A. Leroy, E. Berndt, and K. Fuell: VIIRS Imagery: Transitioning Novel Ideas into Operations. STAR JPSS Annual Science Team Meeting, College Park, MD, 14-17 August 2017.

Torres, J., C. Seaman, S. Miller, W. Straka III and D. Lindsey: The Day/Night Band, 2017 NWA Annual Meeting, Garden Grove, CA, 18-22 September 2017.

Torres J., B. H. Connell, and S. D. Miller, 2018: JPSS Products, Applications and Training. *AMS 14th* Annual Symposium on New Generation Operational Environmental Satellite Systems, Session: Education, Training and User Readiness for GOES-R and JPSS – Part II, 10 January, Austin, TX.

PROJECT TITLE: CIRA Support to the JPSS Proving Ground and Risk Reduction Program: JPSS Satellite Training for NOAA Users

PRINCIPAL INVESTIGATORS: Bernadette Connell and Steve Miller

RESEARCH TEAM: Jorel Torres, E. Dagg

NOAA RESEARCH TEAM: Brian Motta and Anthony Mostek NOAA/ NWS/OCLO/ Forecast Decision Training Division, Leroy Spayd (NWS/OCLO)

FISCAL YEAR FUNDING: $200,000

PROJECT OBJECTIVES:

This project supports a Satellite Liaison and research team at the Cooperative Institute for Research in the Atmosphere (CIRA) as links between the Joint Polar Satellite System (JPSS) program and National Oceanic Atmospheric Administration (NOAA) operational end users primarily at National Weather Service (NWS) Offices and National Centers. This project takes advantage of the expert knowledge of researchers in the fields of education, meteorology, and remote sensing to promote effective learning and knowledge retention strategies for the user while ensuring that the training reflects the strengths and limitations of the imagery and products for proper interpretation and usage in the operational setting. The linkage between research and operations allows for continual feedback between the groups that is beneficial for all involved: Improvements in algorithms and products on the research side with increased understanding of imagery and products in the operational setting.

The Liaison (Jorel Torres) and research team provide training for operational NWS forecast staff on imagery and products from Visible Infrared Imaging Radiometer Suite (VIIRS), Advanced Technology Microwave Sounder (ATMS), and Cross-track Infrared Sounder (CrIS) sensors, as well as the NOAA Unique CrIS ATMS Products (NUCAPS), and Numerical Weather Prediction (NWP) data assimilation. Priority areas include current JPSS Program initiatives such as Smoke and Fire, Hydrology and Flooding, Severe Convective Weather, and Critical Weather Applications. The projects are coordinated with the JPSS Program Office and the NWS Office of the Chief Learning Officer (OCLO), in particular the Forecast Decision Training Division (FDTD) of OCLO.

Specific Objectives:
1--Interact and collaborate with the Satellite Training Advisory Team (STAT) and training partners: the NWS OCLO, NWS Science and Operations Officers (SOOs), the Virtual Institute for Satellite Integrated Training (VISIT) and the Satellite Hydrology and Meteorology (SHyMet) training programs, the Short-term Prediction Research and Transition Center (SPoRT), COMET, and Satellite liaisons; Participate in JPSS Initiative teleconferences
2--Review course objectives and set guidelines for the Satellite Foundation Course for JPSS (SatFC-J); In collaboration with the VISIT Program, develop content for 4 modules for Objective 1 of the Satellite Foundation Course for JPSS (SatFC-J).
3--Create blogs to highlight the use of JPSS imagery and products, particularly for significant weather and environmental events.
4--Develop quick guides for products identified during the JPSS STAT teleconferences and meetings.

5--Participate in Domestic Science Conferences and deliver Short Courses (National Weather Association (NWA), NOAA Satellite Conference (NSC), and the American Meteorological Society (AMS))

PROJECT ACCOMPLISHMENTS:

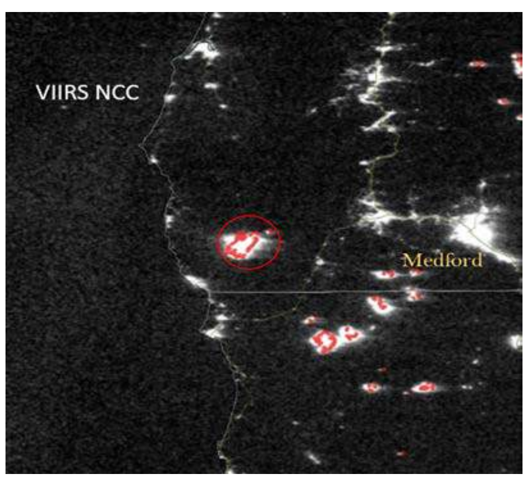
1-- Interact and collaborate with the Satellite Training Advisory Team (STAT) and training partners: The NWS OCLO, NWS Science and Operations Officers (SOOs), the Virtual Institute for Satellite Integrated Training (VISIT) and the Satellite Hydrology and Meteorology (SHyMet) training programs, the Short-term Prediction Research and Transition Center (SPoRT), COMET, and Satellite liaisons; Participate in JPSS Initiative teleconferences

--Interact and collaborate with the STAT and training partners
Background: The primary user that this project targets for training is the NWS forecaster. The NWS Office of the Chief Learning Officer (OCLO) oversees training of its employees and has several divisions devoted to this task: The Training Center (NWSTC), the Warning Decision Training Division (WDTD), and the Forecast Decision Training Division (FDTD). The Satellite Training Advisory Team (STAT) consists of Science Operations Officers (SOOs), satellite liaisons, representatives from the NWS OCLO, and training developers, and was brought together to guide the design, development, tracking, review, and implementation of the Satellite Foundation Course for JPSS (SatFC-J). During the past year, this project participated in weekly STAT calls to provide input on the development of the SatFC-J and to observe the process for the SatFC-G in order to gather feedback relevant to the design of the SatFC-J. The progress of SatFC-J is presented in objective 2 below.

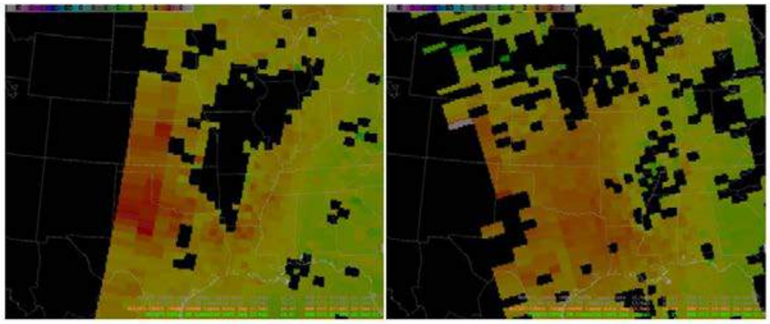
--The satellite liaison, J. Torres, participated in monthly JPSS Initiative teleconferences: River and Ice Flooding, Fire and Smoke, NUCAPS, and Artic. The conference calls bring researchers together to discuss progress and issues associated with their research projects or the transition of products to operations. A few relevant out comes noted over the past year:

- Assisted and coordinated with J. Hoffman at SSEC to help P. Miller, the Science Operations Officer (SOO) at the Colorado Basin River Forecast Center (CBRFC) in Salt Lake City, UT, set up the VIIRS Flood Detection Map Product for their AWIPS-II systems.

- Collaborated with 3 subject matter experts (I. Csiszar, E. Elliott, NOAA NESDIS, and C. Schmidt (CIMSS)) to identify and collect VIIRS imagery products and NUCAPS products for the Chetco Bar Fires in Oregon that occurred from July-September 2017. This was used for the 1 ½ hour Joint JPSS/GOES-R Satellite Training Session held on 17 September 2017 at the National Weather Association Annual Meeting. VIIRS NCC image for the Chetco fire.



16 June NUCAPS lapse rate



- Worked with N. Smith and A. Wheeler (Science and Technology Corporation, STC) to provide NUCAPS information, data and AWIPS-II screenshots of soundings for a case study used during the AMS 2018 JPSS Short Course in Austin, TX. The case study highlighted severe weather events that occurred in the Midwest in June 2017

--CIRA local interactions with NOAA personnel ensure data access and display capabilities on AWIPS-II to be able to adequately address training activities.

2--Review course objectives and set guidelines for the Satellite Foundation Course for JPSS (SatFC-J). In collaboration with the VISIT Program, develop content for 4 modules for Objective 1 of the Satellite Foundation Course for JPSS (SatFC-J). The primary audience of the SatFC-J course is the general forecaster (no distinction between CONUS and OCONUS) and the targeted length is 4 hours.

SatFC-J Training Plan Overview
Objective 1: Introduction to Microwave Remote Sensing
Objective 2: Introducing Suomi-NPP, JPSS, GCOM, GPM
Objective 3: Basic Forecast Applications
Follow on Section: Additional SNPP/JPSS Applications

- In December 2016, the STAT group began receiving feedback on both the GOES-R preparatory course for SOOs and from the SatFC for GOES-R. About the same time, it was announced that JPSS-1 would launch no earlier than the 4th Quarter of FY 17. In light of both feedback and delayed launch, the rapid development of training materials was put on hold pending review of feedback and assessment of the way forward to improve the design, development, and implementation of SatFC-J.

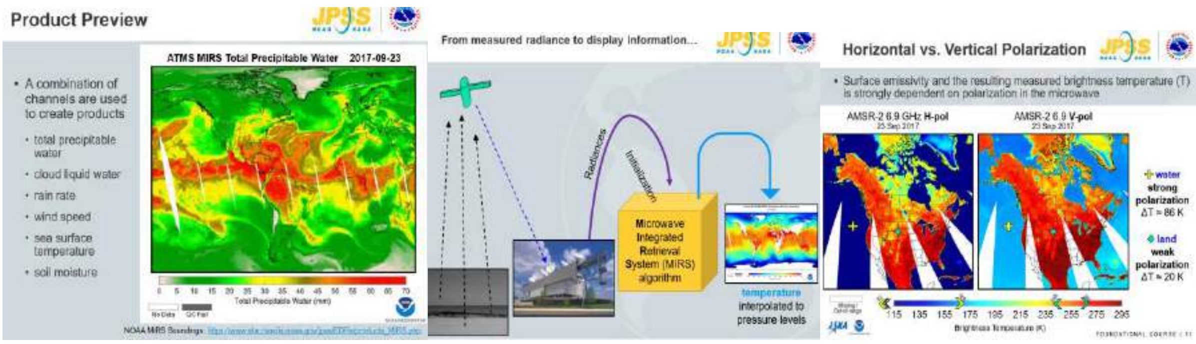
- In-person meetings of the STAT team for JPSS occurred 24-28 April and 8-10 August 2017. The first meeting focused on prioritization of JPSS Products Applications Training (not SatFC-J) and in particular Alaska products. The second meeting focused on recommendations for two types of videos (promotional and usage) and setting realistic completion target dates for SatFC-J modules, Quick Guides, and Quick Briefs.

-- CIRA contributions to SatFC-J Objective 1 training modules:

1) Introduction to Microwave Remote Sensing
2) Oxygen and water vapor absorption bands
3) Surface Emissivity

- In progress:
4) Influence of clouds and precipitation

http://rammb.cira.colostate.edu/training/shymet/training_sessions/satfc-j.asp
Note: This link may change with the finalization of the course web page.



Screen shots representing the first three training modules for Objective 1.

In each of the four training modules, the progression of content was continually discussed: How to preview topics discussed in later modules, how to build on ideas presented in previous modules, as well as how to link to familiar topics without being either overly repetitive or lacking in explanation. One big challenge was/is that many of the imagery and products are not available in the current AWIPS. There was a point when some of the imagery and products were available under the experimental feed, but that disappeared; and we only have tentative information as to when it will return to the SBN.

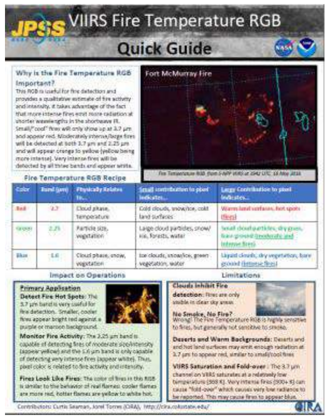
3--Create blogs to highlight the use of JPSS imagery and products, particularly for significant weather and environmental events.

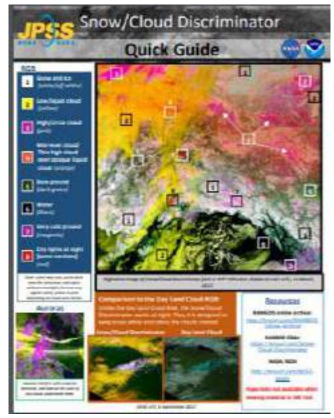
--The blog is intended to open the doors of communication between the Operational, Academic and Training Meteorology communities. The blog averages around 360 views per month and is located on the VISIT program website: http://rammb.cira.colostate.edu/training/visit/blog/. There were 51 blog entries during the time period of interest with topics that focus on operational applications of JPSS and GOES-16 imagery and products.

The NCC product showing the Faka Union Fire within the yellow circle on 7 March 2018.

4--Develop quick guides for products identified during the JPSS STAT teleconferences and meetings.

--Quick guides in progress (developed and under review):
VIIRS Near-Constant Contrast (NCC)
VIIRS Flood Areal Extent
VIIRS active Fires
Cloud/Snow Discriminator
VIIRS Day Land Cloud RGB (or Natural Fire Color RGB)
Fire Temperature RGB





5--Participate in Domestic Science Conferences and deliver Short Courses (National Weather Association (NWA), NOAA Satellite Conference (NSC), and the American Meteorological Society (AMS))
-- See the presentations listed below.

--Development of materials and participation in Short Courses at:
- NOAA Satellite Conference. 15-20 July 2017. New York City, NY.
http://rammb.cira.colostate.edu/training/visit/links_and_tutorials/nsc_2017_jpss_workshop.asp

- NWA 42nd Annual Meeting. 16-21 September 2017. Garden Grove, CA.
http://rammb.cira.colostate.edu/training/visit/links_and_tutorials/nwa_2017_jpss_goesr_workshop.asp

- AMS 98th Annual Meeting in Austin, TX on 6 January 2018
http://rammb.cira.colostate.edu/training/visit/links_and_tutorials/ams_austin_tx_JPSS_workshop_2018.asp

Presentations:

Connell, B., E. Dagg, K.-A. Caesar, M. Garbanzo, and D. Souza, 2018: Linking Data Access and Display, Hands on Exploratory Training, and Adaptations for Learners of Various Skill. 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Austin, TX, Amer. Meteor. Soc., 7-11 January 2018. Presentation.

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Torres and C. Seaman, 2018: Advancing potential new satellite products into operations: CIRA's NWS Proving Ground plans. Poster, 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, 98th Amer. Meteor. Soc. Annual Meeting, Austin, TX, 7-11 January 2018.

Torres, J., B. Connell, and S. Miller, 2018: JPSS Products, Applications and Training. 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Austin, TX, Amer. Meteor. Soc., 8-11 January 2018. Presentation.

Torres, J. 2018: “NOAA CLASS Demonstration.” and “Training Resources Available for JPSS Data Products*.”* AMS Short Course: Using JPSS Data Products to Observe and Forecast Major Environmental Events. Austin, TX, Amer. Meteor. Soc., 6 January 2018. Two Presentations.

Torres, J., B. Connell, and S. Miller, 2017: JPSS Products and Training for NWS forecasters leading up to JPSS-1 Launch. *Remote Sensing*, Garden Grove, CA, NWA Annual Meeting, 16-21 September 2017. Presentation.

Torres, J., S. Miller, and C. Seaman, 2017: Day/Night Band (DNB). *NOAA - JPSS Booth*, Garden Grove, CA, NWA Annual Meeting, 16-21 September 2017. Presentation.

Torres, J. 2017: JPSS Training. *NOAA - JPSS Booth*, Garden Grove, CA, NWA Annual Meeting, 16-21 September 2017. Presentation.

Torres, J. 2017: JPSS Training and Products in AWIPS-II for NWS Forecasters. *2017 Annual Science Team Meeting.* College Park, MD, 14-18 August. Presentation.

Torres, J., B. Connell, and S. Miller, 2017: JPSS Products and Training for NWS forecasters leading up to JPSS-1 Launch. *NOAA Satellite Conference*, New York, NY, 16-21 July. Poster.

Torres, J. 2017: JPSS Online Training Resources. *JPSS Training Workshop*. New York, NY, NOAA Satellite Conference, 16 July 2017. Presentation.

PROJECT TITLE: CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Visiting Scientist Program

PRINCIPAL INVESTIGATOR**:** John Forsythe and Galina Chirokova

RESEARCH TEAM: None

NOAA TECHNICAL CONTACT: Mitch Goldberg (NOAA/NESDIS/JPSS Program)

NOAA RESEARCH TEAM**:** Don Hillger (NESDIS/STAR/RAMMB)

FISCAL YEAR FUNDING: $6,358

PROJECT OBJECTIVES:

This project funding supported two CIRA scientists to undertake Visiting Scientist Program trips in order to collaborate with their partners. Funding was made available by NOAA/NESDIS/StAR’s JPSS Proving Ground Risk Reduction Office.

Trip 1:
JPSS VSP funds were requested to cover a trip by CIRA scientist John Forsythe to visit the NOAA Center for Weather and Climate Prediction (NCWCP) in College Park, MD for collaboration with scientists and forecasters at the Weather Prediction Center (WPC), Satellite Analysis Branch (SAB), and Ocean Prediction Center (OPC). Mr. Forsythe also visited with NESDIS Office of Satellite and Product Operations (OSPO) personnel on upgrades to operational water vapor products developed at CIRA for forecasters. The host for this visit at NCWCP was Dr. Michael Folmer, Satellite Liaison at NOAA/NWS WPC/OPC/TAFB and NOAA/NESDIS SAB.

This trip occurred in summer 2017. The requested JPSS VSP funding was $3,402

Trip 2:

JPSS VSP funds were requested to cover a trip by CIRA scientist Galina Chirokova to visit the National Hurricane Center (NHC) for collaboration with the NHC team to improve the currently developed JPSS Tropical Cyclone (TC) products and to explore the possibility of developing new JPSS and GOES-R TC products. CIRA has a very close working relationship with NHC. For decades, CIRA personnel have developed tools to improve tropical cyclone (TC) forecasting and several of their products have been successfully transitioned into NHC operations. The host for this trip will be Dr. Mark DeMaria, Chief of the Technology and Science Branch at NWS/NCEP/NHC.

This trip has not been taken yet at the time when this Annual Report was written. Requested VSP funding is $ 2,956

PROJECT ACCOMPLISHMENTS:

Trip 1:
John Forsythe of CIRA visited NCWCP from June 26 – 30, 2018 under support from the JPSS PGRR Visiting Scientist Program. There were two objectives for the trip. The first was to participate in one week of the Flash Flood and Intense Rainfall Experiment (FFaIR) at the NOAA Weather Prediction Center (WPC) and evaluate the CIRA Layer Precipitable Water (LPW) product, which is being developed under the JPSS Proving Ground and Risk Reduction program. The second objective was to meet with forecasters at WPC and discuss their usage of the product and suggestions for improvement. As part of the visit, a seminar on CIRA LPW was presented at WPC.

The goal of the 2017 FFaIR four-week experiment was to examine the value of and ways to maximize the utility of high resolution convection-allowing models at longer time ranges than operationally used. The CIRA LPW was evaluated as a tool to see moisture fluxes into potential flooding situations at 0 – 6 hours. CIRA LPW is delivered in AWIPS format to WPC every three hours. The results of FFaIR 2017 are summarized at http://www.wpc.ncep.noaa.gov/hmt/2017_FFaIR_final_report.pdf. The participants generally found the CIRA LPW to be very useful for situational awareness and very short-range flood forecasting as it is not a prognostic field. CIRA LPW was found to be less useful for longer (> 12 hour) forecast time ranges.

Interactions with forecasters at the WPC MetWatch Desk revealed that most forecasters look at CIRA LPW every shift, and are using it in novel ways not previously known by the CIRA team. For instance, atmospheric rivers are examined in the LPW product even in the West Pacific, several days out from CONUS. This helps forecasters assess the depth of moisture in an atmospheric river in a way not obtainable via other forecast tools such as blended Total Precipitable Water (TPW) or geostationary water vapor channel imagery. The visit and participation in FFaIR was very useful to receive feedback on and further improve the CIRA LPW product.

Trip 2:

Will occur in April 2018.

Publications: None

Presentations: None

PROJECT TITLE: CIRA Support to the JPSS STAR Science Program: S-NPP VIIRS EDR Imagery Algorithm and Validation Activities and S-NPP VIIRS Cloud Validation

PRINCIPAL INVESTIGATOR**:** Steve Miller

RESEARCH TEAM: Yoo-Jeong Noh, Curtis Seaman, Matt Rogers, John Forsythe, Scott Longmore, Louie Grasso, Stan Kidder, Steve Finley, Natalie Tourville, Hiro Gosden, Dave Watson, Kevin Micke, Renate Brummer, Rosemary Borger

NOAA TECHNICAL CONTACT: Lihang Zhou and Andy Heidinger (NOAA/NESDIS/StAR)

NOAA RESEARCH TEAM: Don Hillger, Deb Molenar (NOAA/NESDIS/STAR/RAMMB)

FISCAL YEAR FUNDING: $369,800

PROJECT OBJECTIVES:

The Suomi National Polar-orbiting Partnership (S-NPP) mission, a risk-reduction mission to the Joint Polar Satellite System (JPSS), was launched successfully on 28 October 2011. The Visible/Infrared Imager/Radiometer Suite (VIIRS) on board S-NPP provides atmospheric, cloud, and surface imagery for both weather and climate applications. JPPS-1 launched in November 2017.

The conversion of VIIRS Sensor Data Record (SDR) radiances and brightness temperatures into value-added “Level 2” Environmental Data Records (EDR; physical parameters) is a critical step to the real-time operational use of S-NPP VIIRS. The EDR algorithms are currently implemented at the Integrated Data Processing Segment (IDPS), and the EDRs produced from these algorithms are delivered as a standard suite of products to end-users. The principal objective of the calibration/ validation (cal/val) efforts of this project is to provide a quantitative and qualitative assessment of EDR performance.

This is a multi-agency research project with teams involved from NOAA/NESDIS/StAR, CIRA, CIMSS, NRL, NCEI-Boulder, NGAS, and Aerospace. CIRA’s research in this area is divided in into two distinct elements: Project I) Support of VIIRS Imagery Validation Activities and
Project II) Support of VIIRS Cloud Validation Activities.
Progress on each element is detailed below.

These projects directly address NOAA’s Weather and Water goal, which seeks to serve society’s needs for weather and water information. This research also falls within the NOAA-defined CIRA thematic area of Satellite Algorithm Development, Training and Education, as calibration/validation is an integral and critical first step in the algorithm development process. Outcomes of the current research may in some cases lead to adjustments in the original algorithm to correct issues discovered during the calibration/validation analysis.

Project I--Support of the VIIRS Imagery Validation Activities

Research Objectives

During FY17, CIRA continued its work on tasks which began successfully back in FY12. The utilization of VIIRS Imagery, as a Key Performance Parameter (KPP), is critical to S-NPP/JPSS success. With S-NPP VIIRS data being received in near real-time, operational-phase validation activities are important measures of successful utilization of the VIIRS data stream. JPSS-1 data validation was conducted after JPSS1 satellite was launched and the first data became available to the EDR Imagery Team.

For FY17, the CIRA JPSS Imagery Team focused on supporting the EDR lead for Imagery checkout activities.

The CIRA team's contribution to this project were:

1--Report on the analysis of the VIIRS Imagery EDR software, imagery, and image products produced from that imagery – Either as uncovered, or end of term.

2--Document any EDR software and imagery issues that might be uncovered, whether in the image data, or products derived from that imagery – Either as uncovered, or end of term.

3--Contribute to StAR Long Term Monitoring (LTM) website, with Imagery products over either conus or Alaska.

4--The CIRA Team is committed to presenting its research results at JPSS Science meetings and national/international conferences and will publish results in refereed journals.

5--Provide monthly reports on the VIIRS Imagery EDR Team activities and spending

PROJECT ACCOMPLISHMENTS:

1--The JPSS EDR Imagery Team holds regular monthly meetings/teleconferences. These meetings involve all available project participants from CIRA, NOAA/NESDIS/StAR, CIMSS, NCEI, NRL, NGAS, and Aerospace. The purpose of these meetings is to discuss recent Team activities, updates from the JPSS Program Office including changes to the operational software, recent anomalies with the VIIRS instrument or upcoming planned data outages (if any), and coordinate calibration and validation activities with the VIIRS SDR Team. As Imagery Team Lead, D. Hillger submits weekly reports to the JPSS Program Office on Team activities.

In addition to the reporting requirements, global VIIRS data is acquired by CIRA and various imagery products are produced in near-real time for selected sectors around the globe. Changes in data collection due to new satellite and CSPP changes/updates were accommodated by CIRA IT staff.

2--Analysis of CIRA's near-real time VIIRS imagery is used to identify any issues with the EDR imagery and software. This, combined with feedback from the collaborating institutions is provided back to the VIIRS SDR Team and JPSS Program Office. During this reporting period, the Terrain Correction (TC) for VIIRS Imagery EDR milestone was accomplished, noting the promised testing needed to discover the extent/complexity of the changes needed to implement TC. VIIRS imagery made available on the RAMSDIS Online website now includes random granules displayed at full width with inset world map showing granule location. Additional sectors and products have been made available on RAMSDIS Online, including the Day/Night Cloud/Snow Discriminator for Alaska and various imagery products related to dust detection over the CONUS. JPSS-1 JCT5 Test data were acquired and tested for proper ingest and display in McIDAS and IDL. Block 2.0 data were acquired and tested against equivalent Block 1.2 data. Following the launch of JPSS-1 (NOAA-20), the team has been actively involved with validation of JPSS-1 VIIRS imagery and has coordinated with the SDR Team on the transition of JPSS-1 imagery to Beta and Provisional maturity.

3--The software for producing Alaska DNB Imagery for the StAR Long Term Monitoring (LTM) website was provided to NOAA/NESDIS/StAR and is now being run locally at NCWCP. "Image of the Month" examples continue to be provided for the JPSS StAR website. Interesting VIIRS Imagery continues to be provided to NOAA social media outlets.

4-- CIRA has continued to maintain the VIIRS Imagery and Visualization Team Blog (http://rammb.cira.colostate.edu/projects/npp/blog/). This blog highlights interesting VIIRS images and novel uses of VIIRS imagery. Imagery Team member and JPSS Satellite Liaison, J. Torres, provides VIIRS imagery examples for training purposes on the VISIT Meteorological Interpretation Blog (http://rammb.cira.colostate.edu/training/visit/blog/). Outreach websites, including these blogs as well as near-real time imagery on RAMSDIS Online, continue to be updated with new imagery examples and real-time data. VIIRS-related research results have been presented at a variety of conferences and workshops, including: the Alaska Fire Science Consortium Remote Sensing Workshop (Fairbanks, AK), NOAA Satellite Conference (New York, NY) CSPP User's Workshop (Madison, WI), the JPSS/STAR Annual Science Team Meeting (College Park, MD), the National Weather Association (NWA) Annual Meeting (Garden Grove, CA), EUMETSAT Meteorological Satellite Conference (Rome, Italy), AMS Annual Meeting (Austin, TX), and an invited presentation at NASA Headquarters. The full list of presentations is provided below. JPSS-1 First Light Imagery examples were also provided to JPSS Program and Mitch Goldberg for use in presentations and public relations materials.

5-- Monthly reports on Imagery Team activities are provided.

Project 2--Support of the VIIRS Cloud Validation Activities

PROJECT OBJECTIVES:

1-- Continue coordinating the transition of revised cloud geometric thickness algorithm to the operational NOAA Enterprise processing environment and confirm its correct operation, used for the revised Cloud Base Height (CBH). Continue to examine performance of CBH retrieval vs. CloudSat and CALIPSO.

2-- Continue to support the JPSS VIIRS Cloud Cal/Val Team in its development of an enhanced Cloud Cover and Layers product and display system suitable for use by operational users such as the Aviation Weather Center and the Alaska Region.

3-- Continue to evaluate nighttime CBH, coordinating with NLCOMP nighttime cloud optical thickness based on Atmospheric Radiation Measurement (ARM) program lidar and ceilometer data from the Northern Slope of Alaska (NSA) and Southern Great Plains (SGP) sites. Continue support of the JPSS VIIRS Cloud Cal/Val Team in any other developments related to nighttime cloud properties and associated applications.

4-- Interface with research from a newly selected GOES-R Risk Reduction project (1 July 2017 start; "Improving the ABI Cloud Layers Product for Multiple Cloud Systems and Aviation Forecast Applications," J. Haynes and Y.J. Noh) targeting characterization of overlapping cloud layers with ABI. Compare ABI and VIIRS overlapping cloud detections and assess CBH performance for multi-layer clouds. Leverage GOES-R project to develop a companion algorithm, applicable to VIIRS, for calculation of daytime cloud layer separation distance via exploitation of the 1.38 µm 'cirrus' band common to both VIIRS and ABI instruments.

5-- Prepare reports, contribute materials to presentations, and participate in scientific conferences as requested/coordinated by VIIRS Cloud Cal/Val Team Lead.

PROJECT ACCOMPLISHMENTS:

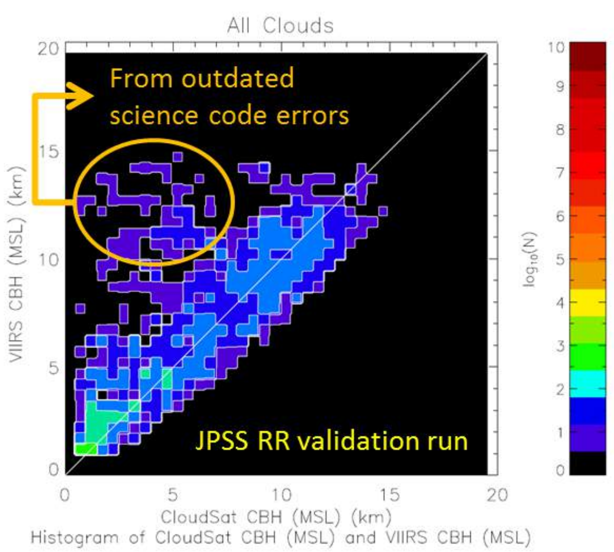
1--We continue to assist the algorithm operation and monitoring in the NOAA computational environment for the NESDIS/STAR Algorithm Scientific Software Integration and System Transition Team (ASSISTT). In collaboration with CIMSS, we have examined the operational output from using CloudSat and CIRA's local runs and reported errors at each periodic DAP (Delivered Algorithm Package) delivery (e.g., nighttime invalid CBH calculation and outdated science code parts) as shown in the figure below. The results shown here are from "within spec" comparisons when CTHs are within an accurate range against CloudSat. A minor code update in supplementary NWP LCL and CCL use for deep convective clouds has been delivered to ASSISTT with error corrections.

2--The CCL algorithm has incorporated the cloud base information. CIRA and CIMSS teams are working on the transition of the improved algorithm to operations. We are also working to extend the algorithm to five flight levels (as requested by NOAT) from the current three (high, mid, and low) layer-based CCL. We displayed sample VIIRS products in AWIPS2 and continue to explore more effective demonstration to operational users.

3--Nighttime cloud optical properties for CBH are retrieved utilizing lunar reflectances from VIIRS DNB data. When moonlight is not sufficient, NWP CWP is used as supplementary data. Since CloudSat is not operational at night due to a battery anomaly, we use ground-based measurements at the Atmospheric Radiation Measurement (ARM) sites to assess the nighttime performance. VIIRS CBHs for October 2015 to April 2016 were compared with ceilometer and micro-pulse lidar (MPL) data from the ARM North Slope of Alaska (NSA) site (the figure below). CBHs utilizing DNB lunar reflectance are indicated in blue. A matchup window of 1-km distance and 5-minute time lag is used between ARM and VIIRS data. Local weather conditions are checked using temperature and precipitation observations at the site. CALIPSO data with near-simultaneous colocation were added to the comparison upon its availability. This addition helps improve the individual case analysis for outliers, which may have multilayered clouds beyond the ground measurements as shown in the sample figure below.

4--As a leveraging research effort, we completed transitional work to implement the statistical CBH algorithm from VIIRS into the ABI framework for our new GOES-R Risk Reduction project. The current CBH and CCL products are displayed in near real-time via the CIRA SLIDER tool (http://rammb-slider.cira.colostate.edu), which is publically available. This project aims to better handle multi-layered clouds. We have collected CloudSat/CALIPSO and co-located ECMWF forecast data and developed a collocation code for CloudSat and CALIPSO within the GOES-16 field of view. From our initial analyses, it has been found that NWP relative humidity can be a useful proxy for multi-layered cloud scenes. We began work to introduce a new 'High + Low' cloud layer category for multi-layers by utilizing NWP humidity data and a multi-spectral approach including 1.38 µm, applicable to both VIIRS and ABI.

5--The CIRA team participated in the VIIRS Cloud Cal/Val teleconferences and regularly contributed input materials to Andrew Heidinger (Cloud Team Lead) for team reviews and reports to support the JPSS VIIRS Cloud Cal/Val Team. An overview presentation of the improved CBH and CCL algorithms and Cal/Val activities was given at 2017 STAR JPSS Annual Science Team Meeting.



Errors "within spec" (3602 points for **20150103**)	All clouds against CloudSat
r^2	0.743
Average error (bias)	-0.7 km
Standard deviation error	1.9 km
RMSE	2.0 km

Figure 1. Evaluation of the NOAA ASSISTT CBH output against CloudSat with error configurations for a periodic DAP (Delivered Algorithm Package) delivery. The statistical analysis shows that the current operational CBs are still within the VIIRS error specification but will be improved with error corrections we have delivered at the latest DAP round.

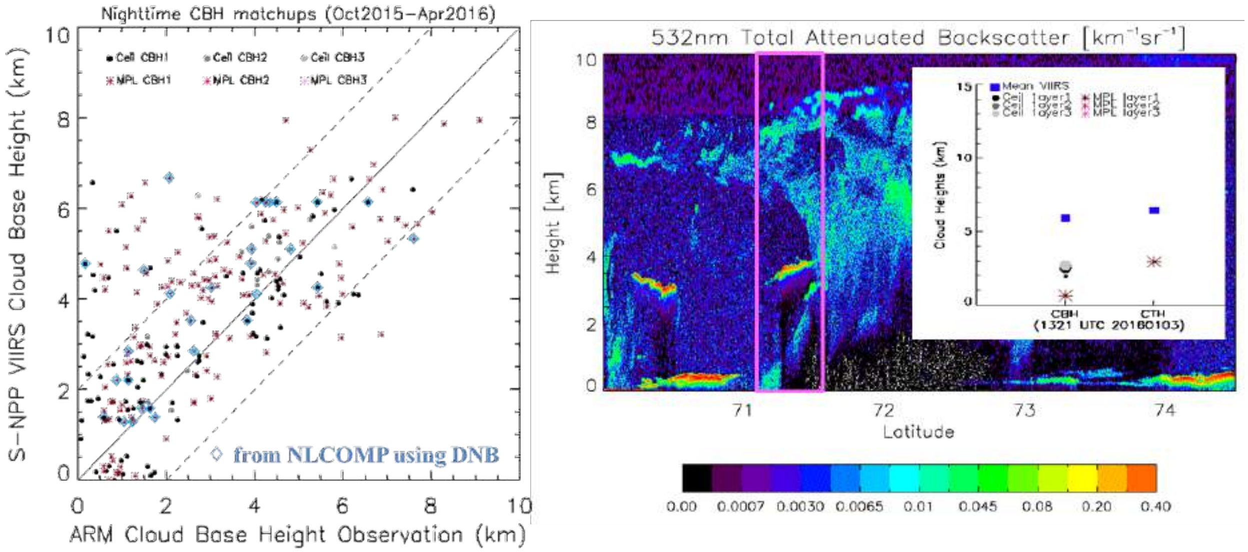


Figure 2. Validation of nighttime CBHs using ground-based ceilometer and lidar data from the ARM NSA site in Alaska (left). The brown/red symbols represent comparisons with ARM lidar (MPL) and black/gray circles are ARM ceilometer CBHs (black for the first cloud layer and gray for the second layer). CBH measurements are considered only when CTHs from MPL and VIIRS are within 2-km error range ("within spec" comparison). CBHs using DNB lunar reflectance are indicated in blue. CALIPSO data with near-simultaneous colocation (upon its availability) is added to the individual case analysis (right).

Publications:

Noh, Y.-J., J. M. Forsythe, S. D. Miller, C. J. Seaman, Y. Li, A. K. Heidinger, D. T. Lindsey, M. A. Rogers and P. T. Partain, 2017: Cloud Base Height Estimation from VIIRS, Part II: A Statistical Algorithm Based on A-Train Satellite Data. J. Atmos. and Ocean. Tech., 34(3), 585-598, doi: 10.1175/JTECH-D-16-0110.1.

Seaman, C. J., Y.-J. Noh, S. D. Miller, A. K. Heidinger and D. T. Lindsey, 2017: Cloud Base Height Estimation from VIIRS, Part I: Operational Algorithm Validation Against CloudSat. J. Atmos. and Ocean. Tech., 34(3), 567-583, doi: 10.1175/JTECH-D-16-0109.1.

Presentations:

Chirokova G., 2017: Proxy - Visible Imagery. STAR JPSS Annual Science Team Meeting, 14-18 August 2017, College Park, MD.

Grasso, L., 2017: Motion of Diffraction Pattern on VIIRS Detectors. STAR JPSS Annual Science Team Meeting, 14-18 August 2017, College Park, MD.

Haynes, J. M., Y. J. Noh, S. D. Miller, D., D. T. Lindsey, A. K. Heidinger, 2018: Improving cloud layer boundaries from GOES-16. 2018 AMS Joint Satellite Conference, 7-11 January, Austin, TX.

Hillger, D. W.**,** T. J. Kopp, C. J. Seaman, S. D. Miller, D. T. Lindsey **and** J. Torres**,** *2018:* First VIIRS Imagery from JPSS-1. AMS 14th Annual Symposium on New Generation Operational Environmental Satellite Systems*,* 8 January, Austin, TX.

Miller, S. D, 2018: Bridging the Nocturnal Gap: Capabilities and Revelations from the VIIRS Day/Night Band. Invited oral presentation with WebEx service. NASA Headquarters, Washington, DC, 8 March 2018.

Miller**, S. D.**, W. C. Straka, III, **C. J.** Seaman, C. L. Combs, A. K. Heidinger, A. Walther, and J. E. Solbrig, 2018: Chasing the Shadows with the VIIRS Day/Night Band. AMS 8th Conference on Transition of Research to Operations*,* Advances in Satellite Observations for Earth Science and Observing Technologies—Part I*,* 8 January, Austin, TX.

Miller, S. D., 2017: Satellite Algorithm Development at CIRA, CIRA Council & Fellows Meeting, 9 May 2017, Fort Collins, CO.

Miller, S. D**.,** W. C. Straka III, **C. J.** Seaman, R. L. Brummer**,** 2017: Double-Take: Possibilities for Improved Nocturnal Environment using VIIRS Day/Night Band sensors on Suomi NPP and JPSS-1. *EUMETSAT Satellite Conference,* 2-5 October, Rome, Italy.

Noh, Y. J., 2017: Satellite Cloud Detection and Height Estimation. An invited talk, Department of Astronomy and Atmospheric Sciences/Kyungpook National University, 20 March 2017, Daegu, South Korea.

Noh, Y. J., S. D. Miller, J. Forsythe, C. J. Seaman, J. Haynes, A. K. Heidinger, D. T. Lindsey, and Y. Li, and S. Wanzong, 2017: The Newly Operational VIIRS Cloud Cover/Layers and Base. STAR JPSS Annual Science Team Meeting, 14-18 August 2017, College Park, MD.

Seaman, C. J., S. D. Miller, J. Torres, D. Hillger, C. Dierking, J. Cable, E. Stevens, A. Leroy, E. Berndt, K. Fuell, K. Strabala and the CSPP Development Team, 2017: VIIRS Imagery: Transitioning Novel Ideas into Operations. STAR JPSS Annual Science Team Meeting, 14-18 August 2017, College Park, MD.

Seaman, C. J, S. D. Miller, W. Straka, III, D. T. Lindsey and J. Torres, 2017: Night Vision: Illuminating the Capabilities of the VIIRS Day/Night Band. STAR JPSS Annual Science Team Meeting, 14-18 August 2017, College Park, MD.

Seaman, C. J., S. D. Miller and D. T. Lindsey, 2017: VIIRS Imagery Applications for Fire Weather Monitoring. Alaska Center for Climate Assessment and Policy (ACCAP) Virtual Alaska Weather Symposium (VAWS), 12 April 2017, Fairbanks, AK.

Seaman, C. J., S. D. Miller and D. T. Lindsey, 2017: VIIRS Imagery Applications for Fire Weather Monitoring. Alaska Fire Science Consortium Remote Sensing in Boreal/Arctic Wildfire Management and Science Workshop, 4-6 April 2017, Fairbanks, AK.

Seaman, C. J.**,** S. D. Miller, D. T. Lindsey, D. W. Hillger, 2017: Multispectral Imagery Applications for the New Generation Weather Satellites. EUMETSAT Satellite Conference, 2-5 October, Rome, Italy.

Torres J.**,** B. H. Connell**,** and S. D. Miller, 2018: JPSS Products, Applications and Training. AMS 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Session: Education, Training and User Readiness for GOES-R and JPSS – Part II, 10 January, Austin, TX.

Torres, J., C. Seaman, S. Miller, W. Straka III and D. Lindsey: The Day/Night Band, 2017 NWA Annual Meeting, Garden Grove, CA, 18-22 September 2017.

PROJECT TITLE: CIRA Support of NOAA's Commitment to the Coordination Group for Meteorological Satellites: Enhancing the International Virtual Laboratory

PRINCIPAL INVESTIGATORS: Bernadette Connell

RESEARCH TEAM: Luciane Veeck, Erin Dagg, and Dan Bikos

NOAA RESEARCH TEAM: Anthony Mostek NOAA/ NWS/OCWWS Training Division

FISCAL YEAR FUNDING: $70,000

PROJECT OBJECTIVES:

The World Meteorological Organization (WMO) Virtual Laboratory for Education and Training in Satellite Meteorology (VLab) is a collaborative effort joining major operational satellite operators across the globe with WMO regional training centers of excellence in satellite meteorology. Those regional training centers serve as the satellite-focused training resource for WMO Members. Through its cooperative institute for Research in the Atmosphere (CIRA) at Colorado State University (CSU), NOAA/NESDIS sponsors Regional Training Centers of Excellence (CoE) in Argentina, Barbados, Brazil, and Costa Rica.
The top-level objectives of the VLab are:

1--To provide high quality and up-to-date training and supporting resources on current and future meteorological and other environmental satellite systems, data, products and applications;
2--To enable the regional training centers to facilitate and foster research and the development of socio-economic applications at the local level through the National Meteorological and Hydrological Services.

Enhanced training and coordination of training that is specifically targeted for the GOES-R series satellites and accomplished under this project will prepare forecasters, researchers, and managers on how to utilize imagery and products to provide services and training in these areas. Other CIRA RAMMB projects are leveraged to meet the VLab top level objectives.

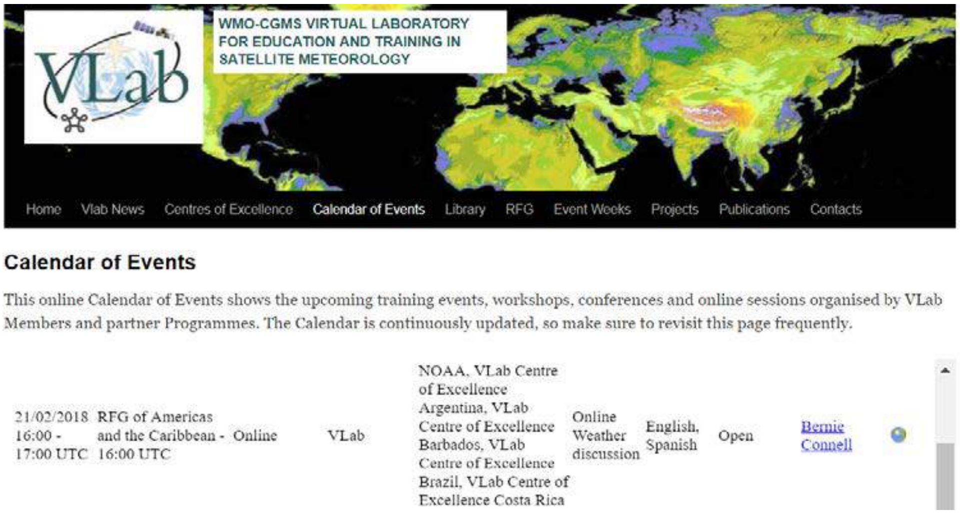
Specific Objectives:

1--Provide partial support (1.5 months) for the WMO Technical Support Officer (TSO) position.
2--Provide virtual JPSS imagery and product examples and partial support for monthly weather briefing sessions of the WMO VLab Regional Focus Group (RFG) of the Americas and the Caribbean.
3--Participate in virtual and in-person meetings of the WMO VLab Management Group, activities of the NOAA GEONETCast Americas (GNC-A) coordination group, and the WMO WMO Satellite Data Requirements (SDR) group.
4--Leverage NOAA and WMO VLab partners to organize and deliver virtual and in-person JPSS training on data and product access, display, and interpretation.

PROJECT ACCOMPLISHMENTS:

1--This project provided partial monetary support (2 months) for a WMO VLab Technical Support Officer (TSO), Luciane Veeck. Her efforts provide a very important stabilizing factor for the global coordination of training efforts under the umbrella of the WMO VLab. Member countries have access to her resources through the entire year. Luciane was also supported through CIRA under a WMO grant and another CIRA project during the past year. Highlights of her work that benefit the WMO community and the US include:

-- Maintenance of the VLab central website and the VLab calendar of events http://vlab.wmo.int



--Support to VLab Management Group (VLMG) online meetings (4 and 5 April, 25 October, 28 November, 12 and 13 December, all in 2017, and 30-31 January 2018). Activities include the coordination and organization of meeting logistics and agenda, collection of Satellite Operator and Centre of Excellence Status reports, analysis of reports, and participation in the meetings.

-VLab global partners developed a survey on "What have we learned about training for use of RGBs" to assist in organizing a Global Train the Trainer event on RGBs. Select VLMG members met in November to have a focused discussion on a Global Train the Trainer event for either RGB or more broadly for image enhancement which includes RGB.

-VLMG met in October to review VLMG-8 action items and discuss global coordination efforts. Another VLMG meeting was held in December for select members to review the "Satellite Skills and Knowledge for Operational Meteorologists" document.

- The dates for the next face-to-face VLMG meeting were confirmed as 16 to 20 July 2018. WMO accepted NOAA's letter offering to host the meeting at CIRA in Fort Collins, Colorado, USA. Invitation letters were sent to VLMG members in February 2018. Preparations are underway.

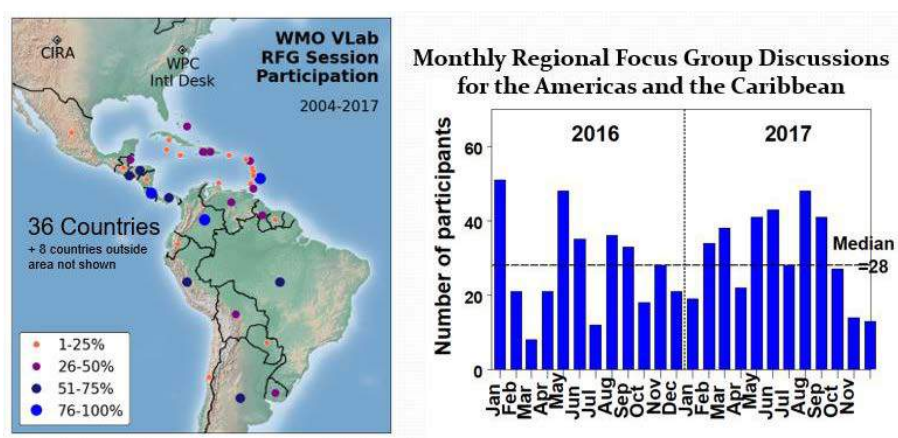
-- WMO Trainer Resources Portal – For four years now (including 2017), the TSO has been supporting the annual WMO Online Course for Trainers by writing training resources and helping with the facilitation of the course. To make the materials used in this course more accessible to all WMO Members, the VLab collaborated with the Global Campus initiative of the WMO- Education and Training (ETR) program to organize the resources in a Portal. The Trainer Resources Portal is now accessible at http://etrp.wmo.int/moodle/course/view.php?id=30 (no login required). Efforts will continue to make the Portal available in Spanish, French and Russian.

- VLab reports annually to the Inter-Programme Exert Team on Satellite Utilization and Products (IPET-SUP) and the Coordinating Group for Meteorological Satellites (CGMS). Reports and slides were prepared by the TSO and presented online by the VLab Co-Chair Kathy-Ann Caesar at both meetings:

IPET-SUP-3 (Geneva-Switzerland, 2-5 May 2017) and CGMS-45 (Jeju Island-Republic of Korea, 11-16 June 2017). The full reports can be downloaded from the VLab website listed above under Publications/Other reports.

-Best practices in implementing learning and development activities were both presented and gathered at the CALMet 2017 conference hosted by the Bureau of Meteorology in Melbourne, Australia in late August.

2--Provide JPSS imagery and product examples and partial support for monthly weather briefing sessions of the WMO VLab Regional Focus Group (RFG) of the Americas and the Caribbean.



On the left is the Regional Focus Group Monthly Weather and Climate virtual discussion session country participation from March 2004 through December 2017. The graph on the right reflects number of participants reached over the past 2 years. The median number of participants was 28 and the median number of countries participating was 12. (The median number of participants over all years is 27 and the median number of countries is 11!).

-The WMO Virtual Laboratory Regional Focus Group of the Americas and Caribbean conducted 12 monthly bilingual (English/Spanish) weather briefings. The briefings made use of VISITview software to present GOES and POES satellite imagery from CIRA and GoToWebinar for voice communication over the Internet. Over the calendar year 2017, the participants from the U.S. included: CIRA, the NWS International Desk at NCEP/WPC, NWS/Office of the Chief Learning Officer (OCLO) Forecast Decision Training Division (FDTD), the UCAR/JOSS-NWS International Activities Office, NASA Short-term Prediction Research and Transition Center (SPoRT), and the Universal Weather and Aviation Private/Corporation. Thirty-one countries outside the US participated: Argentina, Antigua, Bahamas, Barbados, Belize, Bolivia, Brazil, Cayman Islands, Colombia, Costa Rica, Dominica, Ecuador, El Salvador, Germany, Grenada, Guatemala, Guyana, Haiti, Honduras, Italy, Jamaica, Mexico, Panamá, Paraguay, Peru, Saint Kitts and Nevis, Saint Lucia, Spain, Suriname, Trinidad and Tobago, and Uruguay. M. Davison and J. Galvez at the NCEP International Desks led the discussions (11 and 1 respectively). Participants offered comments and questions for their regions. The number of countries participating each month ranged between 9 and 22 (average 13); and the number of participants each month ranged between 13 and 48 (average 30).

The sessions were recorded and can be accessed here:
http://rammb.cira.colostate.edu/training/rmtc/fg_recording.asp

3--Participate in virtual and in-person meetings of the WMO VLab Management Group, activities of the NOAA GEONETCast Americas (GNC-A) coordination group, and the WMO Satellite Data Requirements (SDR) group.
CIRA participated in online meetings of the WMO VLab Management Group (VLMG-8) mentioned in accomplishment 1 above.
The main topics include
--Satellite skills and knowledge for operational meteorologists
--Language translation of training resources
--Evaluation of training impact
--User readiness (particularly relevant for GOES-R)
--Climate services
--Global training campus


Guidelines on Satellite Skills and Knowledge for Operational Meteorologists[1]

The motivation behind VLab activities is to build a strong training foundation to make it is easier to get messages, information, and data to the user.

GEONETCast-Americas (GNC-A) is a great way to provide instructional material to users as well as provide products. It is a low cost alternative to many users in countries that still do not have adequate internet access. It is also a good backup for emergency preparedness. GNC-A usage is strongly linked to training and aspects of this are covered in the next objective.

The WMO Satellite Data Requirements (SDR) Group for Regions III and IV was held in conjunction with the NOAA Satellite Conference. http://www.wmo.int/pages/prog/sat/meetings/RA-3-4-SDR-3.php
CIRA participated in the meeting to listen to user feedback and address user needs where applicable and possible.

4--Leverage NOAA and WMO VLab partners to organize and deliver virtual and in-person GOES-R training on data and product access, display, and interpretation.

Left: Train the Trainer Workshop 15-16 July 2017 prior to the NOAA Satellite Conference; and right: GEONETCast Workshop at the Americas Global Earth Observation System of Systems (AmeriGEOSS) Meeting 31 July – 4 August 2017

Exercises were developed for two workshops: the WMO/NOAA VLab Train the Trainer workshop on "Satellite Data Usage: Access through GEONETCast Americas, Display, Interpretation, and Usage in Training" occurring on 15-16 July 2017 in New York City, and the AmeriGEOSS "Training on Satellite Data: Access through GEONETCast Americas, Display, Interpretation, and Usage" occurring on 31 July - 4 August 2017, occurring in San José, Costa Rica. The agendas and two exercises reviewed at each workshop can be found on this web page:
http://rammb.cira.colostate.edu/training/rmtc/mcv_exercises.asp
Both workshops had a focus on display and interpretation of imagery from the next generation satellites which included both GOES-16 and JPSS. The exercises focused on linking information from online training modules with on hands-on data exploring activities. For participants that were not familiar with the new GOES-16 satellite or JPSS, online training modules were recommended for review prior to the workshops.

Presentations:

Connell, B., E. Dagg, K.-A. Caesar, M. Garbanzo, and D. Souza, 2018: Linking Data Access and Display, Hands on Exploratory Training, and Adaptations for Learners of Various Skill. 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Austin, TX, Amer. Meteor. Soc., 7-11 January 2018.

Connell, B., K.-A. Caesar, M. Garbanzo, D. Souza, N. Rudorff, and M. Campos 2018: 17 Years of Interactions between NOAA and the WMO VLab Members in Regions III and IV to Ensure Satellite Usage through Training. Third Symposium on Special Sessions on US-International Partnerships, Austin, TX, Amer. Meteor. Soc., 7-11 January 2018.

Connell, B., E. Dagg, A. Trotman, K.-A. Caesar, M. Garbanzo, and D. Souza, 2017: Linking Data Access and Display, Hands-on Exploratory Training, and Adaptations for Learners of Various Skills. 12th International Conference on Creating Activities for Learning Meteorology, Melbourne, Australia, 29 August – 1 September.

Connell, B., 2017: NOAA's contributions to International Activities for Training in Satellite Meteorology via the WMO VLab. NOAA Satellite Conference, 17-20 July, New York, NY.

Parrish, P., B. Muller, and L. Veeck, 2017: The WMO Global Campus has arrived. 12th International Conference on Creating Activities for Learning Meteorology, Melbourne, Australia, 29 August – 1 September.

Parrish, P., and L. Veeck, 2017: The WMO Trainer Resources Portal. 12th International Conference on Creating Activities for Learning Meteorology, Melbourne, Australia, 29 August – 1 September.

Thomas, J. R., S. Goodman, E. Madsen, J. Peronto, B. Connell, A. Stevermer, K. Mozer, and M. Seybold, 2018: GOES-R Series International Training Working Group. 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Austin, TX, Amer. Meteor. Soc., 7-11 January 2018.

Veeck, L., 2017: Embracing the Translation Challenge. 12th International Conference on Creating Activities for Learning Meteorology, Melbourne, Australia, 29 August – 1 September.

Workshops (Development and delivery of materials and presentations):

AmeriGEOSS workshop "Training on Satellite Data: Access through GEONETCast Americas, Display, Interpretation, and Usage", 31 July **-** 4 August 2017, University of Costa Rica, San José, Costa Rica.

WMO/NOAA VLab Train the Trainer workshop on "Satellite Data Usage: Access through GEONETCast Americas, Display, Interpretation, and Usage in Training", 15-16 July 2017, The City College of New York, New York, NY.

PROJECT TITLE: CIRA Support to RAMMB Infrastructure for GOES-R Rebroadcast Data Collection at CIRA/CSU

PRINCIPAL INVESTIGATOR**:** Renate Brummer and Michael Hiatt

RESEARCH TEAM: Renate Brummer, Michael Hiatt, Natalie Tourville

NOAA TECHNICAL CONTACT: Steve Goodman and Dan Lindsey (NOAA/NESDIS)

NOAA RESEARCH TEAM**:** Don Hillger and Deb Molenar (NESDIS/STAR/RAMMB)

FISCAL YEAR FUNDING: $75,000

PROJECT OBJECTIVES:

CIRA and RAMMB are key players in the GOES-R Proving Ground, GOES-R Risk Reduction activities, and GOES-R/S algorithm development. GOES-R ground station funding received by CIRA over FY15 and FY16 from the GOES-R Program Office, NESDIS/StAR and Colorado State University, put CIRA into a position to purchase a GOES-R 4.5 Meter S-Band Antenna, High Performance Low Noise Amplifier (LNA), and pay for the GOES-R antenna installation including foundation, Cables, and Conduits, GOES-R Receiver, GOES-R SDI Pre-processor, GOES-R Ingest Server /Processor computers, and an Archive and Distribution System. Algorithm development work in preparation for GOES-R data resulted in CIRA/RAMMB generating a GOES-R true color imagery which was used in the GOES-16 ABI first light imagery release. Shortly afterwards, CIRA's GOES-R Rebroadcast Data Collection went into operation and became fundamental for CIRA to generate a large number of near-real time GOES-R imagery and products which became quickly very popular with NWS WFO forecasters and National Centers.

In order to prepare for the upcoming launch of GOES-S schedule in March 2018, CIRA did receive funding from the GOES-R Program Office which allowed for the purchase of a GOES-S ground station. The objective of this project is to build a second ground station for GOES-S which will be nearly identical to the existing GOES-R ground station.

PROJECT ACCOMPLISHMENTS:

The following equipment pieces were purchased and installed to support reception of GOES-S data:

1-Quorum Communications: GOES GRB 4.5M antenna, Dual polarity feed, Demodulator, Cables, and Dehydrator:
2-Antenna concrete pad, antenna construction (work performed by CSU Facilities)

Project management and coordination was conducted by CIRA's Primary Ground Station Engineer Michael Hiatt in partnership with Renate Brummer (CIRA Program Manager), Don Hillger, Daniel Lindsey and Debra Molenar (all NOAA/NESDIS/StAR).

Timeline: October 1, 2017 – June 30, 2018

Figure 1. CIRA's Primary Ground Station Engineer Michael Hiatt (left) oversees the installation of the new GOES-S antenna next to the CIRA building in Fort Collins, Colorado on 6 October 2017.

Publications**:** None

Presentations**:** None

PROJECT TITLE: CIRA Support for Research and Development for GOES-R Risk Reduction for Mesoscale Weather Analysis and Forecasting and Training

PRINCIPAL INVESTIGATOR: Steve Miller

RESEARCH TEAM: Karina Apodaca, Dan Bikos, Renate Brummer, Jack Dostalek, John Forsythe, Kathy Fryer, Brody Fuchs, Hiro Gosden, Louie Grasso, John Haynes, Michael Hiatt, Stan Kidder, Scott Longmore, Kevin Micke, Yoo-Jeong Noh, Karly Reimel, Matt Rogers, Steven Rutledge, Curtis Seaman, Jeremy Solbrig, Natalie Tourville, Tom VonderHaar, Dave Watson, Ting-Chi Wu, Milija Zupanski

NOAA TECHNICAL CONTACT: Satya Kalluri / Jeff Key, Andrew Heidinger (NOAA/NESDIS/StAR), Avichal Mehra (NOAA/NCEP/EMC), Steve Goodman/Dan Lindsey (NOAA/NESDIS/GOESR Program Office)

NOAA RESEARCH TEAM: Don Hillger, John Knaff, Dan Lindsey, Deb Molenar (all NESDIS/STAR), Andy Edman (NWS Western Region), Limin Zhao (NOAA/NESDIS/OSPO), Mark Klein (NOAA/NWS/WPC), Andrew Orrison (NOAA/NWS/WPC), Steve Weiss (Chief, Science Support Branch, Storm Prediction Center), Avichal Mehra (NOAA/NCEP/EMC), Mark DeMaria (NOAA/NCEP/HRC), Mike Pavalonis (NESDIS/STAR).

FISCAL YEAR FUNDING: $970,211

PROJECT OBJECTIVES:

The GOES-R era is part of a global observing system that includes polar-orbiting satellites with comparable spatial and spectral resolution instrumentation. The GOES-R/GOES-16 Advanced Baseline Imager (ABI) offers vastly improved spectral, spatial and temporal resolution relative to the current GOES I-P series satellites. The Geostationary Lightning Mapper (GLM), together with the ABI, also offer the potential to significantly improve the analysis and forecasts of mesoscale weather and natural hazards. GOES-R was successfully launched on Nov. 19, 2016 and was renamed to GOES-16 when it reached geostationary orbit a few weeks later. This annual report combines twelve CIRA research projects conducted in the areas of GOES-R Risk Reduction (R3). The overall goal of these science studies is to contribute to the reduction of time needed to fully utilize GOES-R/GOES16, provide the necessary proxy data to the algorithm groups for testing proposed algorithms and therefore to contribute to an improved algorithm selection and algorithm refinement, and –now with GOES-16 in orbit- to transition CIRA's decision aid products to ABI.

CIRA's GOES-R projects directly address NOAA's Weather Ready Nation (WRN) objectives. The projects also fit under the Satellite Algorithm Development, Training and Education theme of CIRA's Cooperative Agreement with NOAA.

This Annual Report covers the following twelve projects:

Project 1--Developing an Environmental Awareness Repertoire of ABI Imagery ('DEAR-ABII') to Advise the Operational Weather Forecaster
Project 2--Improving the ABI Cloud Layers Product for Multiple Layer Cloud Systems and Aviation Forecast Applications
Project 3--Using the New Capabilities of GOES-R to Improve Blended, Multisensor Water Vapor Products for Forecasters
Project 4--GOES-R ABI channel differencing used to reveal cloud-free zones of 'precursors of convective initiation'.
Project 5--ProbSevere: Upgrades and Adaptation to Offshore Thunderstorms
Project 6--Data assimilation of GLM observations in HWRF/GSI system
Project 7--Support of GOES-R Imagery Team
Project 8--Support of GOES-R Cloud Team
Project 9--CSU/Atmospheric Science Department Colorado Lightning Mapping Array / GLM
Project 10--GOES-R Visiting Scientist Program

Project 11--Senior Advisory Support for the GOES-R Program (ADEB)
Project 12--CIRA/RAMMB Administrative Support

PROJECT ACCOMPLISHMEMTS:

Project 1--Developing an Environmental Awareness Repertoire of ABI Imagery ('DEAR-ABII') to Advise the Operational Weather Forecaster

PROJECT OBJECTIVES:

The Himawari-8 Advanced Himawari Imagery (AHI) has provided a golden opportunity to develop multispectral and data-fusion imagery products tailored to an assortment of operational forecaster situational awareness needs in advance of GOES-R. Value-added applications such as Rayleigh-corrected true color, GeoColor (a data fusion product), fire temperature, 'blue-light' and background-reduced dust, snow/ice, and other enhancements have been crafted to provide context and a sanity check for the suite of quantitative (Level-2) products supported by the ABI. Several of these applications have followed the natural progression from polar-orbiting platforms (based on the MODerate-resolution Imaging Spectroradiometer (MODIS) leading into the Visible/Infrared Imaging Radiometer Suite (VIIRS).

This DEAR ABII project proposes to transition, further refine, and demonstrate through established Satellite Proving Ground channels these AHI-based imagery applications to first-light ABI data. The products will be made available to operational centers and National Weather Service (NWS) forecasters in the AWIPS-II display environment.

PROJECT ACCOMPLISHMENTS:

1--Develop, demonstrate, and refine true color product for ABI based on AHI-developed atmospheric correction, synthetic 510 nm green band, and hybrid-green adjustment.
2--Prepare ancillary datasets necessary for GeoColor and DEBRA.
3--Begin transition of VIIRS Cloud/Snow to ABI, Work with Satellite Liaisons and NWS forecasters on concepts for custom products.
4--Adapt heritage protocols for porting of imagery products to AWIPS/NAWIPS.
5--Initial products will be demonstrated on the web and in AWIPS/NAWIPS.

1--The synthetic, hybrid, atmospherically corrected (SHAC) true color product for ABI was used in the "first light" imagery and promotional materials by the GOES-R program office, as detailed in the previous annual report. We continue to refine the LUTs to improve the characterization of scenes that are not well represented within the AHI domain, such as in shallow water areas off the Bahamas, turbid river waters in South America and other minor issues. LUTs that include or exclude sun glint are in development. Additional details of this research activity are listed under Project 7: Support of GOES-R Imagery Team below, as this work applies to both projects. CIRA GOES-16 ABI True Color / GeoColor imagery is frequently being used on NESDIS/StAR home page, like on 28 August 2017 when Hurricane Harvey hit the Texas coast https://www.star.nesdis.noaa.gov/star/news2017_201708_HarveyGOES16.php as well as by NESDIS News & Articles, like in July 2017, when NESDIS chose to depict a GOES-16 GeoColor night imagery over Peru and Bolivia showing strong convection over those countries (http://campaign.r20.constantcontact.com/render?m=1120935055224&ca=20c24bba-5635-491e-84c5-b95a90511f79)

The CIRA GeoColor gets frequently feedback from NWS WFO forecasters who think very highly of the GeoColor product. On 14 September 2017, Bryan Ruby, Information Technology Officer at the NWS WFO Sioux Fall, South Dakota, summarized his experience with using GeoColor in the following tweet: "@CIRA_CSU NOAA GOES-16 Geocolor (CIRA) in AWIPS II is freaking awesome"

GOES-16 GeoColor imagery is also frequently used by NWS forecasters to highlight smoke events. During a heavy wildfire smoke event over the western part of the USA on 4 September 2017, NWS WFO

Boulder forecaster David Barjenbruch generated a set of slides with GOES-16 GeoColor imagery clearly showing the smoke plumes over Colorado.

GOES-16 GeoColor has proven to also be really great for dust detection over the Atlantic. On 17 October 2017, it depicted a big dust layer moving its way across the Atlantic today. Once GOES-16 moved to GOES-E the perspective got even much better.

Since September 2017, GOES-16 GeoColor imagery is being provided to Science on a Sphere (SoS) in real time.

CIRA's Fire Temperature RGB was first developed at CIRA for VIIRS and has since been applied to ABI with much positive feedback from the user community. Perhaps, it could be said to have "spread like wildfire". CIRA and SPoRT have also collaborated with Chad Gravelle (OPG) to make the Fire Temperature RGB one of the standard RGBs in AWIPS. GOES-16 GeoColor and Fire Temperature products have also become very popular for wildland firefighters who use it imagery for tracking fires. The imagery can be frequently found on the firefighter forum page at http://hotlist.wildlandfire.com/.

The first SHAC true color/Geocolor image from GOES-16 in its new position at 75.2 °W was created on 12 December 2017, 2000 UTC (Figure 1). LUTs that include or exclude sun glint are in development.

Figure 1. The first SHAC true color/Geocolor image from GOES-16 in its new position at 75.2 °W (2000 UTC, 12 December 2017).

2--Ancillary data sets for the atmospheric correction, viewing geometry, surface elevation, nighttime lights, land/water masking and scene classification for use in the true color and GeoColor imagery have been developed for both the GOES-R/S checkout location (95 °W longitude) and the operational GOES-East location (75.2 °W longitude). We are in the process of creating cloud-cleared backgrounds for use in DEBRA. An example can be found in Figure 2 below.

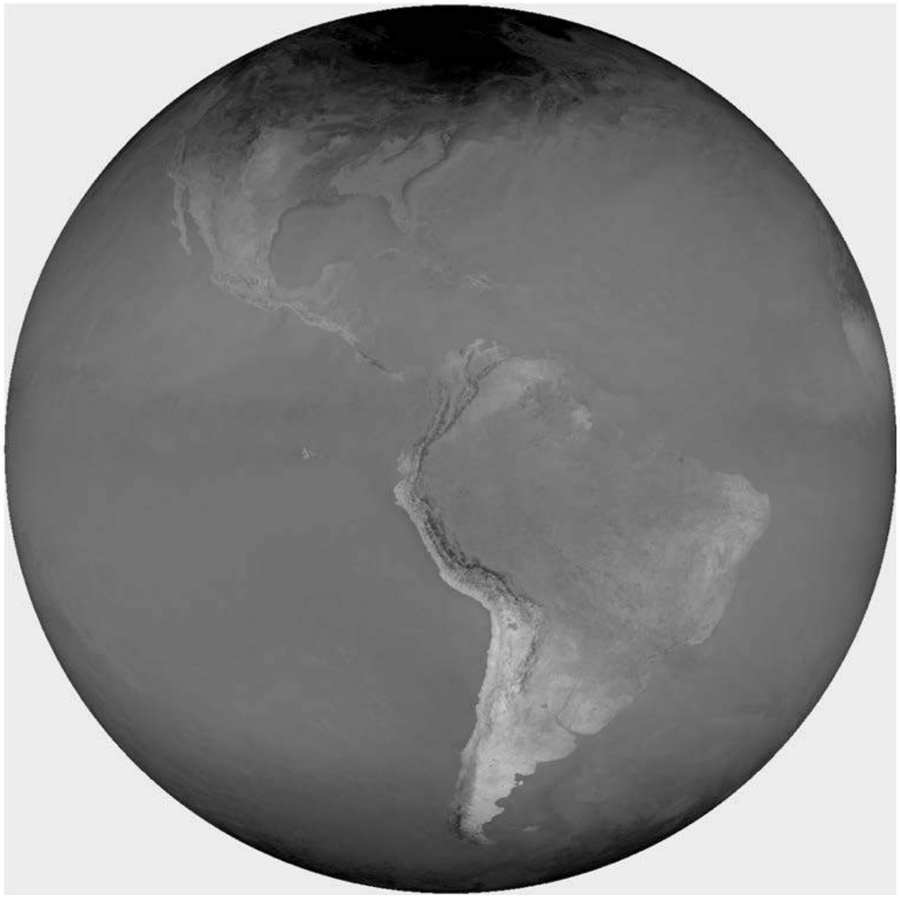


Figure 2. 11µm IR cloud-cleared image from the ABI for 1730UTC on 21 January 2018.

3--Two versions of the daytime VIIRS Cloud/Snow Discriminator algorithm have been developed for ABI: a "binary" discriminator that highlights all clouds in yellow and snow and ice in white, and a "high/low" discriminator that colors clouds by height, with yellow low clouds, orange mid-level clouds, and magenta high clouds (Figure 3).

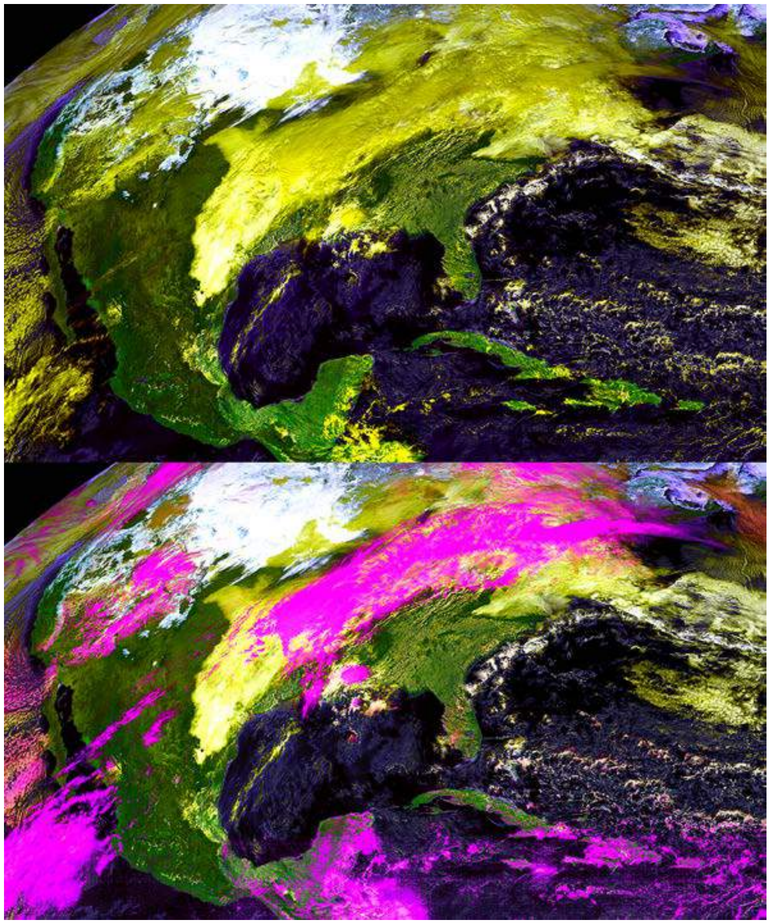


Figure 3. The Cloud/Snow Discriminator in "binary" (top) and "high/low" (bottom) versions for the GOES-16 CONUS domain (18:17 UTC 23 February 2018).

4--GeoColor is currently being provided to forecasters in AWIPS/NAWIPS and is used heavily by NWS WFOs and National Centers. We are in the initial stages of adapting this protocol for porting the Cloud/Snow Discriminator and DEBRA imagery products to AWIPS/NAWIPS. This task is expected to be completed by June 2018. The Fire Temperature RGB was easily added to AWIPS through the "on-the-fly" RGB module developed at NASA SPoRT, and all NWS WFOs throughout CONUS have access to it. This "simple" RGB is created from the operational GOES data feed and, as such, is not delivered through the LDM.

5--True color/GeoColor imagery is available on the RAMMB SLIDER website (http://rammb-slider.cira.colostate.edu). This algorithm has been provided to NOAA/NESDIS/StAR where it is running in real-time. In addition, GeoColor is available in AWIPS and NAWIPS as mentioned above. The Cloud/Snow Discriminator and suite of RGB composites (including recipes from EUMETSAT as well as CIRA) are available on the SLIDER website. DEBRA is expected to be available on SLIDER and the LDM for AWIPS/NAWIPS users by June 2018.

Special Achievements:

CO-LABS Governor's Award for High-Impact Research: The Colorado Laboratories (CO-LABS) 2017 Governor's Award for High-Impact Research ceremony was held at the Denver Museum of Nature and Science on the evening of 5 October 2017. S. Miller, D. Lindsey and C. Seaman were one of four Colorado-based research teams recognized for "projects having a significant impact on society" as a result of research performed as part of this project. Video of the event has been posted on the CO-LABS website (http://co-labs.org/news/2017-governor-s-awards) and a video highlighting the research performed by the team has also been posted on YouTube (https://www.youtube.com/watch?v=pb4CFMRceMk).

Steve Miller and Curtis Seaman won the 2017 CIRA Research and Service Initiative Award: For "Outstanding contributions to scientific research: True-Color Imagery from GOES-16". (July 2017).

Steve Miller and Dan Lindsey were part of a large team recognized for the 2017 NASA Honor Award - GOES-R Team Group Achievement Award: For "Excellence resulting in the successful GOES-R satellite launch, providing the nation's foundation for the world's highest quality weather monitoring and forecasting."

CIRA/RAMMB worked with writers from the New York Times to provide customized GOES-16 GeoColor imagery covering the time frame 5-11 September 2017 showing three simultaneous hurricanes in the Atlantic basin, including Hurricane Irma. The story was on the front page of their website on the morning of 12 September and can be viewed here: https://www.nytimes.com/interactive/2017/09/12/us/hurricane-irma-satellite-images.html

GOES-16 ABI captured the total solar eclipse that crossed the contiguous U.S. on 21 August 2017. It is important to note that non-trivial modifications had to be made to the Rayleigh-correction used in CIRA's synthetic true color imagery to account for the loss of radiation within the eclipse shadow, providing the best view of the eclipse from any satellite (Figure 4).

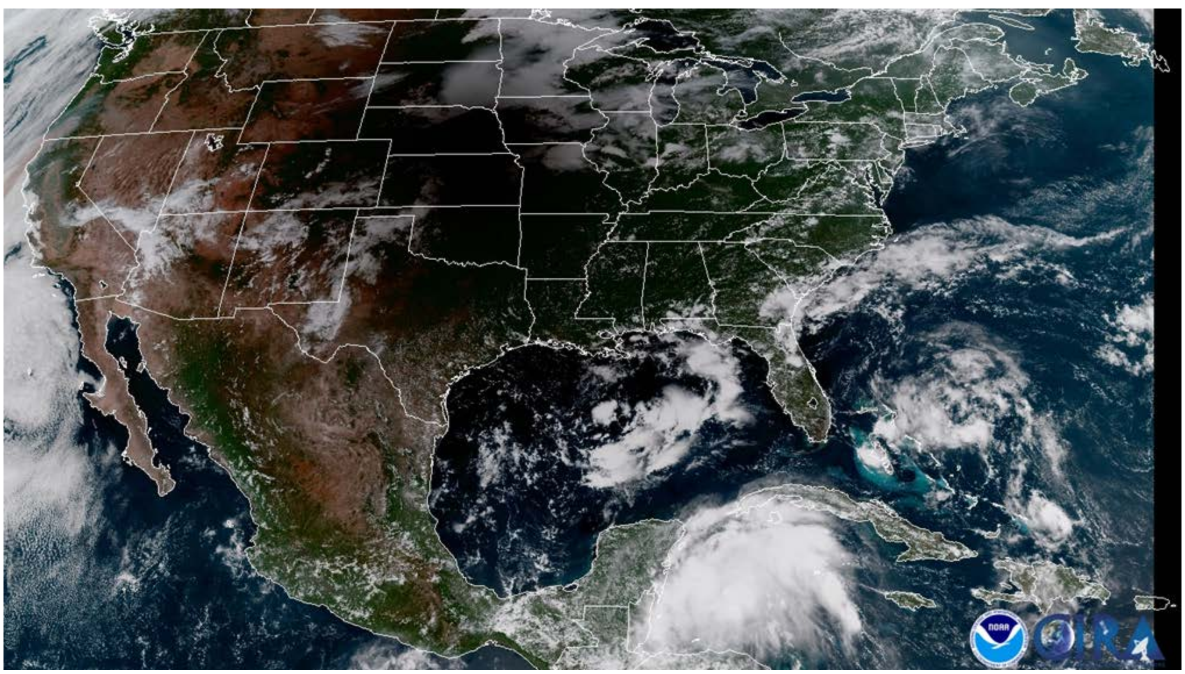


Figure 4. GOES-16 ABI captured the total solar eclipse: CIRA/RAMMB's GOES-16 Geocolor product from 1802 UTC on 21 August 2017, when the moon's shadow covered the central U.S.

Ancillary data from NASA, which predicted the solar obscuration as a function of space and time, was leveraged to adjust the magnitude of the Rayleigh corrections (which assume full-sun). This imagery was used by numerous media outlets and a special website was created highlighting this imagery at CIRA: http://rammb.cira.colostate.edu/misc/solar_eclipse_2017/

The GOES-R Program Office was provided the modified synthetic true color imagery in real-time, along with several animations and/or videos that were widely shared on traditional and social media outlets.

Steve Miller and Dan Lindsey were interviewed by the media about this imagery, and it provided great fodder for our GOES-16 Loop of the Day website:
http://rammb.cira.colostate.edu/ramsdis/online/loop.asp?data_folder=loop_of_the_day/goes-16/20170821000000&number_of_images_to_display=200&loop_speed_ms=100

The CIRA GeoColor solar eclipse imagery (full disk animation) made it onto the NESDIS/StAR home page (on 21 August 2018). NESDIS/StAR gave the CIRA GeoColor team very special credit in the figure caption of this imagery: “The animation was generated from GOES-16 imagery by the StAR GOES imagery team using the award-winning work of the CIRA-RAMMB team to output full color images.”

Feedback from the GOES-R Program Office was very positive:
“Dan, Curtis, and everyone . . . what an incredible eclipse day! Thank you so much for your hard work to bring these images to the public. The traffic on our sites is unbelievable--I think people are really inspired to see these images.
My sincere thanks,” -Renata Lana (renata.lana@noaa.gov)

“I second that, Renata! This is team work at its best! Excellent job!” -John Leslie (john.leslie@noaa.gov)

Media outlets that shared our ABI eclipse imagery include:
Time Magazine: http://time.com/4909517/total-solar-eclipse-moon-shadow-video/
The Huffington Post: http://www.huffingtonpost.com/entry/total-solar-eclipse_us_599b157fe4b06a788a2ab10a
The Denver Channel (Denver ABC affiliate): http://www.thedenverchannel.com/news/eclipse/icymi-the-moment-the-moon-eclipsed-the-sun
9News (Denver NBC affiliate): http://www.9news.com/news/eclipse/cool-videos-from-scientists-at-csu-track-eclipse-shadow/466536683
NBC26 (Green Bay NBC affiliate): http://www.nbc26.com/news/eclipse/icymi-the-moment-the-moon-eclipsed-the-sun

Other Media Coverage:

Discover Magazine: An article appeared in Discover Magazine on 21 July 2017 highlighting GOES-16 imagery created at RAMMB/CIRA: http://blogs.discovermagazine.com/imageo/2017/07/21/amazing-goes-16-satellite-sees-blaze-and-smoke-of-detwiler-fire/#.WXJv7ojytaQ The animation they highlight was created using a combination of the Fire Temperature RGB and the Geocolor product, both conceived and produced at CIRA.

Discover Magazine (blog): Both CIRA and CIMSS tropical cyclone products and loops were highlighted in a Discover Magazine blog posting entitled “Images from space reveal the beauty and potentially deadly nature of Typhoon Noru, Earth’s strongest storm of 2017.” -August 2, 2017. The link is http://blogs.discovermagazine.com/imageo/2017/08/02/images-from-space-reveal-beauty-and-deadly-nature-of-typhoon-noru/#.WYNkMYjyuM8.

Discover Magazine Article on Northwest U.S. Smoke: Another article in Discover Magazine (2 Aug 2017) used CIRA/RAMMB imagery, this one highlighting the extensive smoke from wildfires in the Pacific Northwest: http://blogs.discovermagazine.com/imageo/2017/08/02/northwest-bakes-in-heat-wave-and-chokes-on-thick-wildfire-smoke/#.WYNmuojytaR

Washington Post (25 August, 28 August, 31 August, 2 September 2017):
Washington Post showing GeoColor imagery of Hurricane Harvey:
https://www.washingtonpost.com/national/2017/live-updates/weather/hurricane-harvey-updates-preparation-evacuations-forecast-storm-latest/watch-hurricane-harveys-eye-spin-toward-the-texas-coast/?utm_term=.2b1c66a75046

Washington Post using SLIDER/GeoColor imagery to cover Hurricane Irma in the Atlantic: https://www.washingtonpost.com/news/capital-weather-gang/wp/2017/08/31/two-new-tropical-threats-are-taking-shape-in-the-gulf-of-mexico-and-atlantic-ocean/?utm_term=.17b34cba62a7
https://www.washingtonpost.com/amphtml/news/capital-weather-gang/wp/2017/09/02/hurricane-irma-remains-a-potential-u-s-threat-expected-to-become-a-category-4-in-days-ahead/

International media "The Australian" displays GOES-16 GeoColor imagery of Hurricane Irma http://www.theaustralian.com.au/video/id-5348771529001-5563537033001/Hurricane-Irma-s-Path-Still-a-Question-Mark--Credit---CIRA-RAMMB-NOAA-via-Storyful

CIRA's GeoColor and Fire Temperature RGB products shown by 9News: On 4 September 2017 at the evening news, the Colorado TV station 9News (NBC) covered Colorado's strong smoke/haze event. They showed CIRA's GOES-16 GeoColor and Fire Temperature RGB imagery to explain how smoke from fires burning in western Montana, Idaho, Washington, Oregon, and California was drifting towards the Northern Colorado Foothills. 9News also put an article with the CIRA imagery onto their webpage at http://www.9news.com/weather/weather-colorado/special-satellite-filter-pinpoints-source-of-front-range-haze/470771650 .

CIRA GeoColor Featured on Front Page of New York Times Website: CIRA/RAMMB worked with writers from the New York Times to provide customized GOES-16 GeoColor imagery covering the time frame 5-11 September 2017 showing three simultaneous hurricanes in the Atlantic basin, including Hurricane Irma. The story was on the front page of their website on the morning of 12 September 2017 and can be viewed here: https://www.nytimes.com/interactive/2017/09/12/us/hurricane-irma-satellite-images.html

New York Times (29 September 2017): GeoColor of Hurricane Maria making landfall on Puerto Rico. https://www.nytimes.com/interactive/2017/09/18/world/americas/100000005438629.app.html

CIRA GeoColor Imagery Featured on Front Page of The Atlantic webpage: The Atlantic magazine webpage featured a CIRA GeoColor image on their front page (12 September 2017) with an article about "An extraordinary week of hurricanes in North America". https://www.theatlantic.com/science/archive/2017/09/an-extraordinary-week-in-north-american-weather/539544/ .

New York Times Article: RAMMB/CIRA again provided GOES-16 GeoColor and Fire Temperature RGB graphics to the New York Times on 16 September 2017. Using the imagery, they put together a multi-day animation over the Northwest U.S. showing many active wildfires. A sample image from the animation is below, and the article can be found here: https://www.nytimes.com/interactive/2017/09/16/us/wildfires-smoke-pacific-northwest.html

New York Times Article: RAMMB/CIRA provided GOES-16 GeoColor imagery to the New York Times on 18 September 2017 for use in a story on Hurricane Maria making landfall on Puerto Rico. A screen capture from the animation is below, and the loop and story can be found here: https://www.nytimes.com/interactive/2017/09/18/world/americas/100000005438629.app.html

GOES-16 Natural Fire Color Imagery on The Today Show: Al Roker showed examples of the "Natural Fire Color" RGB from GOES-16 on The Today Show, Tuesday, 10 October 2017 (Figure 11). This was during a discussion of the devastating wildfires in the Napa Valley region of California. The Natural Fire Color RGB was developed at CIRA for both VIIRS and GOES-R ABI, and uses information from the visible (0.64 μm, blue), near-IR vegetation band (0.86 μm, green) and mid-wave IR (3.9 μm, red) for fire monitoring. The 3.9 μm band is sensitive to active hot spots, the 0.86 μm band is sensitive to vegetation health and burn scars, and the 0.64 μm band is sensitive to smoke. Natural Fire Color imagery is produced in real-time on CIRA's SLIDER web display tool (http://rammb-slider.cira.colostate.edu), which is where the show acquired the images after one of the producers contacted us to request permission.

Interviews on California Wildfires: D. Lindsey did two interviews on 10 October 2017 about the wildfires affecting the Napa Valley region of California. One was for SFGATE, a news organization out of San Francisco; the story is posted here: http://www.sfgate.com/news/article/California-fires-NOAA-GOES-16-

Satellite-imagery-12266587.php The second was a radio interview for KCBS, an all-news radio station out of San Francisco.

Weather Channel using CIRA GeoColor Imagery: The 'Weather Channel' utilized CIRA's GeoColor imagery in a posting about a powerful storm which intensified rapidly before striking Alaska's Aleutian Islands on 24 November 2017. https://weather.com/news/news/2017-11-26-powerful-alaska-aleutian-storm

Project 2--Improving the ABI Cloud Layers Product for Multiple Layer Cloud Systems and Aviation Forecast Applications

PROJECT OBJECTIVES:

This project seeks to improve the classification and categorization of multilayer cloud scenes by the GOES-16 ABI, while simultaneously improving the Cloud Cover Layers product that identifies the height category of clouds in any given ABI pixel. The general methodology is threefold: (1) To investigate the usefulness of certain cloud proxies, such as layer relative humidity, by training on actively-sensed cloud layer boundaries; (2) To develop a new multispectral retrieval that uses ABI radiances to determine separation between cloud layers in known multilayer situations; and (3) To fuse this information together with our own statistical cloud base algorithm, which has been trained on radar and lidar-observed cloud boundaries.

PROJECT ACCOMPLISHMENTS:

We are well on-track towards meeting our FY17 milestones. The milestones that we have actively addressed in the July to December 2017 reporting period are discussed below.

1--Begin translational work to bring statistical cloud base algorithm from the world of VIIRS and AHI into the ABI framework.

Our statistical cloud base algorithm was originally developed and implemented for VIIRS and Himawari-8/9 AHI; in this reporting period, we have applied the algorithm for the first time to GOES-16 data. This expanded algorithm represents an extension to the Cloud Cover Layers product that allows three additional cloud height categories: High+Mid and Mid+Low, and High+Mid+Low. Changes have been submitted for evaluation and eventual incorporation into the NOAA Enterprise Algorithms. We have made this data available publically available in near real-time via the CIRA SLIDER tool (http://rammb-slider.cira.colostate.edu).

Our current and future work will build on these changes to better handle multilayer cloud situations.

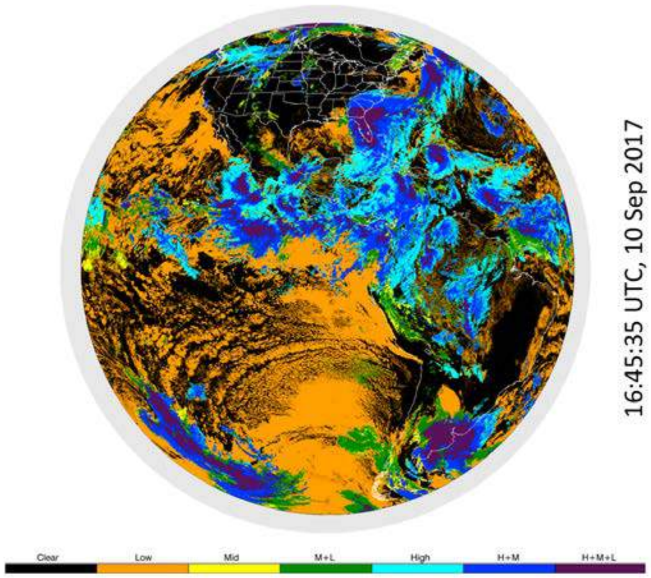


Figure 5. The improved Cloud Cover Layers product as displayed in CIRA's SLIDER tool. The product features three additional cloud height categories, High+Mid and Mid+Low, and High+Mid+Low.

2--Collect six years of CloudSat and CALIPSO cloud mask data, and co-located relative humidity data from NWP analysis

We have collected all applicable CloudSat revision 4 products, including the joint CALIPSO lidar cloud mask data. (Revision 5 products are currently being produced by the CloudSat team, and will offer an improved cloud mask. We will obtain this data when it is available.)

For our initial numerical weather prediction (NWP) analyses, we have collected ECMWF operational forecast data, as it is already co-located within the CloudSat footprint. (Our improved GOES algorithm will ultimately likely use either NAM or GFS data.)

We have developed code that collocates CloudSat and CALIPSO within the GOES-16 field of view. Our initial analyses (Figure 5) of collated radar reflectivity profiles and GOES-16 (NOAA Enterprise Algorithm) retrievals of cloud type has shown that multilayer cloud occurs in many of the GOES-16 cloud type categories, but is most common in the overlapping, opaque ice, cirrus, and overshooting categories. Characterization of the cloud types of GOES-16 observations that are most likely to contain multiple cloud layers is invaluable in our current work to quantify the boundaries of these clouds using GOES-16 measurements together with active-sensor based training data.

3--Build database of actively sensed cloud occurrence and corresponding probability of hydrometeor presence; determine best ways to segregate the data.

We have begun performing analysis of collocated actively-sensed cloud boundaries from CloudSat and CALIPSO with cloud layer relative humidity (RH) from NWP. We are segregating the data by season and region to determine the utility of RH as a predictor of cloud occurrence in situations where GOES retrievals are problematic (e.g. multilayer scenes). Contingency-table type analysis reveals that RH does have predictive skill, but only in certain regimes. In particular, skill in mid-latitudes is much higher than in the tropics, which is encouraging for use over the continental U.S. (In the tropics, where RH is consistently higher, other variables like vertical motion are key in identifying cloudy scenes.) We continue to update and analyze these results.

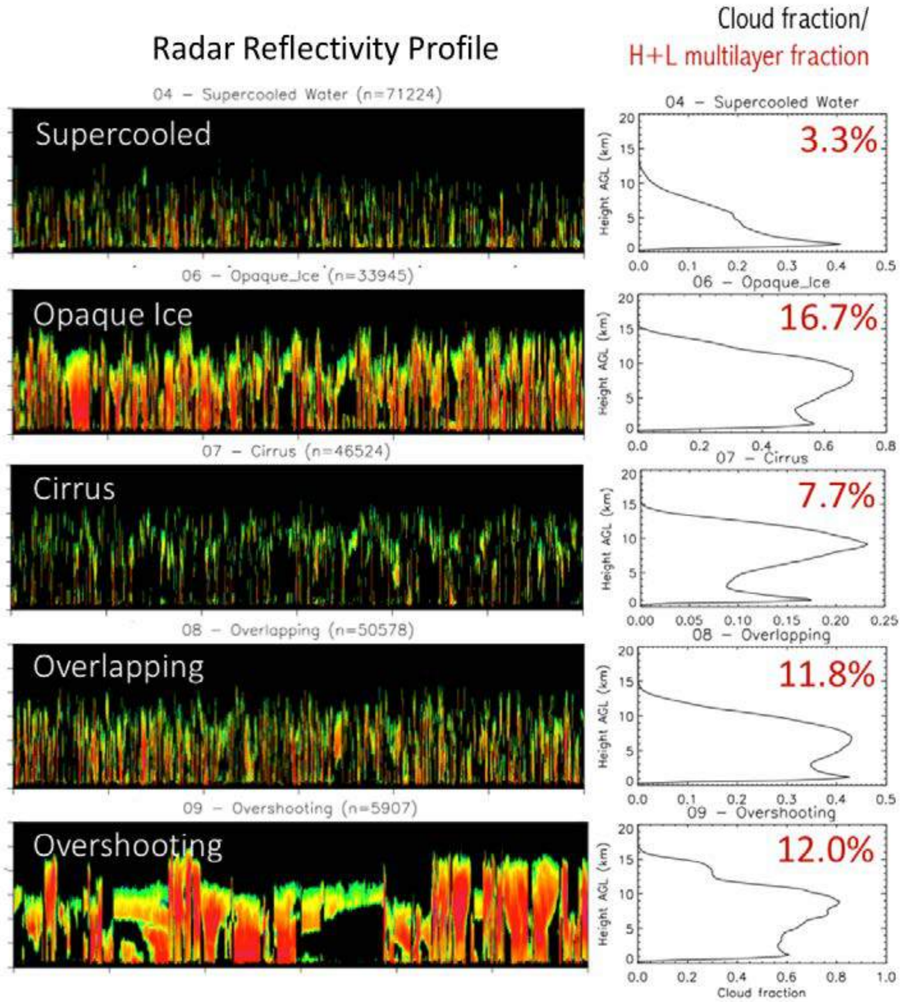


Figure 6. Left panels show co-located radar reflectivity as a function of five different GOES-16 (CLAVR-X) cloud types. Right panels show the radar-derived cloud fraction within each of these categories. Red numbers are a metric representing the fraction of GOES pixels containing high cloud separated from low cloud in the same column.

<u>Project 3--Using the New Capabilities of GOES-R to Improve Blended, Multisensor Water Vapor Products for Forecasters</u>

PROJECT OBJECTIVES:

The GOES-R series of spacecraft provide much increased spatial and temporal resolution for the retrieval of total precipitable water (TPW) over the previous data available from the GOES Sounder. GOES-R retrieves TPW every 15 minute over the full disk, while the previous GOES Sounder imaged a limited sector near CONUS every hour. This project is investigating how the increased temporal and spatial resolution of GOES-R can be used to improve the usefulness of blended water vapor products for forecasters. The GOES-R TPW and layer precipitable water (LPW) products will be characterized with respect to other polar orbiting and surface-based sensors for blended analysis products for forecasters. GOES-R TPW retrievals will be merged into the existing multisensor blended TPW product at CIRA, which is a shadow version of the NOAA operational blended TPW product. The increased spatial and temporal coverage of GOES-R is expected to have a positive impact as compared to the previous GOES Sounder, and require modifications to the blending approach to fully utilize the new capabilities. New cloud-free GOES-R water vapor channel imagery will be derived from the passive microwave water vapor sounding product. At project completion, a new blended TPW product version is expected which leveraged GOES-R to help forecasters.

PROJECT ACCOMPLISHMENTS:

This project began in July 2017. Initial progress involved receiving the GOES-R TPW products in near-real-time from the NOAA ESPC Product Distribution and Access (PDA) system. GOES-R CONUS Level 2 TPW retrievals are now flowing into CIRA every 5 minutes.

A near-real-time website, http://cat.cira.colostate.edu/ABI_TPW/ABI_TPW.htm, has been created using the CIRA ingest to animate the remapped CONUS sector TPW. A major achievement this reporting period was to read and remap GOES-16 TPW data with the CIRA Data Processing and Error Analysis (DPEAS) system. DPEAS is a critical link to future R2O success as it is also the operational system running at NESDIS OSPO which produces operational blended TPW. In other words, the research system used in this project is also the target operational system for future operational transitions. Initial inspection of the animations indicates that the product appears to be of high quality, without evidence of cloud-contaminated retrievals.

In order to use GOES-R TPW in the blended TPW product, it must be characterized with respect to the other sensors. In blended TPW, these are passive microwave retrievals from polar orbiting spacecraft using the NOAA Microwave integrated Retrieval System (MiRS) and surface-based Global Positioning System (GPS) TPW retrievals. Since GOES-R TPW is flowing through the same DPEAS system used to process these datasets, near-real-time comparisons are possible. A comparison with a Suomi-NPP overpass is shown in Figure 7, and a comparison against surface-based GPS TPW is shown in Figure 8.

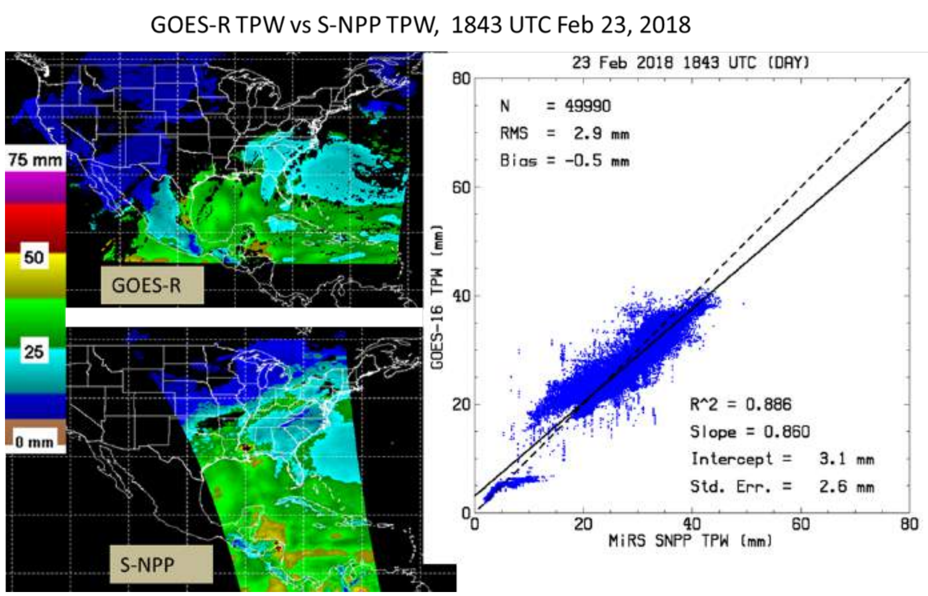


Figure 7. GOES-16 CONUS sector TPW vs Suomi-NPP TPW at the same time on 23 Feb. 2018.

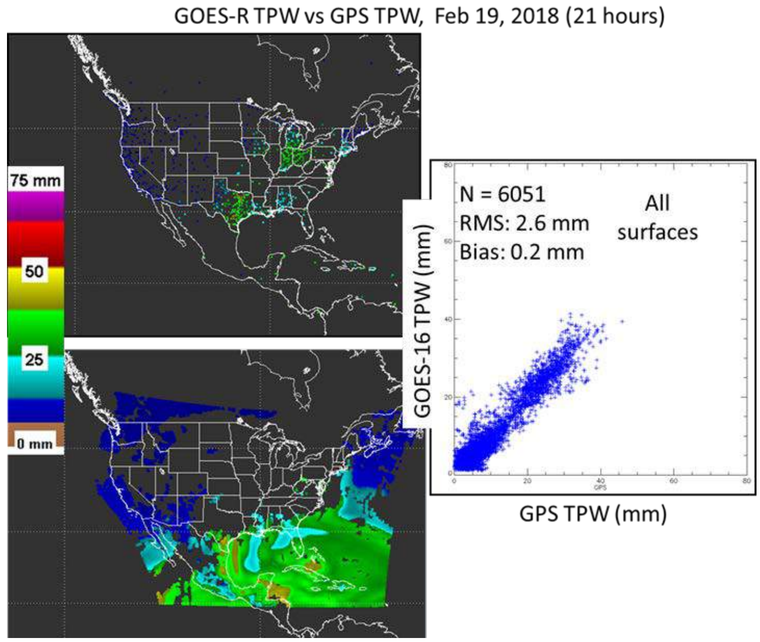


Figure 8**.** Results of a 21-hour matchup between GOES-16 and GPS stations for Feb. 19. 2018. An example of GPS GOES-R TPW is shown, as well as the scatter plot from the 6051 matchups.

Project 4--GOES-R ABI Channel Differencing Used to Reveal Cloud-free Zones of 'Precursors of Convective Initiation'

PROJECT OBJECTIVES:

Introduction: Previous GOES-R funding has been used to allow CIRA to generate real-time synthetic GOES-R ABI imagery. A cooperative effort was established between CIRA and NSSL whereby 4 km NSSL WRF-ARW data is sent to CIRA. Synthetic GOES-R ABI imagery was generated within the CONUS domain of the NSSL WRF-ARW forecasts. Imagery for several ABI bands were produced, and the difference between 10.35 µm band 13 and 12.3 µm band 15 was found to be associated with cloud-free zones of 'precursors of convective initiation'. This project will apply these findings to real GOES-R data and make the product displayable in the NWS AWIPS operational display system.

Project Description: In order for forecasters to benefit from the 10.35-12.3 µm difference and to identify cloud-free zones of low-level water vapor pooling, CIRA plans on utilizing observed GOES-16 ABI data that will pass through the Satellite Broadcast Network (SBN) to AWIPS-2 workstations. In AWIPS-2, the D2D perspective has the ability to create 10.35-12.3 differences, assuming that the 16.4.1 Redhat Package Manager (RPM) or later has been downloaded and installed from the NWS Virtual Lab. The first task will be to test this difference in AWIPS-2 and make any necessary changes to the .xml file, including changes to the upper and lower bounds of the difference values. In addition, CIRA will create appropriate color tables—keeping in mind those with visual challenges—and deliver the potentially modified AWIPS-2 .xml file and new color tables to the NWS Virtual Lab for inclusion in a future RPM release. This is the method currently being used to supply changes to operational AWIPS-2 machines throughout the NWS until the AWIPS-2 freeze ends. We will also make the appropriate modifications in NAWIPS so that the SPC and other National Centers will be able to view and evaluate the product (NAWIPS will continue to be used by the National Centers in operations for at least another year before they transition to the National Centers Perspective of AWIPS-2). In addition, the Virtual Institute for Satellite Integration Training (VISIT) program will be leveraged by developing training modules in FY17 on 10.35-12.3 µm imagery. In order to develop statistics, CIRA will collect ABI imagery for the 2017 and 2018 convective seasons. At times, 18-19 UTC special soundings are launched to support NWS forecasters during severe weather events. CIRA will also collect these soundings for the purpose of complementing the channel difference data. One important component of the work contained in this proposal are the annual visits to the Hazardous Weather Testbed Spring Experiment in Norman, OK, to help the participating operational forecasters, from SPC, Aviation Weather Center (AWC), and WFOs in the interpretation of 10.35-12.3 µm imagery.

Similar to low-level precipitable water retrieval of Chesters, et al. (1983), a three-channel product, bands 13, 14, and 15, which utilizes a single-layer approximation to the radiative transfer equation, will be used to retrieve values of Boundary layer Precipitable Water (BPW). Chesters, et al. (1983) used two infrared channels and required an approximation to the low-level air temperature. The addition of a third channel in the BPW retrieval eliminates the need for such an approximation. In addition, no NWP forecast profiles of temperature and water vapor are required for BPW, unlike the GOES-R Total Precipitable Water (TPW) baseline product. Since the weighting function of each of the three bands peaks in the boundary layer, and their differences are due primarily to low-level water vapor, retrieved values of BPW would be related to values of Convective Available Potential Energy (CAPE), which is available during convective initiation. The TPW GOES-R Baseline Product makes use of additional IR bands and forecast profiles of temperature and water vapor, but for the application in this proposal we are only interested in the BPW due to the relationship between CAPE and convective morphology. Retrieving BPW is a more quantitative approach than the 10.35-12.3 µm difference alone, and will potentially set the stage for the information to be assimilated into NWP models sometime in the future. Initial testing of BPW will begin in FY17 with observed GOES-R data followed by any necessary improvements in FY18-19.

PROJECT ACCOMPLISHMENTS:

1--Configure AWIPS-2 and NAWIPS to display the GOES-R 10.35-12.3 µm ABI channel difference, create appropriate color tables, and deliver the AWIPS-2 information to the NWS Virtual Lab for inclusion in a subsequent Red Hat Package Manager (RPM).

ABI data is displayed on AWIPS-II display systems for NWS forecasters; a color table has been developed to display the difference in brightness temperatures between 10.35 and 12.3 um.

2--Train forecasters on the interpretation of the GOES-R 10.35-12.3 µm ABI channel difference.

A training webinar has been developed on this subject under the VISIT program and delivered to NWS forecasters.

3--Evaluate BPW from soundings and ABI (10.35, 11.2, and 12.3µm) associated with cloud-free zones of 'precursors of convective initiation'.

Pending

4--Collect ABI imagery for case studies and 18 UTC special soundings when available.

Due to the shift between the project start time and the 2017 convective season, cases from non-operational GOES-R ABI of the following select cases have been collected:

15 June 2017 – northwest Kansas (Figure 9),

29 April 2017 – western Bangladesh / eastern India,

16 May 2017 – Texas panhandle,

14 April 2017 – eastern Colorado,

30 June 2017 – undular bore in northwest Texas,

13 April 2017 – western Bangladesh / eastern India

5--Visit the HWT/SPC for product demonstration and collaboration.
Pending

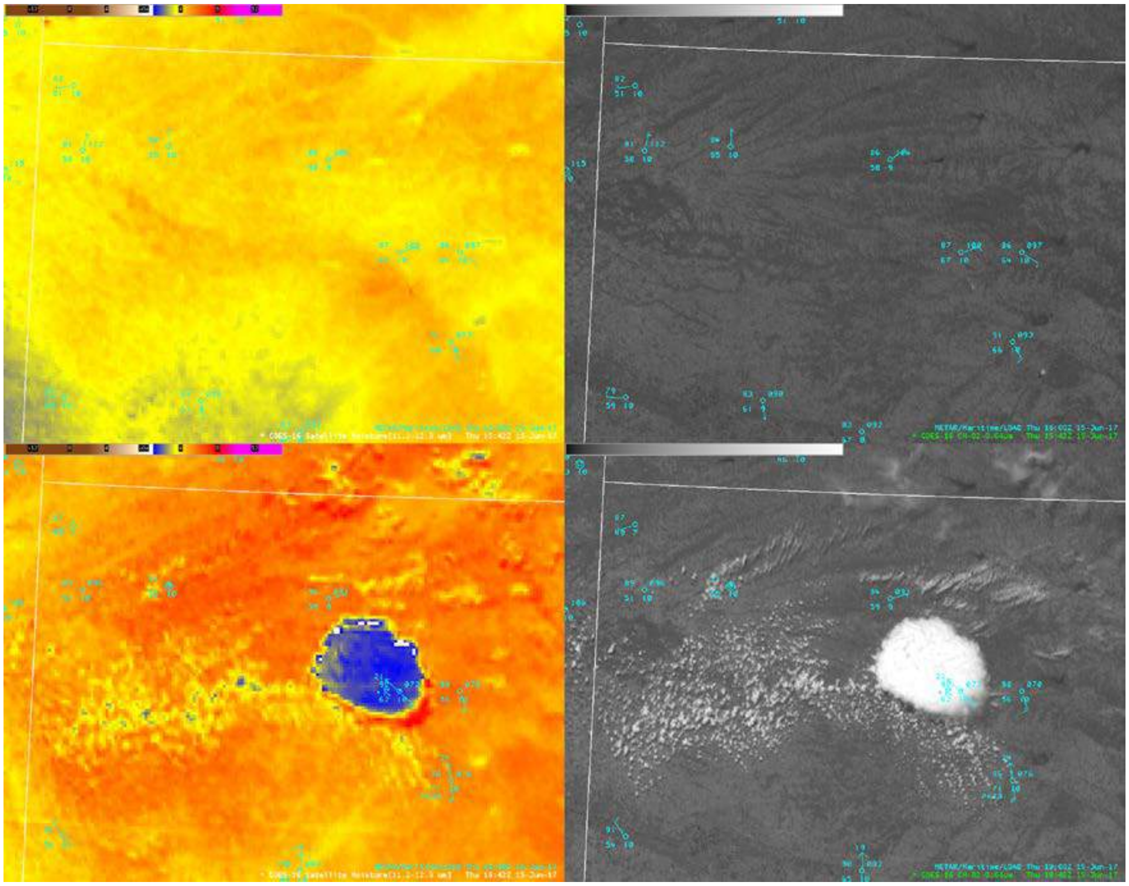


Figure 9. Non-operational G0ES-R Tb(10.35)-Tb(12.3) and 0.64 µm imagery over northwest Kansas on 15 June 2017. Imagery at 15:42 UTC exhibited a pinwheel shaped local maximum of values of the channel difference (upper left) along with clear skies at 0.64 µm (upper right). At 18:42 UTC imagery contains convection in the channel difference (lower left) and in 0.64 µm (lower right).

Project 5--ProbSevere: Upgrades and Adaptation to Offshore Thunderstorms

PROJECT OBJECTIVES:

In this new project, CIRA will continue working with CIMSS on the ProbSevere algorithm. The new focus is on locating the best predictors for large hail. Feedback from previous Hazardous Weather Testbed experiments from forecasters included that they would like a version of ProbSevere for each severe weather hazard (hail, wind, tornadoes). A second focus of the project is to create a version that will work in offshore regions. Given the lack NEXRAD data there, the near storm environment predictors are even more important, so CIRA will use its expertise in this area to assist the ProbSevere developers in selecting the best predictors to maximize verification statistics.

At the direction of the project PI (Mike Pavolonis, NOAA/NESDIS), the work involving the identification of storm environment predictors for large hail was changed to researching the ProbSevere predictor storm relative environmental helicity (SREH). CIRA investigated whether it is better to use a value of SREH computed from the observed storm motion in conjunction with vertical wind profiles from the Rapid Refresh Model (RAP), or the SREH given directly from the RAP, which uses an assumed storm motion.

Research Conducted during the first year:

1--Identify a set of near storm environment predictors for large hail for the CONUS version of ProbSevere.
2--Provide the hail predictors to the developers and help to incorporate them into the real-time version of the CONUS algorithm.
3--Use statistical techniques to investigate the best near storm environment predictors for the new offshore version of ProbSevere.

1,2--Using a thunderstorm near Dimmitt, TX on 14 April 2017, four versions of SREH were compared:
--SREH as computed by the RAP.
--SREH computed from actual storm motion and RAP 10-m wind and 0-1 km wind shear.
--SREH computed from actual storm motion and RAP 80-m wind and 0-1 km wind shear.
--SREH computed from actual storm motion and Real Time Mesoscale Analysis (RTMA) surface wind and RAP 0-1 km wind shear.

These four values of SREH were compared to the SREH calculated from the actual storm motion and the vertical wind profile taken from the nearby radiosonde at Amarillo, TX. There was a special 2100 UTC launch on 14 April in addition to the regularly scheduled 0000 UTC launch on 15 April. The results are given in the following table of SREH (m^2s^{-2}):

Launch	Method 1	Method 2	Method 3	Method 4	Radiosonde
21Z	78	50	68	54	89
00Z	122	95	124	24	105

The results were not quite as expected. It was assumed that using the actual storm motion would produce better SREH values compared to the radiosonde "truth" than the RAP SREH field. While Method 3 (RAP 80-m wind and 0-1 km wind shear) was close, the RAP values (Method 1) were closer to the values computed using the radiosonde wind profiles.

Several issues must be considered when interpreting the results however, including:

--The RAP uses a storm motion of the right-mover from the method of Bunkers et al. (2000). This method is quite accurate for right moving storms.
--There are only two matchups. Finding enough matchups to generate accurate statistics may be untenable. Small scale effects such as outflow boundaries may go undetected, and the radiosonde station "truth" may be some distance away from the storm (in both space and time). See Figure 10 below.
--The approximation to the SREH calculation, necessary because of the lack of vertical resolution in the AWIPS RAP wind field, may not be of sufficient accuracy.
--The estimation of the actual storm motion in this case was not as accurate as would be used in the actual real-time running of ProbSevere.

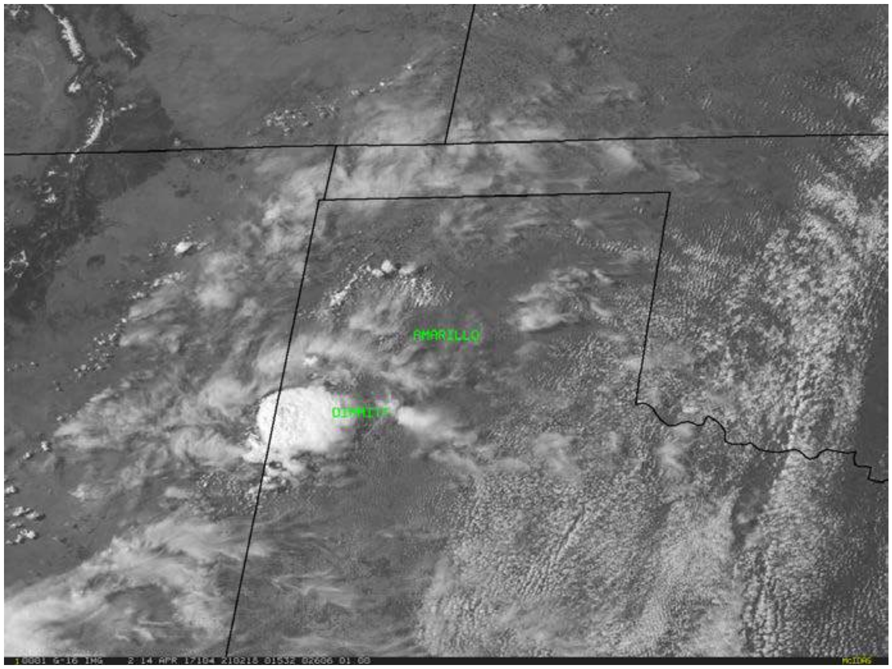


Figure 10. GOES-16 visible image from 2102 UTC 14 April 2017 showing the nascent thunderstorm and the locations of Dimmitt and Amarillo. The differing cloud fields demonstrate the small-scale influences on convectively active days.

References:

Bunkers, M. J., B. A. Klimowski, J. W. Zeitler, R. L. Thompson, and M. L. Weisman, 2000: Predicting supercell motion using a new hodograph technique. Wea. Forecasting, 15, 61-79.

3--The data set for use with the offshore version of ProbSevere is still under development. CIRA's task of looking for the best environmental predictors will commence once the data set is complete.

Project 6--Data Assimilation of GLM Observations in HWRF/GSI System

PROJECT OBJECTIVES:

In this research we exploit the unique capabilities of the Geostationary Lightning Mapper (GLM) instrument through data assimilation with the NOAA Hurricane WRF operational system. We will add the GLM assimilation capability to the HWRF data assimilation system, which is based on the hybrid Gridpoint Statistical Interpolation (GSI) algorithm. This project is a collaboration between Avichal Mehra of NOAA/NCEP/EMC and his colleagues, Mark DeMaria of NOAA/NCEP/HRC, and the Cooperative Institute for Research in the Atmosphere (CIRA), led by Milija Zupanski on the CIRA side. Collaboration with EMC HWRF team will assure that our research is aligned with EMC/HWRF operational plans, with clear path to operations. The proposed research will be the first application of assimilation of real GLM observations with NOAA HWRF/GSI assimilation/prediction system.

The Scientific focus of this project is to examine and assess the impact of assimilating GLM lightning flash rates on the analysis and forecast of hurricane intensity, track, and structure in NOAA operational HWRF system. We will (1) examine and adjust our GLM lightning observation operators for use with HWRF, (2) conduct detailed assessment of the impact of assimilating GLM lightning observations on HWRF analysis and forecasts, and (3) verify HWRF lightning forecast against GLM observations, and if warranted, assist NHC in research to operation (R2O) transition.

PROJECT ACCOMPLISHMENTS the first half-year:

The reporting period addresses the FY17 Milestone #1: Prepare for using GLM lightning data in GSI data assimilation, with tasks:(1) Prepare the format of input lightning data for use in GSI (i.e., BUFR), and (2) Optimize the transformation from lightning strikes to lightning flash rates for HWRF.

1--Prepare the format of input lightning data for use in GSI (i.e. BUFR)

Since the NOAA operational data assimilation system, hybrid Gridpoint Statistical Interpolation (hybrid-GSI), requires input observations to be in the NCEP BUFR format, the GLM observations have to be transformed to the BUFR format. Building on our previous work with Global Forecast System (GFS) data assimilation, we developed the transformation from binary format to BUFR format. In principle, we can transform from other common formats, such as NETCDF or HDF. The most challenging aspect of this work was to create BUFR mnemonic tables suited for a new observation such as GLM. Our algorithm was successfully completed and tested.

2--Optimize the transformation from lightning strikes to lightning flash rates for HWRF

GOES-R GLM data are the snap-shots of total lightning strikes. However, assimilation and forecast threat estimation of lightning planned in this project requires lightning flash rate. Therefore, preparation for GLM data assimilation needs to include a transformation from the original GLM strikes to lightning flash rates. Lightning flash rates (FR) are typically calculated as number of strikes (NS) per area and per time interval. A common approach is to use a regular horizontal grid to define the locations of flash rate observations, making the calculation of area relatively easy. Resolution of the grid is chosen to be 10 km, approximately corresponding to an average resolution of GLM data. The time interval is typically chosen to correspond to the assimilation window, i.e. 6 hours for the current HWRF DA system.

The standard calculation of the FR is conducted in the immediate vicinity of each grid point, without an overlap. Although essentially correct, the standard calculation does not take into account the distances from the central point. Therefore, an improvement to the standard RF calculation can be to weigh lightning strikes according to their relative distance from the central grid point, with closer strikes having more impact on the FR calculation. The calculation of weighted FR is illustrated in Figure 11.

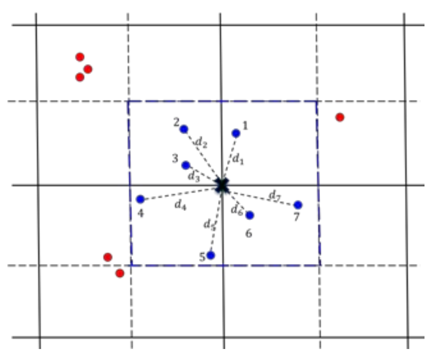


Figure 11. A schematic of calculation of weighted flash rate observations. The full black lines denote the gridded domain where FR observations are calculated, and the dashed black lines denote the middle-line between the grid points. The black x-sign denotes the central grid point at which the FR calculation is performed, and the blue dashed line encompasses the area that impacts the calculation at the central point. The circles represent the lightning strikes: blue circles denote the strikes that impact the central point, and red circles the strikes that impact other points. Therefore, in this example, there are 7 lightning strikes that impact the central point. Associated with each lightning strike is also a distance from the central grid point at which FR is calculated. Relative weights are calculated based on inverse distances, giving more weight to the lightning strikes closer to the central grid point. so that the FR is calculated as a weighted mean of surrounding lightning strike points.

Project 7--GOES-R AWG Imagery Team

PROJECT OBJECTIVES:

CIRA's contribution to the GOES-R Imagery Team includes two primary components: 1) Assist with the GOES-16 Post-Launch Test by closely examining the ABI imagery products and providing feedback to the team leads on any problems and/or issues that are observed. This includes helping with the preparations and delivery of presentations for Peer-Stakeholder Product Validation Reviews (PS-PVR); and 2) Develop an algorithm to simulate a green band so that true color imagery can be approximated from GOES-16; this imagery was requested by NESDIS as part of the GOES-16 First Light Imagery data release in January 2017, and they now want to begin running the algorithm in real time so the true color imagery can be made available by web pages hosted by NESDIS.

PROJECT ACCOMPLISHMENTS the first year:

1--Participate in ongoing evaluation of ABI cloud and moisture imagery (CMI) during the post-launch test (PLT) and extended validation periods, with the goal of achieving provisional and full levels of product maturity.
2--Document CMI issues and help write ADRs as needed.
3--Prepare and deliver presentations for PS-PVRs.
4--Refine (as-needed) the Rayleigh atmospheric corrections for ABI response functions.
5--Continue work on synthetic green LUT based on multi-scene/multi-seasonal AHI data.
6--Continue investigating algorithm performance improvements via stratifying the LUTs based on scene surface type (as a way of mitigating potential scene-dependent weak-correlation issues).
7--Evaluate performance of true color for various challenging environmental scenes.
8-Support any necessary algorithm improvements as flagged during interactions in the GOES-R Satellite Proving Ground.
9--Help to ensure CMI fidelity after GOES-16 is moved to either the –West or –East position for operational transition.
10--Examine performance near the terminator and accommodate for possible issues with Rayleigh corrections at high solar/satellite zenith angles.
11--Attempt spatial resolution sharpening to enable a 500 m resolution true color product. Use the ABI band 2 (500 m resolution) as the basis for sharpening bands 1 and 3. Create a synthetic green band at 500 m resolution used for true color.
12--Present results at relevant scientific GOESR meeting. Submit a manuscript to a peer-reviewed journal serving as updated documentation of the ABI true color product.
13--Provide quarterly reports detailing progress and findings.
14--Manuscript on ABI true color algorithm implementation.

1--Cloud and Moisture Imagery (CMI) was declared Provisional in June 2017, but work is still ongoing to help the ground system fix various problems, and to identify new problems as we march toward full product maturity later in 2018. Several issues have been identified by the CIRA team and reported to the Imagery Team and the Calibration Working Group (CWG).

2--As noted above, several issues with CMI have been identified and reported to the Imagery Team and the CWG. Examples include: 1) the PICA effect resulting in a regular calibration offset in the CONUS and Meso- scans during Mode 3, 2) horizontal and vertical striping in the visible bands, and 3) an odd brightening passing west to east (which turned out to be related to direct backscatter to the satellite). The CIRA team helped the CWG prepare ADRs on some of these issues.

3--Input was provided to the Imagery Team leads at ASPB/CIMSS, who put together and delivered the PS-PVR for CMI. The product has been declared Provisional.

4--It has been determined that the Rayleigh corrections are working nominally. All work on the Rayleigh atmospheric corrections for ABI response functions has been completed.

5--We have identified an issue with the synthetic green look-up table (LUT) related to the use of the land/water mask. This mask differentiates “shallow” waters from “deep” water and is used in the scene classification used by the LUT. The sharp boundary between “shallow” and “deep” ocean is causing an apparent discontinuity in coloration of water near the coast of the Bahamas. We are transitioning to the use of a global bathymetry dataset provided by NCEI to more smoothly blend between shallow and deep ocean waters and improve scene classification used by the LUT. As opposed to selecting a LUT based on the classifier (producing this boundary), we produce a dynamic blend between the results of the deep and shallow LUTs according to water depth.

6--As mentioned above, use of the bathymetry dataset is expected to improve the results of the LUT. Work on refining the LUTs is ongoing.

7--An issue was found in the Parana River in South America, whereby the turbid waters of the river appear too red (Figure 12). This is a known limitation of the synthetic green technique in turbid waters, where the near-infrared vegetation band offers poor correlation with the true green value. Another aspect of this issue on the Parana River may relate to the uncommon nature of this particular coloration, where limited population of data points in the shallow water LUT exist for high levels and unusual orange (clay/iron-rich) coloration of turbidity. This work is ongoing – daily ABI loops are closely being examined for any problems. This monitoring helped to reveal anomalies associated with the Great Salt Lake and the deep/shallow LUT discontinuity mentioned above.

8--Close interaction with the GOES-R Satellite Proving Ground team members ensures that the true-color/GeoColor development benefits from any user suggestions for improvements. We have received positive feedback on GeoColor from NWS forecasters, including this comment from Daniel Porter (NWS Albuquerque SOO): “To my knowledge everyone is using it [GeoColor], or has at least loaded it into a procedure of some kind. It is particularly useful for both day and night applications.”

Figure 12. Comparison between synthetic true color from ABI (left) and true color from MODIS (right) for the Parana River along the border between Argentina, Brazil and Paraguay (12 November 2017).

9--GOES-16 was successfully moved from its checkout location to the GOES-East position (nominally 75.2 °W longitude) beginning on 30 November 2017, and was declared operational on 18 December 2017. During the 2-week transition period, processing software was updated to account for the new sub-satellite longitude. When data transmission resumed in mid-December, CMI was found to perform nominally. Figure 1 (Project 1) shows the first full disk GeoColor image from the GOES-East position.

10--Performance near the terminator has been examined, and has been refined several times to optimize the image quality. It has been found that we can approach very close to the terminator with the fidelity of the current atmospheric correction software, leading to a superior true color product. As such, this milestone is considered completed.

11--A spatial resolution sharpening method is being applied to test cases of GOES-16 ABI. Preliminary results are promising, but also revealed a possible issue with Band 2 noise patterns. We have contacted the ABI cal/val team concerning these patterns and this matter is being reviewed. If a satisfactory fix is not provided to the upstream data to eliminate these artifacts (pending), we have a plan to overcome the issue in our processing. Work on this milestone is ongoing.

12--GOES-16 imagery was presented at the NWA Annual Meeting in Garden Grove, CA (18-21 September 2017), EUMETSAT Satellite Conference in Rome, Italy (2-6 October 2017), the AGU Fall Meeting in New Orleans, LA (11-15 December 2017) and the AMS Annual Meeting in Austin, TX (6-11 January 2018). References for these presentations are provided below.

13--Quarterly reports were filed.

14--S. Miller and D. Lindsey provided input to a manuscript led by Kaba Bah of UW/CIMSS related to a simplified method for rendering an ABI green band via a linear combination of adjacent bands and leveraging our "hybrid green" approach. A manuscript detailing the GeoColor algorithm is currently in progress.

Project 8--GOES-R AWG Cloud Team

CIRA's initial AWG Cloud Team contributions (performed with FY16 funding) involved the ongoing development of the CGT algorithm, evaluation of CGT against CloudSat, and application of a version of the CGT algorithm to AHI data. Over the course of this work, GOES-R has launched successfully and transitioned to GOES-16. The ABI is operating nominally and is on schedule for operational transition as either GOES-E or GOES-W pending NOAA decision.

For FY17 we proposed to port our CGT/CBH/CCL algorithms to GOES-16 ABI. This includes reconfiguring our code to work with the GOES-R data stream and working on an improved ABI cloud cover and layers (CCL) application desired by aviation forecasters. In addition, we had formal demonstrations with users and evaluation of product performance in the operational environment.

PROJECT OBJECTIVES:

1--Migration of algorithm to ABI
1.1-Continue development of CGT integrated within CLAVR-x
1.2-Configure CGT algorithm to work on ABI data stream
1.3-Conduct preliminary evaluation of ABI performance

2--ABI Algorithm Evaluation—Match-ups to CloudSat/CALIPSO
2.1-Conduct case study evaluations against CloudSat/CALIPSO
2.2-Begin to examine possible updates to algorithm using ABI+CloudSat/CALIPSO
2.3-Work with the Aviation Weather Center for possible operational evaluations

3--Prepare reports and contribute materials to presentations as requested by Team Lead

PROJECT ACCOMPLISHMENTS:

1--We completed transitional work to apply the statistical CGT/ CBH algorithms to GOES-16 ABI, which has been originally developed for VIIRS and Himawari-8/9 AHI (Seaman et al. 2017; Noh et al. 2017). GOES-16 ABI CBH (derived from cloud top height and cloud geometric thickness) and CCL (improved by CGT/CBH to modulate lower cloud layers) products are produced using the CLAVR-x system at CIRA in near-real time and publicly displayed for general/operational users via CIRA's SLIDER tool (http://rammb-slider.cira.colostate.edu). One sample for ABI CONUS is shown with a GEOcolor image in the figure 13 below.

2--Interfacing with research from a newly selected GOES-R Risk Reduction project (1 July 2017 start; "Improving the ABI Cloud Layers Product for Multiple Cloud Systems and Aviation Forecast Applications," J. Haynes and Y.J. Noh at CIRA), we developed a collocation code for CloudSat/CALIPSO within the GOES-16 field of view and have collected CloudSat/CALIPSO data. Our initial analysis with the active sensor data shows that the current 'overlapping' cloud type (derived from CLAVR-x) often fails to determine multi-layered clouds. The results were presented at 2018 AMS annual conference (Haynes et al. 2018). Leveraging research efforts, we began work to introduce a new 'High + Low' cloud layer category for multi layers by utilizing NWP humidity data and a multi-spectral approach including 1.38 µm.

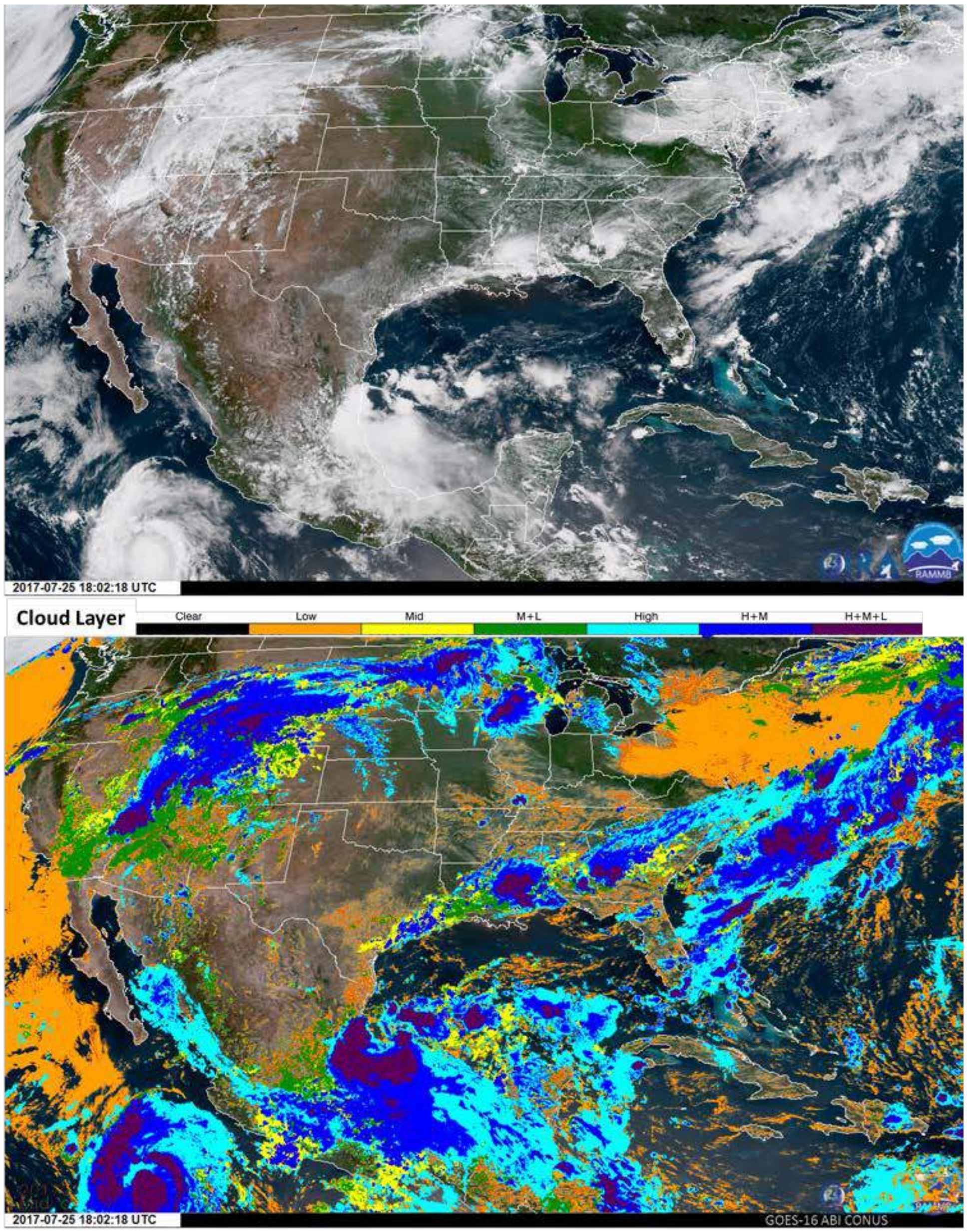


Figure 13. GOES-16 ABI GeoColor image (top) and the improved cloud layers (bottom) using the CGT information (CONUS at 1802 UTC on 25 July 2017), displayed in CIRA's SLIDER (publically available at http://rammb-slider.cira.colostate.edu).

3--The CIRA team participated in the Cloud Team teleconferences and regularly contributed input materials to Andrew Heidinger (Cloud Team Lead) for reviews and reports.

Project 9--CSU/Atmospheric Science Department Colorado Lightning Mapping Array/GLM

With the successful launch of GOES-R/GOES-16 carrying the Geostationary Lightning Mapper (GLM), many new opportunities for nowcasting severe weather utilizing GLM lightning observations were established. For example, NWS offices can now further integrate lightning data into their warning decision process. Before such applications can achieve their full potential, it is important to validate the GLM observations against other lightning measurements. Equally important is the conduct of studies documenting GLM lightning flash rate behavior to observed changes in convective storm behavior, including evolution of radar echo patterns. Steve Rutledge's CSU Atmospheric Science team is taking part in both of these activities.

PROJECT ACCOMPLISHMENTS:

Four supercellular and two non-supercellular tornadic storms were analyzed and compared to determine how total lightning characteristics differ between dynamically different tornadic storms. This work is motivated by the launch of GOES-R, which is envisioned to play a big role in "nowcasting" severe weather based on lightning observations. Supercellular tornadoes require a downdraft to form while landspout tornadoes form within an intensifying updraft acting on pre-existing vertical vorticity. The supercellular tornadoes we studied showed a decrease in flash rate and a decrease in lightning mapping array (LMA) source density heights prior to tornadogenesis. This decrease may indicate the formation of a downdraft. In contrast, lightning flash rates increased during landspout formation in conjunction with an intensifying updraft. To further understand how storm microphysics and dynamics impact the relationship between lightning behavior and tornadogenesis, two of the tornadic supercells were analyzed over Colorado and two were analyzed over Alabama. Colorado storms typically exhibit higher flash rates and anomalous charge structures in comparison to Alabama storms that are typically normal polarity and produce fewer flashes. The difference in microphysical characteristics does not appear to affect the relationship between total lightning trends and tornadogenesis.

We have carefully analyzed data from the GOES R ground validation field campaign, focusing on the gold-mine 8 May case day during which the NASA ER-2 overflew intense convection in northeast Colorado. Both normal and inverted storms were sampled. The NE Colorado LMA network, supported by this COLMA funding component, was used to estimate total flash rates. Placing LMA and GLM lightning observations in the context of radar observations, we found for the intense 8 May inverted storm that GLM flash detection varied between 10-20%. The smallest DE's were found when LMA flash rates peaked, also times when flash areas were small (< 10 km^2). We generally concluded that for inverted storms, compact flashes are centered deep in the cloud (lower flash heights compared to normal polarity storms) so it may be possible that optical energy is reduced by ice scattering, rendering a significant fraction of these flashes going undetected by GLM. We also carried out an analysis of TRMM LIS flash rates compared to flash rates/flash areas observed by the AL and OK LMA networks (using LIS as a proxy for GLM). We found that flashes with areas less than 10 km^2 were only detected by LIS when they were within the top most km or two of the cloud top. Flashes with areas exceeding 10 km^2 were better detected regardless of location in the cloud. Since high flash rate storms have compact flashes in general, we need additional verification of this observation through additional case studies, which will be part of next year's COLMA project focus.

Project 10–GOES-R Visiting Scientist Program

We have received financial support to cover a trip by Thomas Blackmore, a British Met Office (UK) Scientist, to visit RAMMB/CIRA at Colorado State University for collaboration with RAMMB/CIRA scientists in July 2017.

The purpose of this visit was to foster a collaboration and share information between the Met Office and CIRA/RAMMB, with particular focus on three key areas:
1--Lessons learned from the pre-operation phase of GOES-16 as the Met Office will use GOES-16 data and imagery and the instrument is similar to that which will fly on Meteosat 3rd Generation (MTG) in 2021.

2--Lessons learned from the GOES-R Proving Ground activities to prepare Meteorologists for the new data and products from GOES-R that may help with the preparing UK Operational Meteorologists for MTG. 3. Look at the uses for, methods (including radiative transfer models) and products for producing and displaying simulated/synthetic satellite imagery at both the Met Office and by RAMMB/CIRA, and build collaboration and ideas sharing in this area.

PROJECT ACCOMPLISHMENTS:

The visit was a valuable exchange of ideas and has bought benefits to both the Met Office and CIRA/RAMMB, and this will continue as further collaboration develops. Thomas would like to thank the GOES-R VSP for funding the trip.

Summary
The primary collaboration during this visit was between Thomas, who works in the Satellite Applications group at the Met Office, and Dr. Dan Lindsey (RAMMB). Thomas and Dan Lindsey had many useful discussions and shared information covering the three key elements listed above. Thomas also spoke to other scientists at CIRA and sat in on various presentations, including an update on the GOES-R program by Steve Goodman, who was visiting CIRA.

<u>GOES-16</u>
GOES-16 imagery products produced were demonstrated and discussed in detail, including lessons learned in creating these products.
CIRA's SLIDER webpage was demonstrated which is a very promising-looking resource; it includes an image slider tool similar to the one Thomas developed for comparing satellite products. The different RGBs and other products from GOES-16 in SLIDER were demonstrated by Dan. The products and imagery created using the channels that aren't available in SEVIRI were of particular interest, such as the Fire Temperature RGB and the Geocolor product.
Steps to creating true color imagery from ABI were discussed. The use of true color has most value in communicating imagery to the public, and less so for forecasters. Dan pointed out however that it has some forecast application for distinguishing smoke and aerosol from cloud.

<u>USER prep</u>
Dan demonstrated how simulated imagery was used as part of the GOES Proving Ground to simulate the bands and products before launch to prepare forecasters.
Thomas also had the opportunity to sit in on a webinar delivered by Dan to regional Weather Service centers where Dan delivered a demonstration of the GOES-16 Geocolor product in the SLIDER webpage. This was a good introduction to how training on satellite products is delivered by scientists to users. Dan kept this webinar short and sharp, introducing one product and keeping it very applications focused, showing how the product can benefit the users. This is a useful comparison to how this sort of information is disseminated to users at the Met Office, and the situation is slightly different as many Met Office forecasters are based in the same building as the scientists; however, we will consider adopting a similar webinar technique to reach out to our regional forecast centers.

<u>Simulated imagery</u>
Thomas learnt how CIRA simulates satellite images and demonstrated the Met Office simulated imagery system, describing how it is used by operational meteorologists. Thomas also demonstrated how the Met Office system allows our parallel development version of our NWP models to be compared with the operational model, and also how we produce images in the same format from ECMWF Global Model simulated data for multi–model comparison.

The uses of simulated imagery have been quite different between the UK and USA so far, with the primary use of the imagery being for verification of the NWP model by forecasters against the real satellite.
We discussed how Dan might go about putting a real time web display of simulated satellite imagery into the SLIDER webpage and how the interface would work based on Met Office experiences of displaying simulated imagery for direct comparison with observations to forecasters.

Dan plans to work with Kevin Micke (CIRA) to get NSSL WRF simulated imagery into SLIDER and will look into simulating satellite imagery from the NAM CONUS nest.

Thomas and Dan discussed the high value of future collaboration on simulated imagery development, and ideas to compare our systems and products side by side and write a joint paper on any findings of a collaboration project.

During the visit Thomas also had the opportunity to discuss multi-channel simulated imagery products with Louis Grasso (CIRA).

Project 11--GOESR Program ADEB Senior Advisory Support

Professor Tom Vonder Haar, Member of the National Academy of Engineering, continues to serve on the Independent Advisory Committee (IAC) for GOES-R. The IAC reports directly to the GOES-R SDEB. It supports tasks assigned to them and by the GOES-R Program Scientist. The range of advisory tasks include all aspects of the Program such as algorithm development and testing; Instrument and Product Cal/Val both before and after launch; User preparation and outreach; Science and operational applications; and combined products from GOES and JPSS.

PROJECT ACCOMPLISHMENTS:

During this reporting period, Professor Vonder Haar supported the GOES-R Program as an ADEB Advisor at discussions in Fort Collins, CO. He also attended the 2018 AMS Annual Meeting in Austin, TX, where he attended GOES-R presentations and poster sessions. He attended an informal meeting of the GOES IAC with Dr. John LeMarshall (chair) and others on the exciting new GOES-16 imagery and products. We reviewed the papers and posters presented regarding the GOES. Professor Vonder Haar also reviewed the “first look “data from ABI as it was studied and processed by CIRA’s GOES-R Team.

Project 12--GOESR/RAMMB Administrative Support

Consistent with our long-standing Memorandum of Understanding between NOAA and Colorado State University, the CIRA GOES-R project includes a budget specifically to support administrative and clerical personnel directly associated with the technical and managerial administration of this project. This support is “quid pro quo” for the reduced indirect cost rate agreed upon in the long-standing subject memoranda. CIRA Administrative Staff will provide communication support, assist in the acquisition and distribution of reference materials relevant to the conception and execution of the project, collection of reports and conference papers. In addition, CIRA also provides some administrative support for the wider GOES-R program, including tracking of project progress reports. CIRA also provides federal travel documentation and makes all of the travel arrangements for the Federal RAMMB Employees.

Publications:

Noh, Y. J. and S. M. Miller, 2017: Detection of mixed-phase clouds from shortwave and thermal infrared satellite observations. In C. Andronache (Ed.), Mixed-phase Clouds: Observations and Modeling (Chapter 3, p. 43-67). ISBN: 978-0-12-810549-8, Elsevier, 288 pp.

Noh, Y. J., J. M. Forsythe, S. D. Miller, C. J. Seaman, Y. Li, A. K. Heidinger, D. T. Lindsey, M. A. Rogers, and P. T. Partain, 2017: Cloud base height estimation from VIIRS. Part II: A statistical algorithm based on A-Train satellite data. J. Atmos. Ocean. Tech., doi: 10.1175/JTECH-D-16-0110.1.one.

Miller, S. D., R. L. Bankert, J. E. Solbrig, J. M. Forsythe, and Y.-J. Noh, 2017: A Dynamic Enhancement with Background Reduction Algorithm: Overview and Application to Satellite-Based Dust Storm Detection. JGR-Atmospheres, 122(23), 12,938–12,959, doi.org/10.1002/2017JD027365.

Seaman, C. J., Y. J. Noh, S. D. Miller, A. K. Heidinger, and D. T. Lindsey, 2017: Cloud base height estimation from VIIRS. Part I: Operational algorithm validation against CloudSat. J. Atmos. Ocean. Tech., doi: 10.1175/JTECH-D-16-0109.1.

Note: the DEBRA publication (Miller et al. 2017, listed above) was designated as a “Journal Highlight” by Zhanqing Li, the Editor of JGR: Atmospheres. JGR Highlight Title: “Addition by Subtraction: Raising the Bar for Satellite Imagery”. Full JGR highlight text: https://eos.org/editor-highlights/addition-by-subtraction-raising-the-bar-for-satellite-imagery

Presentations:

Forsythe, J, S. Kidder, A. Jones, D. Bikos, E. Szoke, and S. Kusselson, 2018: Tracking Water Vapor with Multisensor Blended Products for Forecasters. AMS Annual Meeting, Austin, TX, 8-11 January 2018.

Grasso, L., J. Dostalek, and D. T. Lindsey: GOES-16 ABI channel differencing used to reveal cloud-free zones of ‘precursors of convective initiation’ 22nd Conference on Satellite Meteorology and Oceanography, 98th AMS Annual Meeting, 7-11 January 2018, Austin Convention Center, 500 East Cesar Chavez, Austin, TX

Haynes, J. M., Y.- J. Noh, S. D. Miller, D. T. Lindsey, A. K. Heidinger, and J. M. Forsythe, 2018: Improving Cloud Layer Boundaries from GOES-16. AMS 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Session: Algorithm Development and New Science Innovation—Part I, 11 January, Austin, TX.

Kreidenweis, S., Q. Bian, L. D. Grasso, X. Xu, J. Bukowski, S. C. van den Heever, J. E. Solbrig, and S. D. Miller, 2018: Disappearing Dust Plumes: Exploring the Roles of Water Vapor and Dust Properties in Detection from Satellite Observations. AMS 10th Symposium on Aerosol–Cloud–Climate Interactions, Soil Dust III: Lofting, Transport, Characterization, and Interactions with Clouds and Climate, 8 January, Austin, TX.

Lindsey, D. T, and S. D. Miller, 2017: GOES-16: A New Era in Geostationary Satellite Observations, ATS/CIRA Colloquium, Colorado State University, Fort Collins, CO, 25 August 2017.

Lindsey, D. (for T. Schmit) and Coauthors: An early look at the imagery from the Advanced Baseline Imager (ABI) on GOES-16. Oral presentation. EUMETSAT Meteorological Satellite Conference, Rome, Italy, 2-6 October 2017.

Lindsey, D., (for S. Miller) and Coauthors: Where East Meets West: How Himawari-8 enables True Color capabilities for GOES-R ABI. Oral presentation. EUMETSAT Meteorological Satellite Conference, Rome, Italy, 2-6 October 2017.

Lindsey, D. and Coauthors: Operational use of GOES-16 imagery by the U.S. National Weather Service. Oral presentation. EUMETSAT Meteorological Satellite Conference, Rome, Italy, 2-6 October 2017.

Lindsey, D. T., S. D. Miller, C. J. Seaman, and S. J. Goodman, 2018: Highlights of the First Year of GOES-16 Imagery. AMS 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Development and Communication of Next-Generation Satellite Information for Forecasting Extreme Weather—Part II, 9 January, Austin, TX.

Micke, K. P., S. D. Miller, D. W. Hillger, R. L. Brummer, S. Finley, N. D. Tourville, D. A. Molenar, D. T. Lindsey, 2018: SLIDER: A Satellite Imagery Looper Capable of Viewing Every Pixel of GOES-16 Imagery in Real-Time Over the Web. AMS 34th Conference on Environmental Information Processing Technologies, Session: Visualization Techniques for Climatology and Meteorology, 9 January, Austin, TX.

Miller, S. D., W. C. Straka, III, C. J. Seaman, C. L. Combs, A. K. Heidinger, A. Walther, and J. E. Solbrig, 2018: Chasing the Shadows with the VIIRS Day/Night Band. AMS 8th Conference on Transition of Research to Operations, Advances in Satellite Observations for Earth Science and Observing Technologies—Part I, 8 January, Austin, TX.

Miller, S. D., D. T. Lindsey, C. J. Seaman, J. E. Solbrig, Y. J. Noh, L. Grasso, and K. Micke, 2018: Advanced Imagery Applications Development for GOES-16 ABI. AMS 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Special Session on GOESR, 9 January, Austin, TX.

Miller, S. D., D. T. Lindsey, C. J. Seaman, J. E. Solbrig, Y.-J. Noh, L. D. Grasso, and K. P. Micke, 2018: Advanced Imagery Applications Development for GOES-16 ABI. AMS 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Special Session on GOESR, 9 January, Austin, TX.

Miller, S. D., 2017: Satellite Algorithm Development Research Theme -- The Return of True Color to Geostationary Satellites, CIRA Executive Board Meeting, 7 July 2017, Fort Collins, CO.

Miller, S.D. and C. J. Seaman, 2017: A Sight for Sore Eyes: Bringing Back True Color Imagery for the New Generation Weather Satellites, CIRA Research Initiative Award Ceremony, 28 July 2017, Fort Collins, CO.

Noh, Y. J., S. D. Miller, J. Forsythe, C. J. Seaman, J. Haynes, A. K. Heidinger, D. T. Lindsey, and Y. Li, and S. Wanzong, 2017: The Newly Operational VIIRS Cloud Cover/Layers and Base. STAR JPSS Annual Science Team Meeting, 14-18 August 2017, College Park, MD.

Rogers, M., S. D. Miller, L. Grasso, J. Haynes, Y-J. Noh, J. Forsythe, M. Zupanski, and D. Lindsey: New GOES-R Risk Reduction Activities at CIRA. Poster. AGU Fall Meeting 2017, New Orleans, LA, 11-15 December 2017

Schumacher, A. B., G. T. Stano, C. M. Gravelle, W. Line, S. D. Miller, 2018: Development and Communication of Next-Generation Satellite Information for Forecasting Extreme Weather. AMS 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, 22nd Conference on Satellite Meteorology and Oceanography, and Sixth Symposium on the Weather, Water, and Climate Enterprise, (panel discussion), 9 January, Austin, TX.

Schumacher, A. B., G. T. Stano, C. M. Gravelle, W. Line, S. D. Miller, 2018: GOES-R Series: Products and User Applications. AMS Short Course, 7 January, Austin, TX.

Seaman, C., S. Miller, D. Lindsey and D. Hillger: Multispectral imagery applications for the new generation of geostationary satellites. Oral presentation. EUMETSAT Meteorological Satellite Conference, Rome, Italy, 2-6 October 2017.

Seaman, C., and Coauthors: Connecting with operational forecasters in the GOES-16 era via the NOAA Satellite Proving Ground program. Poster presentation. EUMETSAT Meteorological Satellite Conference, Rome, Italy, 2-6 October 2017.

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, S. D. Miller, J. Torres, C. J. Seaman, D. T. Lindsey, D. Hillger and D. Molenar, 2017: Future Directions for CIRA's NWS Proving Ground Activities Now That GOES-16 Is Operational. 42nd Annual NWA Meeting, Garden Grove, CA, 18-21 September 2017

PROJECT TITLE: CIRA Support for the Satellite Loop Interactive Data Explorer in Real-time (SLIDER) Web Interface for the NESDIS/StAR Webpage

PRINCIPAL INVESTIGATORS: Kevin Micke and Renate Brummer

RESEARCH TEAM: Kevin Micke and Steve Finley

NOAA TECHNICAL CONTACT: Jaime Daniels (NOAA/NESDIS/StAR)

NOAA RESEARCH TEAM: Dan Lindsey and Deb Molenar (NOAA/NESDIS/StAR/RAMMB)

FISCAL YEAR FUNDING: $100,000

PROJECT OBJECTIVES:

The Satellite Loop Interactive Data Explorer in Real-time (SLIDER) web application was recently developed at CIRA to provide a public-facing website where users could explore the immense data sets from the GOES-R series of satellites. The goal of this project was to implement SLIDER on servers at NESDIS/StAR, giving NESDIS/StAR the ability to host full-resolution, real-time GOES-16 satellite imagery for the public in a user-friendly interface. Research objectives included:

1--Complete various upgrades to front end user interface, including but not limited to making it Section 508 compliant, creating a StAR/NOAA theme, and general cleanup of the interface
2--Test real-world performance during and after public launch at CIRA to determine if load balancing to multiple servers will be advisable and/or necessary to ensure a good end user experience during traffic spikes
3--Perform bug fixes and code cleanup on the front end interface to make it perform as well as possible in a wide array of web browsers
4--Complete upgrades to back end satellite imagery processing, including but not limited to separating imagery generation from image tiling, upgrading scour script to allow data to better span multiple disks, and reorganizing data structure to make it more efficient
5--Create documentation to help guide implementation on StAR servers, as well as end user documentation directly in the SLIDER interface
6--Consult with StAR personnel to help implement back end satellite imagery processing on StAR servers
7--Consult with StAR personnel to help implement SLIDER front end interface on StAR servers
8--Provide front end interface upgrades for StAR to deploy on their servers through the end of the project period as SLIDER development continues at CIRA

PROJECT ACCOMPLISHMENTS:

1--Significant upgrades were made to the front end user interface with a focus on making it easier to navigate. Some of the upgrades included making the necessary changes to bring the site into Section 508 compliance, adding a StAR/NOAA theme (see Figure 1), making user interface elements more consistent, and adding additional keyboard shortcuts. Further upgrades upon which work has begun include flow-following/storm-relative loops and major upgrades to the maps available to users.

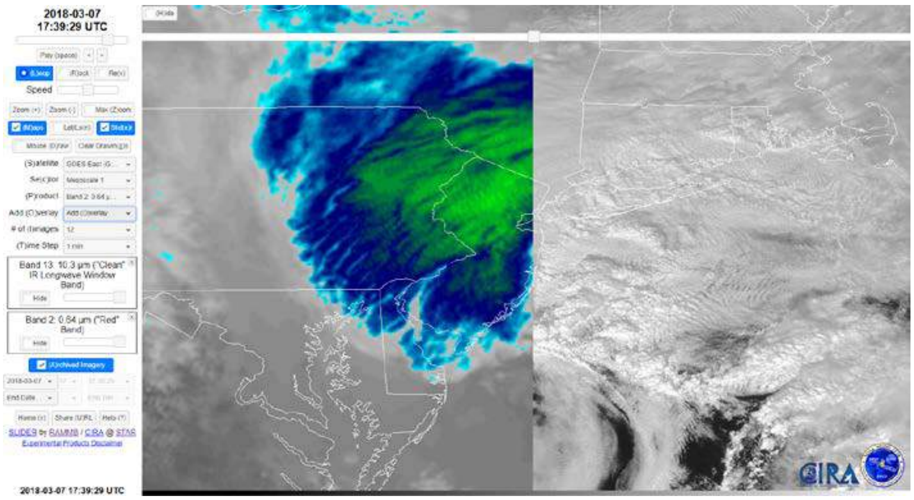


Figure 1. SLIDER installation on StAR development server showing the Nor'easter that hit the US on 7 March 2018. The slider feature is used to compare GOES-16 Band 13 on the left with Band 2 on the right.

2--Real-world performance tests of the SLIDER interface were conducted at CIRA after the site launched publicly on the afternoon of 22 June, 2018 (http://rammb-slider.cira.colostate.edu/) . The following day, the first full day the site was live, over 1,500 different users came to the site for a total of over 2,000 sessions. During the particularly active hurricane and fire seasons of 2017, there were multiple traffic spikes (see Figure 2) that pushed the CIRA server to its limits, at which point the site became less user-friendly due to increased latency. While actions were taken at CIRA to improve performance under heavy loads, such as switching from the Apache web server to NGINX, it was determined that a CDN server setup at StAR would make the site more reliable and user-friendly during heavy traffic.

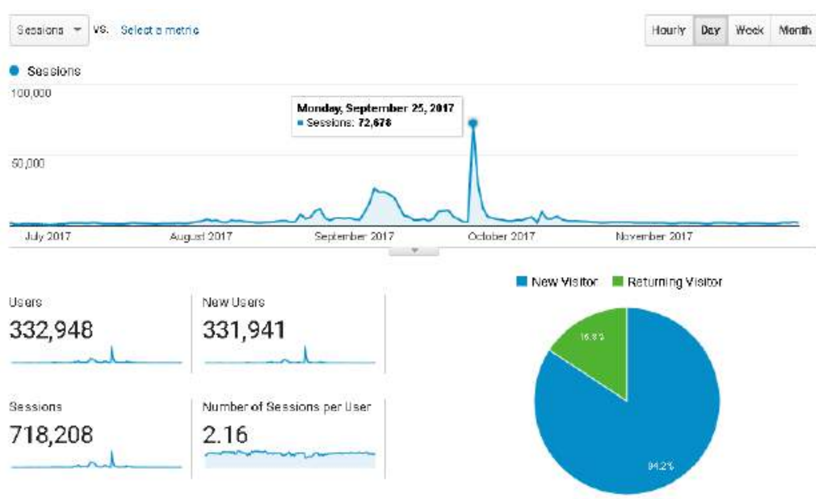


Figure 2. Google Analytics data for the SLIDER installation at CIRA from 23 June 2017 (first full day after public launch) through 30 November 2017 (last day of official Atlantic hurricane season). The largest traffic spike was when SLIDER went viral in China, while other major spikes were associated with major hurricanes, fires, and the solar eclipse. On average, over 2,000 different users came to the site each day.

3--Multiple front end interface bugs were fixed to further improve performance in a variety of browsers. At this point the site is capable of running well in all major browsers, including those on many smartphones.

4--Substantial upgrades were made to the back end satellite imagery processing to make it more efficient and easier to maintain. For example, the Python code for imagery generation was completely separated from the code for turning the large images into small image “tiles” for use by the front end interface. This modularization allows the scripts to run independently and more efficiently, particularly when a large backlog of imagery is being processed. The script used to “scour” or remove older imagery to make room for new imagery was also upgraded, allowing data to span multiple disks on the same server, or even multiple servers. Further, the hierarchy of the data used by the front end user interface was reorganizing so that it could be processed more efficiently.

5--During the SLIDER implementation on StAR servers, detailed notes have been taken to document how all parts of the system are set up and work together. These notes will be expanded upon to create more robust documentation of the back end processing. While much of the front end interface is fairly intuitive, documentation was added directly in the SLIDER interface to help end users fully understand all of the options they have to explore the available data sets.

6--A large proportion of development time was spent getting the back end satellite imagery processing running on StAR’s servers. With help from StAR personnel, primarily Matt Jochum and Brian Keffer, McIDAS was set up so that the imagery could be produced from the GOES-16 NetCDF files. The infrastructure at StAR is different enough from CIRA’s that a substantial rewrite of the part of the Python code that calls McIDAS was necessary, but this also allowed the addition of new features like the ability to easily re-process older data for case studies. After CDN servers were set up to allow mirroring the site on multiple servers, the code was further upgraded to duplicate the necessary data on all servers to allow the site to handle large traffic spikes. During this latest upgrade, additional steps were taken to make the processing of imagery more efficient, further shortening the time between the satellite capturing the data and it becoming available to end users on the site.

7--The SLIDER front end interface was implemented on StAR servers, with real-time imagery being displayed on the development server within the amount of time planned for in the project proposal.

8--As SLIDER development continues at CIRA, upgrades to the front end interface have been deployed on StAR’s servers to use the latest stable releases. Additionally, as upgrades have been made to the back end imagery processing code, those have also been leveraged to improve performance at StAR.

The overall feedback to the public launch of SLIDER at CIRA was very positive and included many media outlets and social media users linking directly to loops of interest. The New York Times wrote an article that linked directly to the SLIDER site, saying “This is a good website for looking at GOES-16 imagery,” which can be found at https://www.nytimes.com/2017/09/06/upshot/how-to-follow-hurricane-irma.html.

Publications:

Micke, K. P., 2018: Every Pixel of GOES-16 Imagery at Your Fingertips. Bull. Amer. Meteor. Soc., Nowcast Article. Submitted in March 2018.

Presentations:

Micke, K. P., 2017: SLIDER: Satellite Loop Interactive Data Explorer in Real-time live demonstration at NOAA exhibitor’s booth. NOAA Satellite Conference, 17-20 July 2017, New York, New York.

Micke, K. P, J. Solbrig, S. D. Miller, D. W. Hillger, R. L. Brummer, S. Finley, N. D. Tourville, D. A. Molenar, D. T. Lindsey, J. Purdom, 2017: SLIDER: Satellite Loop Interactive Data Explorer in Real-time. 8th Asia/Oceania Meteorological Satellite Users’ Conference, 16-21 October 2017, Vladivostok City, Russia.

Micke, K. P., S. D. Miller, D. W. Hillger, R. L. Brummer, S. Finley, N. D. Tourville, D. A. Molenar, D. T. Lindsey, 2018: SLIDER: A Satellite Imagery Looper Capable of Viewing Every Pixel of GOES-16 Imagery in Real-Time Over the Web. AMS 34th Conference on Environmental Information Processing Technologies, Session: Visualization Techniques for Climatology and Meteorology, 7-11 January 2018, Austin, TX.

PROJECT TITLE: CIRA Support for Upgrade to the Multi-Platform Satellite Tropical Cyclone Surface Wind Analysis Product

PRINCIPAL INVESTIGATOR**:** Jack Dostalek

RESEARCH TEAM: Natalie Tourville, Robert DeMaria

NOAA TECHNICAL CONTACT:

NOAA RESEARCH TEAM: John Knaff (NOAA/NESDIS/StAR)

FISCAL YEAR FUNDING: $110,000

PROJECT OBJECTIVES:

Information regarding the surface wind field surrounding tropical cyclones is of interest to forecast agencies worldwide. The most accurate information comes from direct measurements such as surface stations, buoys, and dropsondes released from aircraft. These sources, however, provide limited information as tropical cyclones spend most of their lifetimes over the ocean, away from routine surface observations. In addition, the United States is the only country that regularly performs aircraft reconnaissance of tropical cyclones, and those flights are conducted almost exclusively on systems near the Atlantic Coast. Remotely sensed data are therefore needed to monitor the wind field around tropical cyclones on a regular basis. CIRA has developed a product called the multi-platform satellite tropical cyclone surface wind analysis (MTCSWA). This product combines measurements from four satellite sources to produce surface wind analyses of tropical cyclones worldwide. The four sources are: 1) Scatterometry (ASCAT from MetOp-A, 2) Cloud drift winds from geostationary visible and near infrared channels, 3) Flight-level proxy winds based on geostationary longwave infrared imagery, and 4) Flight-level winds based on nonlinear balance wind fields derived from AMSU measurements. In addition to United States' NHC, CPHC, JTWC, and SAB, this product is also used by forecast agencies in other countries such as Meteo France and Australia's Bureau of Meteorology.

The updates of the data sources include use of ASCAT data from MetOp-B, imagery from GOES-16 and Himawari-8, new nonlinear balance winds derived from AMSU and ATMS measurements processed by the MIRS retrieval algorithm, and updated techniques for inner-core GOES winds. The algorithm will be improved by incorporating a refined method for flight-level to surface wind reduction, and using a parameterization of inflow wind angles based on intensity and azimuth. The product will be run every three hours to update the six-hourly, synoptic time fixes (00Z, 06Z, 12Z, and 18Z) with the latest information. Output will be generated in legacy formats (e.g. ATCF fixes) as well as netCDF files. The output will be distributed via ftp, web and DDS servers, and migrating to the PDA solution to enable users to obtain the information in a timely manner.

This two-year project began 1 July 2017.

Research conducted the first year:

1--Run prototype analysis at CIRA and post results to the web; coordinate with JTWC/NHC/CPHC and WMO RMSCs
2--Preliminary Design Review/Critical Design Review

1--The prototype analysis at CIRA is running and output is available at (http://rammb.cira.colostate.edu/products/tc_realtime/).
2--The Preliminary Design Review/Critical Design Review was conducted on January 26, 2018.

Publications: None

Presentations: None

PROJECT TITLE: CIRA Support of the Virtual Institute for Satellite Integration Training (VISIT)

PRINCIPAL INVESTIGATORS: Dan Bikos and Bernadette Connell

RESEARCH TEAM: Edward Szoke, Erin Dagg, Kevin Micke, Rosemary Borger, and Tim David

NOAA TECHNICAL CONTACT: Chris Brown (NOAA/NESDIS) and Philip Hoffman / NOAA/OAR Cooperative Institute Program

NOAA RESEARCH TEAM: Dan Lindsey (NOAA/NESDIS/STAR/RAMMB)

FISCAL YEAR FUNDING: $242,248

PROJECT OBJECTIVES:

The primary objective of the VISIT program is to accelerate the transfer of research results based on atmospheric remote sensing data into National Weather Service (NWS) operations. This work was done in close collaboration with experts at CIRA, the Cooperative Institute for Meteorological Satellite Studies (CIMSS), the Short-term Prediction Research and Transition Center (SPoRT), the Cooperative Institute for Mesoscale Meteorological Studies (CIMMS), COMET, and the National Weather Service (NWS) Office of the Chief Learning Officer (OCLO) which includes the Training Center (NWSTC), the Warning Decision Training Division (WDTD), and the Forecast Decision Training Division (FDTD). The transfer of research results into NWS operations is accomplished through a variety of distance learning methods. Asynchronous training delivery methods include online videos, quick guides, quick briefs, job aides and blog entries, these exist on web-pages and may be taken anytime. Synchronous training delivery methods include live webinars and teletraining, these utilize a combination of a conference call and software and occur live at a scheduled time. The combination of synchronous and asynchronous distance learning methods (Figure 1) reaches out to as broad an audience as possible given the busy schedule of NWS forecasters. Due in large part to the SatFC-G course being taken by all NWS employees, there have been over 15,000 asynchronous training completions over the past year and over 47,000 VISIT training completions since April 1999. CIRA is also actively involved in tracking of participants, and the collection and summarization of course feedback material. Because the VISIT program has been successful within the NWS, it is being leveraged for other training activities in the US (Satellite Hydrology and Meteorology Courses (SHyMet), and the GOES-R/16 Proving Ground) and is being utilized by the International community in training programs under the World Meteorological Organization (WMO). For more information on the VISIT program, see: http://rammb.cira.colostate.edu/visit/

Specific Objectives:

1--Develop and deliver teletraining, recorded modules, quick guides, quick briefs, job aides, and blog entries on the utilization of new satellite products that are available on AWIPS. This includes collaborating with and offering assistance to the GOES-R and JPSS satellite proving ground projects and other NOAA offices in the development and delivery of training materials.
2--Conduct bi-weekly virtual “FDTD GOES-16 Applications Webinars”.
3—Utilize the NOAA Commerce Learning Center for delivery of recorded modules with quizzes, teletraining registration and training participation metrics.
4--Attend meteorological and education conferences and symposiums and participate in other relevant organizational meetings. Engage in Community Outreach.

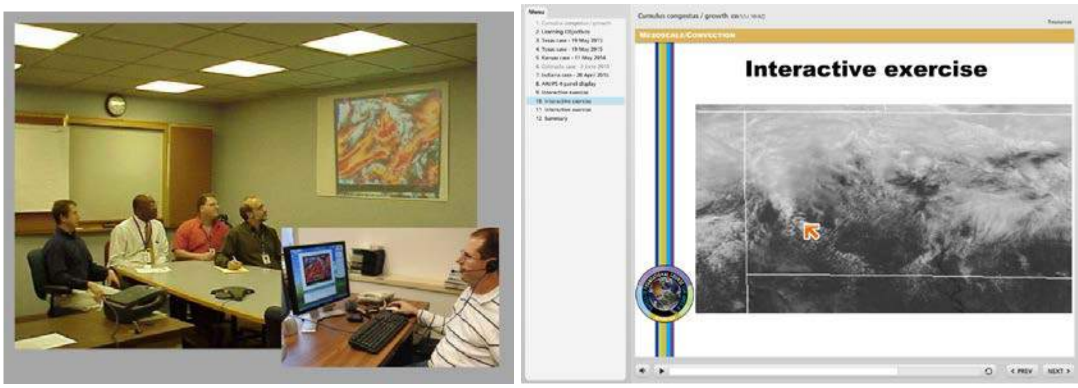


Figure 1. Examples of synchronous training - Live VISIT teletraining (left), and asynchronous training - audio / video playback VISIT training module from SatFC-G course (right).

PROJECT ACCOMPLISHMENTS:

1--Training sessions:

Upon completing 17 modules for the SatFC-G course in 2016, CIRA staff began developing Level 2 applications training as directed by the Satellite Training Advisory Team (STAT). These training items consist of Quick Guides and Quick Briefs, rather than (longer) modules as was used in the SatFC-G course. CIRA has completed 8 Quick Guides / Quick Briefs while 5 are still in progress.

Completed:

--Creating new color enhancements in AWIPS.
--Satellite Color Tables: Ranges.
--Day Land Cloud Convection RGB.
--Color table defaults in AWIPS.
--Infrared satellite enhancement.
--AWIPS remapping, scales, and spatial resolution.
--Day Cloud Phase Distinction RGB.
--Total Precipitable Water product.

In progress:

--Sea Surface Temperature product.
--Day Snow/Fog RGB.
--Differences between imagers on different satellites.
--Feature ID with weighting functions in the pre-convective environment.
--SO_2 RGB.

Other:

--"Advected Layer Precipitable Water product". The VISIT structure was leveraged for this product, which was in collaboration with the Advected Layer Precipitable Water JPSS Proving Ground Risk Reduction Project.

VISIT blog:

--The blog is intended to open the doors of communication between the Operational, Academic and Training Meteorology communities. The blog averages around 360 views per month and is located here: http://rammb.cira.colostate.edu/training/visit/blog/. There were 51 blog entries during the time period of interest with topics that focus on operational applications of GOES-16 and JPSS imagery and products.

2—FDTD GOES-16 Application Webinars / VISIT Satellite Chat:

--Since February 2012, the VISIT team at CIRA and CIMSS has led chat sessions to discuss recent significant weather events with the objective of demonstrating satellite products that can be applied to operational forecasting. Through March 2017, these presentations were known as "VISIT Satellite Chat" sessions. In April 2017 these were renamed to "FDTD GOES-16 Applications Webinar". In addition to increased visibility in coordination with the Forecast Decision Training Division (FDTD), the webinars are led by NOAA/NWS staff to promote peer to peer (SOOs or forecasters training other SOOs or forecasters) training. We collaborated with CIMSS to develop a template and coordinated with presenters to focus on operational usage of GOES-16. Webinars are recorded and made available (at http://rammb.cira.colostate.edu/training/visit/satellite_chat/) so that the community may benefit from these presentations when unable to attend live (example shown in Figure 2):

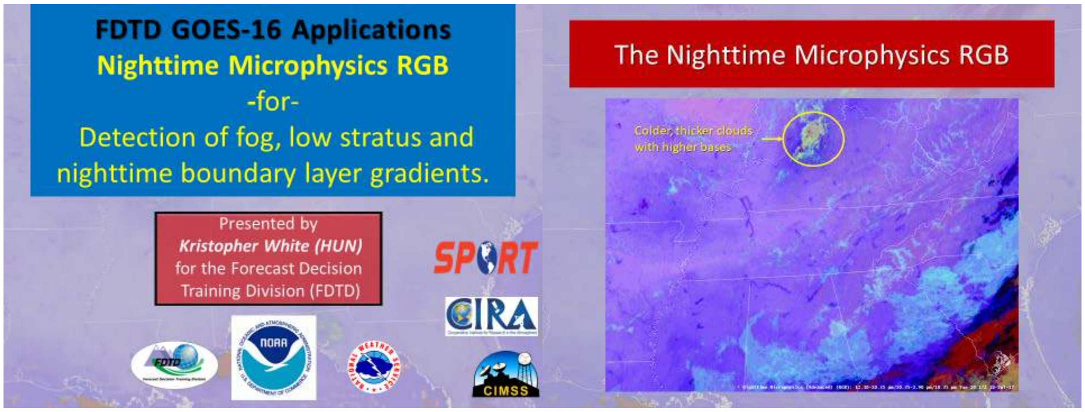


Figure 2. Live FDTD GOES-16 Applications Webinar recording made available on VISIT web-pages.

Examples of webinar topics include GOES-16 operational applications towards convective initiation, heavy snow events, wildfires, fog/low stratus, hail swaths, blowing dust and flooding. Imagery and products from the ABI include single band, band difference products, RGB products in addition to lightning data from the GLM.

In the past year, 18 webinars have been given with a total of 320 office participants (about 18 offices per webinar). WFO participation in the webinars is given in Figure 3.

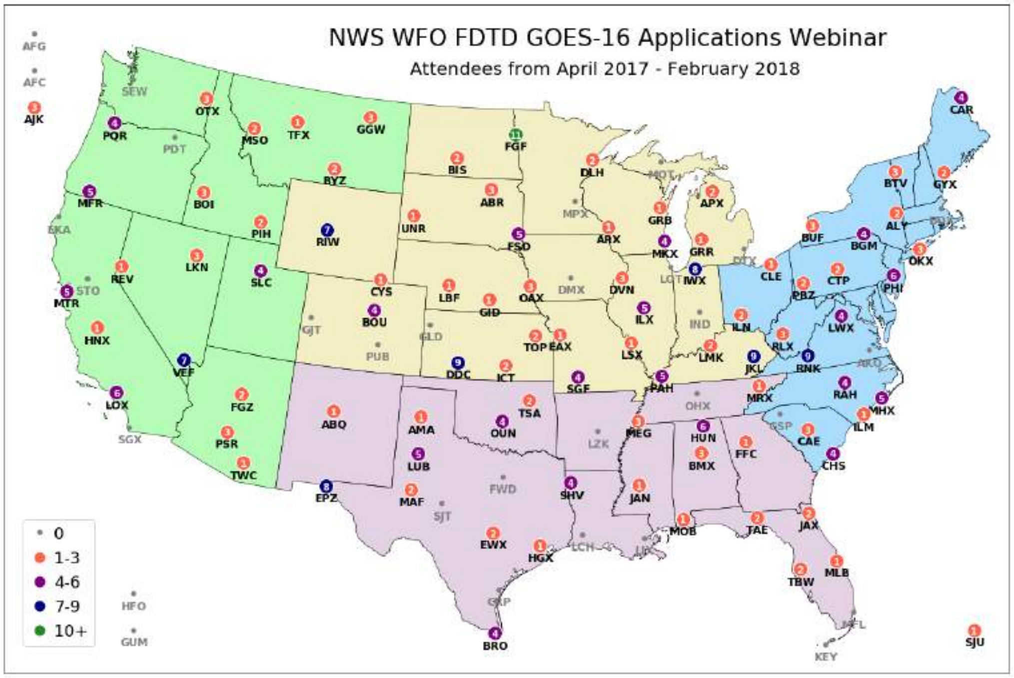


Figure 3. NWS WFO participation in FDTD GOES-16 Applications Webinars April 2017 – February 2018.

3--VISIT training metrics April 1, 2017 – February 19, 2018:

--Live teletraining (not SatFC-G related): 18 sessions delivered to 58 participants.
Audio / video playback (through NOAA's Learning Management System as well as directly through CIRA's web interface): 15,667 participants (mostly SatFC-G modules).

4--Community Outreach at CIRA / Atmospheric Sciences / Colorado State University:

--B. Connell, E. Dagg, and A. Schumacher volunteered for the inaugural "Colorado Weatherfest" on Saturday, 24 June. CIRA led a hands-on demonstration of how to interpret the red, green, and blue components of a camera picture and put them together to create a color image. The SLIDER software was used to show the near "true color" current images from GOES-16.   The event was hosted by the Northern Colorado Chapter of the AMS (FORTCAST) and featured hands-on activities and demonstrations from the CSU Department of Atmospheric Sciences, the National Weather Service in Boulder, the CSU Little Shop of Physics, the Colorado Climate Center, Ball Aerospace, and others.
--E. Szoke gave a weather talk to 4 visiting classes during "8th Grade Science Days" on 17 and 19 October at NOAA in Boulder. Another weather talk was given to a visiting 5th Grade class on 2 November in Boulder.

Publications:

Gitro, C.M., M. Jurewicz, S. Kusselson, J. Forsythe, S. Kidder, E. Szoke, D. Bikos, A. Jones, C. Gravelle, C. Grassotti, 2017: Using the Multisensor Advected Layered Precipitable Water Product in the Operational Forecast Environment. *J. Operational Meteor.*, in review.

Lindsey, D.T., D. Bikos, and L. Grasso, 2018: Using the GOES-16 Split Window Difference to Detect a Boundary Prior to Cloud Formation. *Bulletin of the American Meteorological Society*, in review.

Presentations:

Bikos, D., S. Lindstrom, S. Bachmeier, E. Szoke, B. Connell, C. Gravelle, D. Lindsey, C. Gitro, M. Jurewicz, 2017: VISIT / SHyMet Training on New Applications of GOES-16 Imagery. Poster, National Weather Association (NWA) Annual Meeting, 16-21 September, Garden Grove, California.

Bikos, D., 6 December 2017: Invited lecturer as part of a course at COMET in Boulder, CO for forecasters from the Korean Meteorological Agency. Title of presentation "Himawari-8 Using New Spectral Bands for Meteorological Applications".

Connell, B., E. Dagg, K.-A. Caesar, M. Garbanzo, and D. Souza, 2018: Linking Data Access and Display, Hands on Exploratory Training, and Adaptations for Learners of Various Skill. 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Austin, TX, Amer. Meteor. Soc., 7-11 January 2018. Presentation.

Connell, B., K.-A. Caesar, M. Garbanzo, D. Souza, N. Rudorff, and M. Campos 2018: 17 Years of Interactions between NOAA and the WMO VLab Members in Regions III and IV to Ensure Satellite Usage through Training. Third Symposium on Special Sessions on US-International Partnerships, Austin, TX, Amer. Meteor. Soc., 7-11 January 2018. Presentation.

Connell, B., E. Dagg, A. Trotman, K.-A. Caesar, M. Garbanzo, and D. Souza, 2017: Linking Data Access and Display, Hands-on Exploratory Training, and Adaptations for Learners of Various Skills. 12th International Conference on Creating Activities for Learning Meteorology, Melbourne, Australia, 29 August – 1 September. Presentation.

Connell, B., 2017: NOAA's contributions to International Activities for Training in Satellite Meteorology via the WMO VLab. NOAA Satellite Conference, 17-20 July, New York, NY.

Szoke, E.J., and D. Bikos, 25 April 2017: E. Szoke and D. Bikos were invited to present a GOES-R training seminar at the NWS WFO in Cheyenne, WY on 25 April 2017.

Szoke, E, 6 and 10 April 2017: E. Szoke gave a GOES-R Proving Ground and HRRR talk at the Boulder NWS WFO Spring Workshop.

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Torres and C. Seaman, 2017: Future directions for CIRA's NWS Proving Ground activities now that GOES-16 is operational. Poster, National Weather Association (NWA) 42nd Annual Meeting, 16-21 September, Garden Grove, California.

Szoke, E, 2 and 5 October 2017: E. Szoke gave a GOES-R Proving Ground and HRRR talk at the Boulder NWS WFO Winter Workshop.

Szoke, E., D. Bikos, B. Connell, R. Brummer, H. Gosden, D. Molenar, D. Hillger, S. Miller, D. Lindsey, J. Torres and C. Seaman, 2018: Advancing potential new satellite products into operations: CIRA's NWS Proving Ground plans. Poster, 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, 98th Amer. Meteor. Soc. Annual Meeting, Austin, TX, 7-11 January 2018.

Thomas, J. R., S. Goodman, E. Madsen, J. Peronto, B. Connell, A. Stevermer, K. Mozer, and M. Seybold, 2018: GOES-R Series International Training Working Group. 14th Annual Symposium on New Generation Operational Environmental Satellite Systems, Austin, TX, Amer. Meteor. Soc., 7-11 January 2018. Presentation.

PROJECT TITLE: CSU/CIRA Support for ATMS SI Traceable Calibration Effort

PRINCIPAL INVESTIGATORS: Christian Kummerow, Thomas Vonder Haar

RESEARCH TEAM: Wes Berg (ATS), John Forsythe (CIRA)

NOAA TECHNICAL CONTACT: Satya Kalluri, NOAA NESDIS

NOAA RESEARCH TEAM: Ninghai Sun NOAA/NESDIS/STAR/SMCD

FISCAL YEAR FUNDING: $74,612

PROJECT OBJECTIVES:

Task 1--Intercalibration of NPP and NOAA-20 ATMS Window and Water Vapor Channels

Since the launch of JPSS1 (now NOAA-20) in November of 2017, the ATMS SDR team has been focused on calibration/validation activities for this new instrument. Provisional status for the ATMS TDR/SDR data products was achieved in late January of 2018. Currently the ATMS SDR team is working towards validated status for the ATMS data products at launch plus 6 months, or early May of 2018. While the original Cal/Val efforts focused mainly on the antenna temperature or TDR product, focus has now shifted more towards the SDR brightness temperature data. We have been closely working with the ATMS SDR team to investigate the NOAA-20 SDR product by applying several different intercalibration approaches to compare the resulting brightness temperatures with other sensors, focusing on the NPP ATMS. Figure 1 shows the expected brightness temperature differences between the NPP and NOAA-20 ATMS window and water vapor sounding channels (1-2 and 16-22) based on the pre-launch spectral response characterization. The density plots showing these differences in Figure 1 are based on a full day of geophysical profiles from the ECMWF ERA5 reanalysis dataset. For most of the channels the differences are within a few hundredths of a Kelvin, but there are differences of up to several tenths of a Kelvin for the 183+/-7 (channel 18) and 183+/-3 GHz (channel 20) channels. Note that there is a bit of uncertainty in the spectral response as only one side of the dual-passband 183 GHz channels was measured for the NPP ATMS and only broadband measurements were available for the NOAA-20 ATMS water vapor sounding channels due to last minute rework of multiple instrument components.

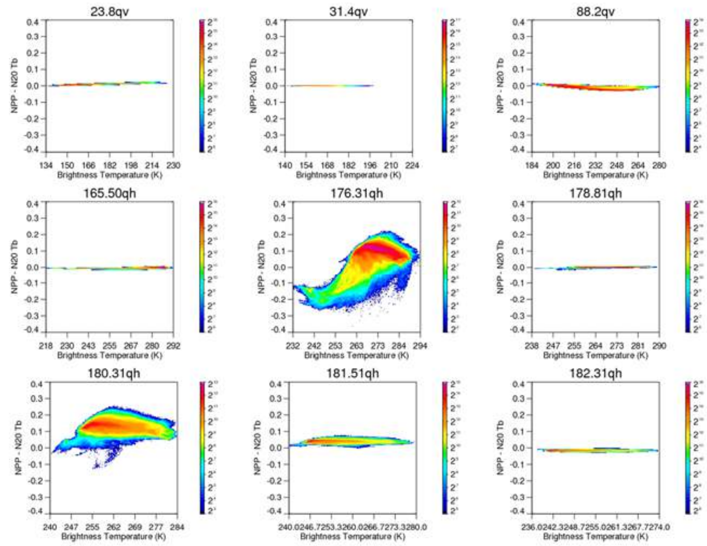


Figure 1. Difference in expected brightness temperatures between NPP ATMS and NOAA-20 ATMS for the window and water vapor sounding channels (i.e. channels 1-2 and 16-22).

Using geophysical profiles from the recently released ERA5 reanalysis and the spectral response information for NPP and NOAA-20 ATMS, simulated minus observed brightness temperatures were computed for both instruments. The results are shown in Figure 2. While the agreement in the calibration for the window channels (channel 1-2) is quite good, there are differences of up to 2.5 Kelvin for some of the water vapor sounding channels. Note that this simple approach comparing observed and simulated brightness temperatures is susceptible to errors in the radiative transfer models (i.e. atmospheric absorption and ocean emissivity), errors in the assumed geophysical parameters (i.e. ERA5 reanalysis), and limitations of the screening used. The advantage of a single difference approach like this is the use of all of the available data, as opposed to double differencing approaches that use only coincident observations between sensors. The primary disadvantage is that errors in the simulated Tb may not cancel out as they largely do for coincident scenes. Table 1 shows a comparison of the mean NPP vs. NOAA-20 ATMS calibration differences based on this single difference approach versus two double differencing approaches using coincident observations with GPM GMI and Megha-Tropiques SAPHIR. There is very good agreement in the single difference results versus the SAPHIR-based results, however, SAPHIR only has water vapor sounding channels near the 183 GHz water vapor line. Comparisons with GMI-based double differences are also fairly consistent, although many of the coincident matchups are at higher latitudes and there are significant differences in the channel specifications, especially since GMI is a conical-scanning radiometer.

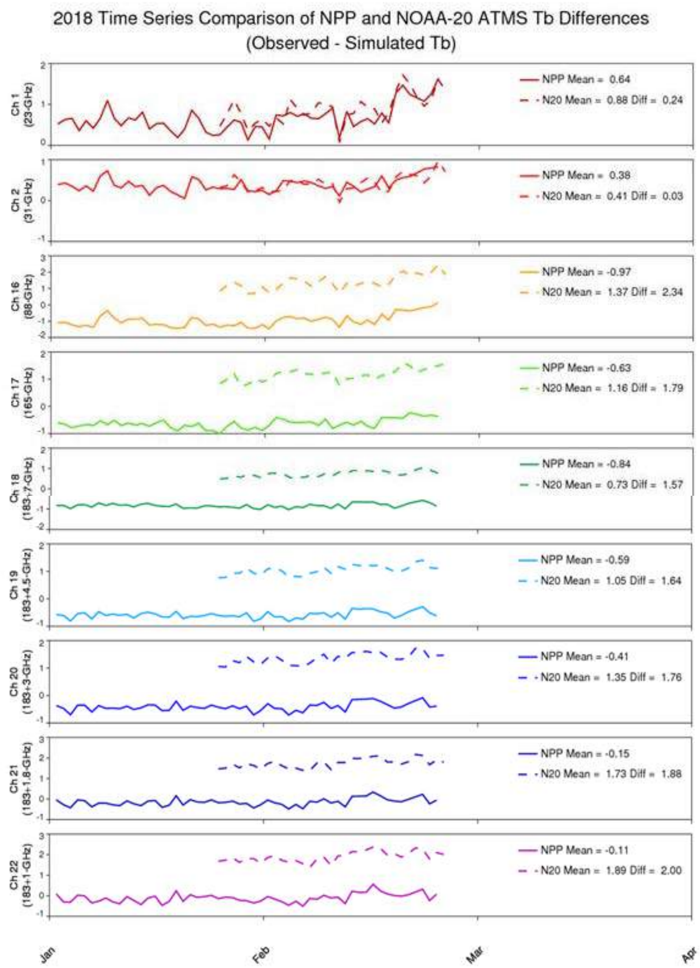


Figure 2. Daily mean observed minus simulated brightness temperatures for 2018 from NPP and NOAA-20 ATMS for the window and water vapor sounding channels. The data have been filtered to include only non-precipitating ocean scenes with minimal variability within a 1x1 degree lat/lon box.

Channel	Single Differences (K)	GMI Double Differences (K)	Saphir Double Differences (K)
1) 23 GHz	0.21	0.00	-
2) 31 GHz	0.01	0.12	-
16) 88 GHz	2.29	2.09	-
17) 165 GHz	1.76	1.58	-
18) 183+/-7.0 GHz	1.55	1.60	1.63
19) 183+/-4.5 GHz	1.61	1.47	1.66
20) 183+/-3.0 GHz	1.74	1.59	1.83
21) 183+/-1.8 GHz	1.86	1.74	1.90
22) 183+/-1.0 GHz	1.99	1.92	2.06

Table 1. Intercalibration differences for the NPP vs. NOAA-20 ATMS window and water vapor sounding channels based on three different approaches. These include 1) single differences (i.e. observed minus simulated Tb) that are not matched in space and time, and double differences based on coincident observations for 2) GPM GMI and 3) Megha Tropiques SAPHIR.

The results shown here are preliminary as they are based on just over 1 month of data. The NOAA-20 ATMS SDR correction table was updated on January 23, 2018, so only data past that date can be used for validation purposes. These results have been shared with the full ATMS SDR team, which is working to investigate the SDR corrections using both pre-launch data as well as data from calibration maneuvers done after launch. We will continue to work with the ATMS SDR team to meet the early May deadline for validated data release. Ongoing intercalibration activities will include 1) extending the analysis with additional data, 2) investigating differences in cross-scan biases between NPP and NOAA-20, and 3) verifying subsequent changes to the SDR corrections using the techniques discussed here. Note that these results will also be used to potentially investigate issues with the NPP SDR corrections.

Task 2--Demonstration of a Global Total Precipitable Water Climate Data Record

Water vapor surpluses and deficits are a key factor in high-impact hydrological events such as floods and droughts. It is expected to increase at rate of roughly 7 % per 1 K increase in atmospheric temperature over the oceans. These water vapor increases are further expected to add a positive feedback to greenhouse forcing, at a rate of about +2.0 to +2.8 $Wm^{-2}K^{-1}$.
Climate models predict that heavy rain events will become more intense with more extreme precipitation due to this increased water vapor.

NOAA and CIRA scientists produce and maintain an operational, near-global, multisensor blended Total Precipitable Water (TPW) product for forecasters, which is widely used by NWS. A rich variety of sensors including passive microwave sensors like ATMS are used in this product. NOAA does not produce a similar water vapor product for climate research and monitoring and characterization of extreme events. The second task in this project builds upon the creation of stable, calibrated radiance records from passive microwave instruments to break ground for a water vapor climate data record.

The NOAA Microwave Integrated Retrieval System (Boukabara et al. 2011) is producing water vapor retrievals in near-realtime, and could potentially be used for a climate record. An example of MiRS Version 11 TPW retrievals from the ATMS instruments on Suomi-NPP and newly available NOAA-20 retrievals (preliminary, non-operational data) is shown in Figure 3. Only the portions of the swath which overlap are shown. Suomi-NPP samples 50 minutes before NOAA-20.

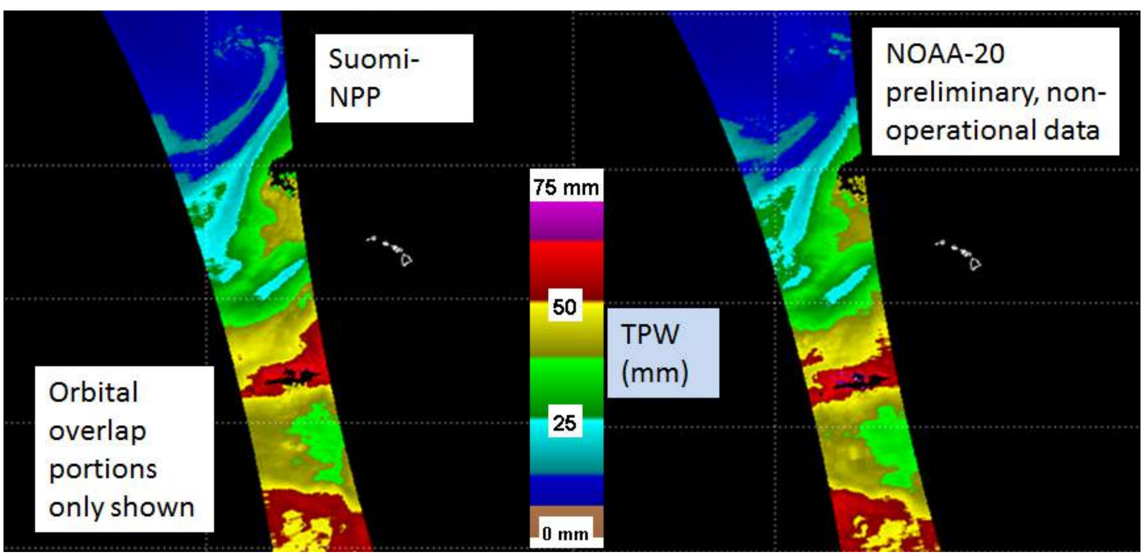


Figure 3. TPW retrievals from portions of Suomi-NPP and NOAA-20 overpasses which overlap on March 2, 2018, 0054 UTC. Black areas are outside of the overlap or not retrieved due to precipitation flagging.

A scatter plot of the overlapping regions is shown in Figure 4. These early results from NOAA-20 show excellent agreement with minimal bias. NOAA-20 retrievals will likely be adjusted slightly as improved radiance bias corrections are implemented in 2018.

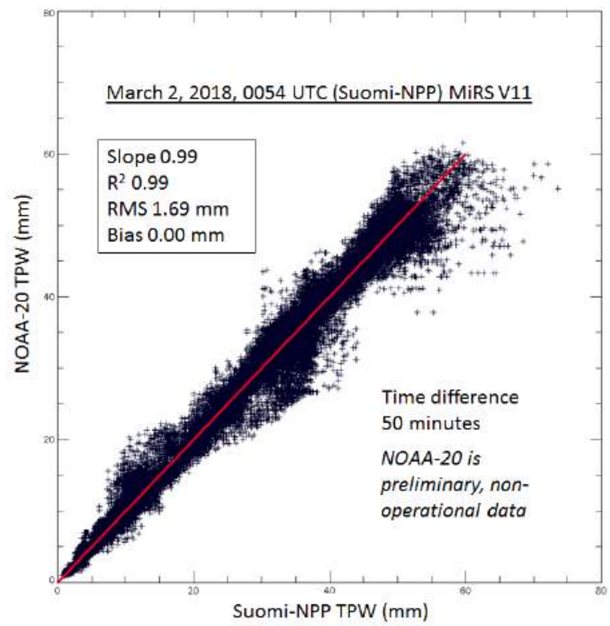


Figure 4. Scatter plot of the overlapping Suomi-NPP and NOAA-20 TPW retrievals shown in Figure 3.

The TPW retrieval from the Duncan and Kummerow (2016 – DK 2016) 1DVAR retrieval for a portion of NOAA-20 data swath from Fig. 3 is shown in Fig. 5. The DK 2016 TPW retrieval from GMI shows performance which rivals benchmark products, with RMS errors of < 3 mm. In the case of the new NOAA-20 retrieval, the bias is about -4 mm. This likely indicates that further radiance intercalibration is needed. These efforts provide the groundwork to create future multidecadal water vapor datasets with the 1DVAR retrieval and a variety of heritage passive microwave sensors.

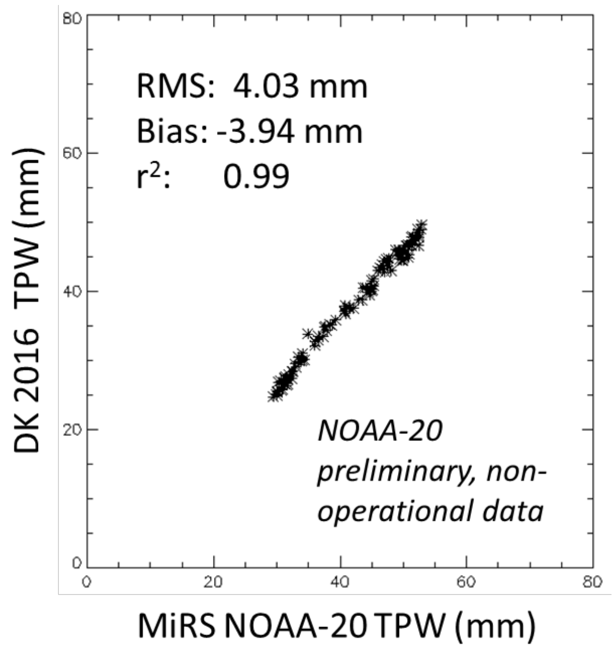


Figure 5. Comparison of TPW retrieved from MiRS V11 from NOAA-20 and the Duncan and Kummerow (DK 2016) 1DVAR retrieval from 02 March 2018.

PROJECT TITLE: JPSS-1 Readiness for Blended Hydrometeorological Products

PRINCIPAL INVESTIGATOR: Andrew Jones

RESEARCH TEAM: Stan Kidder, John Forsythe

NOAA TECHNICAL CONTACT: Limin Zhao (NESDIS/OSPO/SPSD/SPB)

NOAA RESEARCH TEAM: Limin Zhao (NESDIS/OSPO/SPSD/SPB), John Paquette (NESDIS/OSPO/SPSD), Ralph Ferraro (NESDIS/STAR/CRPD/SCSB), and others

FISCAL YEAR FUNDING: $128,103

PROJECT OBJECTIVES:

Update the operational Blended Total Precipitable Water (TPW) and Blended Rain Rate (RR) products with JPSS-1 capabilities in real time at ESPC.

Single sensor products are generated via NOAA's Microwave Integrated Retrieval System (MiRS). The MiRS system ingests passive microwave radiances from a variety of sensors and retrieves atmospheric moisture, temperature and hydrometeor profiles. Among many retrieved atmospheric variables, MiRS-derived total precipitable water (TPW) and rain rate (RR) are used in multisatellite blended products to create analysis fields for National Weather Service (NWS) forecasters. This work blends these single sensor viewpoints, intercalibrates the sensors dynamically in near real-time, and performs needed corrections to improve the product quality for NWS forecaster use.

PROJECT ACCOMPLISHMENTS:

The Development Phase for this project began in September 2017. The milestones through the reporting period and how they were accomplished are as follows:

Sep 17: Develop the access capability to PDA from CIRA, using S-NPP data as a test of the JPSS-1 PDA data flows to CIRA.

Access to PDA has been a challenge. CIRA accesses PDA data via STAR PDA linkages as direct PDA linkages from CIRA were prohibited by new NESDIS policies. Thus, STAR is facilitating our linkages to PDA via an indirect data transfer from PDA to STAR to CIRA. This is our new “normal” for research data access to PDA. These data are pushed to CIRA in an automated manner by STAR, and involved CIRA setting up a separate hardware system to receive the PDA data set push from STAR. Various data sets are being transitioned to the PDA (STAR to CIRA) data push, and only recently (Feb. 2018) have MiRS V11 data been made available to CIRA. To mitigate these issues on our project’s required tests, CIRA has made use of numerous OSPO test data sets made available to us via non-PDA transfer means. These measures are temporary, but have allowed the project to continue with its successful milestone progress.

Oct 17: Bring new hardware online at CIRA

Due to the PDA access delays, the project hardware purchase was temporarily delayed. This was fortunate, as now the project is expecting to reduce hardware costs via lease of disk drive storage on CSU’s new centralized mass data storage system. This mass storage system is locally installed at CSU and has an initial 370+TB capacity and is expandable to 90PB. The costs are estimated to come in at $70/TB/yr. The CSU mass data storage system has been successfully installed and is now undergoing tests. This NOAA project has been one of the first projects at CSU to successfully test the new CSU mass storage system. CSU is now working to commission the system as “production worthy”, as well as institute a chargeback quota system for research project use. If the system commissioning is delayed we plan to continue with our original hardware purchase plans, but at this time the tests of the CSU storage performance appear adequate for our purposes.

Nov 17: Start prototype development of software for processing JPSS-1 data at CIRA focusing on data flows.

Development was started on schedule.

Jan 18: Expect first JPSS-1 MiRS test data available

We received our first NOAA-20 (JPSS-1) data on 18 January 2018. NOAA-20 data was not originally available in near-real-time as the data was in the "preliminary, non-operational" stage as of February 2018. Archives with one-day latency are available, as once-a-day, the MiRS system at NESDIS processes all the data for the previous day and packages them in a 3 GB TAR file.

Jan 17: Test software for processing near real-time JPSS-1 data at CIRA.

The ingest software has been written and tested using static data sets. Real-time testing awaits full implementation of the new PDA pushed data from STAR, which is currently being implemented at CIRA, as it became just recently available to us (late Feb. 2018).

Feb 17: Near-real time ingest of JPSS-1 MiRS experimental data completed at CIRA

This work is currently underway, having just recently received access to the STAR PDA near real-time data sets.

Mar 17: Test case processed for TPW and RR.

We have completed a test case. The following figure (Figure 1) shows the Total Precipitable Water for one orbit of NOAA-20. One problem remains to be solved: The NOAA-20 MIRS data are currently only available in 32-second (12 scan line) granules, 188 granules (files) per orbit. Suomi NPP files are also available in 33-minute granules, 3 files per orbit. Timing tests show that it takes 20 times as long to process one orbit of NOAA-20 data as it does to process one orbit of Suomi NPP data. This is makes real time DPEAS processing more difficult. In order to implement real time processing at NESDIS, we will have to get 33-minute NOAA-20 files from NESDIS (as is done for SNPP), or we will have to develop code to create the 33-minute files from the 32-second NOAA-20 data files.

Publications: None

Presentations: None

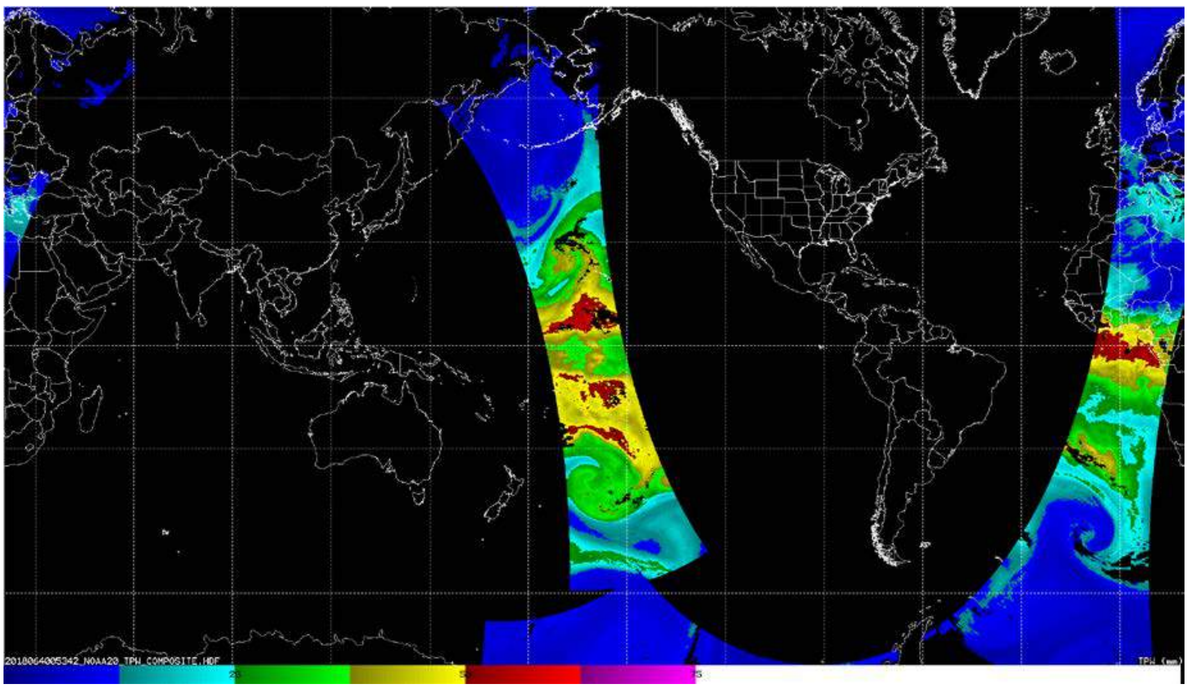


Figure 1. Total Precipitable Water (TPW) for one orbit of NOAA 20 data on 02 March 2018.

PROJECT TITLE: NESDIS Environmental Applications Team, I-Wen Chu – Research Scientist

PRINCIPAL INVESTIGATORS: Steven Miller, Cliff Matsumoto

RESEARCH TEAM: Mike Chu (CIRA/CSU)

NOAA TECHNICAL CONTACT: Menghua Wang (NOAA)

NOAA RESEARCH TEAM: Menghua Wang (NOAA)

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVES:

--Continue with post-launch analysis of NOAA-20 VIIRS, specifically in collaboration with Dr. Junqiang Sun, analyze critical calibration functions and results as well as study new topics necessary for NOAA-20 VIIRS.
--To evaluate the early mission radiometric performance of NOAA-20 VIIRS reflective solar bands, and conduct inter-sensor comparison analysis referencing to other sensors.
--To continue to evaluate and examine SNPP VIIRS bands as in prior years.
--To complete the two-year evaluation/validation of the Sentinel-3 OLCI radiometric performance via intersensor comparison methodology referencing to the OC SDRs. This requires further code development, more detail examinations of data including the geolocational variations which are not trivial for the "nadir-tilted" Sentinel-3 OLCI.
--To continue misc research topic, numerous of which also with Dr. Junqiang Sun, on the calibration of multispectral sensors and the evaluation/validation of instrument radiometry

PROJECT ACCOMPLISHMENTS:

--Completed the evaluation of the sensor data record for SNPP VIIRS M1-M8 generated by the team and validated its accuracy to mid-2016 (Submitted for publication). Article published.
--Successfully evaluated the performance stability of SNPP VIIRS M11 using a newly conceived approach over snowy scenes. Article published.
--Developed, in collaboration with Dr. Junqiang Sun, a new variant of the current standard calibration methodology for reflective solar bands of SNPP VIIRS using the scattered light through the nadir-port. Article published.
--Developed, in collaboration with Dr. Junqiang Sun, another new variant of the current standard calibration methodology for reflective solar bands of SNPP VIIRS using the full profile of the direct solar illumination that extends the angular range of the standard calibration methodology. Article submitted.
--In progress of the evaluation of the radiometric evaluation of Sentinel-3 OLCI, and had successfully evaluated the first year performance of Band OaO2.
--Participated in the post-launch discussions and activities for the calibration of NOAA-20 VIIRS, and had worked, also in collaboration with Dr. Junqiang Sun,

Publications:
Chu, M., J. Sun, and M. Wang: Radiometric evaluation of the SNPP VIIRS reflective solar band sensor data records via inter-sensor comparison with Aqua MODIS. J. Atmos. Ocean. Technol., 35, 385-403 (2018).

Chu, M., J. Sun, and M. Wang: Radiometric Evaluation of SNPP VIIRS Band M11 via Sub-Kilometer Intercomparison with Aqua MODIS Band 7 over Snowy Scenes. Remote Sens. 10, 413 (2018).

Sun, J., M. Chu and M. Wang: Visible Infrared Imaging Radiometer Suite reflective solar bands on-orbit calibration using solar diffuser illuminated by scattered light through the nadir port, Appl. Opt., 57, 273-1283 (2018).

Conference Proceedings:

2017 Optics and Photonics, San Diego, CA; 2-5 August 2016:

Chu, M., J. Sun, and M. Wang: The curious case of the intersensor radiometric comparison of SNPP VIIRS M11 with Aqua MODIS B7, Proc. SPIE 10402, Earth Observing Systems XXII, 104022E (2017). doi:10.1117/12.2272434

Chu, M., J. Sun and M. Wang: The inter-sensor radiometric comparison of SNPP VIIRS reflective solar bands with Aqua MODIS updated through June 2017, Proc. SPIE 10402, Earth Observing Systems XXII, 1040222 (2017). doi:10.1117/12.2272437

Sun, J., M. Chu, and M. Wang:. RSB calibration of SNPP VIIRS using solar diffuser illuminated by scattered ligh", Proc. SPIE 10402, Earth Observing Systems XXII, 104021Y (2017). doi:10.1117/12.2272898

* Presented 3 posters in the local NOAA Annual JPSS Science Team Meeting 14-18 Aug 2017

PROJECT TITLE: NESDIS Environmental Applications Team, Yanni Ding – Post Doc

PRINCIPAL INVESTIGATOR(S): Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Yanni Ding

NOAA TECHNICAL CONTACT: Alexander Ignatov

NOAA RESEARCH TEAM: Alexander Ignatov, Irina Gladkova, Kai He, Matthew Pennybacker, Yury Kihai, Boris Petrenko, Peter Hollemans

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVE:

Sustain and improve NOAA ACSPO (Advanced Clear-Sky Processor for Ocean) Regional Monitor for SST (Sea Surface Temperature) system (ARMS); Develop and optimize ACSPO Level 3U (U=Uncollated) (L3U) code for all ACSPO L2 SST products.

PROJECT ACCOMPLISHMENTS:

ACSPO Regional Monitor for SST (ARMS):

During the reporting period, ARMS (www.star.nesdis.noaa.gov/sod/sst/arms/) was updated to version 2.1.

The ARMS system was initially designed to monitor the performance of ACSPO polar SST products in selected challenging regions of the ocean, including dynamic and coastal zones, cloudy areas, and high latitudes. The polar platforms and sensors monitored in ARMS include VIIRS onboard S-NPP, MODISs onboard Terra and Aqua, and AVHRRs onboard multiple NOAA and Metop satellites. For Metop A/B, both GAC and FRAC products are included.

In ARMS versions prior to 2.1, one ACSPO geostationary platform (AHI onboard Himawari-8) was monitored. Furthermore, several level 4 (L4) datasets (including JPL MUR, Met Office OSTIA and NOAA Geo Polar Blended) have been added, for comparison purpose only. Users can compare the selected polar SST to the L4 SST of the same day or geostationary SST of the closest UTC.

In ARMS v2.1, two modules (polar and geostationary) have been added (Figure 1). The polar page is same as in previous versions. In the geostationary page (Figure 2), the new ACSPO L2 collated (L2C, data aggregated in hourly interval) geostationary SST products (AHI onboard Himawari-8, and ABI onboard GOES-16) are presented in 10 regions for AHI and 12 regions for ABI. Gridded L3U/L3C counterparts corresponding to L2P/L2C SSTs are also available. Users can monitor the continuous hourly SST evolution by clicking the middle blue button under the image.

In addition to the incorporation of geostationary module, the number of monitored regions has increased from 21 to 29. Eight new regions were added per users' request, including five regions around the Australia, Great Lakes, East China Sea and Georges Bank/Nantucket Shoals. A complete line of L3U SSTs is available for all ACSPO polar L2 products.

In ARMS v2.1, the SSES (Single-Scanner Error Statistics) bias corrected SST and ΔSST (SST minus reference SST) have been added. The SSES bias correction reduces errors in SST due to regional biases, effects of residual cloud, view zenith angle and diurnal warming, and brings it closer to in situ SSTs. Users can examine the performance of SSES bias by checking and unchecking the "SSES bias correction" button.

Moreover, another overlay for the "front mask" (which is a new layer in the next version of ACSPO product) is being explored in one of the ARMS testing pages. By checking this button, the location of thermal front will appear. The "front mask" button will be enabled once the new ACSPO data is ready.

For the "Compare to" part, one high-resolution global L4 SST, Canadian Met Centre, CMC 0.1º SST, and one regional L4 product, Australian Bureau of Meteorology (BoM), RAMSSA, have been added, bringing the total number of available L4 SSTs in ARMS to five. Meanwhile, a new layer, Level 3 super-collated (L3S; L3U data from different sensors are remapped and aggregate), is included. Currently we present two BoM L3S products: generated from AVHRR only, and the other one which additionally uses VIIRS.

VIIRS onboard NOAA20 images are ready but only visible in internal page according to the data policy. Images of GOES-17 will be added once data are ready.

The ARMS system was presented at the joint 1st BoM-NOAA SST Workshop in Melbourne, Australia, in April 2017; in the 18th GHRSST meeting in Qingdao, China, in June 2017; in the JPSS Annual Meeting in College Park, MD, in August 2017, and in several JPSS and GOES-R Reviews.

ACSPO Level 3 Uncollated (L3U) Code:

The ACSPO L3U code is updated to v3 during the reporting period. In previous L3U versions, only VIIRS L3U SST product was reported. In v3, a consistent line of L3U products has been launched for all 9 ACSPO polar and 2 geostationary ACSPO L2P SSTs. The resolution for L3U v3 is uniformly 0.02º (~2km, around equator) for all sensors. The L3U data are reported in the same time internal as in L2P, with a significantly smaller data size (for example, 0.4 GB/day for L3U compared to ~27 GB for VIIRS L2P).

The L2P-to-L3U (swath-to-equiangular) code employs the same algorithm for all high-resolution sensors, i.e. bi-lateral weighted averaging approach, but adjusting window size and the weighting parameters depending on the sensor. The SST value at each grid cell is computed based on spatial proximity to the cell, as well as the proximity of the SST value to a median SST of the spatially-close L2 swath values. This approach is known to better reduce noise, while preserving the edges, thus minimizing distortions to the high-resolution SST structure in swath L2P data. For low-resolution L2P data (AVHRR GAC), it is first upscaled to FRAC resolution using a Gaussian kernel-based interpolation technique. After that, the same bi-lateral weighted averaging approach is applied.

The L3U v3 code is able to process both L2P and L2C geostationary data.

The whole set of L3U v3 data (both polar and geostationary) is continuously monitored and tested in the NOAA SQUAM system (https://www.star.nesdis.noaa.gov/sod/sst/squam) and regionally in ARMS system (https://www.star.nesdis.noaa.gov/sod/sst/arms). The L3U v3 SST shows global statistics similar to those of the corresponding L2Ps when compared to L4 (CMC). All discrepancies between ACSPO L3U and L2P are minimized. Figure 3 is one example from VIIRS L2P and L3U on Dec. 28, 2017. The clear-sky ratio (P) is similar between L2P and L3U. The standard deviation (SD) for L2P is comparable/slightly smaller than that for L3U in both daytime and nighttime. This trend is consistent in time for all platforms and sensors regardless of original L2 resolution and orbit type. However, for geostationary sensors, the magnitude of L3U diurnal cycle is ~10% smaller than L2.

The spatial features and data sharpness and spatial pattern in L2P are well preserved in L3U v3 for both polar and geostationary satellites (Figure 4), including the SST gradients, front location *etc*. The upscaling process for AVHRR GAC brings the original low-resolution SST image much closer to the high-resolution AVHRR FRAC (Figure 5).

Next step, we will work on applying the upscale process to geostationary L2 data. The resolution for AHI and ABI is high at nadir (~2 km) but low at the end of swath, where the satellite zenith angle and footprint are much larger than nadir. Another optimization of the L3U code would be bring the current smaller diurnal cycle of L3U geostationary data closer to L2.

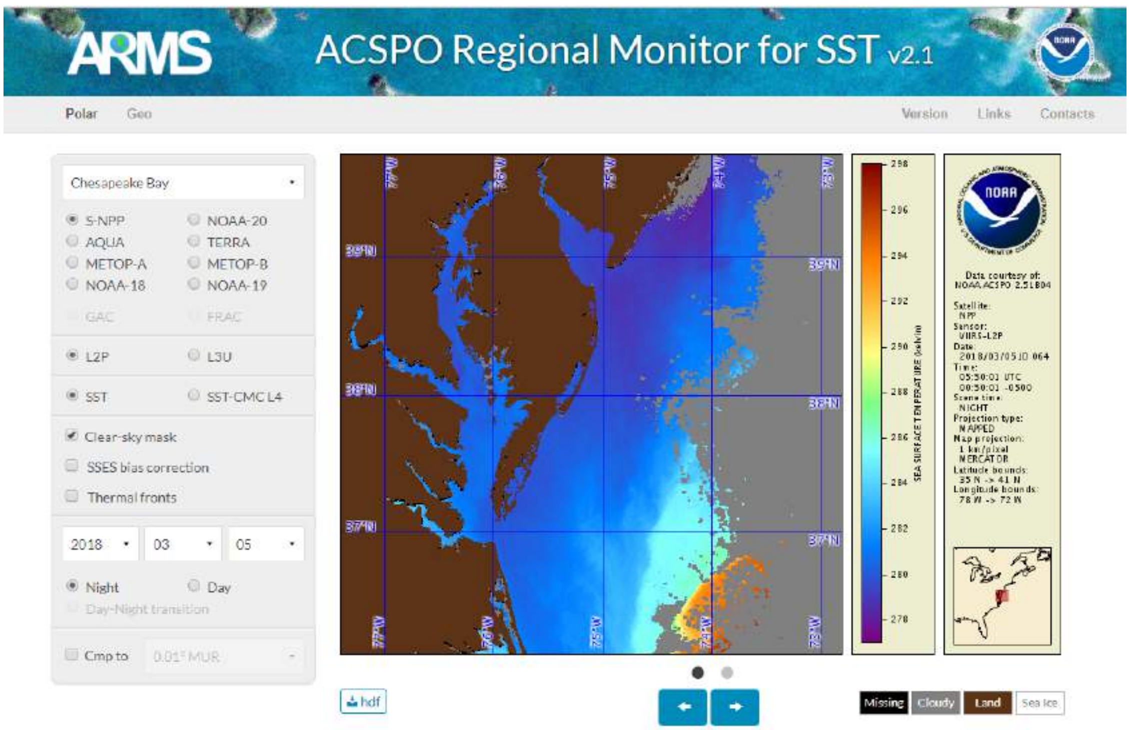


Figure 1. Screenshot of the ARMS system version 2.1 polar page (default).

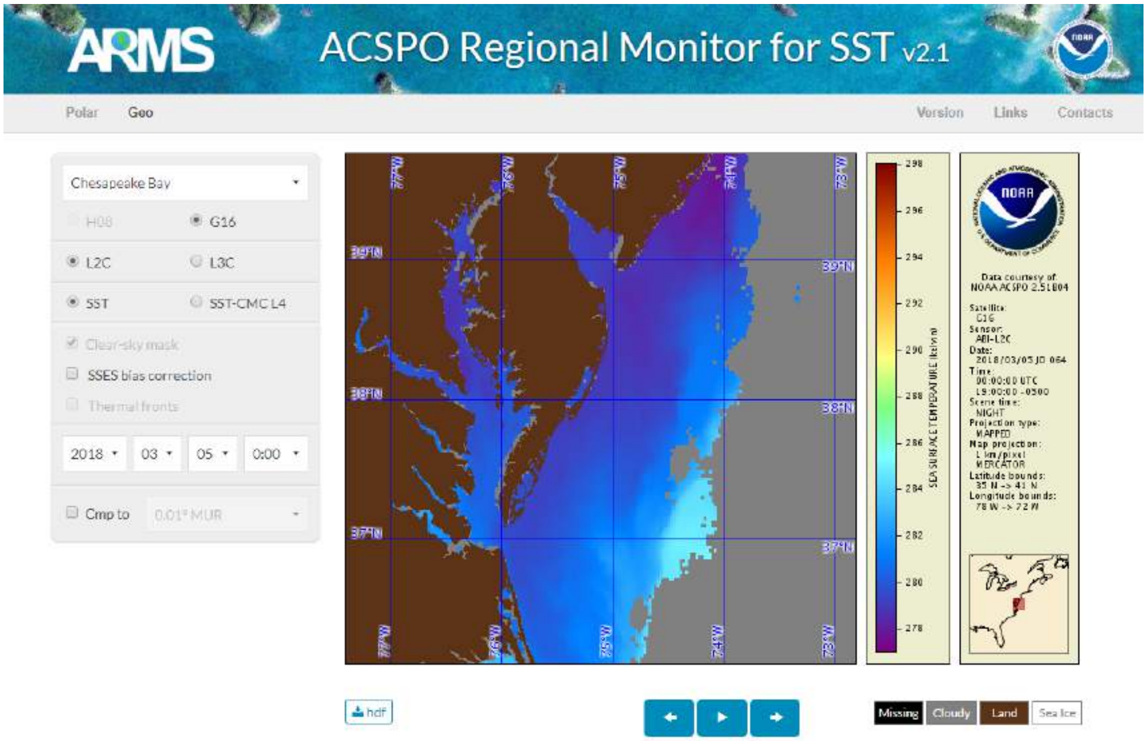


Figure 2. Screenshot of the geostationary page for the ARMS system version 2.1.

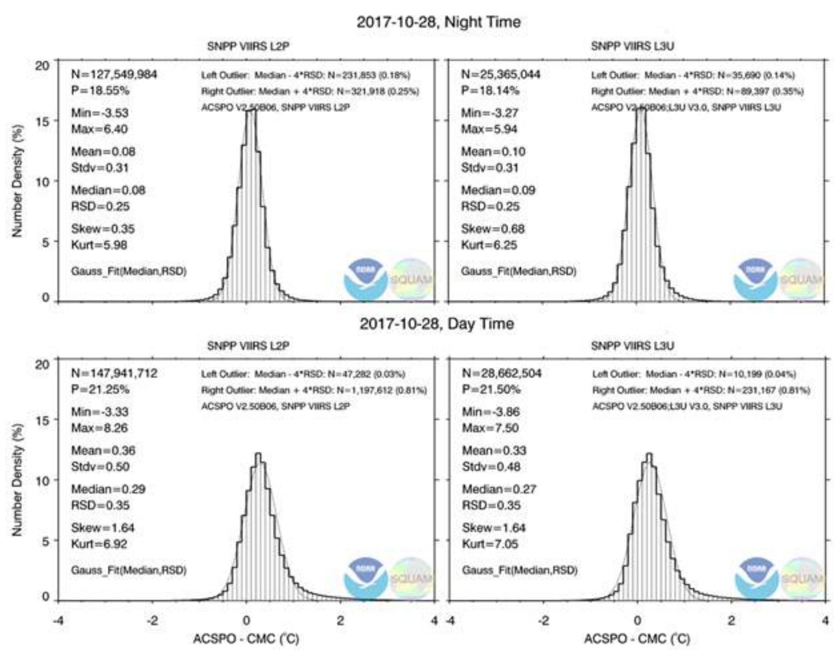


Figure 3. Histogram of differences between VIIRS L2P SST and CMC L4 SST (left panels), and between L3U SST and CMC L4 SST (right panels), nighttime (top) and daytime (bottom) separately.

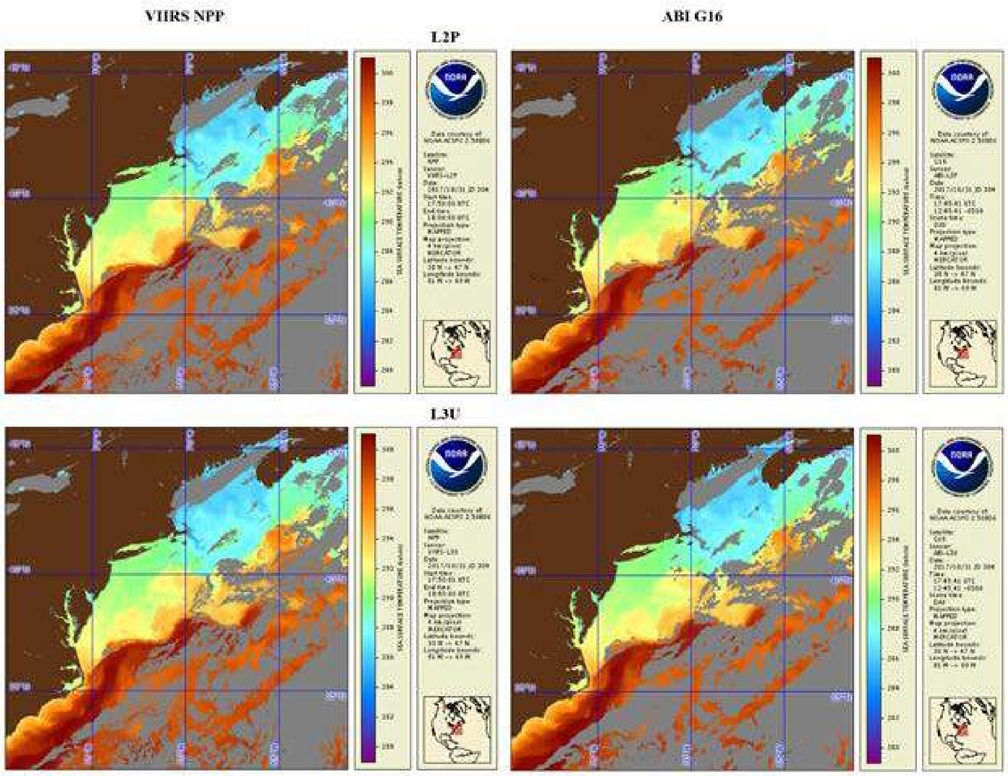


Figure 4. An example showing VIIRS L2P SST (top left) and L3U v3 product (bottom left), and ABI L2P SST (top right) and L3U v3 product (bottom right) over Middle Atlantic Ocean.

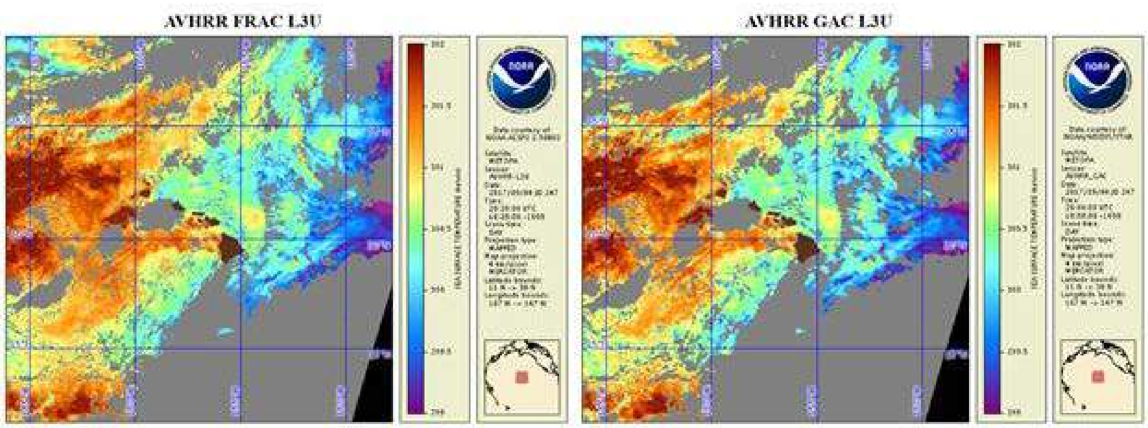


Figure 5. An example showing AVHRR FRAC L3U v3 SST (left) and AVHRR FRAC L3U v3 SST (right) around Hawaii Islands.

Publications and Presentations:

Ding, Y., A. Ignatov, M. Grossberg, I. Gladkova, and C. Chu: ARMS: Advanced Clear-Sky Processor for Ocean (ACSPO) Regional Monitor for SST, 1st BoM-NOAA SST Workshop, Apr. 2017, Melbourne, Australia.

Ding, Y., A. Ignatov, M. Grossberg, I. Gladkova, and C. Chu: Toward Regional Validation and Potential Enhancements to NOAA Polar SST Products, 18th GHRSST meeting, Jun. 2017, Qingdao, China.

Ding, Y., A. Ignatov, M. Grossberg, I. Gladkova, and C. Chu: ARMS: Advanced Clear-Sky Processor for Ocean (ACSPO) Regional Monitor for SST, 2017 JPSS Annual Science Team Meeting, Aug. 2017, College Park, MD.

Ignatov, A., B. Petrenko, Y. Kihai, I. Gladkova, X. Zhou, Y. Ding et al.: Satellite SST Products at NOAA, EUMETSAT Conference, Oct. 2017, Rome, Italy

Ignatov, A., B. Petrenko, Y. Kihai, I. Gladkova, X. Zhou, Y. Ding et al.: VIIRS SST: from SNPP to J1, JPSS Science Meeting, Nov. 2017, Vandenberg AFB, CA.

PROJECT TITLE: NESDIS Environmental Applications Team, Lide Jiang – Research Scientist

PRINCIPAL INVESTIGATORS: Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Lide Jiang

NOAA TECHNICAL CONTACT: Menghua Wang, STAR/SOCD/MECB

NOAA RESEARCH TEAM: Menghua Wang

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVES:

1--VIIRS/SNPP project support, including VIIRS ocean color Level-1 -> Level-2 -> Level-3 data processing, reprocessing and distribution

2--NOAA-20 VIIRS project support, including VIIRS ocean color Level-1 -> Level-2 -> Level-3 data processing

3--Implement new sensor processing capability in MSL12 and produce ocean color products

4--Implement new and improved ocean color algorithms in MSL12 and apply them to ocean color related studies

5--Near-real-time and science quality ocean color data support

PROJECT ACCOMPLISHMENTS:

1--VIIRS/SNPP project support, including VIIRS ocean color Level-1 -> Level-2 -> Level-3 data processing, reprocessing and distribution:

a--Began the routine of daily generation of science quality near-real-time data stream for VIIRS ocean color products based on STAR ocean color team's calibration;

b--Finished the second mission-long reprocessing for VIIRS-SNPP ocean color products including newly added I-band normalized water-leaving radiance and quality assessment product QA score. In addition, improvements include using sensor data with ocean color calibration version 4.0 and re-derived vicarious gains, as well as improved NO_2 correction and non-negative spectral adjustment. Develop an online tool to monitor F-factor and F-factor ratio for various versions of ocean color SDR and IDPS SDR of VIIRS-SNPP.

2--VIIRS/NOAA-20 project support, including VIIRS ocean color Level-1 -> Level-2 -> Level-3 data processing, reprocessing and distribution:

a--Began the routine of daily generation of near-real-time VIIRS ocean color data as early as December 13, 2017 (Figure 1);

b--Identified early launch issues and prelaunch LUT inaccuracies through routine monitoring;

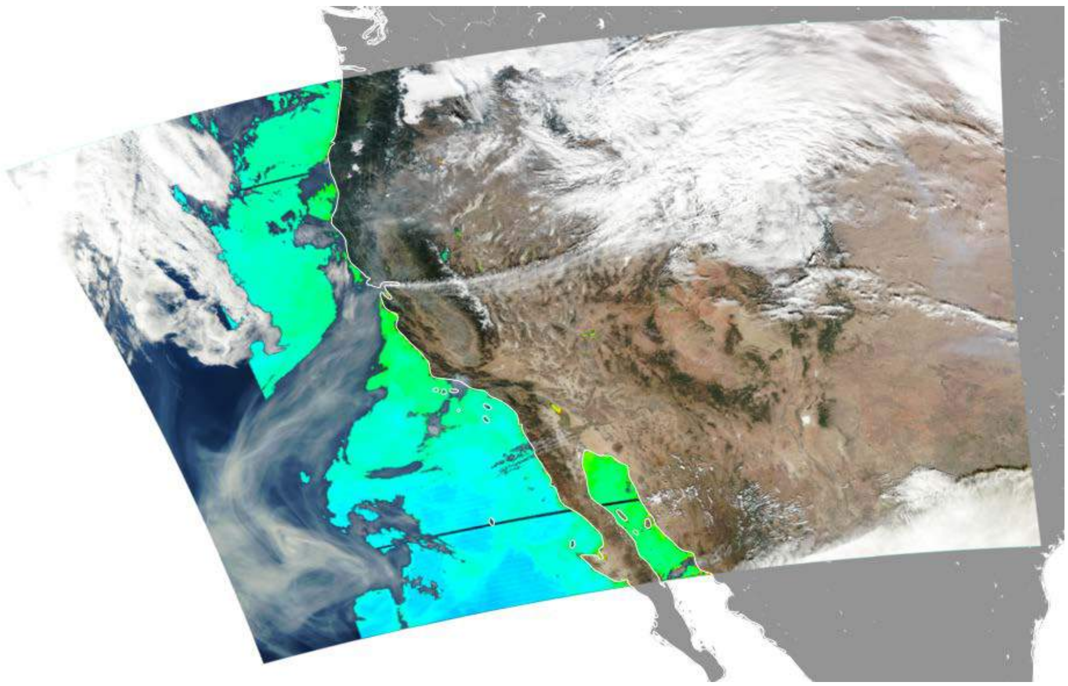


Figure 1. VIIRS/NOAA-20 Chlorophyll-a image near U.S. west coast on December 13, 2017 overlaid on true color

3--Implement new sensor processing capability in MSL12 and produce ocean color products

a--Integrated VIIRS/NOAA-20 processing capability into MSL12;

b--Implemented new and improved aerosol products: averaged flat angstrom "angstrom_ave" and aerosol optical thickness at any wavelength “aot_xxx”;

c--Added new attribute “start_orbit_number” in file metadata and enabled more accurate value assignment for “processing_version” attribute in file metadata: uses software version defined in code and gets rest from the parameter file

4--Implement new and improved ocean color algorithms in MSL12 and apply them to ocean color related studies

a--Improved BRDF correction with f/Q effect

b--Improved epsilon-corrected atmospheric correction under conditions of strong absorbing aerosol for pixels with negative short-wavelength nLws;

c--Used ocean color data from VIIRS/SNPP and GOCI to study ocean response to major tropical cyclones in the 2017 hurricane season.

d--Gave an oral presentation titled “Ocean Color Remote Sensing of Oceanic Response to Passage of Tropical Cyclones” at 2018 Ocean Science Meeting, Portland OR, Feb.11-16, 2018 (Figure 2);

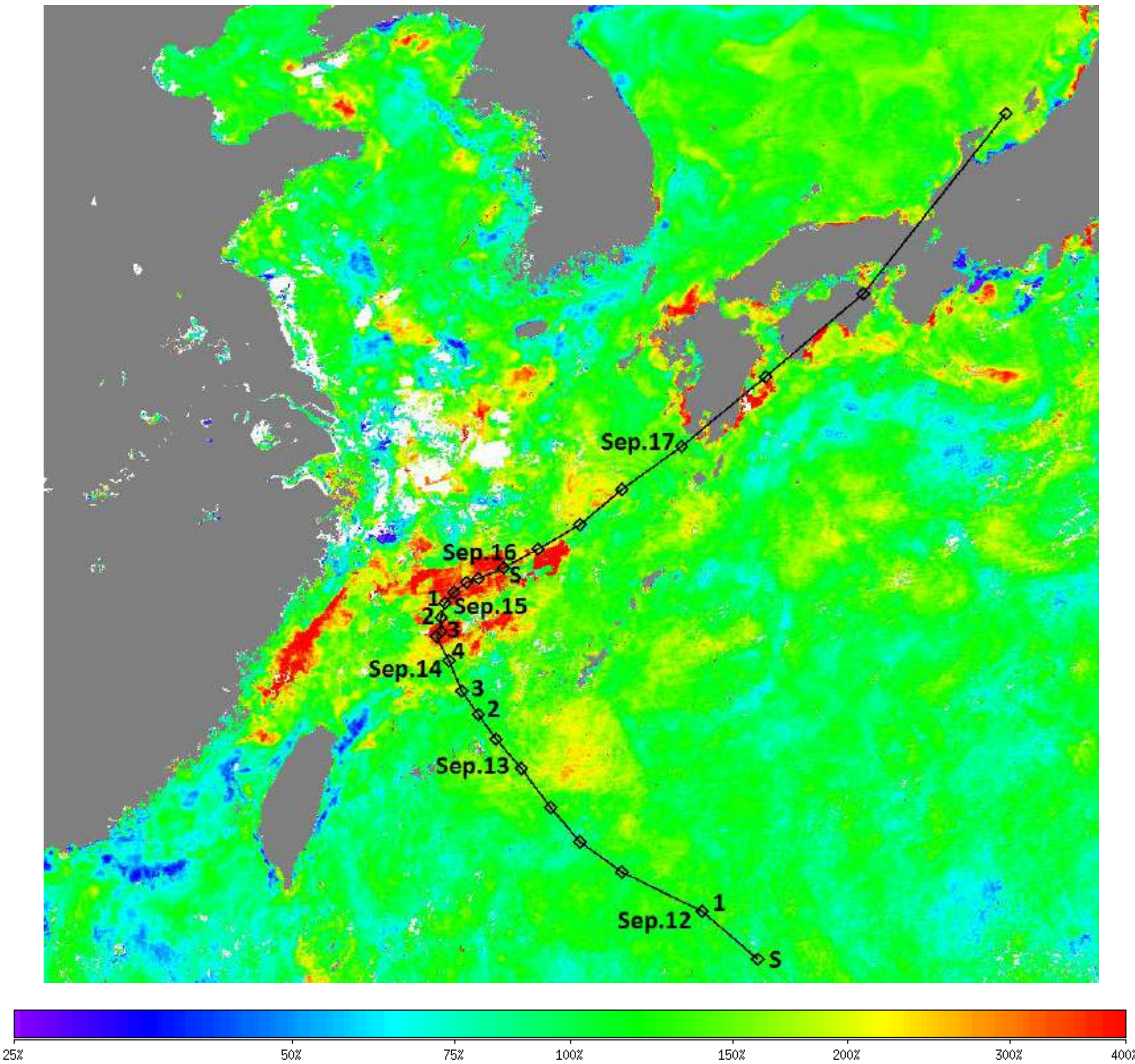


Figure 2. Chlorophyll-a change after passage of Typhoon Talim

5--Near-real-time and science quality ocean color data support

a--Processed and provided science quality VIIRS Level-2 ocean color data in support of the Cal/Val Team members including Chuanmin Hu from University of South Florida, Zhongping Lee from University of Massachusetts and Robert Arnone from University of Southern Mississippi

Publications:

Jiang, L. and M. Wang, 2017: Diurnal currents in the Bohai Sea derived from the Korean Geostationary Ocean Color Image", IEEE Trans. Geosci. Remote Sens., 55, 1437-1450. doi:10.1109/TGRS.2016.2624220

Jiang, L. and M. Wang, 2018: Ocean color remote sensing of oceanic response to passage of tropical cyclones", presented at 2018 Ocean Science Meeting, Feb.11-16, 2018, Portland, OR

Wang, M. and L. Jiang, 2018: VIIRS-derived ocean color product using the imaging bands, Remote Sens. Environ., 206, 275-286 (2018). doi:10.1016/j.rse.2017.12.042

PROJECT TITLE: NESDIS Environmental Applications Team, Shuyan Liu – Research Scientist

PRINCIPAL INVESTIGATORS: Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Shuyan Liu

NOAA TECHNICAL CONTACT: Quanhua Liu, NOAA/NESDIS/STAR

NOAA RESEARCH TEAM: Christopher Grassotti, Cooperative Institute of Climate and Satellite-MD/Earth System Science Interdisciplinary Center, University of Maryland

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVES:

1--Develop NOAA Microwave Integrated Retrieval System (MiRS)
2--Validate products from MiRS
3--Maintain MiRS software, data, and website

PROJECT ACCOMPLISHMENTS:

1--Developed MiRS N20 ATMS capability, MiRS has been publishing N20 retrieval products on an internal website since the first day of data were downlinked.
2--Validated MiRS retrieved CLW against ARM observations, emissivity against SURF RAD and ECMWF, temperature against ECMWF

Publications and Presentations:

Ferro R., P. Meyers, P. Chang, Z. Jelenak, C. Grassotti, and S. Liu, 2017: Application of GCOM-W AMSR2 and S-NPP ATMS hydrological products to a flooding event in the United States, IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, doi: 10.1109/JSTARS.2017.2696304.

Grassotti S., Q. Liu, and S. Liu, 2018: Microwave Integrated Retreival System (MiRS): Recent Activity, Science Improvements, and First Look at NOAA-20/ATMS. AMS 2018 Annual Meeting, Austin, TX.

Liu S., C. Grassotti, J. Chen, and Q. Liu, 2017: GPM products from the Microwave Integrated Retrieval System (MiRS), IEEE Journal of Selected Topics in Applied Earth Observations and Remote Sensing, doi: 10.1109/JSTARS.20172716356.

PROJECT TITLE: NESDIS Environmental Applications Team – Xiaoming Liu, Research Scientist - Ocean Color Algorithm Development and Ocean Process Study with Satellite Ocean Color Remote Sensing

PRINCIPAL INVESTIGATORS: Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Xiaoming Liu

NOAA TECHNICAL CONTACT: Menghua Wang

NOAA RESEARCH TEAM: Menghua Wang

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVES:

1--Calibration/Validation and monitoring of VIIRS ocean color products
2--Conduct ocean color related applications and research

PROJECT ACCOMPLISHMENTS:

1--Calibration/Validation and Monitoring of VIIRS Ocean Color Products

--Added the routine cal/val and monitoring for NOAA-20 VIIRS ocean color data products in regions of interests, including Hawaii, South Pacific Gyre, Chesapeake Bay and U.S. east coast regions. The in situ data at four NOAA-funded stations including MOBY, AERONET-CSI, AERONET-LISCO and AERONET-USC, are routinely compared with VIIRS/NOAA-20 ocean color products. These processes are automated on our Linux servers and posted on the web weekly. For example, Figure 1 shows the comparison of NOAA-20 VIIRS ocean color products with MOBY in situ data as an example (http://www.star.nesdis.noaa.gov/sod/mecb/color/CalVal_n20.php).

--Added the routine monitoring of NOAA-20 VIIRS ocean color data products in global deep waters, oligotrophic waters, and coastal/shallow waters. The NOAA-20 VIIRS ocean color data are also routinely compared with SNPP VIIRS data. Figure 2 shows the comparison of NOAA-20 VIIRS data with SNPP VIIRS data at MOBY site.

--Added the routine cal/val and monitoring for SENTINEL-3 OLCI ocean color data products in regions of interests. The in situ data at MOBY site are routinely compared with OLCI ocean color products. These processes are automated on our Linux servers and posted on the web weekly.

--Added the monitoring the QA-scores for evaluation of the quality of ocean color products for both SNPP VIIRS and SENTINEL-3 OLCI sensors. Figure 3 shows the average QA-scores of the two sensors at global deep waters, oligotrophic waters, and coastal/inland waters.

--Added the routine monitoring of the SNPP SDR products including F-LUTs and vicarious gains in visible bands.

--Continue cal/val of SNPP VIIRS ocean color data at MOBY and AERONET-OC stations, and monitoring in regions and global (https://www.star.nesdis.noaa.gov/sod/mecb/color/CalVal.php).

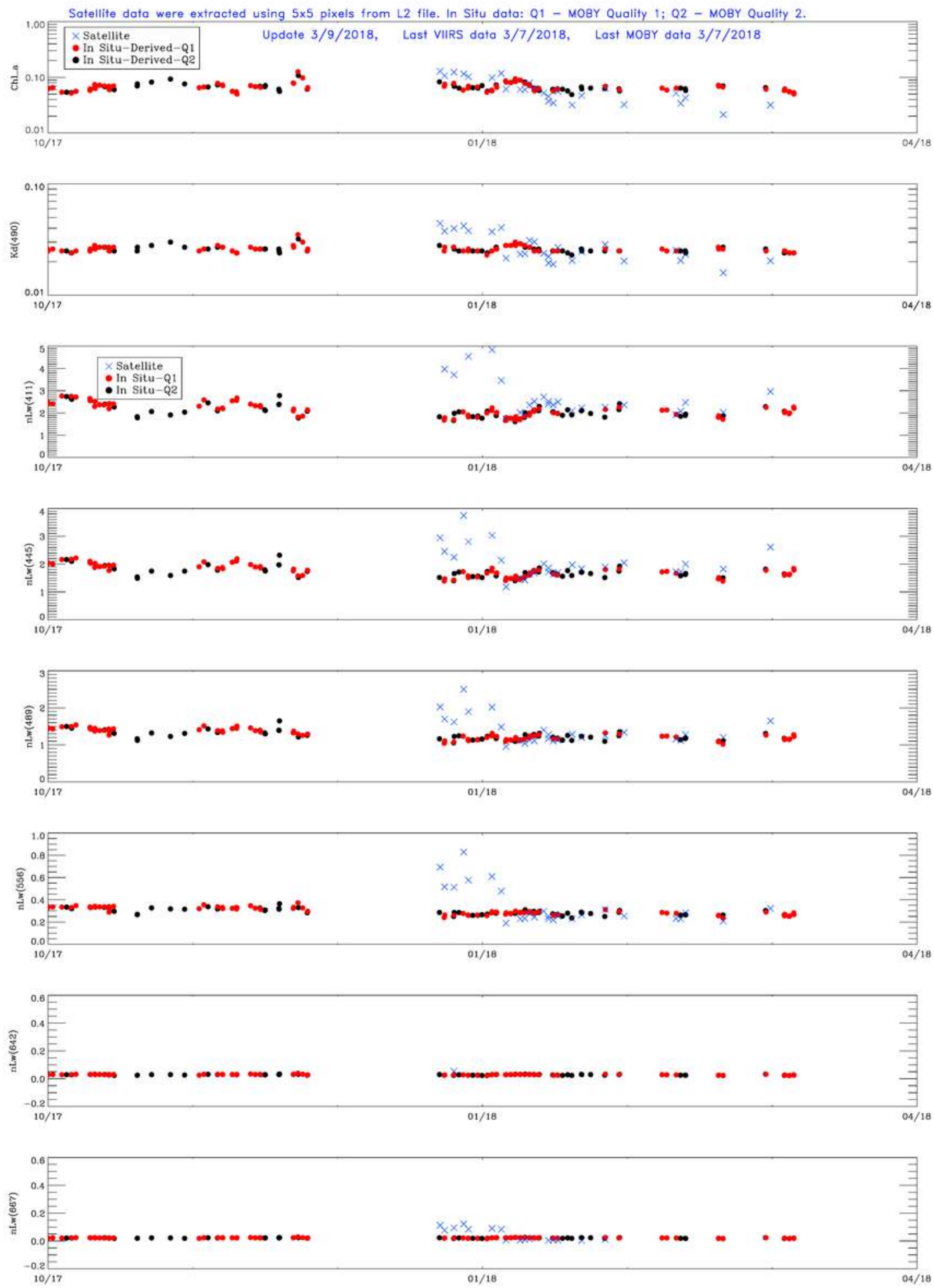


Figure 1. Near-real-time monitoring of NOAA-20 VIIRS ocean color data with MOBY in situ data. (http://www.star.nesdis.noaa.gov/sod/mecb/color/CalVal_n20.php).

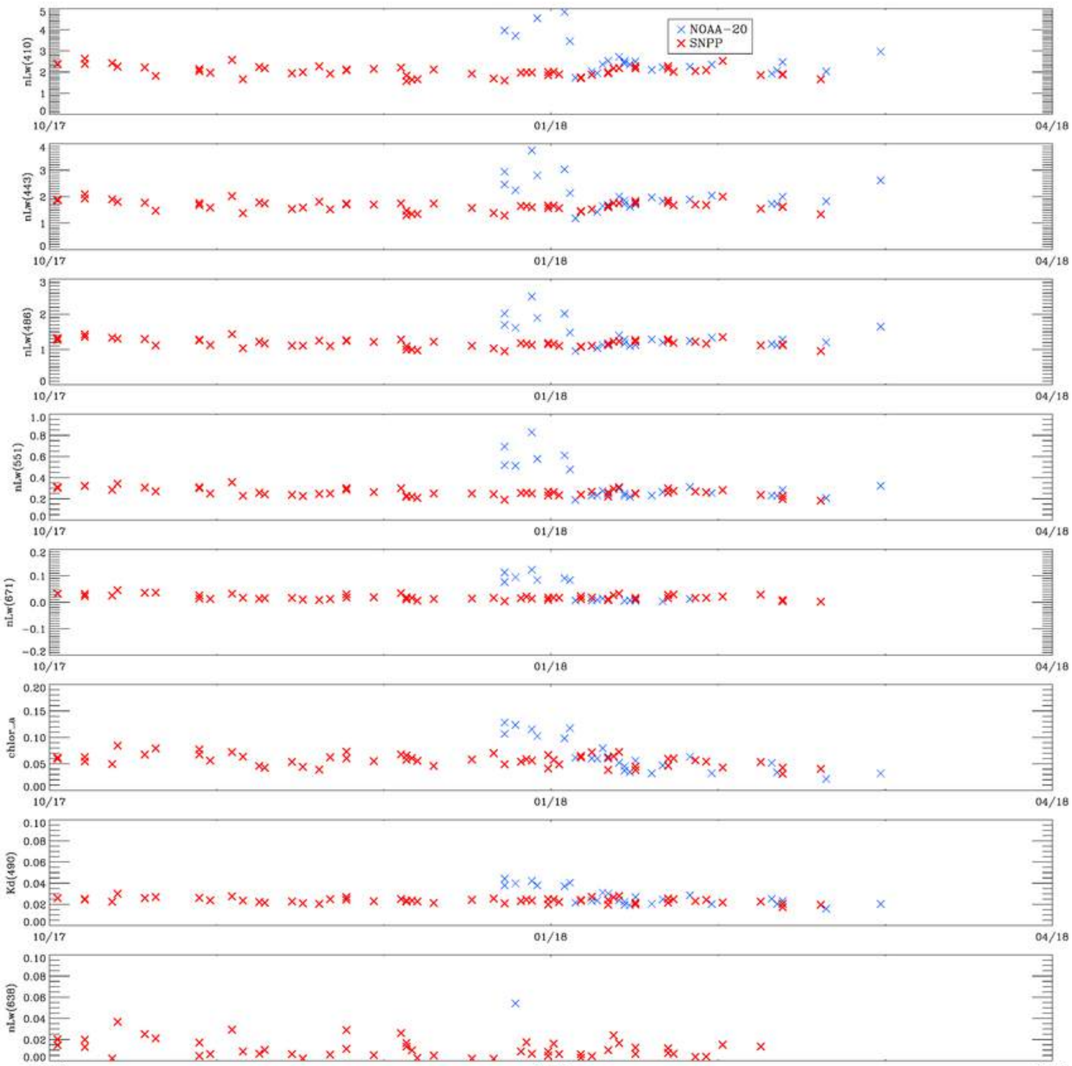
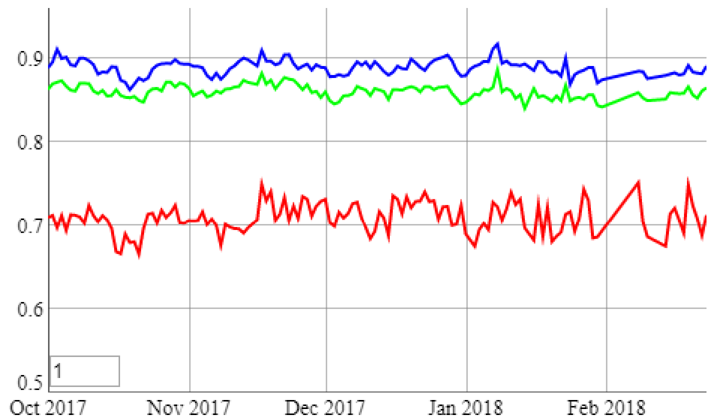


Figure 2. Comparison of NOAA-20 (blue) VIIRS ocean color data with SNPP (red). The results are updated automatically online at: https://www.star.nesdis.noaa.gov/sod/mecb/color/intuse/n20-npp.php

(a)



(b)

Figure 3. Time series of QA-scores of (a) SNPP VIIRS ocean color products, and (b) SENTINEL-3 OLCI ocean color products (blue-global oligotrophic waters; green-global deep waters; red-coastal/inland waters).

2--Conduct Ocean Color Related Applications and Research

Liu, X. and M. Wang: Gap Filling of Missing Data for VIIRS Global Ocean Color Products Using the DINEOF Method , submitted to *IEEE Trans. Geosci. Remote Sensing*, in review

Abstract: Ocean color data are critical for the monitoring and understanding of biological and ecological processes and phenomena, and the data are also important sources of input data for physical and biogeochemical ocean models. The Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP) has continued to provide global ocean color data since its launch in October 2011. However, there are always many missing pixels in the original VIIRS-measured ocean color images due to clouds and various other reasons. The Data Interpolating Empirical Orthogonal Functions (DINEOF) is a method to reconstruct (gap-filling) missing data in geophysical datasets based on the Empirical Orthogonal Function (EOF). In this study, the DINEOF is applied to VIIRS-derived global Level-3 binned ocean color data of 9-km spatial resolution, and the DINEOF reconstructed ocean color data are used to fill the gaps of missing data. In particular, daily, 8-day, and monthly VIIRS global Level-3 binned ocean color data, including chlorophyll-a (Chl-a) concentration, diffuse attenuation coefficient at 490 nm (K_d(490)), as well as normalized water-leaving radiance spectra ($nL_w(\lambda)$) at the five VIIRS visible bands, are tested and evaluated. To validate and evaluate the gap-filled data, a set of original valid non-missing pixels in the VIIRS images are selected randomly and treated as missing pixels in the DINEOF process, so that the reconstructed pixels can be compared with the original

data. Results show that the DINEOF method can successfully reconstruct and gap-fill meso-scale and large-scale spatial ocean features in the global VIIRS Level-3 images, as well as capture the temporal variations of these features.

Liu, X. and M. Wang, 2018: Study of the Global Ocean Features Using the Gap-Filled VIIRS Ocean Color Products, 2018 Ocean Science Meeting, Feb. 11-16, Portland, Oregon

PROJECT TITLE: NESDIS Environmental Applications Team, Wei Shi – Research Scientist - NPP VIIRS Calibration and Validation, Ocean Color Algorithm Development and Ocean Process Study with Satellite Ocean Color Remote Sensing

PRINCIPAL INVESTIGATORS: Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Wei Shi

TECHNICAL CONTACT: Menghua Wang (NOAA)

NOAA RESEARCH TEAM: Menghua Wang

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVES:

--Development of new satellite ocean color algorithm
--NPP VIIRS calibration and validation
--Application of satellite ocean color data for coastal and in-land water ecosystem monitoring

RESEARCH ACCOMPLISHMENTS:

During this period, conducted research on NIR and SWIR-Based on-orbit vicarious calibrations for satellite ocean color sensors. Research was also conducted to study the stabilization of SNPP VIIRS ocean color products after vicarious calibration. I also conducted the study to derive the total suspended matter concentration from the near-infrared-based inherent optical properties over turbid waters.
--Characterization of particle backscattering of global highly turbid waters from VIIRS ocean color observations
--Ocean Dynamics Observed by VIIRS Day/Night Band Satellite Observations
--Deriving total suspended matter concentration from the near-infrared-based inherent optical properties over turbid waters: A case study in Lake Taihu.

Publications:

Title: Characterization of Particle Backscattering of Global Highly Turbid Waters from VIIRS Ocean Color Observations

Author(s): Shi, Wei; Wang, Menghua

Shi, W., & Wang, M., 2017: Characterization of particle backscattering of global highly turbid waters from VIIRS ocean color observations. *Journal of Geophysical Research*: Oceans, 122. https://doi.org/10.1002/2017JC013191

Abstract: Normalized water-leaving radiance spectra $nL_w(\lambda)$ at the near-infrared (NIR) from five years of observations (2012–2016) with the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP) are used to derive the particle backscattering coefficients $b_{bp}(\lambda)$ for global highly turbid coastal and inland waters. Based on the fact that the absorption coefficient of sea water $a_w(\lambda)$ is generally much larger than those of the other constituents $a_{iop}(\lambda)$ at the NIR wavelengths in coastal and inland waters, a NIR-based $b_{bp}(\lambda)$ algorithm for turbid coastal and inland waters has been developed and used in this study. This algorithm can be safely used for highly turbid waters with $nL_w(745)$ and $nL_w(862)$ less than ~6 and ~4 mW cm^{-2} μm^{-1} sr^{-1}, respectively. Seasonal and inter-annual variations of $b_{bp}(\lambda)$ in China's east coastal region, the Amazon River Estuary, the La Plata River Estuary, the Meghna River Estuary, the Atchafalaya River Estuary, and Lake Taihu are characterized and quantified. The coefficient $b_{bp}(\lambda)$ can reach over ~3–4 m^{-1} in the Amazon River Estuary and China's east coastal region. The Amazon River Estuary is identified as the most turbid region in the global ocean in terms of $b_{bp}(\lambda)$ magnitude. $b_{bp}(\lambda)$ spectra in these five highly turbid regions are also seasonal- and regional-dependent. In the highly turbid waters of China's east coastal region and the Amazon River Estuary, $b_{bp}(\lambda)$ generally increases in wavelength from 410 to 862 nm, while it decreases in the La Plata River Estuary and Atchafalaya River Estuary. This is attributed to the different particle size distributions in these waters. The geophysical implication of the $b_{bp}(\lambda)$ spectral curvatures for different waters is discussed. To improve global $b_{bp}(\lambda)$ for both open oceans and coastal turbid waters, a new combined NIR- and Quasi-Analytical Algorithm (QAA)-based $b_{bp}(\lambda)$ algorithm is proposed and demonstrated.

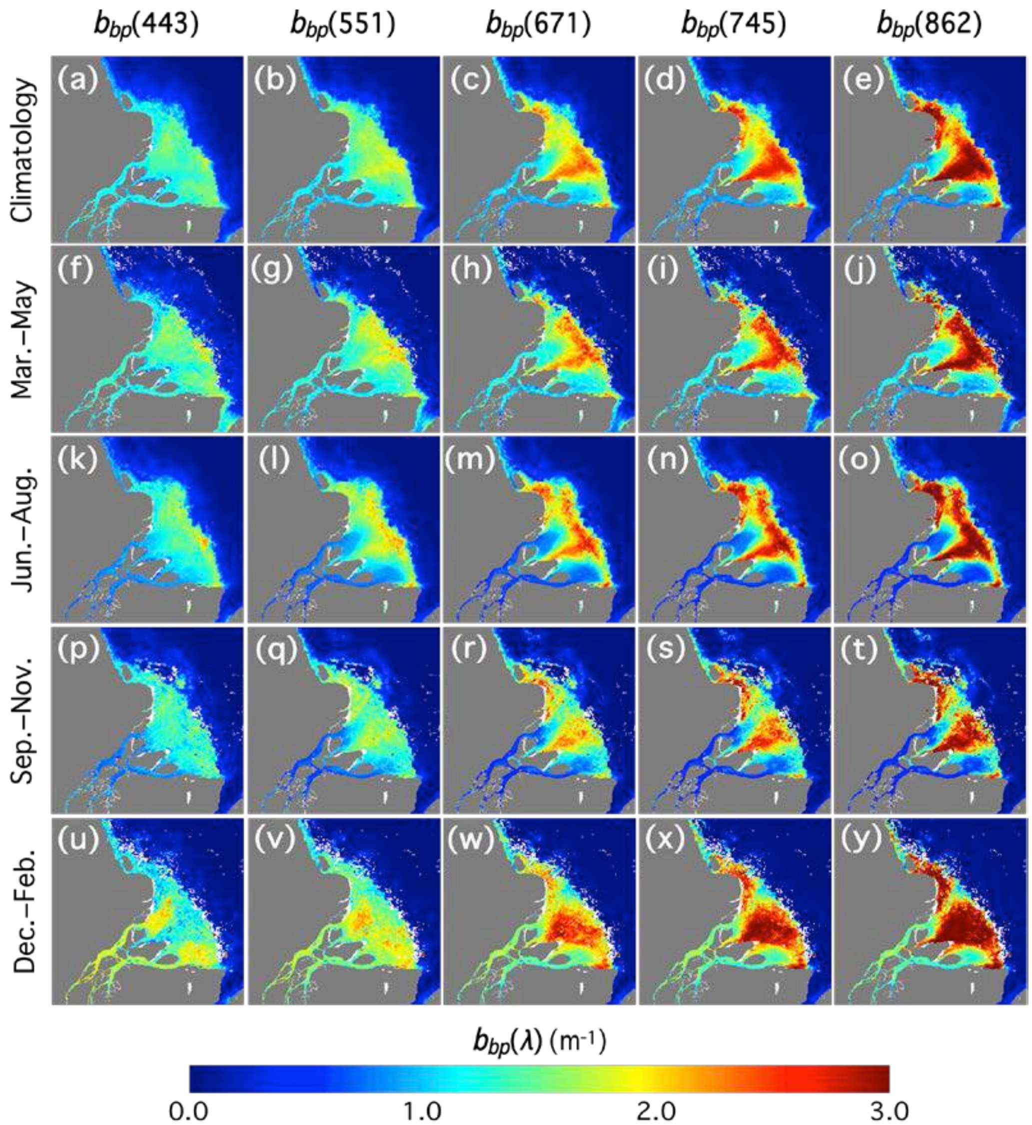


Figure caption:
VIIRS-derived images of b_{bp}(443), b_{bp}(551), b_{bp}(671), b_{bp}(745), and b_{bp}(862) in the Amazon River Estuary for (a–e) climatology from 2012 to 2016, (f–j) March–May, (k–o) June–August, (p–t) September–November, and (u–y) December–February.

Title: Ocean Dynamics Observed by VIIRS Day/Night Band Satellite Observations

Author(s): W. Shi and M. Wang

Shi, W. and M. Wang, 2018: Ocean dynamics observed by VIIRS day/night band satellite observations, Remote Sens., 10, 76. doi:10.3390/rs10010076

Abstract: Three cases of Day/Night Band (DNB) observations of the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP) are explored for applications to assess the ocean environment and monitor ocean dynamics. An approach to use the ratio between the target radiance and the reference radiance was developed in order to better assess the ocean diurnal and short-term environmental changes with VIIRS DNB observations. In the La Plata River Estuary, the sediment fronts showed 20–25 km diurnal inshore-offshore movements on 13 March 2017. In the waters off the coast of Argentina in the South Atlantic, VIIRS DNB measurements provided both daytime and nighttime observations and monitoring of the algal bloom development and migration between 24 and 26 March 2016. This algal bloom generally kept the same spatial patterns, but moved nearly 20 km eastward in the three-day period. In the Yangtze River Estuary and Hangzhou Bay region along China's east coast, VIIRS DNB observations also revealed complicated coastal dynamic changes between 12 and 14 April 2017. Even though there are still some challenges and limitations for monitoring the ocean environment with VIIRS DNB observations, this study shows that satellite DNB observations can provide additional data sources for ocean observations, especially observations during the nighttime.

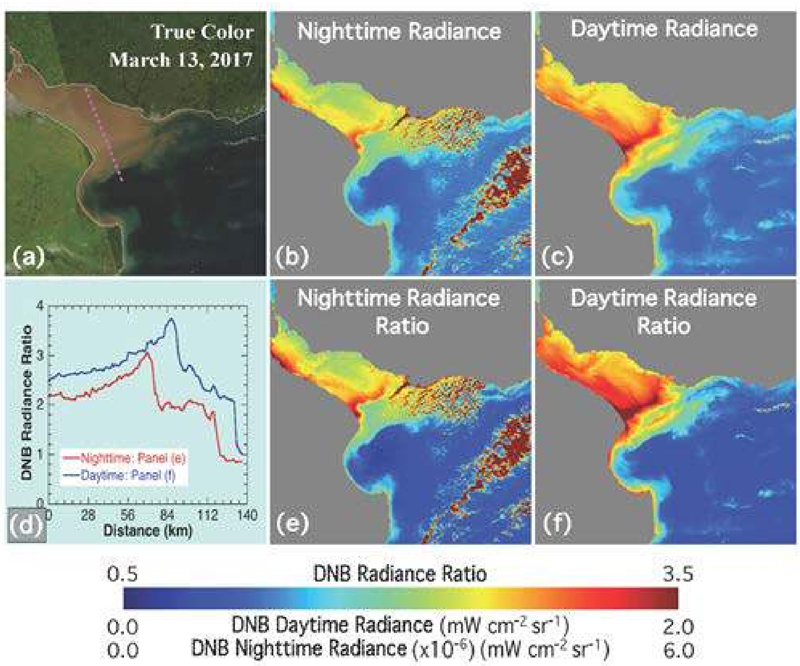


Figure Caption:
VIIRS-observed diurnal change of the La Plata River Estuary for (**a**) RSB daytime true color image at 16:47 UTC on 13 March 2017, (**b**) DNB nighttime TOA radiance at 04:27 UTC on 13 March 2017, (**c**) DNB daytime TOA radiance at 16:47 UTC on 13 March 2017, (**d**) DNB radiance ratio *R* along the transect line indicated in Figure 1a, (**e**) DNB nighttime TOA radiance ratio at 04:27 UTC on 13 March 2017, and (**f**) DNB daytime TOA radiance ratio at 16:47 UTC on 13 March 2017.

Title: Deriving total suspended matter concentration from the near-infrared-based inherent optical properties over turbid waters: A case study in Lake Taihu

Author(s): W. Shi and M. Wang

Shi, W., Y. Zhang, and M. Wang, 2018: Deriving total suspended matter concentration from the near-infrared-based inherent optical properties over turbid waters: A case study in Lake Taihu, *Remote Sens.*, 10, 333. doi:10.3390/rs10020333.

Abstract: Normalized water-leaving radiance spectra $nL_w(\lambda)$, particle backscattering coefficients $b_{bp}(\lambda)$ in the near-infrared (NIR) wavelengths, and total suspended matter (TSM) concentrations over turbid waters are analytically correlated. To demonstrate the use of $b_{bp}(\lambda)$ in the NIR wavelengths in coastal and inland waters, we used in situ optics and TSM data to develop two TSM algorithms from measurements of the Visible Infrared Imaging Radiometer Suite (VIIRS) onboard the Suomi National Polar-orbiting Partnership (SNPP) using backscattering coefficients at the two NIR bands $b_{bp}(745)$ and $b_{bp}(862)$ for Lake Taihu. The correlation coefficients between the modeled TSM concentrations from $b_{bp}(745)$ and $b_{bp}(862)$ and the in situ TSM are 0.93 and 0.92, respectively. A different in situ dataset acquired between 2012 and 2016 for Lake Taihu was used to validate the performance of the NIR TSM algorithms for VIIRS-SNPP observations. TSM concentrations derived from VIIRS-SNPP observations with these two NIR $b_{bp}(\lambda)$-based TSM algorithms matched well with in situ TSM concentrations in Lake Taihu between 2012 and 2016. The normalized root mean square errors (NRMSEs) for the two NIR algorithms are 0.234 and 0.226, respectively. The two NIR-based TSM algorithms are used to compute the satellite-derived TSM concentrations to study the seasonal and interannual variability of the TSM concentration in Lake Taihu between 2012 and 2016. In fact, the NIR-based TSM algorithms are analytically based with minimal in situ data to tune the coefficients. They are not sensitive to the possible $nL_w(\lambda)$ saturation in the visible bands for highly turbid waters, and have the potential to be used for estimation of TSM concentrations in turbid waters with similar NIR $nL_w(\lambda)$ spectra as those in Lake Taihu.

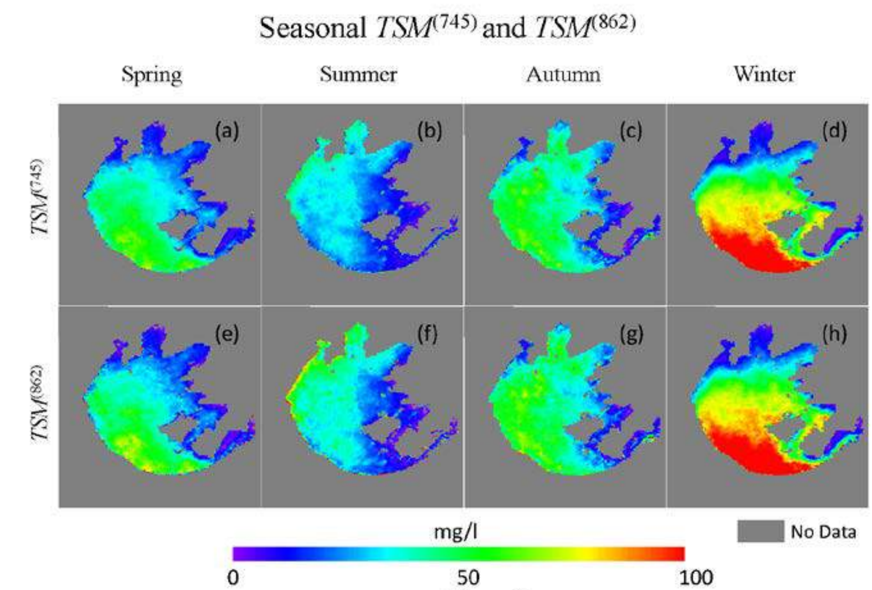


Figure 6

Figure caption:

Seasonal climatology $TSM^{(745)}$ images (a–d) and $TSM^{(862)}$ images (e–h) for spring, summer, autumn, and winter, respectively.

PROJECT TITLE: NESDIS Environmental Applications Team, Seunghyun Son-Research Scientist II

PRINCIPAL INVESTIGATORS: Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Seunghyun Son

NOAA TECHNICAL CONTACT: Menghua Wang, STAR/SOCD/MEB

NOAA RESEARCH TEAM: Menghua Wang

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVES:

1--Processing and validation/evaluation of the JPSS VIIRS data
2--Development of bio-optical and biogeochemical algorithms for the satellite ocean color data use in the various ocean waters (clear open ocean, coastal and inland waters).
3--Processing and validation/evaluation of the Korean GOCI data.

PROJECT ACCOMPLISHMENTS:

1--The VIIRS data sets from various processing methods (e.g., IDPS-EDR, OC-SDR-EDR, NOAA-MSL12) have been being processed over the various clear ocean and coastal/inland waters (Hawaii region, South Pacific Gyre, US east coast, Yellow & East China seas, Mediterranean Sea, etc.). In situ bio-optical data were compared for validation of the VIIRS data in various regions.

2--Regional algorithms for Sea-Ice mask and turbidity for use of satellite ocean color data in the Great Lakes are developed, and the optical properties in the Great Lakes are characterized. The results were published in a peer-reviewed journal.

3--The Korean GOCI data sets have been reprocessed over the Northwestern Pacific area, and evaluated and compared with VIIRS data. The results were presented in international workshops.

4--The OLCI data sets from the European ocean color sensor, Sentinel, have been being processed and routinely validated in the Hawaii MOBY site and various AERONET-OC sites. In addition, the OLCI ocean color products are compared with the VIIRS ocean color data.

5--Routine codes were set up for validation of the ocean color products from the VIIRS on NOAA-20 (previously named as JPSS J-1), which was launched in October 2017, for the Hawaii MOBY site and various AERONET-OC sites.

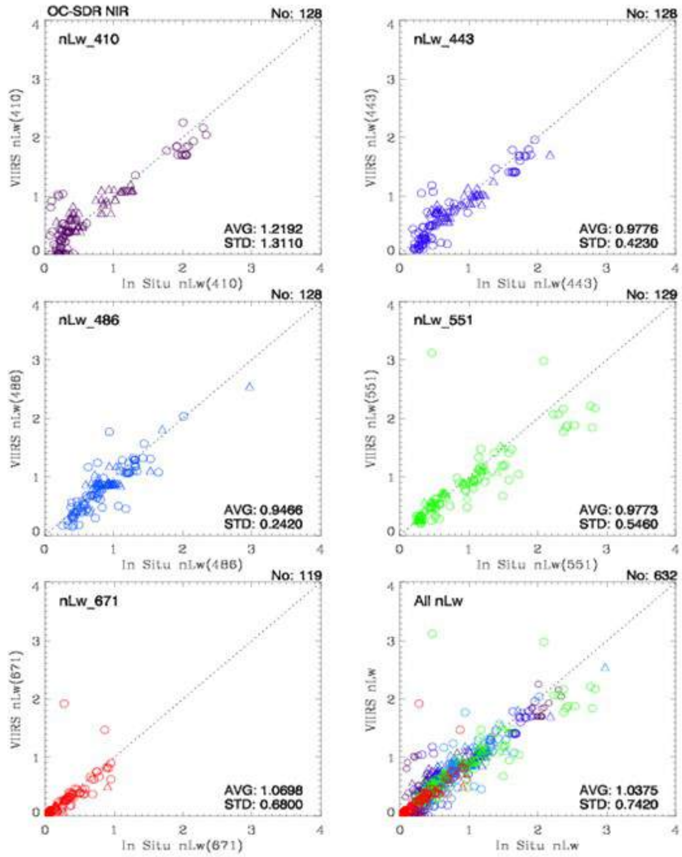


Figure 1. Matchup comparison of the VIIRS-derived $nL_w(\lambda)$ from the OC-SDR NIR processing with the in situ $nL_w(\lambda)$ measurements from the three NOAA/STAR Cal/Val cruises and various field campaigns.

Statistics of VIIRS vs. In Situ Data

VIIRS Product	VIIRS OC-SDR NIR							
	RATIO (VIIRS/In Situ)				DIFFERENCE (VIIRS-In Situ)			
	AVG	MED	STD	No	AVG	MED	STD	%Diff
$nL_w(410)$	1.2192	0.9658	1.311	128	0.0041	-0.0307	0.241	0.600
$nL_w(443)$	0.9776	0.9202	0.423	128	-0.0330	-0.0697	0.191	-4.310
$nL_w(486)$	0.9466	0.9298	0.242	128	-0.0471	-0.0520	0.192	-5.320
$nL_w(551)$	0.9773	0.9316	0.546	129	-0.0783	-0.0415	0.349	-8.830
$nL_w(671)$	1.0698	0.9768	0.680	119	-0.0102	0.0013	0.181	-4.120
All	1.0375	0.9383	0.742	632	-0.0333	-0.0290	0.241	-4.750

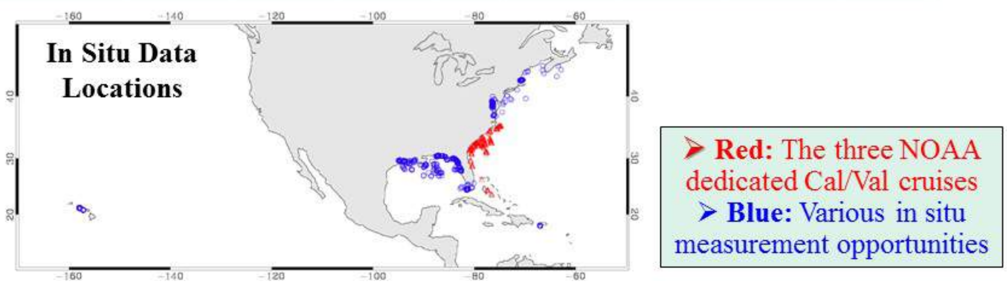


Figure 2. Statistics of Match-up comparison of the VIIRS-derived $nL_w(\lambda)$ from the OC-SDR NIR processing vs. the in situ $nL_w(\lambda)$ measurements from the three NOAA/STAR Cal/Val cruises and various field campaigns.

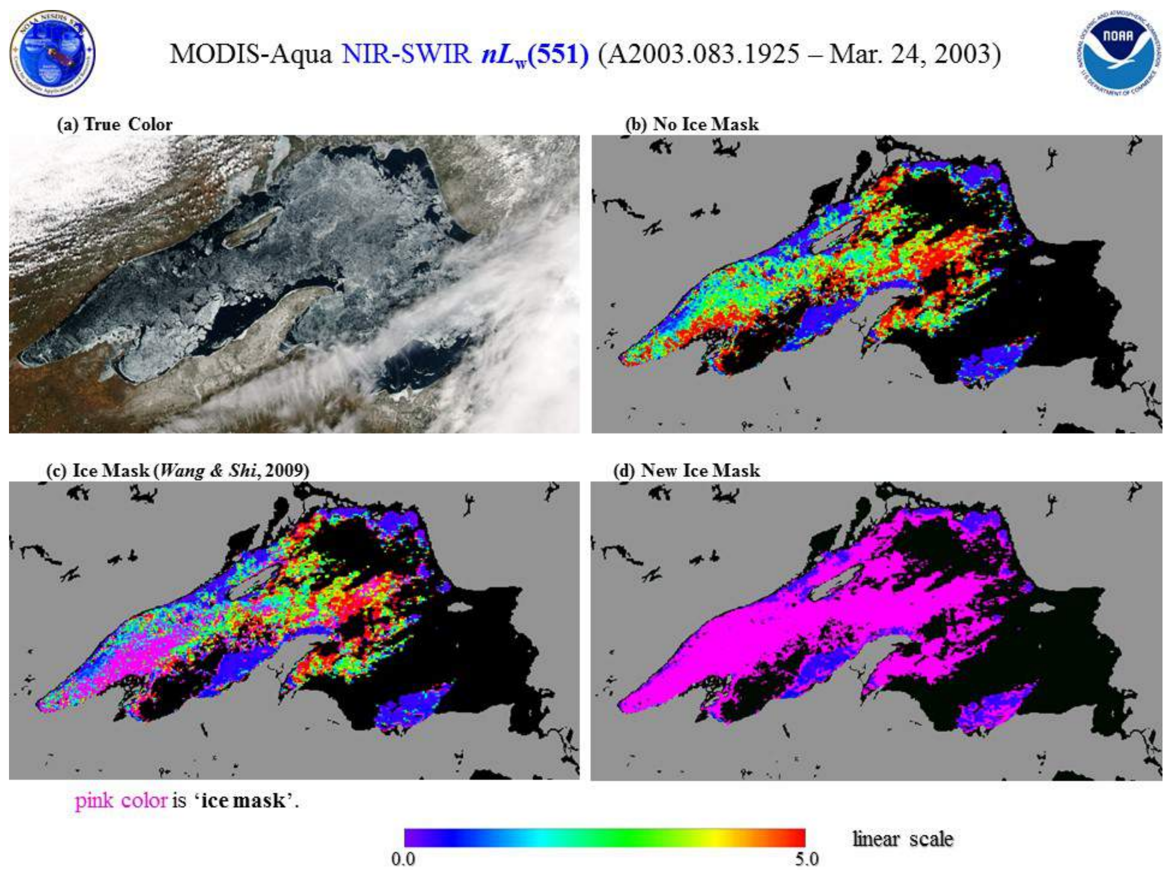


Figure 3**.** (a) MODIS-Aqua true-color image acquired on March 24, 2003 in Lake Superior. (b) nL_w(551) image processed without applying the ice-detection algorithm. (c) nL_w(551) image derived using the ice-detection method from Wang & Shi (2011), (d) nL_w(551) image derived using the new ice detection method. Ice pixels are masked in pink in (c) and (d).

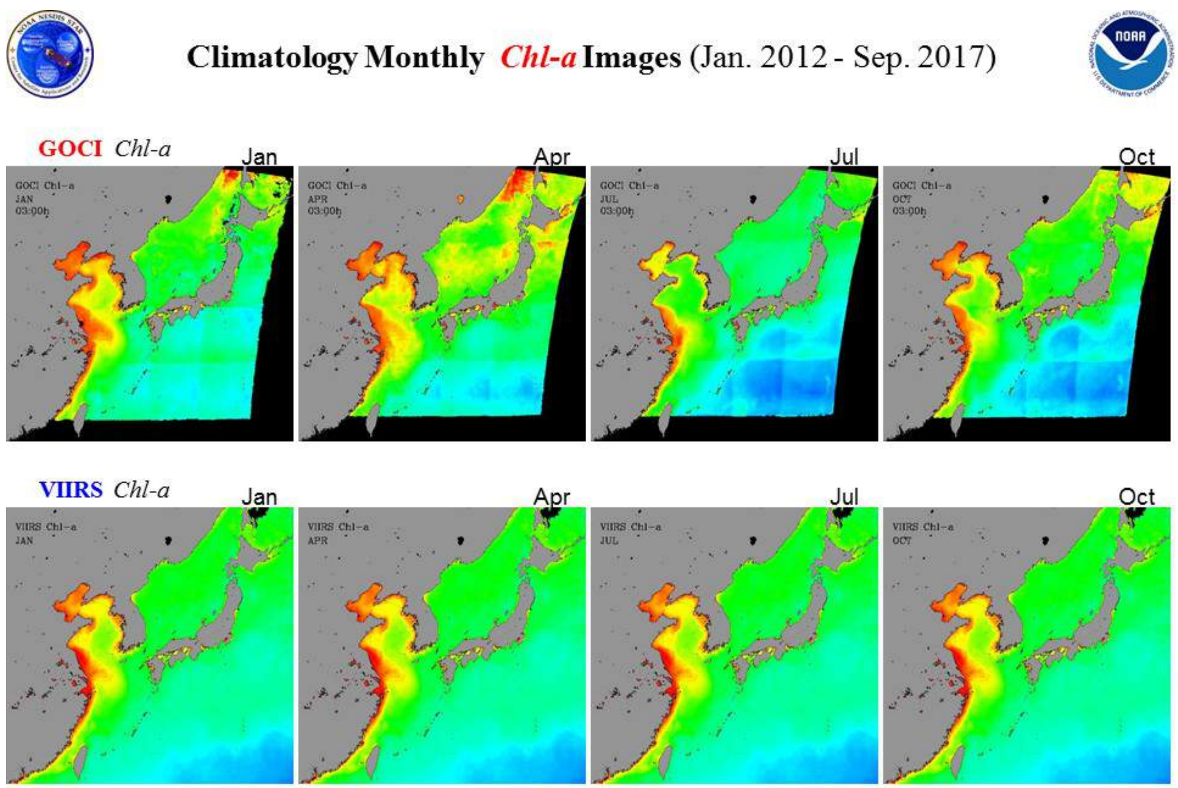


Figure 4. Climatology (January 2012 to December 2017) monthly composite images of GOCI-derived *Chl-a* (upper column) and VIIRS-derived (lower column) *Chl-a* for the months of January, April, July, and October in the Northwestern Pacific area (GOCI coverage).

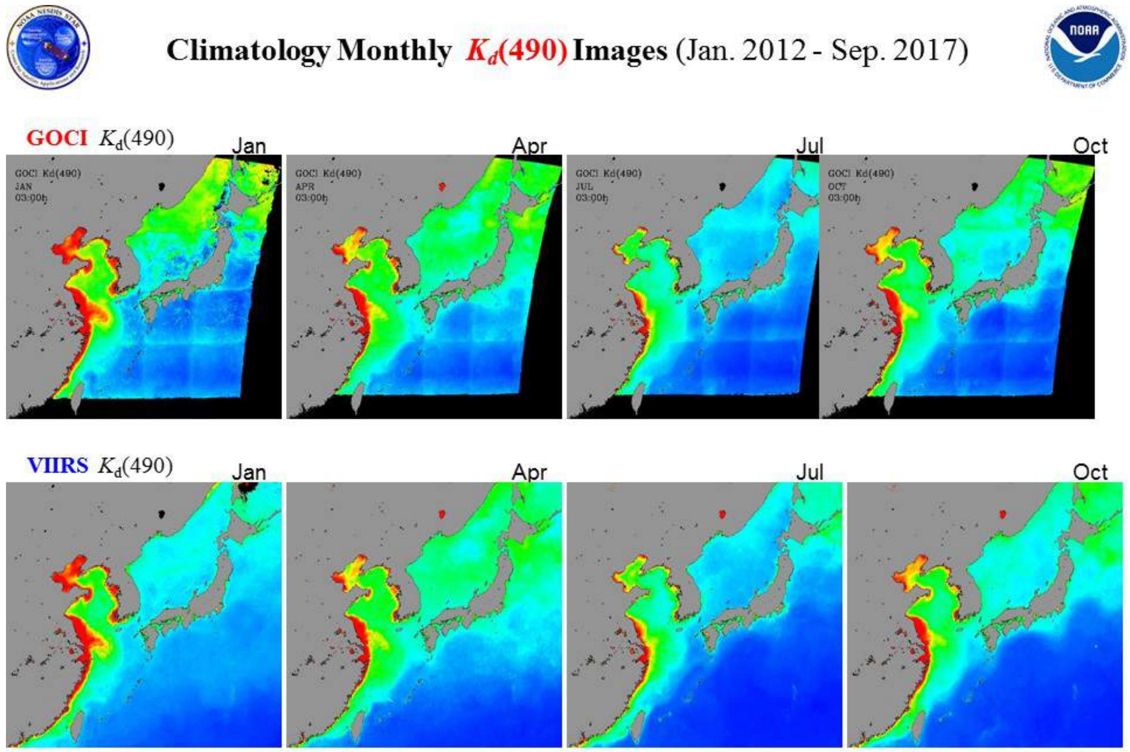


Figure 5. Climatology (January 2012 to December 2017) monthly composite images of GOCI-derived $K_d(490)$ (upper column) and VIIRS-derived $K_d(490)$ (lower column) for the months of January, April, July, and October in the Northwestern Pacific area (GOCI coverage).

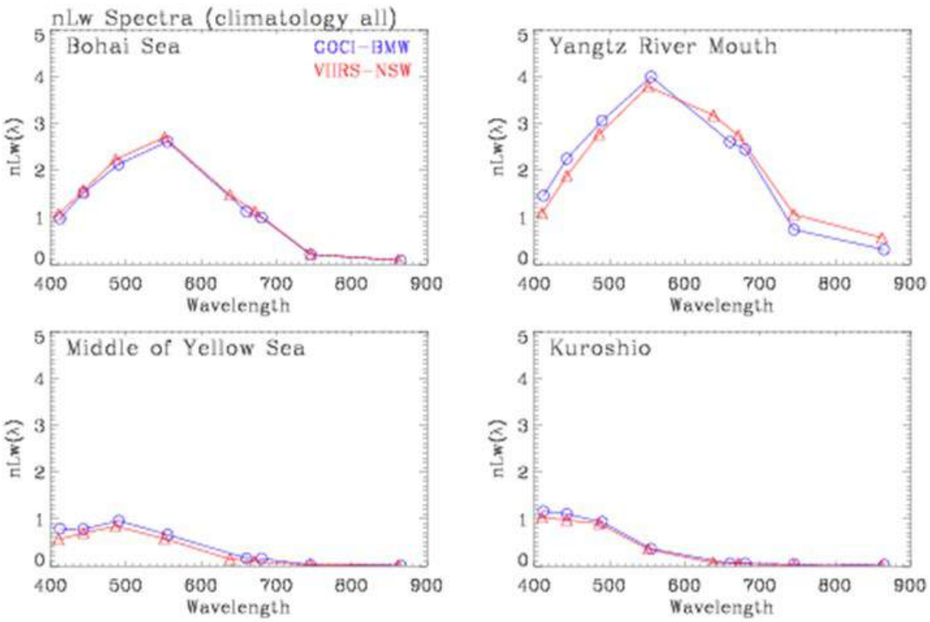


Figure 6. The normalized water-leaving radiances, $nL_w(\lambda)$, spectra from GOCI and VIIRS Climatology (January 2012 to December 2017) composites in four areas (Bohai Sea, Yangtz River Mouth, Middle of the Yellow Sea, and Off coast (Kuroshio region)).

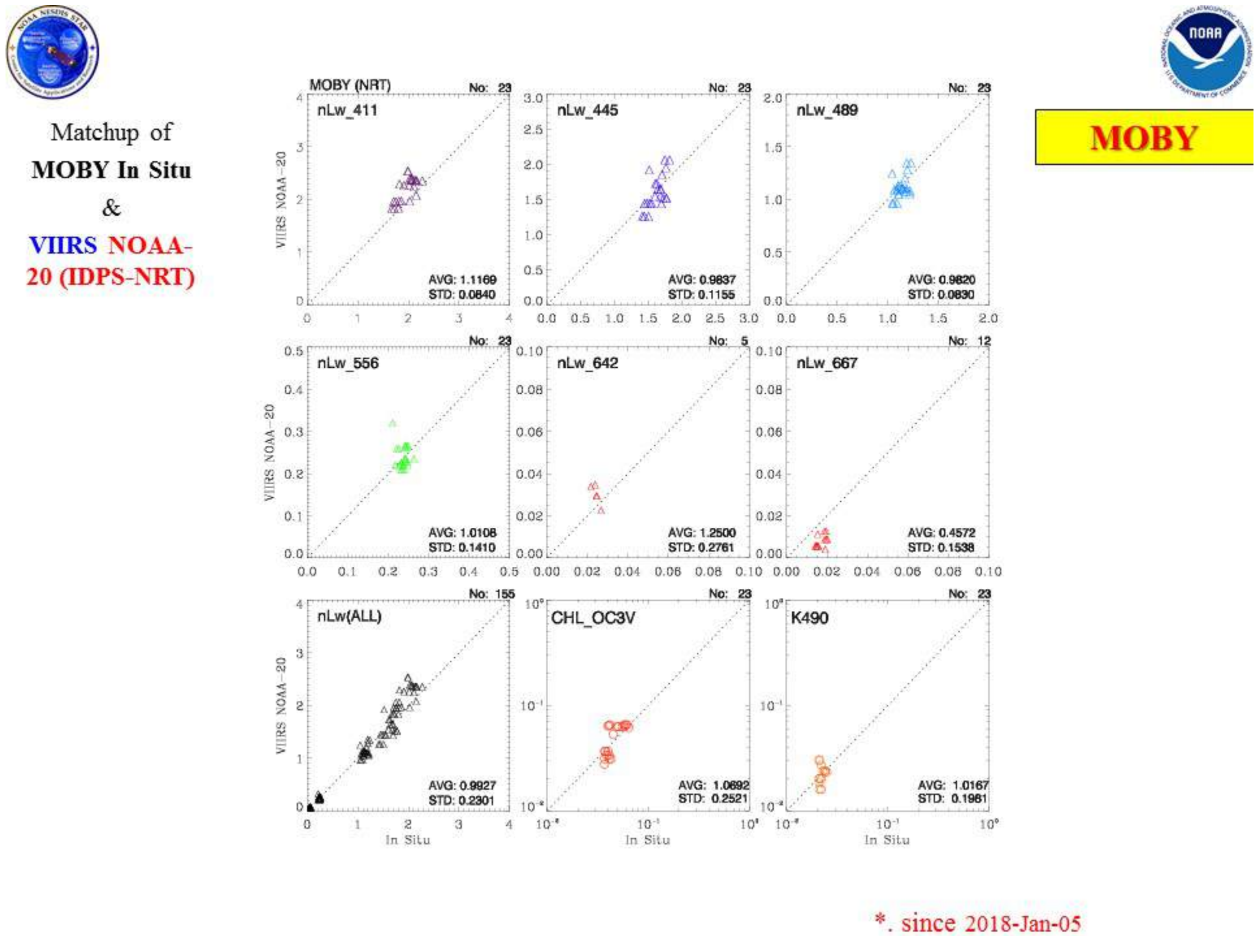


Figure 7. Matchup comparison of $nL_w(\lambda)$ from the VIIRS NOAA-20 derived from IDPS Near-Real Time processing with the in situ $nL_w(\lambda)$ measurements from the Hawaii MOBY site.

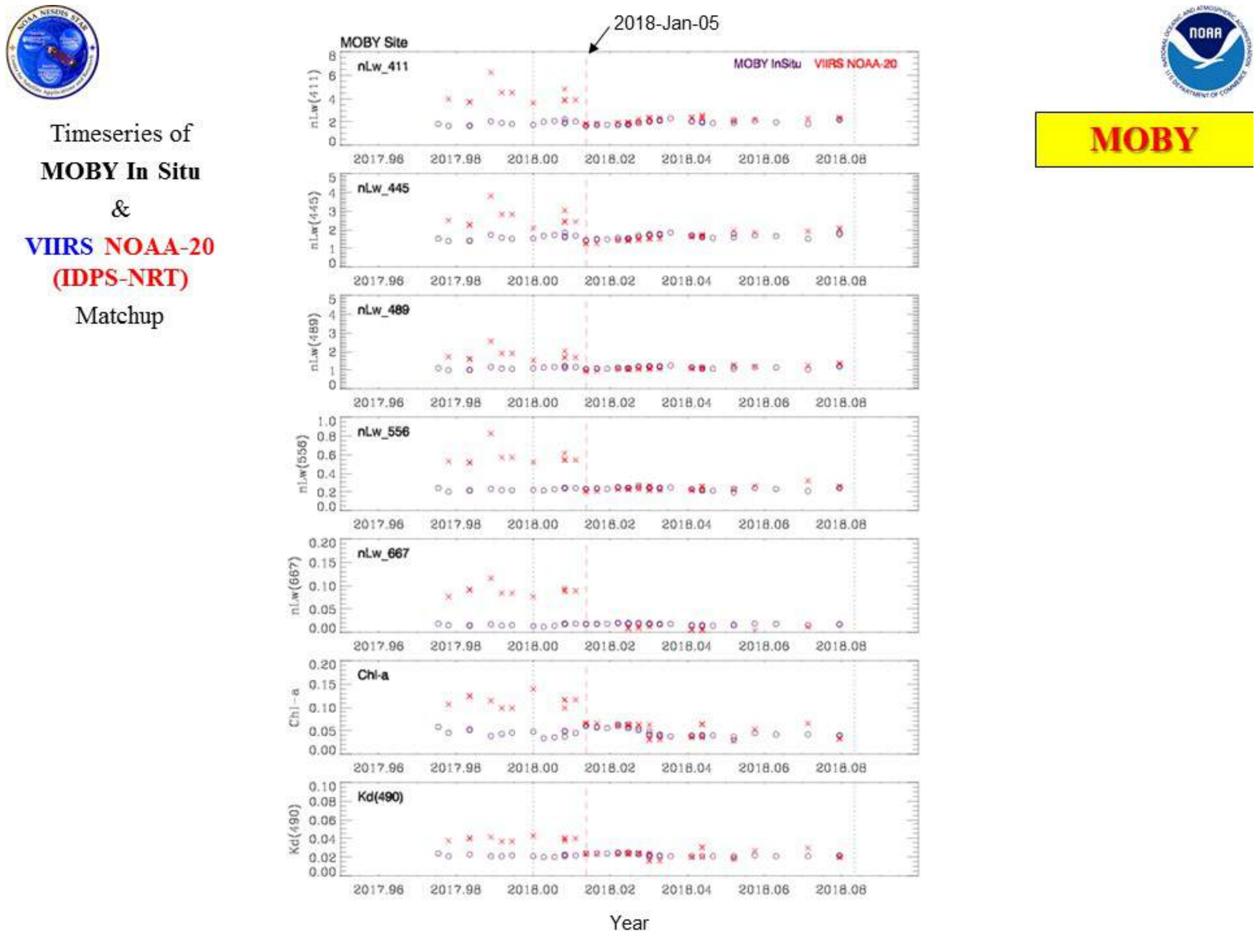


Figure 8. Timeseries of $nL_w(\lambda)$ measurements from the VIIRS NOAA-20 derived from IDPS Near-Real Time processing and from the Hawaii MOBY site.

Publications:

Son, S. & M. Wang (2017), Ice detection for satellite ocean color data processing in the Great Lakes, IEEE Transactions on Geoscience and Remote Sensing, 55(12), 6793-6804.

Wang, M., X. Liu, J. Jiang, & S. Son (2017), The VIIRS Ocean Color Products, Algorithm Theoretical Basis Document (ATBD) Version 1.0, 68 pp., June 2017.

Presentations:

Son, S., M. Wang, & L. Jiang, Comparison of GOCI and VIIRS ocean color products in the Western Pacific Region (at the Ocean Science Meeting 2018, Portland, OR, USA), Feb 12–16.

Son, S. & M. Wang, Comparison of GOCI and VIIRS ocean color products in the Western Pacific region (at the 5th Asian/14th Korea-Japan Workshop on Ocean Color, Busan National University, Busan, South Korea) Dec 14-15, 2017.

Son, S. & M. Wang, Ice detection for satellite ocean color processing in the Great Lakes (at the 5th Asian/14th Korea-Japan Workshop on Ocean Color, Busan National University, Busan, South Korea), Dec 14-15, 2017.

Son, S., M. Wang, & L. Jiang, Comparison of GOCI and VIIRS ocean color products in the Western Pacific Region (at International Ocean Color Symposium 2017, Lisbon, Portugal), May 15-18, 2017.

Son, S. & M. Wang, Evaluation of VIIRS ocean color products in open ocean and coastal/inland waters (at International Ocean Color Symposium 2017, Lisbon, Portugal), May 15-18, 2017.

Wang, M., L. Jiang, X. Liu, S. Son, J. Sun, K. Mikelsons, W. Shi, L. Tan, X. Wang, M. Chu, & V. Lance, VIIRS ocean color products over global open oceans and turbid coastal/inland waters S. Son & M. Wang, (at IGARSS 2017, Fort Worth, TX, USA), July 23-28, 2017.

Wang, M., L. Jiang, X. Liu, **S. Son**, J. Sun, K. Mikelsons, W. Shi, L. Tan, X. Wang, M. Chu, & V. Lance, VIIRS ocean color products over global open oceans and turbid coastal/inland waters, (at the Ocean Science Meeting 2018, Portland, OR, USA), Feb 12–16.

Wang, M., L. Jiang, X. Liu, **S. Son**, J. Sun, W. Shi, K. Mikelsons, L. Tan, X. Wang, and V. Lance, VIIRS Mission-long ocean color data reprocessing and demonstration of global ocean color data monitoring tool (at the 5th Asian/14th Korea-Japan Workshop on Ocean Color, Busan National University, Busan, South Korea), Dec 14-15, 2017.

PROJECT TITLE: NESDIS Environmental Applications Team, Liqin Tan – Research Associate

PRINCIPAL INVESTIGATORS: Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Liqin Tan

NOAA TECHNICAL CONTACT: Menghua Wang

NOAA RESEARCH TEAM: Menghua Wang

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVES:

--Performing VIIRS instrument characterization and calibration for ocean color (OC) data processing and applications. Evaluating the effect of VIIRS instrument performance on the science data quality and quantify the impact
--Understanding, evaluation, and refining VIIRS ocean color (OC) data processing system

PROJECT ACCOMPLISHMENTS:

--Collaborated with VIIRS SDR team and monitored the status and development of SNPP and NOAA-20 VIIRS instrument calibration activities, operational IDPS SDR production, and Discrepancy Records (DRs). Attended VIIRS SDR team weekly teleconference.

--Routinely downloaded the required ANC/AUX data including VIIRS SDR Geo/Calibration LUTs and searching for missing IDPS operational RDR from various data sources (Common CM, JPSS SDR Team and U. of Wisc, etc.) for our SNPP and NOAA-20 VIIRS calibration and characterization analysis and VIIRS SDR data processing.

--Routinely downloaded SNPP and NOAA-20 Ephemeris data for our VIIRS RSB calibration analysis.

--Generated SNPP VIIRS SDR products from ADL4.2_Mx8.11 for new SNPP RSB calibration OC-4 F-LUTs testing.

--Performed new COTS library installation and testing. Compiled, built and tested the new Block 2 ADL5.3.16_Mx03 code on our Linux system. Studied the VIIRS SDR code changes /updates.

--Modified VIIRS RDR to SDR data reprocessing tool to adapt the new changes in ADL5.3.16_Mx03, including ADL ChainRunner and VIIRS Gran Extender. Modified the data reprocessing tool for NOAA-20 granules/global NOAA-20 VIIRS SDR data reprocessing.

--Converted NOAA-20 VIIRS verified RDR HDF5 files from the VIIRS RDR granules for VIIRS RSB calibration analysis.

--Modified VIIRS F-LUTs compiling tool to enable NOAA-20 VIIRS F-LUTs processing. Delivered IDPS operation format OC version 4 SNPP VIIRS RSB F-factor LUT to NASA OPBG.

--Performed daily OC Team operational SNPP and NOAA-20 VIIRS OC EDR products status monitoring (VIIRS Global Ocean Color Composite Images, both Near-Real-Time stream and Science-Quality stream) and data quality check.

--Finished data analysis of the impacts of different Ozone inputs (from NASA and NOAA) to SNPP VIIRS OC EDR L2 and L3 products.

--Supported the JPSS J1 pre-launch SDR calibration data analysis for OC EDR.

PROJECT TITLE: NESDIS Environmental Applications Team – Xiao-Long Wang, Research Associate - Software Development for Satellite Data Analysis and Processing

PRINCIPAL INVESTIGATORS: Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Xiao-Long Wang

NOAA TECHNICAL CONTACT: Menghua Wang

NOAA RESEARCH TEAM: Xiao-Long Wang, Lide Jiang, Xiaoming Liu, Wei Shi, Liqin Tan, SeungHyun Son, and Mike Chu

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVE:

Develop Ocean Color Data Application & Processing System (OCDAPS) to support VIIRS, GOCI, OLCI, and LANDSAT Ocean color products image visualization, data manipulation and processing.

PROJECT ACCOMPLISHMENTS:

Actively made progresses to support various satellite sensor image visualization (VIIRS, GOCI, OLCI and LANDSAT etc.) with capability for data analysis and processing.

1--Constantly improved various satellite image data visualization, analysis and processing. Supported VIIRS(SNPP & NOAA-20), GOCI, OLCI, MODIS, and LANDSAT Ocean Color products in image display, image data manipulation, multiple band image difference computation, data quality flags view, geo-registration, image mapping and re-projection, graphic IO utility, true-color image generation, netCDF input/output and scripts controlled batch data processing.

2--Added supports for VIIRS DNB band images visualizations, multiple granule merge, image rotations and ship-track data analysis etc.

3--Built standard input and display functions for various sensor's L2 data which resulted from MSL12 program package. All VIIRS, MODIS, GOCI, OLCI and LandSAT L2 images have standard L2flags.

4--Extended support for CoastWatch OceanColor data product visualization with navigation info using OCDAPS functions.

5--Created more helping functions to assist team users in image analysis and data comparisons. Such as initial default colors in colorbar, missing values reset for better data scale display, plotting background selection options, automatic product names loading in l2bin function, etc.

6--Performed full support for newly launched NOAA-20 VIIRS SDR/EDR/I-Band testing data files in timely image visualization and data processing.

7--Conducted full investigation for future Java based satellite image visualization and data processing systems (SNAP, Beam, SeaDAS etc.). Tested and compared various functionalities to verify system capability and suitability for ocean-color L1/L2/L3 product use.

8--Accomplished new system development and program modification with various system tests to enable Java based satellite image visualization tool SNAP meet NOAA OceanColor team requirements.

9--Made new color system for NOAA OceanColor products L2 flags display based on NOAA L2flag names standard.

10--Enabled SNAP visualization system to accept NOAA high-resolution L2 data and hybrid L2 data (High resolution and standard resolution mixed) for image visualization with navigation and l2flag supports

11--Assisted colleagues for climatology data batch download and seek missing data recovery.

12--Coordinated with colleagues to perform daily system monitoring for web based satellite image quality. Reported system problems to team for image recovery and image improvement.

13--Continuously building comprehensive system GUI mode / command mode support to perform current and future new satellite data computations and image data analysis and processing for group user's routine batch jobs and command scripts.

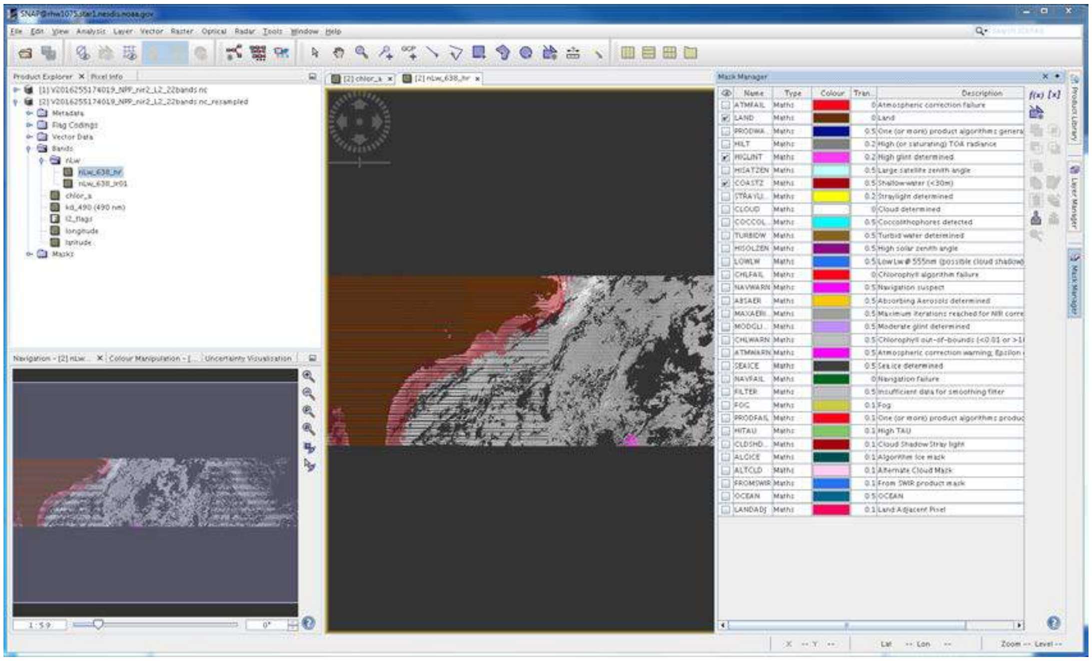


Figure 1. VIIRS SNPP image analysis on L2 Ocean Color products (NOAA High Resolution nLw_638) with new 32 bit L2flag setup on modified Java based SNAP system.

PROJECT TITLE: NESDIS Environmental Applications Team – Xin Xi, Post Doc - Development of Atmospheric and Aerosol Correction for IR SST Retrievals

PRINCIPAL INVESTIGATORS: Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Xin Xi

NOAA TECHNICAL CONTACT: Alexander Ignatov

NOAA RESEARCH TEAM:

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVE:

To improve SST retrievals and monitoring of sensor brightness temperatures (BT) in the NOAA Advanced Clear-Sky Processor for Ocean (ACSPO) SST system

PROJECT ACCOMPLISHMENTS:

MERRA-2 global meteorological and aerosol atmospheric profiles have been tested in the NOAA ACSPO system, to explore their potential for improved SST retrievals, more accurate simulation of sensor top-of-atmosphere (TOA) BTs, and their monitoring in the Monitoring of IR Clear-sky Radiances over Ocean for SST system (MICROS; www.star.nesdis.noaa.gov/sod/sst/micros/). MERRA-2 atmospheric fields have been compared with the NCEP Global Forecast System (GFS) data, which are currently used in ACSPO as input in the Community Radiative Transfer Model (CRTM). Additional simulations have been performed using the European RTTOV model. Preliminary testing shows consistent reduction in BT biases in all IR bands of SNPP/VIIRS used for SST retrievals, when MERRA-2 water vapor and temperature profiles are used.

MERRA-2 data cover full satellite era from 1981-pr, and are well suited for ACSPO long-term Reanalysis (RAN) efforts. Full implementation of the MERRA-2 data set in ACSPO RAN efforts is currently underway. The MERRA-2 data are being downloaded from NASA online repository, converted to formats compatible with ACSPO, processed, and stored at local servers for the use in RAN efforts in STAR for various satellites and sensors, including polar (AVHRR/MODIS/VIIRS) and geostationary (ABI/AHI) sensors. However, MERRA-2 data are not available in real time, and NCEP GFS data will continue to be used in the NOAA ACSPO operations.

In conjunction with Xinjia Zhou and Kai He, an internal version of the MICROS monitoring website has been set up for testing with SNPP/VIIRS data using the MERRA-2 meteorological profiles.

MERRA-2 aerosol data have been also tested using the RTTOV model, and were shown to further reduce the model-minus-observation (M-O) BT biases. Preliminary results demonstrate the potential of MERRA-2 aerosol data to also reduce the SST biases, especially in dust outflow regions (e.g., North Atlantic). Further testing and implementation of the aerosol profiles in ACSPO will be needed to determine and fully realize the potential of MERRA-2 aerosol reanalysis. The goal of this effort is to improve the physically based atmospheric correction of satellite IR signals used for SST retrieval.

Current ACSPO code works with an earlier CRTM version 2.1, which supported coefficients files in two formats. However, the latest CRTM version 2.3 stopped supporting one of these formats – the Optical Depth in Absorption Space (ODAS), and fully transitioned to the Optical Depth in Pressure Space (ODPS) format, which required an upgrade of the ACSPO system. To support the upgrade, CRTM v2.1 and v2.3 for the VIIRS/SNPP and MODIS/AQUA sensors have been cross-evaluated, and ODPS coefficient files have been tested against the ODAS coefficients files. The tests showed generally positive results (e.g., improved consistency of the M-O biases, for different polar sensors, including AVHRRs, MODISs, and VIIRSs). Combined with similar results for the AVHRR sensors conducted by X. Zhou, ACPSO will be updated accordingly for the next release, ACSPO v2.60.

A manuscript titled “exploring MERRA-2 global meteorological and aerosol reanalyses for improved monitoring of VIIRS brightness temperatures and SST retrievals in the NOAA ACSPO system” is in advanced stage and will be submitted for peer review, upon internal review by co-authors. Three figures from the manuscript are shown below to summarize the main results of the study.

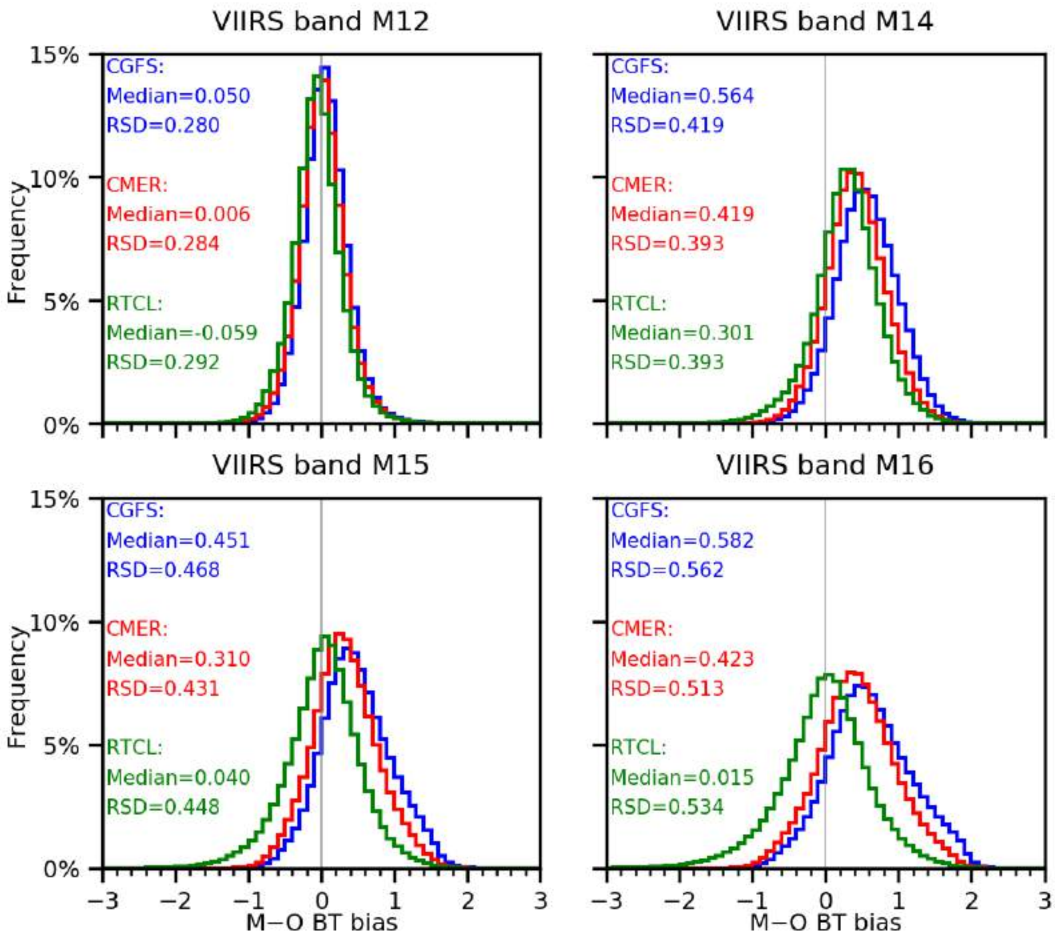


Figure 1. Global histograms of model-minus-observation (M-O) BT biases from three model experiments: CGFS (CRTM simulation using GFS profiles), CMER (CRTM simulation using MERRA-2 profiles), and RTCL (RTTOV simulation using MERRA-2 profiles). All three experiments are conducted for aerosol-free conditions. If the model works as expected, the M-O biases are expected to be close to zero, and have a Gaussian and narrow distribution. Using MERRA-2 profiles in CRTM consistently reduces the median biases, and the robust standard deviations in the longwave IR bands. The biases are further reduced in RTTOV simulations (less so in the band M14 centered at 8.6 µM), but with higher standard deviations.

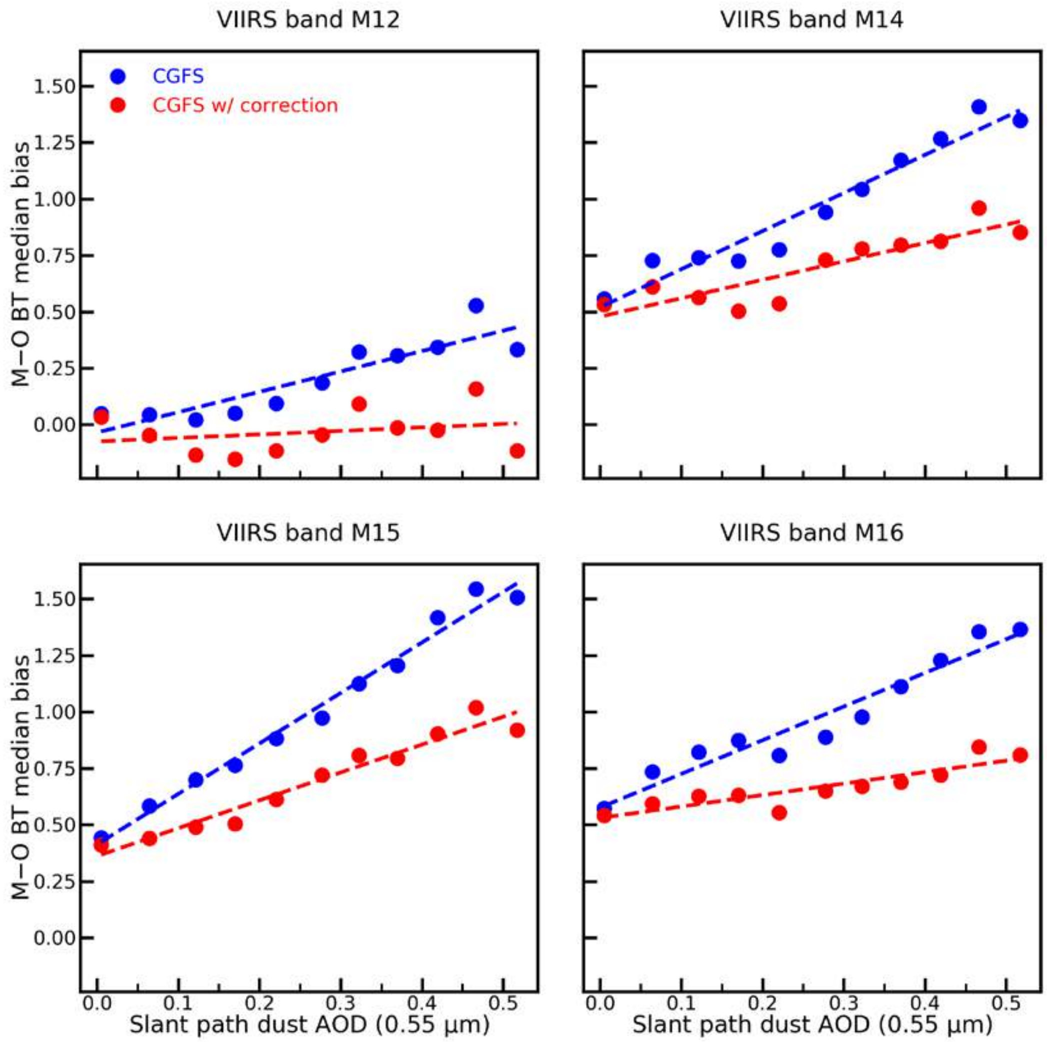


Figure 2. Changes in the M-O BT biases as a function of dust aerosol optical depth (AOD) for the CGFS experiment without (blue symbols and lines) and with corrections for the dust aerosol (red symbols and lines). The correction is based on two stand-alone RTTOV simulations with and without dust aerosol. Their difference is considered the dust signal in sensor observations, and subtracted from the VIIRS observed BTs. This figure shows that for all IR channels, the M-O biases and their dependence on the AOD, are reduced after the dust effect is accounted for. The dependence of M-O biases on dust AOD almost flattens out in VIIRS band M12, and is reduced by ~50% in all longwave bands.

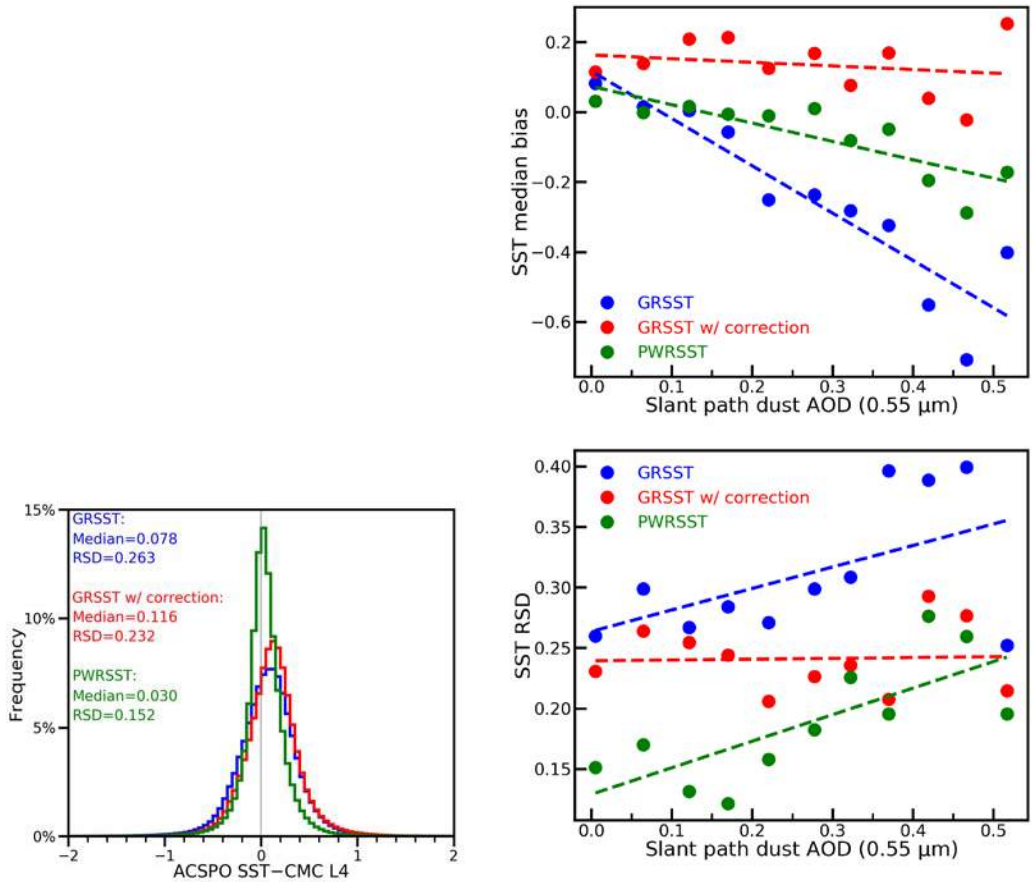


Figure 3. Left panel shows the global histograms of SST biases (with respect to CMC L4 SST) for three SST fields. After dust aerosol correction, the standard deviation of the ACSPO global regression SST is reduced. However, this physical correction is outperformed by the piecewise regression SST (PWRSST) currently adopted in ACSPO to empirically correct for all SST anomalies regardless of physical causes, including dust aerosol. The right panel shows the changes in SST bias (top) and standard deviation (bottom) as a function of dust AOD. The dependence of the global-regression bias is significantly reduced after correcting for dust effects, compared to the global regression without correction and even the PWRSST. This demonstrates the potential of physically-based aerosol correction to minimize the dependence of the SST bias on AOD.

Publications and Presentations:

Ignatov, A., B. Petrenko, Y. Kihai, I. Gladkova, X. Zhou, Y. Ding, K. He, M. Kramar, M. Pennybacker, O. Jonasson, X. Xi, P. DiGiacomo, and J. Sapper, Satellite SST Products at NOAA. 2017 EUMETSAT Conference, 2-6 October 2017, Rome, Italy (Oral.)

Ignatov, A., B. Petrenko, Y. Kihai, I. Gladkova, X. Zhou, Y. Ding, K. He, M. Kramar, M. Pennybacker, O. Jonasson, X. Xi, P. DiGiacomo, and J. Sapper, VIIRS SST: From SNPP to J1. JPSS Science Team Meeting, 8 November 2017, Vandenberg AFB, CA (Oral.)

Xi, X., A. Ignatov, and X, Zhou, Exploring MERRA-2 global meteorological and aerosol reanalyses for improved monitoring of VIIRS brightness temperatures and SST retrievals in the NOAA ACSPO system (in prep for submission).

Xi, X., and A. Ignatov, Developing an atmospheric correction for tropospheric dust in the IR SST retrieval for the NOAA ACSPO system. 18th GHRSST Meeting, 5-9 June 2017, Qingdao, China (poster).

Xi, X., and A. Ignatov, Aerosol Correction for IR SST, GMAO – STAR Meeting, Apr 2017, NASA GSFC. (Oral)

PROJECT TITLE: NESDIS Environmental Applications Team, Xinjia Zhou – Research Associate - NOAA SST Reanalysis, Validation and Monitoring

PRINCIPAL INVESTIGATORS): Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Xinjia Zhou, Yanni Ding

NOAA TECHNICAL CONTACT: Alexander Ignatov

NOAA RESEARCH TEAM: Alexander Ignatov, Boris Petrenko, Yury Kihai, Maxim Kramar, Kai He, Olafur Jonasson

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVES:

1--In conjunction with Kai He and Olafur Jonasson, improve the NOAA SST Quality Monitor (SQUAM; www.star.nesdis.noaa.gov/sod/sst/squam/) and support routine operations.

2--In conjunction with Kai He, improve the NOAA in-situ SST Quality Monitor (*i*Quam; www.star.nesdis.noaa.gov/sod/sst/iquam/) and support routine operations.

3--In conjunction with Kai He and Olafur Jonasson, improve the NOAA IR Clear-Sky Radiance Monitor (MICROS; www.star.nesdis.noaa.gov/sod/sst/micros/) and support routine operations.

4--Work with team members to establish AVHRR FRAC Reanalysis (RAN1) and create GAC RAN2. Work includes full cycle production, from L1B to ACSPO L2 and L3U products, match-ups with *i*Quam2 in situ SSTs, web display in SQUAM/ARMS/MICROS, and archival with NOAA Coast Watch.

PROJECT ACCOMPLISHMENTS:

1--In conjunction with NOAA Technical Monitor and SST Team, working on the Advanced Clear-Sky Processor for Oceans (ACSPO) experiments for JPSS and GOES-R SST including VIIRS onboard SNPP (launched Oct 2011), JPSS-1 (NOAA20; launched Nov 2017) and ABI onboard GOES-R (GOES-16; launched Nov 2016) and GOES-S (GOES-17; launched Mar 2018), displaying results online (also see No.2 and No.4 below), and presenting at national and international meetings. An example of monitoring validation standard deviation of SNPP and N20 nighttime VIIRS SSTs with respect to in situ data in SQUAM is shown in Figure 1. Another example of monitoring G16 ABI SST bias with respect to CMC L4 analysis is shown in Figure 2.

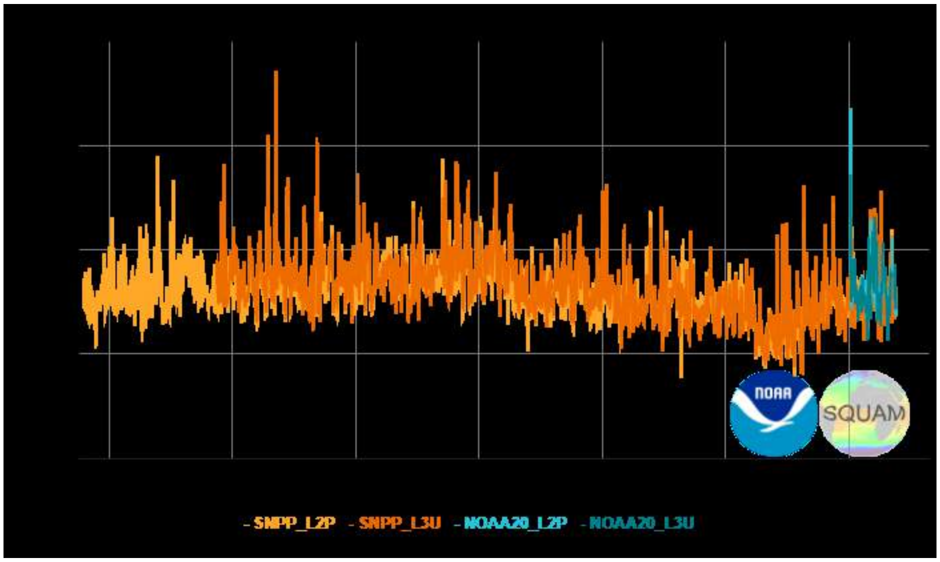


Figure 1. Nighttime *SD* ($T_{Sat} – T_{in\ situ}$) of VIIRS SSTs from SNPP and N20. Each data point represents a daily statistic based on matchups with *in situ* SSTs.

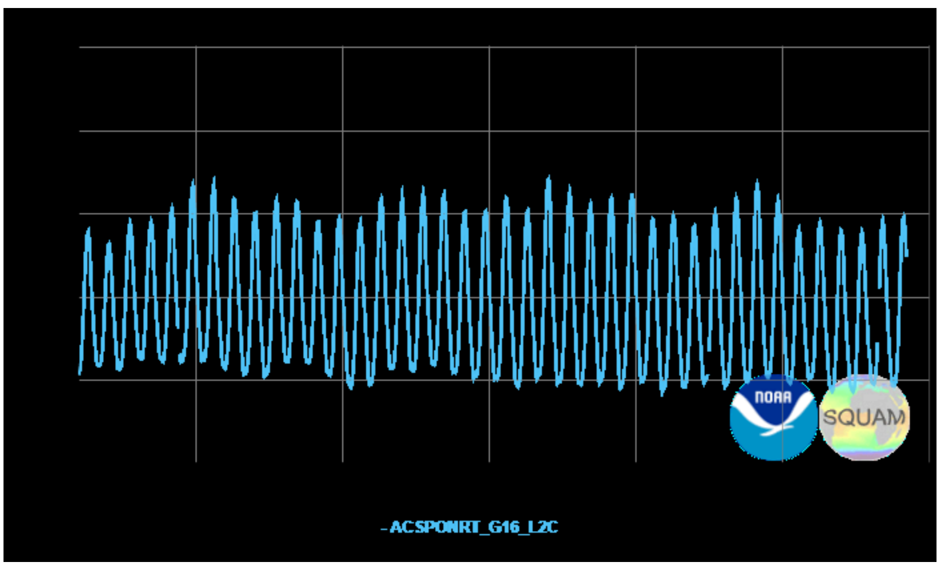


Figure 2. Mean bias ($T_{Sat} – T_{L4\_ref}$) for G16 ABI SST. Each data point represents an hourly statistic derived from match-ups with global Level 4 SST analysis produced by the Canadian Met Centre.

2--In conjunction with NOAA Technical Monitor, Kai He and other team members, released NOAA SST Quality Monitor v2.0 (SQUAM; www.star.nesdis.noaa.gov/sod/sst/squam/), for validation, calibration and cross evaluation of different NOAA and community SST products. In SQUAM v2, three modules, polar orbiter, geostationary and analysis (L4 products) have been established. The NOAA STAR SST retrieval products include near real time and reanalysis (RAN) products. Experimental (developmental) versions of the products are monitored on SQUAM internal pages, for Team’s evaluation. An example of G16 SST monitoring in SQUAM is shown in Figure 3.

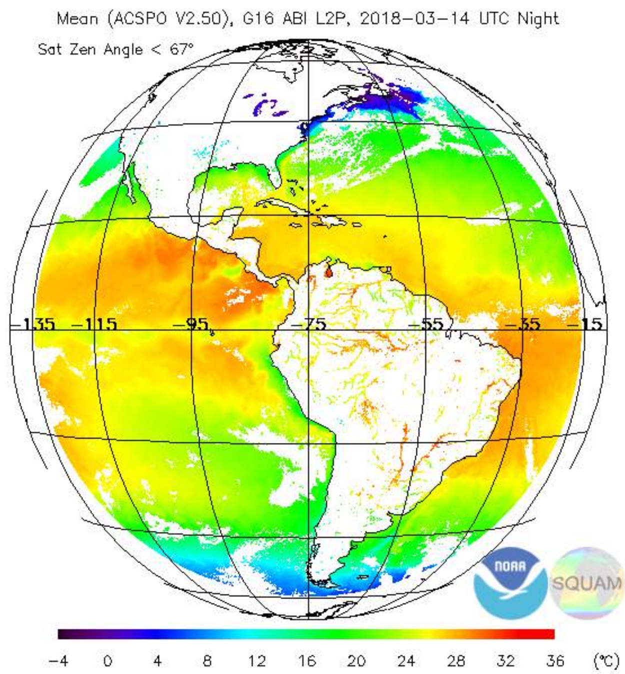


Figure 3. G16 ABI SST is displayed in SQUAM in near-real time.

3--In conjunction with NOAA Technical Monitor and Kai He, released NOAA *in-situ* SST Quality Monitor v2.0 beta (*i*Quam; www.star.nesdis.noaa.gov/sod/sst/iquam/), working on official iQuam v2.0. Several new types of in-situ instruments have been included. The *i*Quam2 is more stable and robust, and offers improved quality control compared with *i*Quam1.

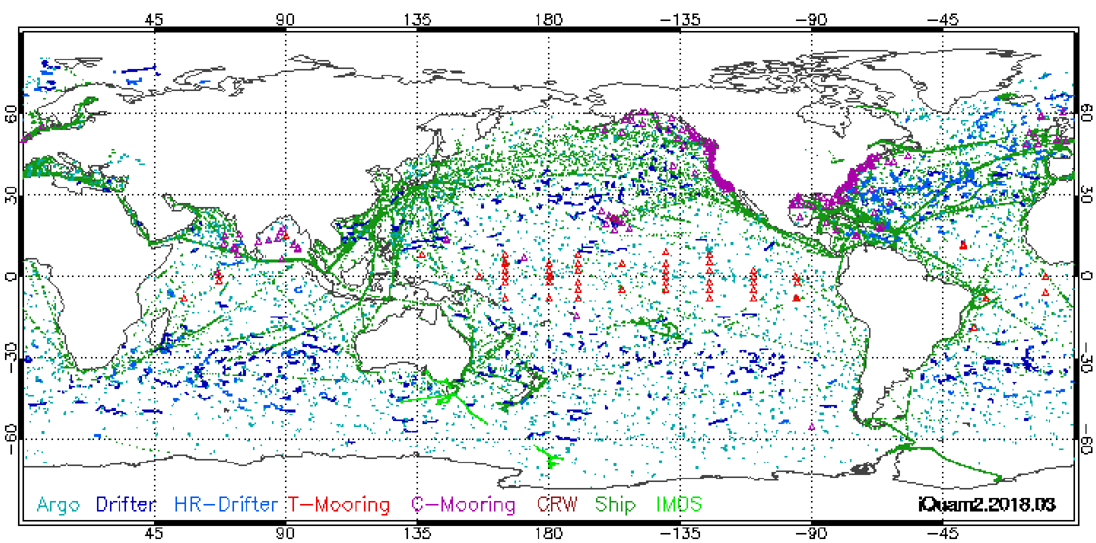


Figure 4. Distribution of different types of *in-situ* measurements in near-real time in *i*Quam2.

4--In conjunction with NOAA Technical Monitor and Kai He, released Monitor for Infrared Clear-sky Radiance over Ocean for SST v2.0 beta (MICROS; www.star.nesdis.noaa.gov/sod/sst/micros2/). Work is underway to release the official MICROS v2.0. In MICROS v2, two modules, polar orbiter and geostationary have been established for better understanding the relationship between brightness temperature and SSTs. MICROS provides feedback to NOAA Community Radiative Transfer Model (CTRM) team which proved valuable to improve the CRTM performance.

5--In conjunction with NOAA Technical Monitor and SST Team, continued working on the next round of ACSPO Reanalysis of AVHRR GAC SST (RAN2), displaying results online for further analysis. Figure 5 shows an example of monitoring BTs in AVHRR channel 4 (centered at 11 µm) from three new AVHRR/2 sensors explored in RAN2, onboard NOAA-11, -12 and -14 satellites. Generally, AVHRR/2s are less stable than AVHRR/3s which will require efforts to stabilize SSTs in RAN2.

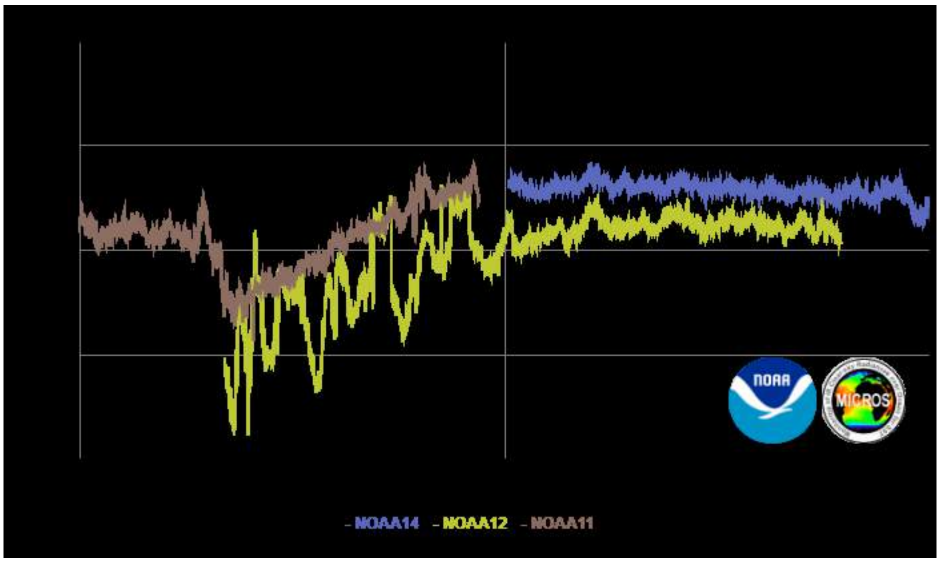


Figure 5. Nighttime mean biases *($BT_{Sat} – BT_{crtm}$)* of AVHRR2s onboard NOAA-11, -12 and -14 satellites. Each data point represents a daily statistic.

Presentations:

Ignatov, A., Irina Gladkova, Yanni Ding, Yury Kihai, Xinjia Zhou, Fazlul Shahriar: ACSPO L3U SST Products from SNPP VIIRS and Metop-A and -B AVHRR FRAC:18-21 April 2017, Melbourne, Australia

Ignatov, A., B. Petrenko, Y. Kihai, I. Gladkova, X. Zhou, Y. Ding et al.: Satellite SST Products at NOAA, EUMETSAT Conference, Oct. 2017, Rome, Italy

Ignatov, A., B. Petrenko, Y. Kihai, I. Gladkova, X. Zhou, Y. Ding et al.: VIIRS SST: from SNPP to J1, JPSS Science Meeting, Nov. 2017, Vandenberg AFB, CA

Petrenko, Boris, Alexander Ignatov, Maxim Kramar, Yury Kihai, Xinjia Zhou, Kai He: Diurnal cycles in the NOAA ACSPO “depth” and “skin” SSTs from the new generation ABI/AHI geostationary sensors, 5-9 June 2017, Qingdao, China

Zhou, Xinjia, Alexander Ignatov, Boris Petrenko, Yury Kihai, Prasanjit Dash, Xingming Liang, John Stroup, Recent Improvement to the NOAA iQuam2 System: 5-9 June 2017, Qingdao, China

Zhou, Xinjia, Alexander Ignatov, Feng Xu, Kai He: NOAA in situ SST Quality Monitor Version 2 (iQuam2):18-21 April 2017, Melbourne, Australia

PROJECT TITLE: NESDIS Environmental Applications Team, Tong Zhu – Research Scientist - Community Radiative Transfer Model Development and Maintenance

PRINCIPAL INVESTIGATORS: Steve Miller, Cliff Matsumoto

RESEARCH TEAM: Tong Zhu

NOAA TECHNICAL CONTACT: Kevin Garrett (NESDIS/STAR)

NOAA RESEARCH TEAM: Quanhua Liu, Sid Boukabara (NESDIS/STAR), Benjamin T. Johnson (UCAR), Min Chen (UMD), Yingtao Ma and Jean-Luc Moncet (AER).

FISCAL YEAR FUNDING (NEAT Total): $1,299,999

PROJECT OBJECTIVES:

1--CRTM coefficient generation
2--CRTM Scientific upgrades and the generation of new release
3--Test CRTM-OSS package
4--Independent assessment of CLBLM
5--CRTM maintenance and user support

PROJECT ACCOMPLISHMENTS:

During the past year, I worked on the JCSDA CRTM development and maintenance, and made some important contributions to the project, including creating CRTM new release REL-2.3.0, generating CRTM coefficients, testing CRTM-OSS (Optimal Spectral Sampling) package, and the independent assessment of the CLBLM. I also provided CRTM user support, responding users' questions and requests, as well as technical support for the STAR Joint OSSE project. The following is a brief summary of these activities.

1--In preparing the CRTM REL-2.3.0 release, one of the first important step is to merge the "Cloud_Fraction" branch into CRTM trunk. I put great effort in solving a lot of conflicts between CRTM trunk and this branch which has about 4 years' development history. I also integrated all other Rel-2.3.0 related implementations and bug fixes into CRTM trunk. After performing the consistency tests, I created the new CRTM release, REL-2.3.0, and made it available on CRTM release ftp site in November 2017.

2--During the past year, I generated CRTM coefficients for many new and updated satellite sensors, including new coefficients for NOAA20 ATMS real SRF, CrIS_N20, CrIS_FSR 431 subsets for SNPP and N20, and for Small/Cube Satellites of Compact Ocean Wind Vector Radiometer (COWVR), TROPICS, TEMPEST and EON-MW, and updated the coefficient of COMS_MI sensor for a SRF shift of the WV channel.

3--After integrating the Optimal Spectral Sampling (OSS) model into CRTM v2.2.0 and generating the CRTM-OSS alpha release, I performed further testing, and found that there was some difference between K-Matrix (KM) and Forward Finite Difference (FFD) water vapor Jacobians calculations. The testing results and data were sent to AER (Jean-Luc Moncet's team) to help them find out the issue.

4--I also performed the independent assessment of the Community Line-by-Line Model (CLBLM), and working towards the generation of CRTM IR sensor coefficient using the CLBLM model.

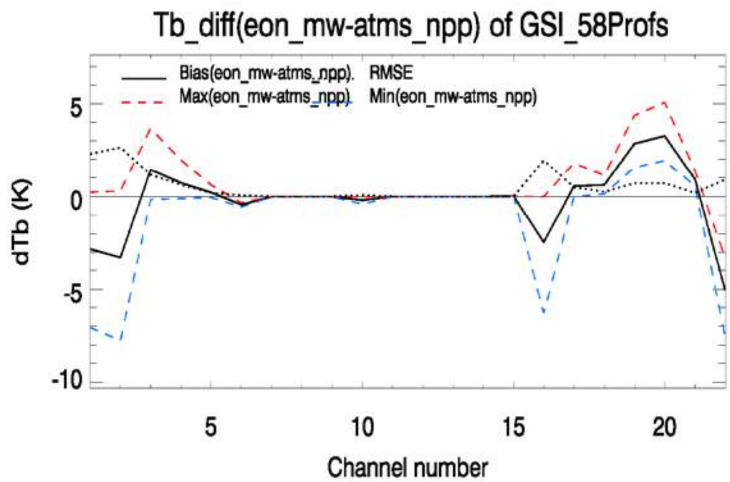


Figure 1. CRTM simulation of the Earth Observing Nanosatellite-Microwave (EON-MW) and compared with that of ATMS_NPP sensors

Publications:

Boukabara, S-A., K. Ide, N. Shahroudi, Y. Zhou, **T. Zhu**, R. Li, L. Cucurull, R. Atlas, S. P. F. Casey, and R. N. Hoffman. Community global observing system simulation experiment (OSSE) package: CGOP. Part II: Observations simulation validation. *J. Atmospheric Oceanic Technology*, 35(1):207–226, Jan. 2018. doi:10.1175/JTECH-D-17-0077.1.

Liu, Q., **T. Zhu**, B. Johnson, M. Chen, Y. Chen, L. Lin, and F. Weng (2018) Community Radiative Transfer Model (CRTM) for Operational and CubeSat Satellite Applications. *The 98th AMS Annual Meeting*, January 7 – 11, 2018, Austin, TX.

Zhou, Y., N. Shahroudi, S. A. Boukabara, K. Ide, **T. Zhu**, R. N. Hoffman, and R. Atlas (2018) Assessments of CIRAS Impacts on NWP through the Community Global Observing System Simulation Experiment (OSSE) Package. *The 98th AMS Annual Meeting*, January 7 – 11, 2018, Austin, TX.

Zhu, T., B. Johnson, Q. Liu, Y. Chen, M. Chen, E. Liu, D. Groff, Y. Ma (2017) Preparing Release of CRTM REL-2.3.0 and Its New Features. *The 15th JCSDA Technical Review and Science Workshop on Satellite Data Assimilation*, College Park, Maryland, May 17-19, 2017.
Zhu, T. (2017) Using CRTM as A Standalone RTM. *The 1st CRTM User/Developer Workshop*, College Park, Maryland, May 16, 2017.

Zhu, T., S. Boukabara, and K. Garrett, (2017), Comparing Impacts of Satellite Data Assimilation and Lateral Boundary Conditions on Regional Model Forecasting: Case Study of Hurricane Sandy. *Weather and Forecasting*, 32, 595-608.

Zhu, T., Q. Liu, B. Johnson, Y. Chen, and T. Auligne (2018) Generation of CRTM Coefficients for JPSS-1 and ORS-6 Mission Sensors. *The 98th AMS Annual Meeting*, January 7 – 11, 2018, Austin, TX.
Shahroudi, N., Y. Zhou, **T. Zhu**, S. A. Boukabara, K. Ide, R. N. Hoffman, and R. Atlas (2018) Global Observing System Simulation Experiments (OSSE) for CubeSat MicroMas-2. *The 98th AMS Annual Meeting*, January 7 – 11, 2018, Austin, TX.

PROJECT TITLE: CIRA Support for Tropical Cyclone Model Diagnostics and Product Development - Hurricane Forecast Improvement Project (HFIP)

PRINCIPAL INVESTIGATOR: Kate Musgrave

RESEARCH TEAM: Andrea Schumacher, Robert DeMaria, Chris Slocum

TECHNICAL CONTACT: Fred Toepfer (NOAA/NCEP/EMC)

NOAA RESEARCH TEAM: John Knaff (NOAA/NESDIS/STAR)

FISCAL YEAR FUNDING: $158,360

PROJECT OBJECTIVES:

The National Oceanic and Atmospheric Administration (NOAA) initiated the Hurricane Forecast Improvement Project (HFIP) to reduce the errors in tropical cyclone track and intensity forecasts. This reduction will be accomplished through improved coupled ocean-atmosphere numerical hurricane models, better use of observations through advanced data assimilation techniques and ensemble forecasts. Model diagnostic techniques will also be developed to determine the sources of model errors and guide future improvements. The CIRA team performed tasks for three objectives that contribute to this HFIP effort. Details on these tasks are described in the next section.

The CIRA HFIP activities directly address NOAA's Weather Ready Nation objectives. This research falls within the NOAA-defined CIRA thematic area of Satellite Algorithm Development.

PROJECT ACCOMPLISHMENTS: Covering July 2017-March 2018

1--SHIPS/LGEM/RII Improvements

--Tasks associated with this objective fall into three general areas. The first area involves updating the SHIPS/LGEM/RII database with the 2017 season, and is ongoing. Code upgrades are being implemented in the SHIPS/LGEM/RII code to include new storm structure guidance. The second area focuses on the inclusion of models in SPICE. Previous work focused on implementing the ECMWF version of SHIPS/LGEM/RII on WCOSS and testing a two-model ensemble with GFS and ECMWF as inputs for SPICE. Current work focuses on adapting the base version of SPICE to remove the no longer operational GFDL model and replace it with HMON, and is currently being tested with the 2017 season. The third area focuses on implementing GOES-R (now GOES-16) into the operational SHIPS/LGEM/RII code. The satellite readers have been adapted to the new data and delivered to NHC for inclusion in the operational code. Preliminary testing indicated minimal changes to the values of the satellite-derived predictors, so the operational SHIPS/LGEM/RII should not require bias corrections to the GOES-16 data to bring it in line with the developmental dataset.

2--Improving the Monte Carlo Wind Speed Probability Model

--Two updates were made to the MC model to correct for observed high biases in the wind speed probabilities over land. The first correction involves checking whether or not a realization crosses land at each hourly interval between 12-hour forecast positions. If a realization indeed crosses over land, a higher resolution temporal interpolation scheme is used (hourly vs. 6-hourly) so the inland decay model is applied to the realization intensity even at times when the realization crosses a narrow island or peninsula. The second update also involves using a higher resolution temporal interpolation scheme when a TC approaches land. As soon as a realization's 34-kt wind field comes onshore, a fixed reduction factor (0.8) is applied to the realization's intensity and the resulting reduced wind radii are used for land grid points. This correction results in reduced wind speed probabilities over land, which is physically consistent with observations. Two examples of these wind speed probabilities corrections are shown below. The first example is for Harvey on 23 August 2017, and shows a reduction in the wind speed probabilities over land as Harvey approaches landfall. The second example is for Typhoon Doksuri 13

September 2017 and shows a reduction in WSPs over both Hainan Island and the mainland. Updated MC Model code package, which included both inland corrections and updated forecast error distributions for 2013-2017, was delivered to NHC TSB in January 2018 and was implemented into operations by NCO in March 2018.

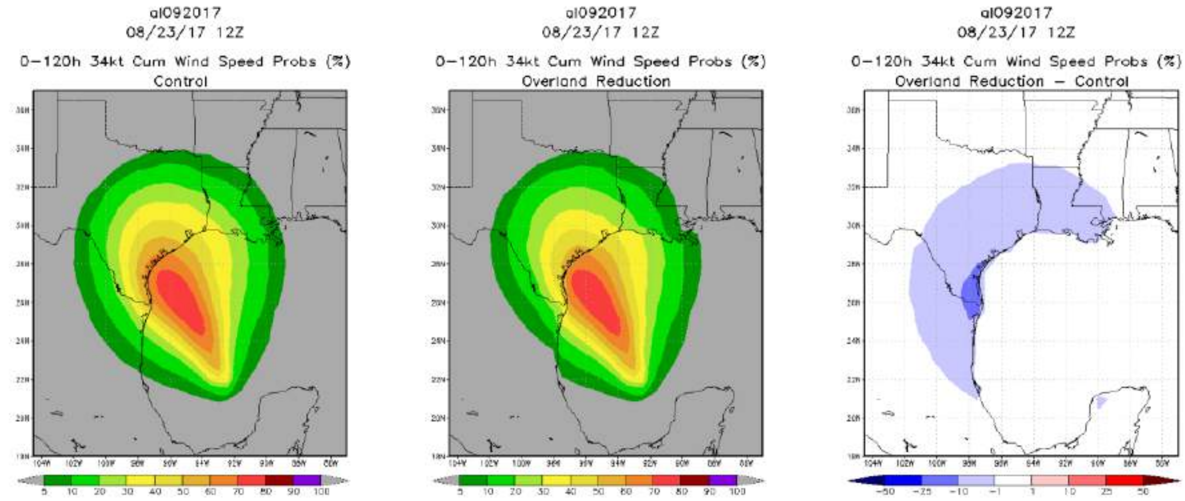


Figure 1. 34-kt 0-120-hr wind speed probabilities for Hurricane Harvey on 23 August 2017 at 12Z without (left) and with (center) the new inland corrections. The probability differences are shown in the plot to the right.

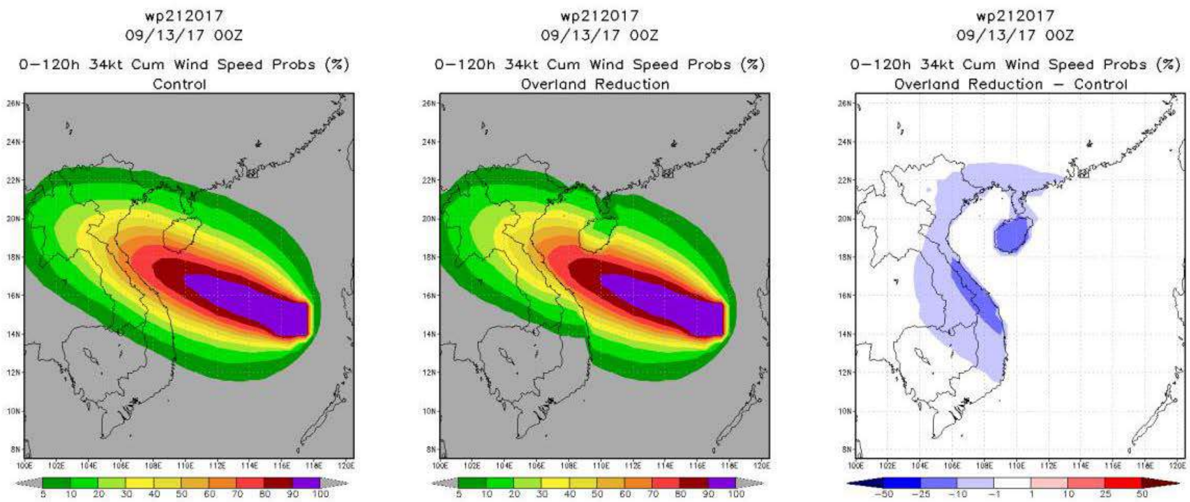


Figure 2. 34-kt 0-120-hr wind speed probabilities for Typhoon Doksuri on 13 September 2017 at 00Z without (left) and with (center) the new inland corrections. The probability differences are shown in the plot to the right.

--Previous research supported by HFIP lead to the development and testing of a hybrid statistical-dynamical wind speed probability product using global model ensemble tracks to define the MC model realizations. Building upon this research, two new methods for incorporating numerical model ensemble tracks into the MC model that are more consistent with the official NHC track and intensity forecasts were developed in this past year. Preliminary verification results suggest that both of these new methods have improved forecast skill over both the operational and hybrid WSPs at longer forecast times. A paper on these findings is currently in preparation.

3--Developing Statistical Products for Rapid Intensification Forecasting

--The addition of rapid intensification index (RII) probabilities to the ATCF database has been completed and added to the operational SHIPS/LGEM/RII code at NHC. The code has also been provided to additional groups upon request. The RII code in SPICE was updated from the 2013 version to the 2015 version, and work is underway to bring in the additional datasets required to update SPICE to the latest version of the RII.

Publications:

Bender, M. A., T. P. Marchok, C. R. Sampson, J. A. Knaff, and M. J. Morin, 2017: Impact of storm size on prediction of storm track and intensity using the 2016 operational GFDL hurricane model. Wea. Forecasting, 32(4), 1491-1508, https://doi.org/10.1175/WAF-D-16-0220.1

Knaff, J. A., and R. T. DeMaria, 2017: Forecasting tropical cyclone eye formation and dissipation in infrared imagery. Wea. Forecasting, 32(6), 2103-2116, https://doi.org/10.1175/WAF-D-17-0037.1

Schubert, W. H., C. J. Slocum, and R. K. Taft, 2017: Basic concepts involved in tropical cyclone boundary layer shocks. arXiv:1709.00101v1 [physics.ao-ph].

Slocum, C. J., 2018: The Role of Inner-Core and Boundary Layer Dynamics on Tropical Cyclone Structure and Intensification. Dissertation, Colorado State University, 106 pp.

Presentations:

Musgrave, K. D., and M. DeMaria, 2018: Further development of a statistical-dynamical ensemble for tropical cyclone intensity prediction. AMS 33rd Conference on Hurricanes and Tropical Meteorology, April 16-20, Ponte Vedra, FL.

Schumacher, A.B., and M. DeMaria, 2018: New methods for incorporating situation-specific track uncertainty into the Monte Carlo Wind Speed Probability Model. AMS 33rd Conference on Hurricanes and Tropical Meteorology, April 16-20, Ponte Vedra, FL.

Slocum, C. J., 2018: Shock-like structures in the tropical cyclone boundary layer. AMS 33rd Conference on Hurricanes and Tropical Meteorology, April 16-20, Ponte Vedra, FL.

Slocum, C. J. and W. H. Schubert, 2018: A forced, balanced model for tropical cyclone intensification. AMS 33rd Conference on Hurricanes and Tropical Meteorology, April 16-20, Ponte Vedra, FL.

Slocum, C. J., J. P. Kossin, R. K. Taft, and W. H. Schubert, 2018: Instability between the concentric eyewalls of Hurricane Maria (2017). AMS 33rd Conference on Hurricanes and Tropical Meteorology, April 16-20, Ponte Vedra, FL.

PROJECT TITLE: Using JPSS Retrievals to Implement a Multisensor, Synoptic, Layered Water Vapor Product for Forecasters

PRINCIPAL INVESTIGATOR: John Forsythe

RESEARCH TEAM: Andy Jones, Stan Kidder, Dan Bikos, Ed Szoke

NOAA TECHNICAL CONTACT: Ralph Ferraro, NOAA/NESDIS/STAR Satellite Climate Studies Branch

NOAA RESEARCH TEAM: Ralph Ferraro (NOAA/NESDIS/STAR), Michael Folmer (Satellite Liaison at NOAA/NWS WPC/OPC/TAFB)

FISCAL YEAR FUNDING: $125,000

PROJECT OBJECTIVES:

This JPSS/PGRR project began in August 2015 with an objective of developing new multisatellite, blended, layered water vapor products and delivering them to forecasters at national centers and select NWS offices. To achieve this goal, NOAA Microwave Integrated Retrieval System (MIRS) satellite soundings from multiple polar orbiting spacecraft (Suomi-NPP, NOAA-18/19, Metop-A/B, and DMSP F17/18) are blended together every three hours to create a four-layer, four-dimensional view of precipitable water vapor. These products are highly complementary to the CIRA-developed blended total precipitable water (TPW), TPW anomaly and blended rain rate products which were successfully transitioned to NOAA operations in 2009 and are used throughout the NWS. Layered precipitable water (LPW) allows forecasters to understand the vertical distribution of water vapor not apparent from TPW, particularly over the data-sparse oceans. The product leverages the Data Processing and Error Analysis System (DPEAS) processing tool to enable seamless research-to-operations transitions. DPEAS is the research system at CIRA and runs operationally at NESDIS Office of Satellite and Product Operations (OSPO), and so facilitates future operational transitions.

Advected LPW (ALPW) products are being delivered to National Centers in near-realtime (NOAA WPC, NHC SAB, TAFB and OPC), via collaboration with NASA SPoRT. CIRA has added 11 NWS WFO's which received VISIT teletraining in 2017 to receive the near-realtime data.

Achievements:

ALPW in four layers (surface - 850 mb, 850 – 700 mb, 700 – 500 mb, and 500 – 300 mb) are created in near-realtime at CIRA and distributed in AWIPS format to partner National Centers and forecast offices. Forecasters are using the products to support forecasting of heavy rains, as connections to tropical moisture serve to fuel extreme floods. The products are currently being used in a variety of forecast applications, including atmospheric rivers impacting the west coast and analysis of tropical waves in NHC tropical outlook discussions.

A near-realtime website displaying ALPW over the CONUS domain is available at: http://cat.cira.colostate.edu/sport/layered/advected/lpw_alt.htm.

An example of the ALPW product is shown in Figure 1.

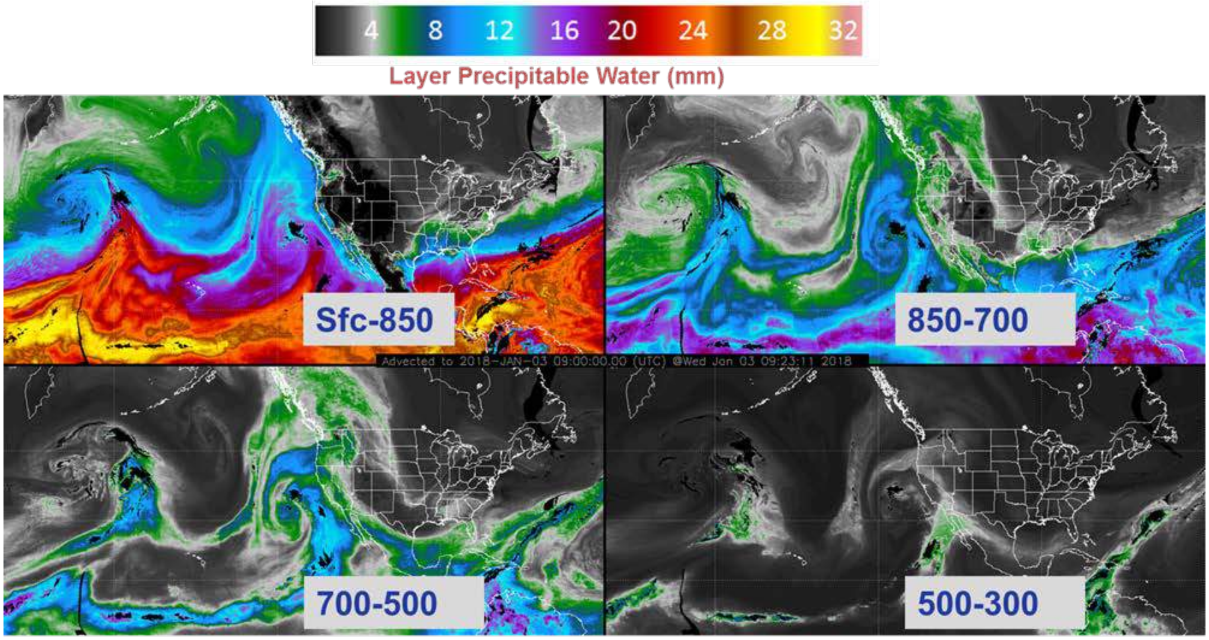
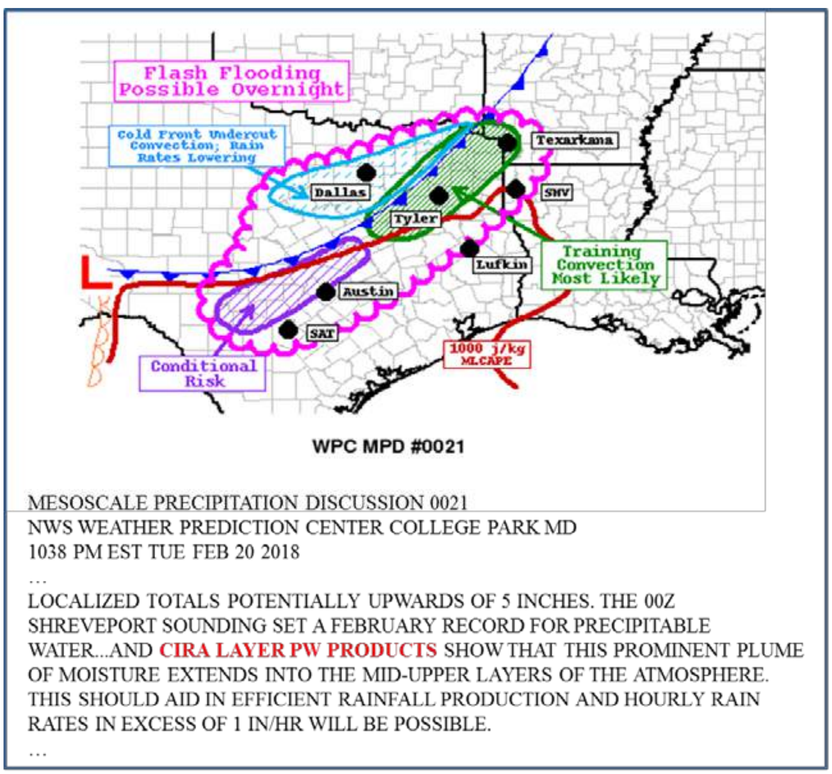


Figure 1. Example of ALPW for 09 UTC 3 Jan. 2018. Several plumes of moisture originating in the tropics are apparent.

An example use of CIRA blended ALPW by the WPC in a Mesoscale Precipitation Discussion for a flooding event over Texas is shown in Figure 2. CIRA ALPW gives forecasters the ability to assess the depth of moisture which can enhance rainfall production, as noted.



MESOSCALE PRECIPITATION DISCUSSION 0021
NWS WEATHER PREDICTION CENTER COLLEGE PARK MD
1038 PM EST TUE FEB 20 2018
…
LOCALIZED TOTALS POTENTIALLY UPWARDS OF 5 INCHES. THE 00Z SHREVEPORT SOUNDING SET A FEBRUARY RECORD FOR PRECIPITABLE WATER...AND **CIRA LAYER PW PRODUCTS** SHOW THAT THIS PROMINENT PLUME OF MOISTURE EXTENDS INTO THE MID-UPPER LAYERS OF THE ATMOSPHERE. THIS SHOULD AID IN EFFICIENT RAINFALL PRODUCTION AND HOURLY RAIN RATES IN EXCESS OF 1 IN/HR WILL BE POSSIBLE.
…

Figure 2. Example usage of CIRA ALPW in WPC Mesoscale Precipitation Discussion 0021**.**

The National Hurricane Center has become a heavy user of CIRA blended LPW to analyze the moisture environment around tropical waves and cyclones. For 28 days in July 2017, in Atlantic Tropical Weather Discussion (TWDAT), CIRA LPW was mentioned 53 times (out of 110 discussions).

A journal paper "Using the multisensor advected layered precipitable water product in the operational forecast environment" led by two NWS forecasters has been submitted to the Journal of Operational Meteorology. This paper shows how the ALPW product would have provided forecasters increased situational awareness of long-distance moisture transport which contributed to four different flash flood events.

A CIRA Virtual Institute for Satellite Integration*Training* (*VISIT*) training module on ALPW has been created by CIRA training experts Dan Bikos and Ed Szoke, with the assistance of close collaborator Sheldon Kusselson (retired NESDIS SAB). The VISIT training has been provided to 9 WFO's so far, and they are receiving the ALPW product in AWIPS format directly from the CIRA Local Data Manager (LDM) server. The training can be viewed at the link below, which also links a Youtube video (Figure 2) with the training:

http://rammb.cira.colostate.edu/training/visit/training_sessions/advected_layer_precipitable_water_product

The ALPW training has been delivered to the NOAA Commerce Learning Center which should bring more forecasters to the training.

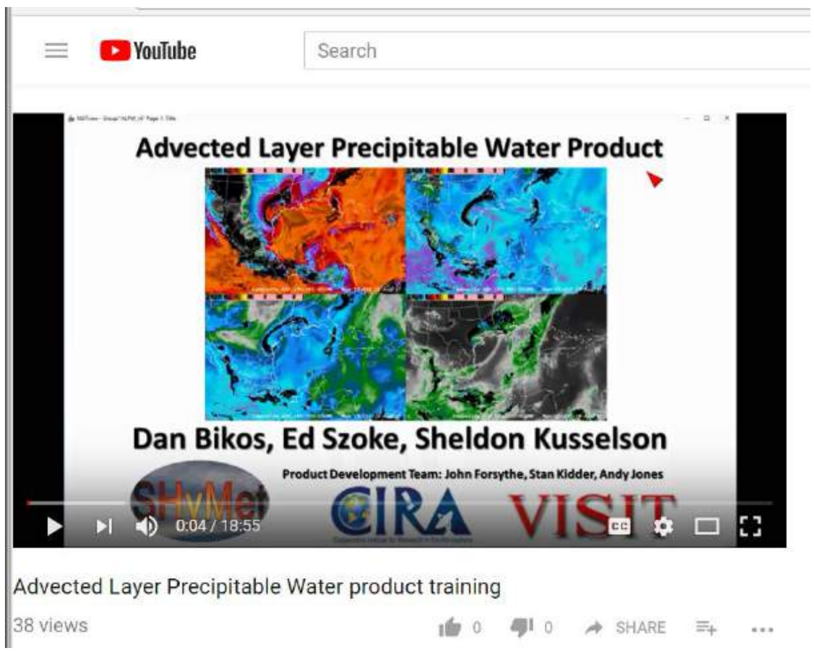


Figure 3. Snapshot of the Youtube version of the ALPW VISIT training module from December 21, 2017.

Publications:

Gitro, C. M., M. L. Jurewicz, S. J. Kusselson, J. M. Forsythe, S. Q. Kidder, E. J. Szoke, D. Bikos, A. S. Jones, C. M. Gravelle, and C. Grassotti, 2018: Using the multisensor advected layered precipitable water product in the operational forecast environment. J. Operational Meteor. In review.

Presentations:

Forsythe, J.M., A. S. Jones, S. Q. Kidder, D. Bikos, E. Szoke, 2015: Blended Multisensor Satellite Products for Forecasting Heavy Precipitation. Poster presentation at National Weather Association Annual meeting, Anaheim, CA September 2017.

REGIONAL TO GLOBAL SCALE MODELING SYSTEMS

Research associated with the improvement of weather/climate models (minutes to months) that simulate and predict changes in the Earth system. Topics include atmospheric and ocean dynamics, radiative forcing, clouds and moist convection, land surface modeling, hydrology, and coupled modeling of the Earth system.

PROJECT TITLE: EAR - Global Model Development

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Ning Wang, James Rosinski, Jacques Middlecoff, Haidao Lin, Julie Schramm

NOAA TECHNICAL CONTACT: Stan Benjamin (OAR/ESRL/GSD)

NOAA RESEARCH TEAM: Georg Grell (OAR/ESRL/GSD/MDB Chief), Jian-Wen Bao (OAR/ESRL/PSD), Mark Govett (OAR/ESRL/GSD/ATO)

FISCAL YEAR FUNDING (Total EAR Project): $4,834,735

PROJECT OBJECTIVES:

Tasks for this project include:
--Develop and improve global atmospheric models for continental scale weather prediction,
--Develop and implement accurate and efficient numerical schemes for numerical weather prediction models on massive parallel computer systems, and
--Design and develop a data assimilation system for weather forecast.

PROJECT ACCOMPLISHMENTS:

The Next Generation Global Prediction System (NGGPS) testing and verification
CIRA researchers provided software support to the Finite-Volume Cubed-Sphere (FV3) model for the ESRL scientists. Based on EMC development repository, version 87170, merge-update version, and public release version 0, CIRA researchers created their corresponding ESRL versions to run on theia and jet. The ESRL version of the model includes modified pre- and post-processing code, build and run scripts, and documents.

CIRA researchers also provide FV3 software support for JEDI and GMTB projects, which include assistance with the gfortran build of FV3 V0 for JEDI project in a Docker container and migrating the modifications made to build and run script on theia to allow a successful build and run of FV3 on Cheyenne at NCAR.

CIRA staff worked with GSD/MDB scientists and software engineers to start the retro- and realtime runs of FV3 to assess the model performance with different physics parameterization schemes.

To better integrate the different physics parameterization schemes to the future Unified Forecast System (UFS), CIRA researchers have been testing various physics parameterization packages on global models, such as FIM, to understand and assess their behaviors and performances. To enable and test different parameterization schemes, new software was added to ingest initial data sets required by these schemes. In addition, a new statistical orographic data set for icosahedral grid cells was created and ingested to improve the parameterization of the orography induced gravity wave drag.

CIRA researchers continued to follow scientific developments with the GFS physics package from NCEP. Specifically, the NUOPC group has defined an init/run/finalize interface to the package and implemented it in the full GFS model. This package was implemented in FIM for the purpose of assessing its numerical performance and improving its computational performance. CIRA researchers continue to improve the computational performance of the two prominent physics packages. These are the GFS physics package from NCEP, and the WRF-based HRRR physics. Accomplishments include assisting researchers with implementation of the HRRR physics in FIM, implementing OpenMP threading in the GFS physics, and examining what will be required to implement OpenMP in the HRRR physics.

Additionally, CIRA staff provided assistance to the GMTB group in implementing the aforementioned NUOPC interface into FV3. The work involved marrying GMTB modifications to the NUOPC interface.

PROJECT TITLE: EAR- High Performance Computing

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Jacques Middlecoff, James Rosinski, Ning Wang, Julie Schramm, Duane Rosenberg, Bryan Flynt, Jebb Stewart

NOAA TECHNICAL CONTACT: John Schneider (OAR/ESRL/GSD/ATO chief)

NOAA RESEARCH TEAM: Mark Govett (OAR/ESRL/GSD/ATO), CIRES: Christopher Harrop, Lynd Stringer, Lidia Trailovic

PROJECT OBJECTIVES:

--Test and evaluate the Fine Grain Experimental (FGE) system. Identify problems with the FGE system and report them to the Theia help system. Create test software to do the testing and evaluation. Also use the Non-hydrostatic Icosahedral Model (NIM) to evaluate the performance of the FGE system. Evaluate the new OpenACC GPU compilers from Portland Group and Cray and the Intel compiler for the Xeon Phi.

--Provide software support to ESRL scientists including software design advice and expertise on a variety of software/web/database technologies. CIRA researchers continue to modify the Flow-following, Finite volume Icosahedral Model (FIM) software and the Finite-Volume Cubed-Sphere (FV3) model.

--Serve on the National Unified Operational Prediction Capability (NUOPC) Common Model Architecture (CMA) and Content Standards (CSC) subcommittees.

--Fine-tune software engineering processes used during FIM development, ensuring that these processes remain suitable for a candidate production NWP code, optimize FIM run-time performance, port FIM to new machines, and incorporate new features such as the ongoing integration of WRF-CHEM and WRF-ARW physics into FIM.

--Assist the Space Weather Prediction Center in maintaining and improving the Ionosphere Plasmasphere Electrodynamics (IPE) code.

--Port FV3 to GPU (NVIDIA) and MIC (KNL) architectures and optimize without degrading performance on the CPU.

--For the operational FV3 and supporting utilities from NCEP, port, optimize, construct, and run scripts for ERSL research environment.

--Develop Project Plan to address Grand Challenge 4 of the GSD Strategic Plan: Modeling in the Exascale Computing Era.

PROJECT ACCOMPLISHMENTS:

CIRA researchers created a program, called sendRecv.F90, for testing MPI message passing on the FGE system. Using sendRecv.F90 CIRA researchers uncovered dozens of problems with the FGE system and highlighted many cases where the message passing performance was inadequate. CIRA researchers used NIM to uncover problems with the FGE system that go beyond message passing including bugs and poor performance. They continued to use NIM to evaluate the new OpenACC GPU compilers from Portland Group and Cray and the Intel compiler for the Xeon Phi. Many compiler bugs and limitations were found and fed back to the vendors yielding improved products that better address our needs.

CIRA researchers enhanced SMS adding more support for the IPE code. They continue to assist SMS users and to find and fix bugs.

CIRA researchers assisted FIM developers with integration, parallelization errors, test suite issues, I/O issues, repository issues, interruptions in real-time runs, and general debugging. Staff assisted the FIM team with several time-critical tasks required to meet FIM project deadlines. They also created a test suite for the coupled FIM-HYCOM and FIM-CHEM systems which are now in regular use by model developers. CIRA researchers continued to extend and maintain the automated overnight continuous integration testing for FIM as new model features and parameterizations are added.

Seasonal forecasting with FIM-HYCOM is a priority in the Earth Modeling Branch (EMB) at ESRL. As such they use the “fim2nc” package developed by CIRA researchers to convert FIM output data to netCDF. CIRA researchers have continued to respond to updated needs of EMB scientists, such as the requirement to properly interpolate vector fields from FIM’s icosahedral-hexagonal grid to a latitude-longitude grid.

CIRA researchers continued to utilize a large time allocation at the TACC computer facility in Texas containing CPU and KNL hardware. This work has allowed ESRL scientists to run coupled FIM-HYCOM simulations.

CIRA researchers continue to collaborate with NCEP, Navy, NCAR, and NASA to define aspects of a Common Modeling Architecture (CMA) for the National Unified Operational Prediction Capability (NUOPC). The primary objective of the NUOPC's CMA is to reduce long-term costs of integrating and sharing software between the nation's three operational global weather prediction centers; Air Force Weather Agency (AFWA), Fleet Numerical Meteorology and Oceanography Center (FNMOC), and NCEP. They also served on the NUOPC Physics Interface to define APIs and conventions to allow easier sharing of physical parameterizations among NWP modeling systems. They continued attending NCEP’s bi-weekly UMIG meetings to discuss ongoing upgrades to NEMS and ensure that FIM continues to be NEMS-compliant.

CIRA researchers participated as part of the Global Model TestBed (GMTB) to devise an Interoperable Physics Driver (IPD), which will allow developers of physical parameterization packages to more easily integrate and test their schemes into the FV3 model, which is the chosen dynamical core for the next generation Global Forecast System (GFS) at NCEP.

Scientists in the Earth Modeling Branch (EMB) at ESRL are working to enable alternative physics packages in global models. Current work involves implementing the HRRR (high-resolution rapid refresh) physics package in FIM and FV3. CIRA researchers are assisting in the software development aspects of this exercise. Examples include enabling support for the Lahey compiler, and ensuring bitwise identical results between offline (single time step, single-column mode) and online (full model) implementations.

CIRA researchers continued evaluating Intel's® Xeon® Phi (a.k.a. MIC, a.k.a. KNL) for the FIM and FV3 models. They work closely with vendor assistance from Intel to tune performance of FV3 on Xeon Phi without adversely impacting performance on traditional CPU architectures.

CIRA researchers continued to improve software engineering processes for FIM and FV3.

CIRA researchers assisted the Space Weather Prediction Center in maintaining the Ionosphere Plasmasphere Electrodynamics (IPE) code. The Space Weather Prediction Center made extensive improvements to the IPE code resulting in a code that only ran in serial. CIRA researchers parallelized new code and did extensive work in optimizing the parallel performance of the new IPE code. As before, load imbalance was a major issue limiting parallel performance. Building on previous work on load balancing the IPE code, CIRA researchers wrote a code to read in output from an IPE run and use the imbalance inherent in the output to create a static load balance that can then be used to greatly improve IPE performance. The resulting code, in spite of major increases in the amount of work done, ran fast enough to fit in the window of computer time allotted for the IPE code.

CIRA researchers assisted with the GSD transition from GSDForge to the NWS's VLab code management system. They assisted software engineers and scientists with the transition from SVN to the GIT version control system. The FIM test suite was also modified to use "git", a more full-featured source code maintenance tool than "subversion", which was used previously.

Other work on the FV3 model involves porting it to the GPU-based FGE system attached to Theia. One CIRA researcher developed a timing library (GPTL) for CPU architectures, which is now being ported to the GPU. A bug was discovered in the OpenACC (PGI's GPU) compiler which prevents the code from working properly. PGI has acknowledged the bug and a fix should be available soon. Once available, we should be able to retrieve fine-grained timings for FV3 as run on the GPU.

Collaboration is ongoing with the Joint Effort for Data-assimilation Integration (JEDI) program on several aspects of the project. Initial work on the JEDI project involves an assessment of the computational performance characteristics of the existing GSI package. The GSI has been profiled for a representative test case on NOAA machine "theia", and we will be focusing on the computational performance of the embedded radiation package, CRTM. The CRTM is a very expensive component of the GSI.

Further work on the CRTM has been successfully migrated by CIRA researchers from the GSI framework to the JEDI framework, now that JEDI is in a functional state. One advantage of the move to JEDI is that the infrastructure allows use of latest/greatest compiler versions. Currently we are working with version 18 of the Intel compiler suite.

Other work on the JEDI project includes evaluation of the Earth Systems Modeling Framework (ESMF) to perform interpolations from the FV3 model to observation locations and integration of the NICAS interpolation routines into the JEDI code base.

As part of the strategy to enable FV3GFS to operate under a broad variety of environments (i.e., different compilers, versions) and to form the basis of production and development roles using the plethora of hardware architectures (e.g., with and without accelerators) characterizing available computing platforms, CIRA researchers have used NOAA's Dependency-Driven Test System (DDTS) software to set up a test suite for the FV3GFS code. The test suite allows regression and run-to-run testing for all types of runs desired for the code to ensure code quality, accuracy, and reproducibility, and is extensible enough to enable individual researchers to test regularly any new FV3GFS code or functionality that is added. The same approach to testing was also used in developing a test suite for the fine-grain FV3 parallelization effort.

Since the strategic plan for FV3GFS requires its use under such broad operating conditions, CIRA researchers use advanced tools and techniques at the forefront of HPC development for enhancing the code's capability to run optimally on different platforms. CIRA researchers have worked closely with software and hardware vendors to ensure that these tools both perform as required and also accommodate modern language syntax and structure by providing them “codelets'' that they can use to diagnose issues. This 'public-private' partnership has been viewed as highly successful in helping to bring some of these forefront technologies to maturity faster than otherwise would have been the case.

CIRA researchers served as the primary driver for and contributor to the development of a Project Plan to address Grand challenge 4 in the GSD Strategic plan regarding exascale computing challenges. The Plan focuses on four “dwarfs” which are targeted and self-contained codes that represent key elements of NWP systems. These elements consist of: (1) dynamical core fluid advection (“Advection Dwarf”) (2) I/O profiling and playback (“I/O Dwaf”); (3) 4DVar data assimilation (“DA Dwarf”); (4) chemistry and convection (“Chemistry Dwarf”). The Chemistry and I/O dwarfs serve mainly to profile the performance of existing capabilities as they might be used in higher resolution scenarios afforded by future exascale systems. The Advection and DA dwarfs are mandated not only to examine performance at large scale, but also to evaluate algorithmic/numerical accuracy and potential utility in NWP systems.

CIRA researchers created a number of documents in support of the Project Plan. These include comprehensive requirement, task plan, and scientific justification documentation, as well as implementation documentation as represented by a software infrastructure and process document. These documents contain details about the dwarfs and will be available in the code repository.

Finally, regarding the Project Plan, CIRA researchers have begun development of the Advection and I/O Dwarfs. For the Advection Dwarf, CIRA researchers set up the code repository and package management system, and begun development of the C++ 1D operators and containers required for the Cube-sphere Discontinuous Galerkin dwarf. Significant time has been spent in identifying, using specific tests, potential performance bottlenecks that arise due to data structure selection, and to find limitations of C++ in applying OpenACC directives, which is a key requirement for the dwarf. CIRA researchers developed a first working version of the I/O Dwarf “trace” tool, which may be loaded with any application in order to capture the application’s low-level I/O events for profiling. This tool has been applied to profile both FV3 and GSI and demonstrated its utility in characterizing I/O patterns and bandwidth utilization in likely forecasting and data assimilation applications.

PROJECT TITLE: EAR – Rapid Update Cycle (RUC), Rapid Refresh (RAP) and High Resolution Rapid Refresh (HRRR) Assimilation Development and Enhancement

PRINCIPAL INVESTIGATOR: Sher Schranz

RESEARCH TEAM: Tracy Lorraine Smith, Haidao Lin, Steve Albers

NOAA TECHNICAL CONTACT: Stanley Benjamin (OAR/ESRL/GSD/ADB Chief)

NOAA RESEARCH TEAM: Curtis Alexander (OAR/ESRL/GSD/ADB), Steve Weygandt (OAR/ESRL/GSD/ADB)

PROJECT OBJECTIVE:

The primary focus of the GSD Assimilation Development Branch (ADB) is the refinement and enhancement of the Rapid Refresh (RAP), High Resolution Rapid Refresh (HRRR) and development of the Weather Research and Forecast (WRF) assimilation systems. In addition to refinement and enhancements of the RAP and HRRR, CIRA researchers collaborate on the development of the Weather Research and Forecast (WRF) model used by CIRA and GSD researchers. Support for the continued operation of the Rapid Update Cycle (RUC) was also conducted, with a major port to the Theia supercomputer and updates to data being ingested into the system.

The HRRR is a NOAA real-time 3-km resolution, hourly updated, cloud-resolving atmospheric model, initialized by 3km grids with 3km radar assimilation over a 1-h period (since 5 April 2013), adding further detail to the HRRR initial conditions otherwise determined by the hourly data assimilation from the 13km radar-enhanced Rapid Refresh .

The primary goal this year was to assimilate convective initiation information derived from GOES satellite data into the RAP and HRRR forecast systems.

PROJECT ACCOMPLISHMENTS:

For this year's research goals, GOES cloud-top cooling rate data provided by the University of Alabama Huntsville (UAH) have been assimilated into experimental versions of the Rapid Refresh (RAP) and High Resolution Rapid Refresh (HRRR) at GSD. Within this RAP modeling framework, the cloud-top cooling rate data are mapped to latent heating profiles and are applied as prescribed heating during the diabatic forward model integration part of the RAP digital filter initialization (DFI). A similar forward integration only procedure is used to prescribe heating in the HRRR one-hour pre-forecast cycle. For both the RAP and the HRRR, the GOES-satellite-based cloud-top cooling rate information is blended with data from radar reflectivity and lightning flash density to create a unified convective heating rate field. In the current HRRR configuration, four 15-min cycles of latent heating are applied during a pre-forecast hour of integration. This is followed by a final application of GSI at 3-km to fit the latest conventional observation data.

Previous work on this project has demonstrated that these cloud-top cooling rates can help with the location and intensity of storms in the RAP and HRRR systems. A retrospective period of June 22-23, 2016 was chosen to continue investigation of the use of cloud top cooling rates in partnership with other satellite derived convective initiation indicators in the HRRR forecasts. This period was quite active with severe storms, with numerous tornadoes and large hail reports over the period. The use of the CI probability in the HRRR was deemed successful enough to add it to the real time experimental HRRR run here at GSD in mid-October 2016. We will continue to evaluate the assimilation of the data with the variation in the vertical structure of the assumed heating profile using information on the cumulus clouds as derived from GOES.

The HRRR Version 2 and RAP Version 3 became operational at NCEP mid May 2016 with significant improvements to the assimilation and modelling components.

PROJECT TITLE: EAR - Unified Post Processor (UPP) Software Support and Community Engagement (DTC-Task)

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Isidora Jankov, Ka Yee Wong

NOAA TECHNICAL CONTACT: Georg Grell (OAR/ESRL/GSD/MDB Chief)

PROJECT OBJECTIVE:

To serve as a bridge between operations and research, the DTC provides a framework for the two communities to collaborate in order to accelerate the transition of new scientific techniques into operational weather forecasting. This framework is based on software systems that are a shared resource with distributed development. The current operational systems are a subset of the capabilities contained in these software systems. Ongoing development of these systems is maintained under version control with mutually agreed upon software management plans.

The Unified Post Processor (UPP) is one such system the DTC supports to the community to facilitate operations to research (O2R) and research to operations (R2O) transitions. Currently, UPP is used in operations with the Global Forecast System (GFS), GFS Ensemble Forecast System (GEFS), North

American Mesoscale (NAM), Rapid Refresh (RAP), High Resolution Rapid Refresh (HRRR), Short Range Ensemble Forecast (SREF), and Hurricane WRF (HWRF) applications. The community UPP distribution is currently compatible with and supported for the Weather Research and Forecasting (WRF) and Nonhydrostatic Multiscale Model on B-grid (NMMB) modeling cores.

With the formation of the Global Model Test Bed (GMTB), the DTC has expanded to supporting both regional and global applications. This, in part, has led to an expanding UPP user base with an increase in requests for support among the research and operational users, especially in regards to implementing new diagnostic fields and utilizing output, in both regional and global downstream applications. As such, it is imperative that the DTC be prepared with procedures and infrastructure to support projects in conjunction with the future NGGPS unified model for post-processing and diagnostic investigations through O2R and R2O efforts.

PROJECT ACCOMPLISHMENTS:

The DTC continued collaboration with EMC to make the UPP tool available to the user community. UPP provides the capability to compute a variety of diagnostic fields, interpolate to pressure levels, de-stagger grids and interpolate to specified grids. These grid manipulations produce GRIB1 and GRIB2 output files that can be used directly by a number of plotting packages and the Model Evaluation Tools (MET) verification package. The community UPP repository has been maintained in a manner such that updates and enhancements may be contributed by, and shared between, both the operational and research communities. A new community release of UPP has been distributed annually, with bug fix release(s) as needed. Associated with each release, extensive testing has been performed. Both NetCDF and binary WRF and NEMS file formats were tested in serial and parallel (using mpi) environments to ensure that a broad range of model output formats are compatible with the UPP software. The full suite of tests has been run on computing platforms available to the DTC (with extension to the NOAA supercomputer, Theia, and the new NCAR supercomputer, Cheyenne, during this period of performance) using a variety of compilers. Updates to documentation were made available to the user community with each release; expansion of current documentation was developed to provide users with enhanced detail on output field options and model dependencies/capabilities (Users Guide and webpage). An online tutorial has been developed including step-by-step instructions and examples on how to run UPP. New procedural documentation has also been developed to guide community users and developers in customizing and contributing to UPP. One example of the documentation provides detailed instructions on how to add new diagnostics to the code base to facilitate R2O development and transitions.

PROJECT TITLE: EAR - Model Evaluation for Research Innovation Transition (MERIT, DTC-Task)

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Isidora Jankov, Jeff Beck

NOAA TECHNICAL CONTACT: Georg Grell (OAR/ESRL/GSD/MDB Chief)

NOAA RESEARCH TEAM: Gerard Ketefian (CIRES)

PROJECT OBJECTIVE:

The goal of the Model Evaluation for Research Innovation Transition (MERIT) project established within the Developmental Testbed Center (DTC) is to foster an environment of active model development and testing, providing a framework for researchers and operational centers to evaluate selected meteorological cases between different operational models. Findings from these comparisons can then be used by the research community to help drive innovations with the ultimate goal of improving operational NWP, encouraging community development, and providing effective infrastructure for R2O and O2R.

PROJECT ACCOMPLISHMENTS:

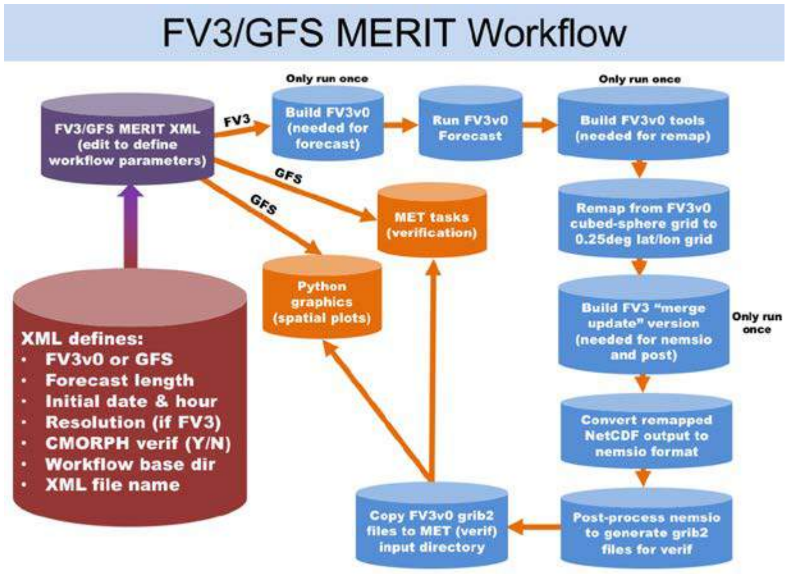


Figure 1. End-to-end FV3 and GFS MERIT Workflow

With these goals in mind, and with the Finite-Volume Cubed-Sphere (FV3) model being selected as the dynamic core for the Next Generation Global Prediction System (NGGPS), an end-to-end workflow was developed (Figure 1), including post-processing, visualization, and verification, to compare three select cases between the FV3 and the GFS at quarter-degree resolution. The three cases were part of the initial FV3 public release and were from 29 September 2016 (Hurricane Matthew), 18 January 2016 (East Coast blizzard), and 12 August 2016 (Louisiana flooding). The end-to-end workflow was run for each model with seven-day forecasts being compared through the use of Python plotting utilities and the Model Evaluation Tools (MET) verification suite.

Comparisons between the forecasts from GFS and FV3 are currently being conducted, including quantitative verification of surface and upper-air temperature, relative humidity, and wind speed (e.g., Fig. 2a), in addition to precipitation as a function of forecast lead time (e.g., Fig. 2b) and threshold.

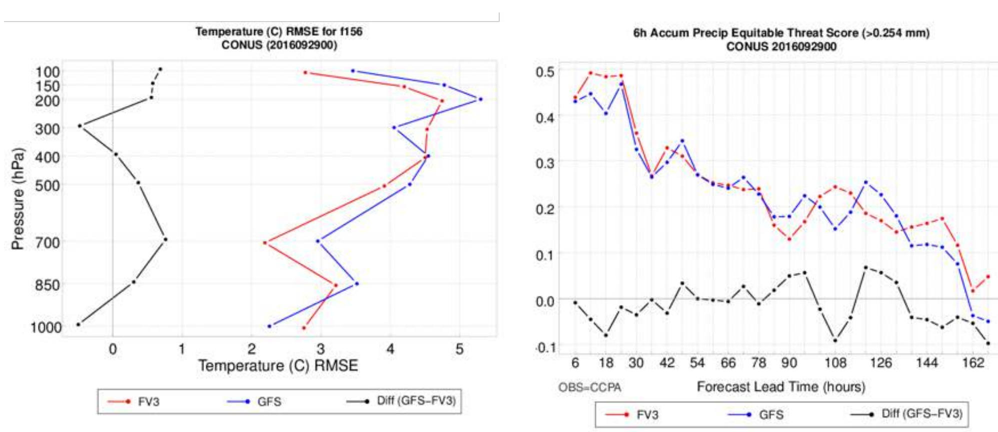


Figure 2. a) FV3 (red) and GFS (blue) average RMSE for vertical profiles of temperature for the 156-hr forecast and b) 6-h precipitation accumulation GSS for the FV3 (red) and the GFS (blue) for the > 0.254 mm threshold from the Hurricane Matthew case.

Qualitative comparison of features specific to each case are also being assessed, such as location and track forecasts for Hurricane Matthew (e.g., Fig. 3) and the East Coast blizzard, and the location of maximum precipitation accumulation for the Louisiana flooding case. Results from these analyses will be complete by the end of March 2018.

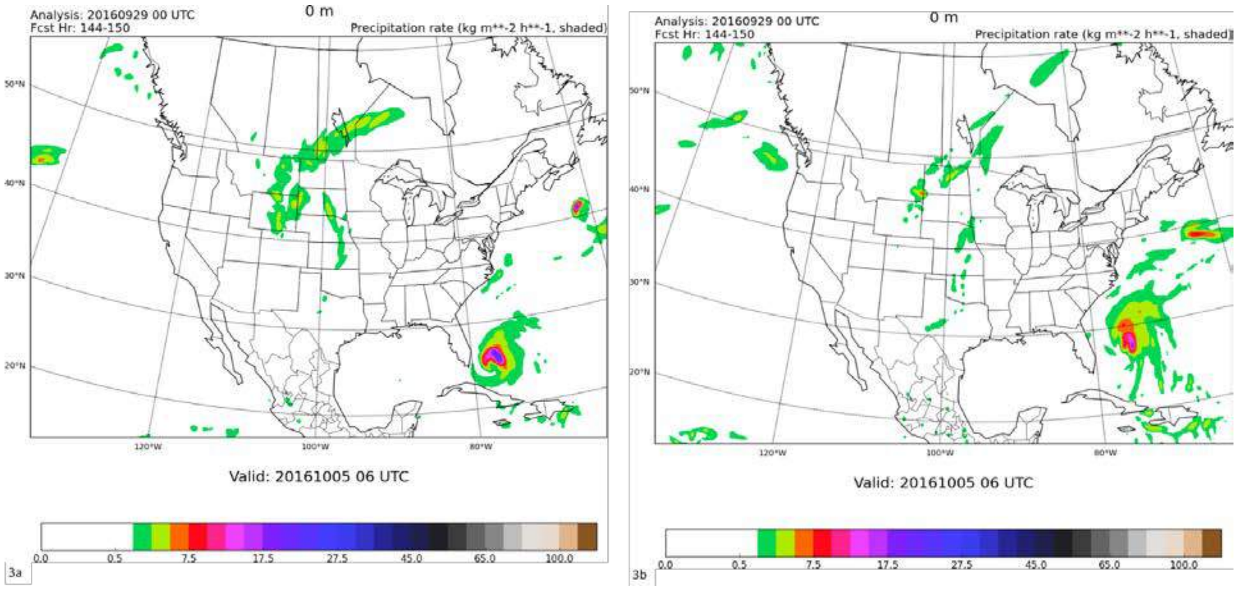


Figure 3. Python plots of precipitation rate for the 144-150 forecast hour period from the Hurricane Matthew case for a) the GFS and b) the FV3.

Presentations:
--The work was presented at the DTC Management Board (7 February, 2018) in order to secure continuous funding for the next year. Funding was approved.
--The work was presented at DTC Science Advisory Board (28-29 September, 2017).

PROJECT TITLE: EAR - Refinement and Evaluation of Automated High-Resolution Ensemble-Based Hazard Detection Guidance Tools for Transition to NWS Operations (GSD-Task)

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Isidora Jankov

NOAA TECHNICAL CONTACT: Georg Grell (OAR/ESRL/GSD/MDB Chief)

NOAA RESEARCH TEAM: Trevor Alcott (OAR/ESRL/GSD/MDB), Curtis Alexander (OAR/ESRL/GSD/ADB Chief)

PROJECT OBJECTIVE:

The overarching goal of this work is to transition a well-tested system for generation of ensemble post-processed hazard guidance products to operational status within the National Weather Service (product generation within NCEP and dissemination of hazard grids to NWS operational forecasters). A direct outcome of the project will be improved ensemble hazard guidance tools for operational forecasters that will reduce the ensemble information overload problem and enable a more efficient and accurate characterization of forecast uncertainty. Ultimately, the quality and usefulness of the weather guidance information provided by the NWS to the public will increase. Success in this project will also enable follow-up work to significantly expand the scope of ensemble hazard guidance product generation.

A main objective for this project is to expand an existing model-ensemble probabilistic product generation capability into a set of algorithms for creating a variety of different automated model ensemble-based hazard guidance tools that will be of maximum utility to NWS forecasters. The existing capability uses a time-lagged sequence of successive HRRR output grids. The idea is to develop a continuum of automated hazard-specific guidance tools, ranging from pure probabilistic guidance (e.g., probability of rain or snow rate exceeding a certain threshold) to automated application of more geometric feature detection algorithms (e.g. identifying tracks of large values of updraft helicity indicative of rotating thunderstorms and a potentially enhanced risk of tornadoes, etc.).

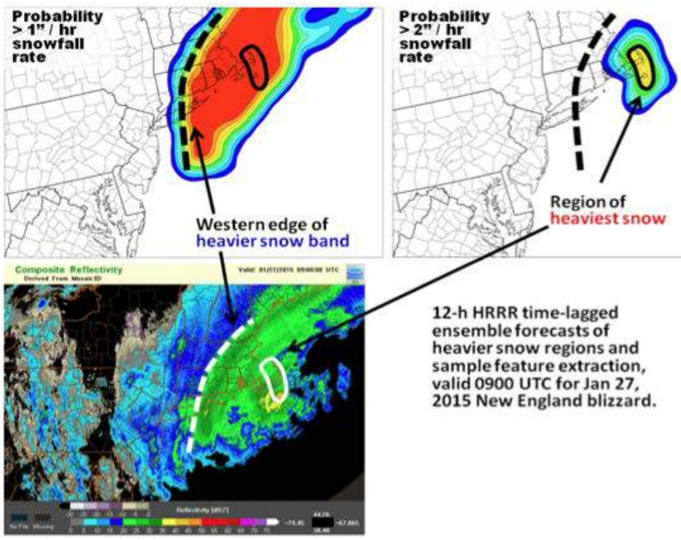


Figure 1 provides an example of this approach for the New England blizzard of 27 Jan. 2015. The storm posed a significant forecast challenge as a very sharp western edge of the heavy snow shield was forecast across the densely populated New York City metropolitan area, with large variation among many different models. As can be seen in Fig. 1, the 12-h HRRR time-lagged ensemble (HRRR-TLE) probability forecasts of heavy snowfall rates indicated the sharp western edge of the heavy snow, and, in turn, correctly predicted the western edge to the east of New York City.

PROJECT ACCOMPLISHMENTS:

--Coordination meeting amongst participating organizations to ensure roles, responsibilities, reporting, etc. (GSD, EMC, NCAR, WPC, WFOs).
--Quarterly presentations and reports to OAR,
--Secured third year funding based on the second year's accomplishments,
--Met deliverables in timely manner,
--Probabilistic products produced in real time and available at: https://rapidrefresh.noaa.gov/hrrr/hrrrtle/

PROJECT TITLE: EAR - Data Assimilation System (GSI and EnKF) Code Management and User Support

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Jeff Beck

NOAA TECHNICAL CONTACT: Georg Grell (OAR/ESRL/GSD/MDB Chief), John Brown (OAR/ESRL/GSD/MDB)

NOAA RESEARCH TEAM: Ming Hu and Guoqing Ge (CIRES)

PROJECT OBJECTIVES:

The NCEP hybrid system uses two separate data assimilation systems for its Global Forecast System (GFS): The Gridpoint Statistical Interpolation (GSI) system, which updates the deterministic analyses, and the Ensemble Kalman Filter (EnKF) system, which updates the ensemble perturbations. For operational regional applications (e.g., NAMS, RAP, etc.), NCEP currently uses the GFS EnKF ensembles for its hybrid system. Supporting NCEP's GSI and EnKF systems to the research community provides an efficient framework for direct research transitions to these two operational systems for both global and regional applications.

PROJECT ACCOMPLISHMENTS:

In the summer of 2017, the DA team of the DTC worked to merge the operational (NCEP) and research versions of GSI and released a new version of the community GSI software through NOAA Vlab to the research community. Prior to the release, this code was compiled and tested on a number of different supercomputer platforms to assure compatibility and functionality.

At the same time as the code release, a GSI/EnKF user tutorial was organized and directed by the DA team of the DTC and held at NCEP. Presentations were given in relation to code compilation, testing, troubleshooting, and analysis of GSI results. A separate practical session was also held at the tutorial in order for the attendees to test the use of GSI and obtain/analyze results. In addition, user support was maintained through the gsi-help@ucar.edu email address, helping the community with various problems related to installing and running GSI.

Project Presentations from Past Year:

--Numerous presentations were given during the Joint DTC/EMC/JCSDA GSI/EnKF Tutorial (11-14 July, 2017) at NCEP related to compilation and testing of the GSI code, as well as analysis of GSI results.
--The work was presented at the DTC Management Board (7 February, 2018) in order to secure continuous funding for the next year. Funding was approved.
--The work was presented at the DTC Science Advisory Board (28-29 September, 2017).

PROJECT TITLE: EAR - Addressing Model Uncertainty through Stochastic Parameter Perturbations within the HRRR Ensemble (DTC-Task)

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Isidora Jankov, Jeff Beck

NOAA TECHNICAL CONTACT: Georg Grell (OAR/ESRL/GSD/MDB Chief)

NOAA RESEARCH TEAM: Joseph Olson (CIRES)

PROJECT OBJECTIVES:

In most existing regional ensemble systems, model-related forecast uncertainty is addressed by using multi-dycore, multi-physics suites, or a combination thereof. While such multi-model ensembles have demonstrated potential, their maintenance is resource-intensive. Also, a multi-physics (and potentially multi-perturbed parameter) ensemble could fail if the members from such an ensemble do not have exchangeable error statistics, depending on how they are constructed. If member 1 always has a positive adjustment to a particular coefficient and member 2 always has a negative, this may create a systematic difference over the period of forecast integration. They then are not reflecting situational uncertainty so much as the bias in different systems.

Recently the National Center for Environmental Prediction (NCEP)/Environmental Modeling Center (EMC) made a commitment to move towards a more unified and sustainable operational forecasting system. For the purpose of designing a unified storm-scale ensemble forecasting system, the utilization of a single dycore with a single physics suite with stochastic approaches would be beneficial. Given that single-dycore ensembles may be underspread, we seek realistic ways to deal with sources of model uncertainty in a single-dycore ensemble as a motivation. We propose to extensively test an alternative option for creating desirable spread and reliability by perturbing the members stochastically within a storm-scale ensemble. The stochastic-dynamic approach results in statistically consistent ensemble distributions. Two widely used stochastic schemes are the Stochastic-Kinetic Energy Backscatter (SKEB) and the Stochastic Perturbations of Physics Tendencies (SPPT). These methods are formulated to represent the effect of unresolved subgrid-scale variability and are added a posteriori to independently tuned models. An additional approach is the Stochastic Parameter Perturbation (SPP) scheme, which targets parameter uncertainty in the physical parameterization schemes directly.

During AOP 2016 and 2017, preliminary tests with the HRRR-based ensemble employing stochastic approaches were performed. The tests included SPP of several variables within the PBL scheme (e.g. cloud fraction, roughness length, mass fluxes). Also, preliminary tests of the impact of stochastic perturbations on the soil-moisture field at the initial time were assessed with some success (subsequent to results shown at the recent DTC MB meeting). Forecast performance of the HRRR-based ensemble with stochastic perturbations were compared to a control multi-physics HRRR ensemble that included variations in PBL and LSM schemes. In addition, the stochastically-perturbed ensemble was compared to a limited number of fields available in the Storm Scale Ensemble of Opportunity (SSEO) obtained from the Storm Prediction Center (SPC) during the 2016 Hazardous Weather Testbed (HWT) Spring Forecasting Experiment (SFE). SSEO is a storm-scale ensemble that includes a variety of dynamic cores, physics suites, and initial conditions. The preliminary results obtained during AOP 2016 indicate a storm-scale ensemble based on a single dynamic-core and single physics suite with stochastic perturbations can perform comparably to a multi-physics ensemble.

PROJECT ACCOMPLISHMENTS:

With the infrastructure established during AOP 2016 to perform computationally complex, storm-scale ensemble simulations over the Continental United States (CONUS), the DTC RE team has been conducting extensive testing of refined stochastic approaches in AOP 2017. The focus has been on testing of impact of stochastic perturbations (SPP) for application on CONUS scale ensemble with a focus on cloud microphysics.

We developed stochastic parameter physics for Thompson cloud microphysics, which is a part of the RAP/HRRR operational physics suite, in collaboration with the developer. We identified a parameter, graupel intercept, of interest and adequate perturbation ranges and evaluated it within case studies and retrospective tests. The applied perturbations were physically based in terms of the perturbations magnitude, spatial and temporal de-correlation lengths, by working in close collaboration with the scheme developer and information from corresponding literature. For this purpose, an 8-member, HRRR-based, 3-km grid spacing ensemble has been used. The focus is on periods characterized by active convective weather. Having in mind that the 3-km grid spacing, CONUS wide ensemble is computationally expensive (e.g. ~1 million core hours per 10-day retrospective run), before performing extensive retrospective runs, an impact of a specific stochastic perturbation was assessed through limited number of case studies. Currently the team is working on setting up the test over a 40-day period.

PROJECT TITLE: EAR - Improving Short-Range Forecasts of Severe Weather and Aviation Weather from the Assimilation of Satellite Data

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Haidao Lin, Amanda Back

NOAA TECHNICAL CONTACT: Stephen Weygandt (OAR/ESRL/GSD/ADB)

NOAA RESEARCH TEAM: Yuanfu Xie (OAR/ESRL/GSD/ADB ret)

PROJECT OBJECTIVE:

Investigate the impact from satellite data on severe storm forecasts in the Rapid Refresh (RAP) and global models and report on the increase in accuracy of short-range mesoscale model forecasts from the assimilation of satellite data into the Rapid Refresh and global models

PROJECT ACCOMPLISHMENTS:

Over the past year, work continued on 1) preparing and completing the upgrade package for radiance assimilation in the Rapid Refresh (RAP) version 4; 2) evaluating the radiance data impact within the RAPv4; 3) evaluating the direct readout data impact within RAPv4 with forecast against radiance data; 4) starting the work to assimilate GOES-16 ABI radiance data into RAP/HRRR. Two journal papers based on previous work were finalized and published.

RAPv4 is planned to be operationally implemented at NCEP in May of 2018. With real-time testing at ESRL and a code hand-off to EMC in June 2017, the work on radiance updates for RAPv4 is complete (including extensive retrospective runs). The new package includes several new radiance data sets for RAPv4, including SEVIRI from M10, ATMS/CrIS from S-NPP, SSMIS from DMSP-17, IASI from METOP-A/B, AIRS/AMSU-A from AQUA. ATMS/CrIS direct readout data from S-NPP are also included. A series of 10-day RAP retrospective runs was conducted with the control run assimilating all available conventional and satellite radiance data in RAPv4 and the experiment runs removing AMSUA data only, MHS only, ATMS only, CrIS only, IASI only, and all radiance data removal. Figure 1 shows the normalized RMSE reduction [(EXPT – CNTL)/CNTL] (%) [(upper left) temperature, (upper right) relative humidity, (lower left) vector wind magnitude] from different experiments (AMSUA denial, MHS denial, ATMS denial, CrIS denial, IASI denial, and all radiance data denial) 1-18 hour forecasts against rawinsonde observations. It can be seen that AMSUA data have the largest positive impact for temperature and wind and MHS data have the largest impact for relative humidity. All radiance data have consistent positive impact for all forecast hours and for all variables with statistical significance within

RAPv4. We also note that due to having the longest time since the last partial cycling, stronger data impact could be anticipated at 6-h and 18-h duration.

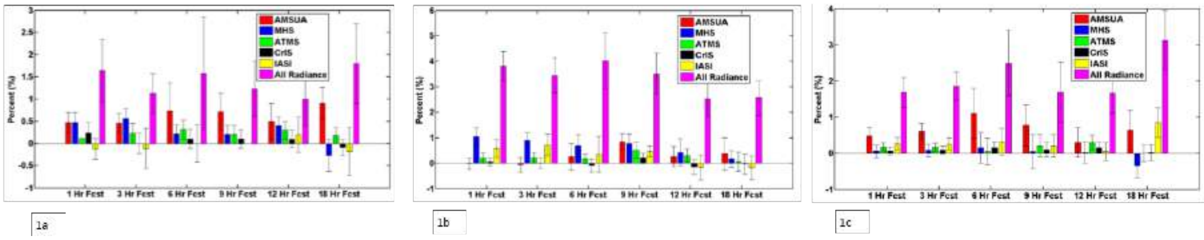


Figure 1. Normalized RMSE reduction [(EXPT – CNTL)/CNTL] [(1a) temperature (K), (1b) relative humidity (%), (1c) vector wind magnitude (m s^{-1})] from different experiments (the AMSU-A denial, MHS denial, ATMS denial, CrIS denial, IASI denial, and all radiance data denial) 1-18 hour forecasts against rawinsonde observations. Statistics are computed for 1000-100-hPa layer over the RAP domain. The retrospective period is from 1-10 September 2017. The error bar indicates the ±1.96 standard error from the mean impact, representing the 95% confidence threshold for significance.

In addition, we performed the work to evaluate the impact from direct readout satellite radiance data within RAPv4. Two 4-week retrospective runs were conducted. The control run assimilated all available conventional and satellite data and the experiment run removed all direct readout (including RARS and direct broadcast data) radiance data. Figure 2 shows the normalized RMSE reduction from direct readout denial experiment 1-18 hour forecasts verified against rawinsonde observations. It can be seen that direct readout radiance data have a very consistent positive impact (from 0.2%-1.6%) for all variables (temperature, relative humidity, and wind) and almost for all forecast lead times (1-18 h) with confidence at the 95% level. Forecast verification work against satellite radiance data is also underway.

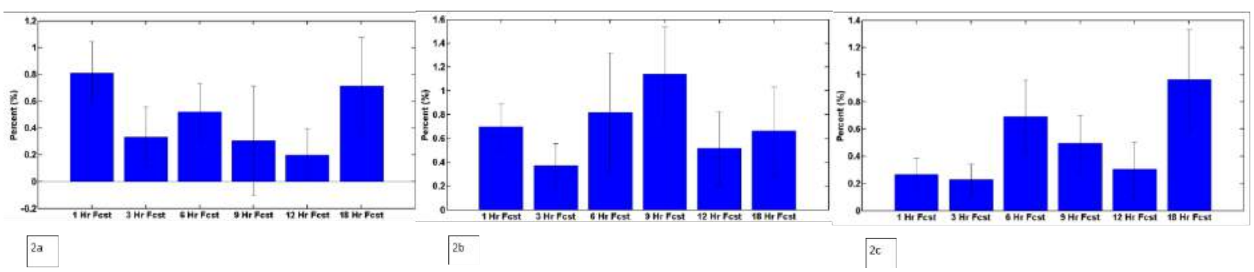


Figure 2. Normalized RMSE reduction [(EXPT – CNTL)/CNTL] (%) [(2a) temperature, (2b) relative humidity, (2c) vector wind magnitude] from RARS and DB denial experiment 1-18 hour forecasts against rawinsonde observations. Statistics are computed for 1000-100-hPa layer over the RAP domain. The retrospective period is from 1-28 September 2017. The error bar indicates the ±1.96 standard error from the mean impact, representing the 95% confidence threshold for significance.

Finally, with the recent availability of GOES-16 ABI radiance BUFR files, we've started the work toward the assimilation of GOES-16 ABI radiance data into RAP/HRRR. Preliminary work on decoding the ABI BUFR files is underway.

PROJECT TITLE: EAR – Verification Work to Support Regional and Global Modeling

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Randy Pierce, James Frimel, Bonny Strong

NOAA TECHNICAL CONTACT: Curtis Alexander (OAR/ESRL/GSD/ADB Chief)

NOAA RESEARCH TEAM: Dave Turner (OAR/ESRL/GSD/ADB), Jeff Hamilton (CIRES), Molly Smith (CIRES), Kirk Holub (OAR/ESRL/GSD/ADB)

PROJECT OBJECTIVES:

The objectives of this project include:
1--Develop a modern web-based verification toolset to replace existing tools which support weather modeling development within GSD.
2--Support modelers within GSD/ADB and GSD/MDB to use verification tools effectively.
3--In collaboration with NCAR, meet planned deliverables within the Developmental Testbed Center (DTC) Verification Task to enhance the MET software package and its associated components, identified as MET+.
4--Complete deliverables for a funded project within the NWS Next Generation Global Prediction System (NGGPS) to support Unified Verification across Research and Operational centers.
5--Develop a verification system to support specific needs of the Wind Forecast Improvement Project (WFIP).

PROJECT ACCOMPLISHMENTS:

Objective 1: Verification Toolset
The Model Assessment Tool Suite (MATS) was developed by the project team to replace the legacy Java Applet-based tools used by GSD model developers with one based on a modern web application framework. During this past year, a focused effort has migrated almost all applications from the legacy framework into the new MATS system. The MATS user interface for one of its apps is shown in Figure 1. The following applications have been implemented within MATS:
--Upper Air
--Aircraft (AMDAR)
--Anomaly Correlation
--Ceiling
--Ceiling 15 Min
--Visibility
--Surface
--Surface land use
--Surface Radiation
--24 Hour Precipitation
--Sub 24 Hour Precipitation
--Composite Reflectivity
--Echo Top
--Vertically Integrated Liquid
--Surface Map

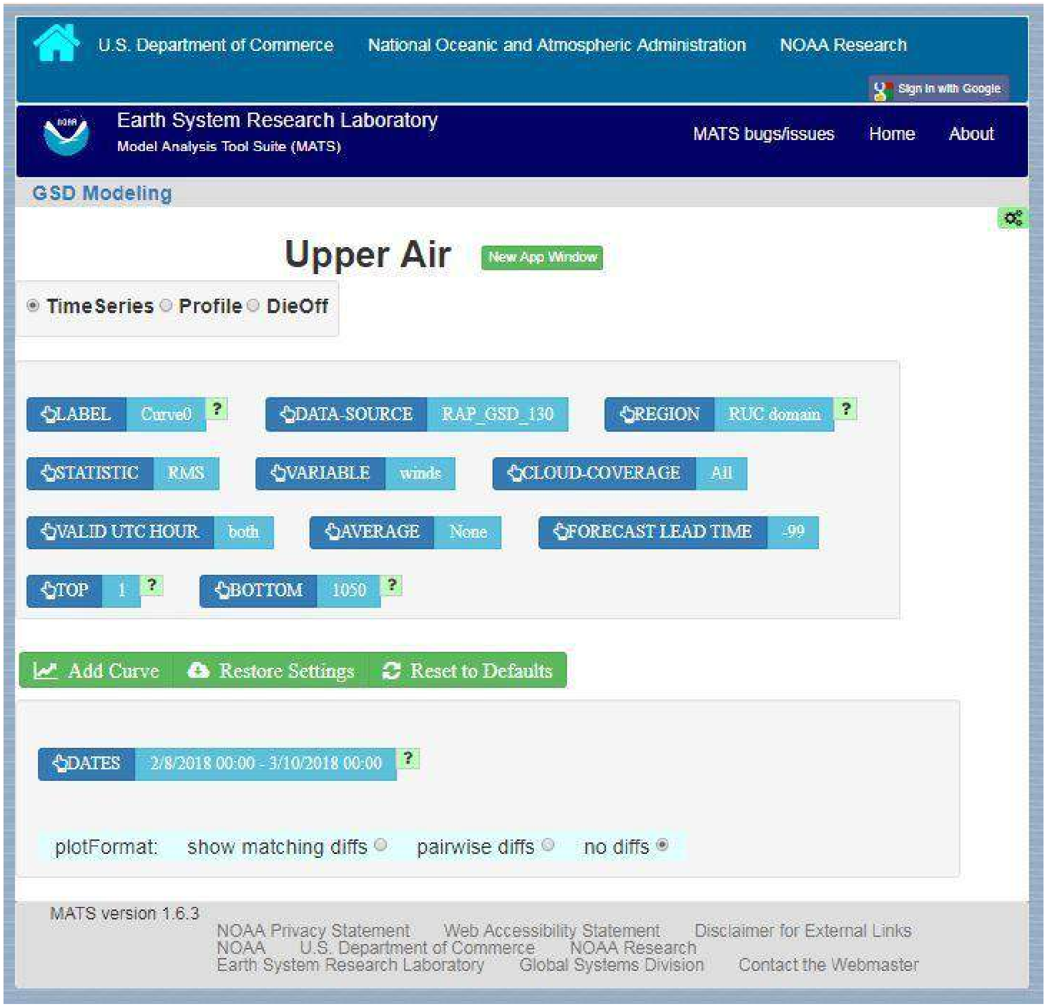


Figure 1. MATS user interface for the Upper Air application.

During this past year a development and deployment process has been created that manages and automates the development, testing, and deployment to production for the MATS applications. An automated testing framework based on Chimp open source software has been implemented as part of this process and a test suite has been developed which is expected to continually expand. Automated testing and management of the deployment process has significantly reduced errors in the production applications.

Objective 2: Support to Modelers
The software development team interacted with the model developers on an almost daily basis to understand their needs clearly, and to identify software issues, bugs, and requested new features. Bugs, issues, and feature requests are tracked through NOAA's VLab Development Service. Requests for major new features are reviewed with the GSD/ADB Leadership Team to assign priorities for team efforts.

Objective 3: DTC Deliverables
For the DTC Verification project, Bonny Strong has served as the GSD node coordinator for the Verification Task, attending the Scientific Advisory Board meeting and Management Board meeting in order to facilitate communications and coordination for the project. The development team met on a regular schedule with NCAR collaborators in order to successfully complete project deliverables.

These deliverables included:
--Development of an automated and unit testing framework and test suite for the METViewer visualization tool associated with the MET system;
--Planning for integration of a new database management system as a backend for the METViewer software package;
--Development of tools to manage workflow for the MET+ software system, and integration of tools into systems running at EMC.

CIRA and DTC are working with EMC to build a unified verification system as a platform that will span across research and operational organizations. The unified verification system is based on MET and METViewer (MET's accompanying database and display system) and has been designated as MET+. A third critical component for the MET+ system has been needed in order to connect MET/METViewer calls within a modeling workflow, and CIRA staff developed a significant portion of these MET+ workflow components during the past year.

A set of python modules have been developed with the flexibility to run MET for various use cases or scenarios. The goal is to "simplify" setting-up and running of MET for scientists, and to systematically plot the fields and results. Currently, this is implemented through the use of MET+ configuration files, designated as "conf files". It is designed to provide a framework in which additional MET use cases can be added. The conf file implementation utilizes a Python package called produtil that was developed by NOAA/NCEP/EMC for the HWRF system.

The MET+ Python application is designed to be run as standalone module files - calling one MET process; through a user defined process list or within a workflow management system on an HPC cluster.

A goal this year has been to also implement all necessary MET+ features needed to replicate the EMC Global deterministic capability, and to install and run MET+ for retrospective runs of the FV3 GFS workflow in parallel with the current EMC VSDB verification system on WCOSS (the operational HPC platform). This will allow for comparison and validation of MET+ capabilities in order to ultimately replace the VSDB system. The MET+ system is depicted in Figure 2.

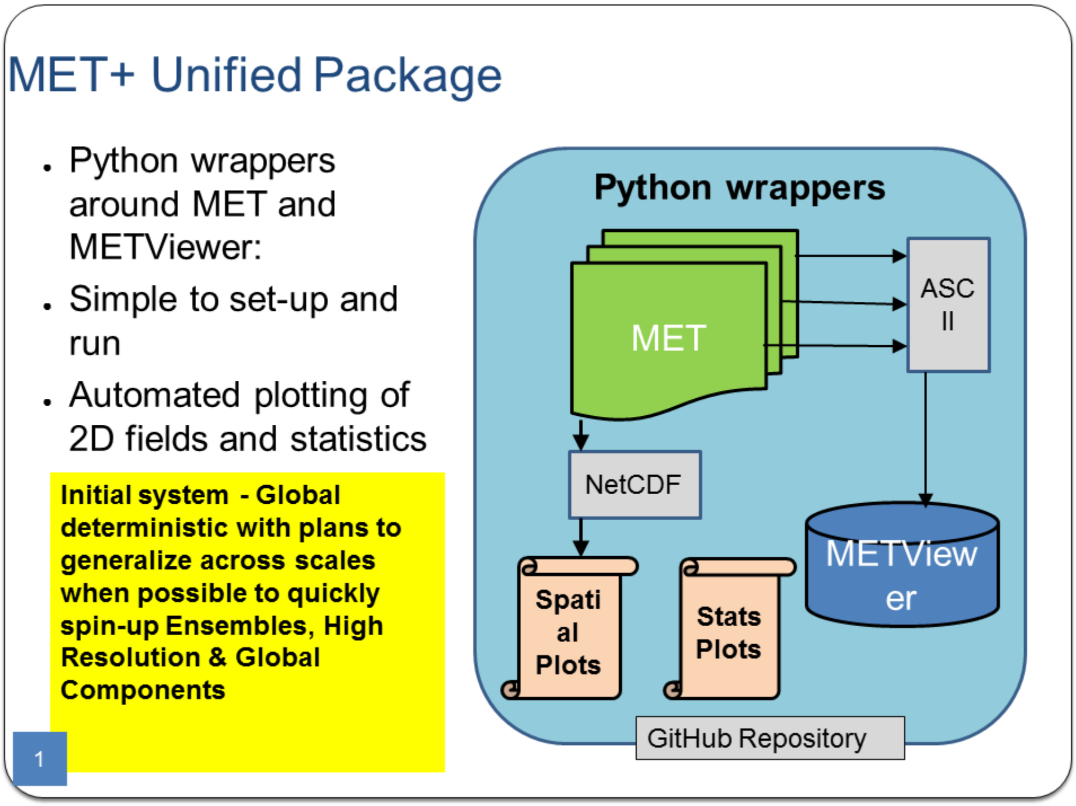


Figure 2. MET+ Unified Package.

Summary of CIRA major contributions/accomplishments to MET+ this year:
--Provided design recommendations and suggestions for the alignment and integration of METplus with the goals of NCEP Unified Workflow plan.
--Integrated the NCEP produtil python library in to the MET+ python code base; ported and implemented packages that handle the MET+ configuration information, running of subprocesses, file operation routines, and job logging.
--Integrated Doxygen documentation in to MET+ code base.
--Analyzed and determined performance issues and the required solution related to the use of the NCEP produtil library package in MET+
--Implemented changes to get the Python codebase to work with the MET codebase.
--Implemented software changes related to refactoring MET+ within the qpf Object Oriented structure and configuration file layout. This aligned the feature relative code base and qpf code base, for a consistent user interaction when running METplus.
--Modified autoconf and makefiles starting in the MET 6.1 build system to publish the Rscripts directory under MET_BASE when running the make install directive.
--Modifed tropical cyclone plotter scripts to be compatible with MET 6.1 Rscripts changes.
--Implemented METplus processing of command line arguments, running the setup launcher, and running the executables, from the primary wrapper.
--Modified internal_unit tests to work with the object command builder structure
--Prepared, planned, and presented one session of the MET+ Tutorial. Also prepared a MET+ Practical for MET Tutorial. See
https://dtcenter.org/met/users/support/OnLinePractical/OnLinePractical_218/metplus/
--Performed code management, testing, and support for the MET+ system--Worked within an EMC-led within an Agile team to integrate MET+ into the overall model workflow.

Objective 4: NGGPS Deliverables
During this past year a proposal was successfully submitted to NGGPS for staff to support the development of the Unified Forecast System. The primary objective of this proposal was to improve the database that serves as the backend to the METViewer software package. That database is currently MySQL which has served well for small evaluation projects. But in building the Unified Verification system that will support operational needs at EMC, the size of this database needs to expand well beyond its current use, and needs to be able to grow easily and incrementally in the future. For this proposal, the verification team at GSD proposed to analyze the requirements at EMC and propose a solution to improve the METViewer database to meet these needs.

The project Period of Performance was May 1, 2017 through March 31, 2018. The major deliverables were:
--Analyze distribution of what types of data will be stored by EMC in the MET+ database
--Work with EMC users who have worked with the prototype METViewer system to identify current problems and issues
--Analyze current available database technologies for:
----Suitability
----Performance
----Ease of migration
----Future maintainability
----Cost
--Measure current performance of prototype METViewer at EMC to determine a baseline for improvement
--Work with NCEP Central Operations (NCO) to determine requirements for a real-time reliable system within the operational infrastructure
--Propose a new database design
--Review proposal with NGGPS, EMC, NCO, and NCAR developers
--Install a new database on GSD hardware for initial testing, along with an adapted version of METViewer to access it
--Work with DTC to determine METViewer code changes required for new database

These deliverables have been completed and recommendations have been provided to EMC. The GSD team submitted a proposal to NGGPS for the upcoming year to continue working with EMC to support database improvements and testing on potential new hardware, and to do further development on a new user interface within the Unified Verification System.

Objective 5: WFIP Deliverables
In order to support model improvements for wind forecasting, the verification team was asked to redevelop the MATS system to support more detailed analysis of model outputs, and to support analysis of model results at individual stations rather than aggregated over a region.

CIRA Staff built a new database and instrument data from the WFIP project were ingested into the database. Additionally, a new user interface built within the MATS framework was completed.

PROJECT TITLE: EAR - WRF-Chem Model Development

PRINCIPLE INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Ka Yee Wong

NOAA TECHNICAL CONTACT: Georg Grell (OAR/ESRL/GSD/MDB chief)

NOAA RESEARCH TEAM: CIRES: Ravan Ahmadov, Li Zhang

PROJECT OBJECTIVES:
--Development of WRF-Chem that simulates the emission, transport, turbulent mixing, and chemical transformation of trace gases and aerosols simultaneously with the meteorology
--Investigation of regional-scale air quality, field program analysis, and cloud-scale interactions between clouds and chemistry
--Diagnosing and resolving atmospheric chemical phenomena using the WRF-Chem

PROJECT ACCOMPLISHMENTS:

--WRF-Chem has major code updates annually contributed by NOAA GSD, NCAR, and the global research communities. We completed our annual major update of the code with the release version 3.9.1 in April 2017
--Completed annual tutorial at NCAR, Boulder in January 2018
--Assisted to complete the dust project by evaluating different dust models as they coupled to the operational High Resolution Rapid Refresh (HRRR) modeling system.
--Continuously provided user support and answered user questions from the online helpdesk
--Redesigned and maintained the WRF-Chem official website

EAR Publications:

Albers, S., D. Nietfeld, and Z. Toth, 2018: The Latest Nowcast: Improved Visibility, *Eighth Conference on Transition of Research to Operations*, Austin, TX, Amer. Meteor. Soc., 13B.3. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper335607.html)

Beck, J., I. Jankov, J. Wolff, M. Harrold, T. Hertneky, P. Skinner, and J. Brown, 2018: An Evaluation of Ensembles Available within the Community Leveraged Unified Ensemble (CLUE) during the Hazardous Weather Testbed (HWT). *25th Conference on Probability and Statistics*, Amer. Met. Soc., 5.6. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper334288.html)

Blake, B., J. Carley, T. Alcott, I. Jankov, M. Pyle, S. Perfater, and B. Albright, 2018: An Adaptive Approach for the Calculation of Ensemble Grid-Point Probabilities, *Wea. Forecasting,* Submitted.

Fenton, K., M. Wandishin, M. Petty, M. Marquis, T. McJunkin, A. Abboud, and J. Gentle, 2018: The Use of HRRR Forecasts in True Dynamic Line Rating, *Ninth Conference on Weather, Climate and the New Energy Economy*, Austin, TX, Amer. Met. Soc., 11.4. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper331345.html)

Govett, M, J. Rosinski, J. Middlecoff, T. Henderson, J. Lee, A. MacDonald, P. Madden, J. Schramm, and A. Duarte, 2016: Parallelization and Performance of the NIM Weather Model for CPU, GPU and MIC Processors. *Bull. Amer. Meteor. Soc*., 98**,** 2201-2213. (https://doi.org/10.1175/BAMS-D-15-00278.1)

Hardin, N., D. Nietfield, T.L. Hansen, and Y. Guo, 2018: Hazard Services: Utilizing Recommenders to Create Hazardous Information, *34th Conference on Environmental Information Processing Technologies*, Austin, TX, Amer. Meteor. Soc., 1A.2. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper326206.html)

Jankov, I., J. Beck, J. Wolff, M. Harrold, J. Olson, T. Smirnova, C. Alexander, and J. Berner, 2018: Stochastic Parameter Perturbation in HRRR-Based Ensemble, *Mon. Wea. Rev*., submitted.

Jankov, I., J. Beck, J. Wolff, M. Harrold, G. Grell, J. Olson, T. Smirnova, J. Berner, C. Alexander, and S. Benjamin, 2018: Stochastic Approaches within a High-Resolution Rapid Refresh Ensemble. *Invited. 32nd Conference on Hydrology*, Austin, TX, Amer. Met. Soc., J53.1. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper335716.html)

Lin, H., S.S. Weygandt, S.G. Benjamin, and M. Hu, 2017: Satellite Radiance Data Assimilation within the Hourly Updated Rapid Refresh, Wea. Forecasting, **32,** 1273–1287, https://doi.org/10.1175/WAF-D-16-0215.1.

Lin, H., S.S. Weygandt, A.H. Lim, M. Hu, J.M. Brown, and S.G. Benjamin, 2017: Radiance Preprocessing for Assimilation in the Hourly Updating Rapid Refresh Mesoscale Model: A Study Using AIRS Data. Wea. Forecasting, **32,** 1781–1800, https://doi.org/10.1175/WAF-D-17-0028.1.

Lin, H., S. S. Weygandt, Y. Xie, M. Hu, C. R. Alexander, and S G. Benjamin, 2018: Satellite radiance data impact in RAP version 4. Proceedings, *Sixth AMS Symposium on the Joint Center for Satellite Data Assimilation (JCSDA)*, Austin, TX, Amer. Met. Soc., 3.1. Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper333887.html)

Petty, M., A. Terborg, P. Hamer, G. Layne, M. Wandishin, M. Rabellino, and M. Turpin, 2018: INSITE: IDSS for Aviation Weather. *34th Conference on Environmental Information Processing Technologies,* Austin, TX, Amer. Met. Soc., 2A.4. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper334353.html)

Petty, M., G. Layne, M. Wandishin, J. Hart, P. Hamer, and M. Rabellino, 2018: An Impact-Based Verification Approach for the TFM Convective Forecast (TCF). *Sixth Aviation, Range, and Aerospace Meteorology Special Symposium*, Austin, TX, Amer. Met. Soc. 361.

Stewart, J.Q., S. McNeil, S. Johnston, D. Hagerty, 2018: Scaling for Unknown Demand through the Use of Cloud Technology for the Eclipse of 2017, *34th Conference on Environmental Information Processing Technologies*, Austin, TX, Amer. Meteo. Soc, 6B.1. (Recorded Presentation Available at: https://ams.confex.com/ams/98Annual/webprogram/Paper337644.html)

DATA ASSIMILATION

Research to develop and improve techniques to assimilate environmental observations, including satellite, terrestrial, oceanic, and biological observations, to produce the best estimate of the environmental state at the time of the observations for use in analysis, modeling, and prediction activities associated with weather/climate predictions (minutes to months) and analysis.

PROJECT TITLE: Data Assimilation Internship Program

PRINCIPAL INVESTIGATOR(S): Christian Kummerow

RESEARCH TEAM (INTERNS): Amanda Back, Matthew Brothers, Alex Libardoni

NOAA TECHNICAL CONTACT: Kevin Kelleher (NOAA/ESRL/GSD) and Vijay Tallapragada (NOAA/EMC)

NOAA RESEARCH TEAM: Various

FISCAL YEAR FUNDING: $140,258

PROJECT OBJECTIVE:

In January 2015, CIRA initiated an internship program in Data Assimilation (DA) to help train a workforce on behalf of NOAA. There is an obvious shortage of scientists in the United States with data assimilation skills as evidenced both from discussions with NOAA scientists working in this area, as well as very small applicant pools for data assimilation positions within CIRA.

The internship program is structured such that the interns will receive formal training in DA at CIRA in Fort Collins, CO, for the first six months. Milija Zupanski will oversee this training program. This will include using the NOAA models and supercomputers, but the training is supposed to cover the basic theory and applications, so it is designed to be broad. While national origin is not important, the ability to gain access to NOAA supercomputers in the current environment will be an important criterion in selecting interns. At roughly six months into the program, CIRA will make arrangements with the sponsor for the interns to visit. Given that this is ultimately a workforce development program, these visits are expected to lead to joint projects that would be of immediate use to NOAA while continuing to develop the interns' learning process. The interns are thus expected to work on NOAA problems during the second six months of the internship.

PROJECT ACCOMPLISHMENTS:

CIRA is currently hosting 3 Interns that started around January 1st of 2018. Amanda Back is funded by ESRL GSD, and currently splits her time between Boulder and Fort Collins, while Matthew Brothers and Alex Libardoni are funded by EMC and have not yet started to work on specific projects with EMC. Their progress, in their own words, is provided below:

<u>Amanda Back</u>

I have been an intern of the CIRA data assimilation training program for four months. Prior to joining the program I knew only the most basic information about DA and about atmospheric observations in general; I've since learned a tremendous amount. Through training meetings led by Milija Zupanski and a handful of other researchers, I've gained knowledge of the theoretical underpinnings of data assimilation for atmospheric science along with some of its practical challenges. I've seen presentations of cutting-edge research on novel assimilation approaches and observation types and have read mountains of related peer-reviewed work. While these classes met twice-weekly, CSU professor Steven Rutledge kindly allowed me to sit in on his graduate-level radar meteorology course, which was tremendously useful in introducing me to the techniques and terminology of a common observation approach and verification source. When I am not at CSU for DA training, I'm at NOAA in Boulder gaining exposure to operational DA in the Assimilation Development Branch, where I'm mentored by Curtis Alexander, Stephen Weygandt and others. At NOAA, through attending meetings and receiving one-on-one instruction, I've been exposed to many challenges of practical DA such as high latency, computing resource constraints, availability of secondary data sources for verification, and quality control. I've heard about novel observation sources currently in testing or in need of testing through listening in on phone calls with NASA, JPSS, and others. Through the opportunity to work with NOAA's high performance computing resources, I've become comfortable utilizing the Rocoto workflow manager, accessing old observations and model runs on mass storage, and editing the kshell scripts that govern various aspects of the HRRR model. I've performed three retrospective HRRR runs to test my configuration against those of colleagues. I had the opportunity to put together a couple slides to show to my CIRA friends last week comparing radar observations, the SATCAST product, and missed reflectivity readings in a control HRRR run to motivate the assimilation of SATCAST as latent heating into HRRR. My next challenge, which commenced last week, is to modify a FORTRAN program that feeds data from various sources into GSI, adapting it to read in SATCAST data and perform the conversion to heating.

Matthew Brothers
Since being hired as a Research Associate (Data Assimilation Intern) at CIRA, I have been shown the increasing importance of connecting models with the vast array of observations. Lectures on the theory behind data assimilation by several members of CIRA's Data Assimilation Group have provided valuable insight into the various methods and approaches to this problem. The knowledge gained has allowed me to begin working with GSI code in order to further my understanding of the framework of these methods before beginning on a specific data assimilation research project. Additionally, guest seminars and meetings with other NOAA lab personnel have provided opportunities to further learn about the current efforts being worked on to improve various data assimilation systems.

Alex Libardoni
When I started, I had no experience in data assimilation, but through the classroom portion of the program and subsequent suggested readings, I have developed a strong understanding of the various methods. My knowledge base has grown significantly to the point where I could follow, comprehend, and think critically about presentations in a recent meeting. I am to the point where I feel comfortable discussing data assimilation research and am confident I could join on and positively contribute to an existing project. Further, I have learned the basic theory of the Gridpoint Statistical Interpolation system and have built and run small test cases on the S4 computing cluster.

Publications: None

Presentations: None

PROJECT TITLE: EAR - Data Assimilation for the High Resolution Rapid Refresh (HRRR)

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Steve Albers

NOAA TECHNICAL CONTACT: Curtis Alexander

NOAA RESEARCH TEAM: Steve Weygandt (NOAA/OAR/ESRL/GSD), Yuanfu Xi (NOAA/OAR/ESRL/GSD ret), Ming Hu (CIRES), Ravan Ahmadov (CIRES)

FISCAL YEAR FUNDING (Total EAR): $4,334,735

PROJECT OBJECTIVES:

--Display camera-like images and assimilate camera data with the HRRR-GSI
--Display camera-like images and assimilate camera data with the HRRR-Alaska
--Display camera and satellite like images and develop visibility algorithms for the HRRR-Smoke.

PROJECT ACCOMPLISHMENTS:

HRRR – GSI All Sky Camera Assimilation
Using a camera mounted on the David Skaggs Research Center rooftop, researchers developed an interface for GSI software to read all-sky camera cloud mask data. The data was successfully read in to the front-end routines of GSI and displayed as a log file output. Concurrently an interface was developed (with help from NOAA colleague Yuanfu Xie), to connect the all-sky image simulation software, also in development, to the GSI. This was run to create red -green- blue (RGB) sky images as a demonstration, though for initial simulation experiments this will be converted into a cloud mask. Preliminary experiments were completed to bring the camera data into the non-variational cloud analysis module within GSI, doing comparisons between camera and simulated cloud masks in the same part of the code. Then the camera cloud mask was used to modify the hydrometeor fields with a cloud clearing step along the camera lines of sight. Imagery was produced illustrating the changing sky appearance from the assimilation with overlays of various contributing grid-points to the cloud analysis and its changes.

HRRR – Alaska Run & Camera Network
A new real-time website was developed that compares camera images from the FAA network operating at airports in Alaska to simulated images from HRRR forecasts. Forecast periods of 00, 03, and 06 hours are being simulated from 10 locations. The cameras are being processed from these sites into hourly mosaics. Each site has up to 4 webcams looking in various directions and the mosaics allow us to see as much of the surroundings as possible in one view. The sky simulations can be compared with verifying camera images as in Figure 1. The number of sites can be expanded up to 185 to cover the entire available network.

Figure 1. Simulated 360-degree panoramic sky view (top) made from a HRRR-Alaska 6 hour forecast. The cloud cover in the FAA camera appears to be more extensive compared with the simulated. In this case the hydrometeors are being underestimated in the forecast, based on the clearer and bluer sky area near the horizon on the right side. The radiative transfer used in the simulated images also needed some refinement in the handling of multiple scattering, based on the appearance of the diffuse sun with respect to the amount of hydrometeors present.

To allow initial experiments with assimilating the camera images, cloud masks are also being produced for each of the simulated sites during the daylight hours. The masks are binary (yes/no) in nature and are produced based on sky color. Ratios of red, green, and blue image counts are compared with thresholds to assign the presence of clouds. These ratios are compared with clear sky reference values, constructed from the Simulated Weather Imagery (SWIM) package that has been developed over the past few years. A clear sky image library is available for each degree of solar elevation angle to allow optimum results at various times of the day.

HRRR – Smoke

Several aspects of smoke and aerosol handing in the HRRR-Smoke system are being explored with Dr. Ravan Ahmadov in the Model Development Branch. This entails devising techniques to post-process the chemistry variable output to provide fields of surface visibility for the user community. One algorithm uses climatological values of smoke mass extinction efficiency to help convert the model variables into extinction coefficient and visibility. Visualization using the Simulated Weather Imagery (SWIM) package Steve Albers developed is being used to assess the model runs. Physically and visually realistic views (natural color and contrast) simulate what an astronaut or satellite would see from space (Figure 2). Some color enhancements are applied to facilitate comparison with similarly enhanced satellite imagery, such as GOES-16 and VIIRS. This has been presented to the NWS Western Region and they are excited enough about this to request that we set it up as a real-time product for dissemination in the NWS experimental platform known as WAVE.

Figure 2. HRRR-Smoke forecast visualized in a physically realistic manner showing the smoke plume from California fires on Dec 7. 2017. This closely resembles what an astronaut would see from space. In addition to the smoke, snowpack from the model output can be seen in the Sierra Nevada Mountains.

Presentations:

Shark-Tank submission**:** CIRA participated in the NWS Central Region Shark-Tank competition held in Boulder in February, 2018. Steve Albers is one of the finalists selected for the next round to be held at NOAA headquarters. The title of the pitch is "Use of Ground- and Space-based Visible Imagery with other data for Model Evaluation and Assimilation".

The pitch is in support of all three project objectives summarized above. It comprises a big picture look at the utility of the simulated weather images for forecast dissemination and model visualization and assessment. The camera data can also be used with satellites in a comprehensive variational cloud & hydrometeor analysis that is tomographic. This means 3-D hydrometeor and aerosol fields can be constrained by the radiances as seen from various ground- and space-based viewing angles. Consideration of multiple scattering in visible wavelengths also yields information about hydrometeors in cloud interiors. The addition of model dynamics to the variational package allows a 4-D solution to be arrived at. The simulated weather imagery can act as a forward model in this type of analysis.

PROJECT TITLE: Joint Center for Satellite Data Assimilation Summer Colloquium on Satellite Data Assimilation

PRINCIPAL INVESTIGATORS: Christian Kummerow, Steven J. Fletcher

RESEARCH TEAM: Steven Fletcher and Holli Knutson

NOAA TECHNICAL CONTACT: James Yoe

NOAA RESEARCH TEAM: Joint Center for Satellite Data Assimilation

FISCAL YEAR FUNDING: $100,000

PROJECT OBJECTIVE:

To identify possible locations to host the JCSDA's Summer Colloquium on Satellite Data Assimilation that can host up to 20 final year Ph.D. Students or early postdocs, in collaboration with representatives from the JCSDA (Drs. James Yoe and Thomas Auligne (Director)), and NRL (Dr. Nancy Baker, (Head of DA)) To procure the contract with the location to host the colloquium and to provide catering, accommodation as well as the meeting facilities to host the colloquium, once the organizing committee decide upon the winning location.

PROJECT ACCOMPLISHMENTS:

The Hilton Garden's Inn in Bozeman was selected to host the colloquium between July 23 – August 3, 2018. Dr. Fletcher worked with the procurement office at CSU to agree the contract between CSU and the Garden's Inn in Bozeman, to secure meeting facilities along with accommodations for the students, admin and the lecturers.

PROJECT TITLE: Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program

International Aviation

PRINCIPAL INVESTIGATORS: Sher Schranz, Bonny Strong

RESEARCH TEAM: Jung-Hoon Kim, Robyn Tessmer

NOAA TECHNICAL CONTACT: Matt Strahan (NOAA/NWS/AWC/IOB Chief)

FISCAL YEAR FUNDING (Total Research Collaboration Project): $2,184,938

PROJECT OBJECTIVES:
1--Enhance calibration of GEFS GTG to improve probabilities of EDR
2--Develop initial methodology to blend WAFC turbulence probability forecasts
3--Evaluations of the enhanced GEFS GTG product against observed EDR data
4--Publish probabilistic forecast techniques and blending methodology in scientific papers and conferences

PROJECT ACCOMPLISHMENTS:

1--Enhance calibration of GEFS GTG to improve probabilities of EDR
The current gridded World Area Forecast System (WAFS) turbulence forecasts use global Numerical Weather Prediction (NWP) model output to estimate an uncalibrated turbulence potential on a 1.25 × 1.25 degree global domain. This is based on a single empirical turbulence diagnostic, the Ellrod index (Ellrod and Knapp 1992), which depends on vertical wind shear and total deformation. The International Civil Aviation Organization (ICAO) and World Meteorological Organization (WMO) have requested an upgrade of the current WAFS turbulence product to provide a calibrated severity atmospheric turbulence metric, viz., an energy dissipation rate to the 1/3 power (EDR; $m^{2/3}$ s^{-1}) for multiple sources of turbulence, and finally to produce probabilistic forecasts with better spatial and temporal resolutions (WMO/ICAO 2014).

To accomplish this goal, we extend the Graphical Turbulence Guidance (GTG) version 3 (Sharman and Pearson 2017) to the global domain by using the National Oceanic and Atmospheric Administration's (NOAA's) Global Ensemble Forecast System (GEFS) on a 0.5 × 0.5 degree domain with the enhancement of the calibrations by three sequential procedures. These procedures include: 1) computing the individual Clear-Air Turbulence (CAT) and Mountain Wave Turbulence (MWT) diagnostics, 2) remapping those diagnostics to the Energy Dissipation Rate (EDR)-scale, and 3) providing an optimal probabilistic EDR forecast.

The 15 CAT and MWT diagnostics used in this study were selected from the suite of the GTG3 component diagnostics that have relatively higher skill scores than others when verified against a long period of upper-level in situ EDR observation data over the Contiguous US (CONUS) as well as outside of the CONUS. The conversion methodology uses the Probability Density Functions (PDFs) of the individual turbulence diagnostics from the forecast data. Raw turbulence potential values are remapped to EDR by assuming that the predicted turbulence diagnostics follow a lognormal. Figure 1 shows an example snapshot of three CAT (Ellrod3, |DIV|/Ri, and RTKE) and three MWT diagnostics (MWT3, MWT5, and MWT12) remapped to an EDR-scale at the 300 hPa level, derived from an 18-hr forecast based on the GEFS model output valid at 18 UTC on 6 Jan 2016.

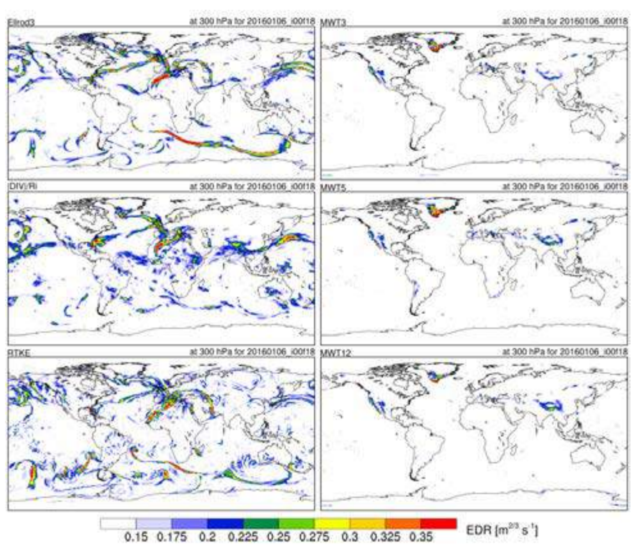


Figure 1. Snapshot of three Clear-Air Turbulence (CAT) [left; *Ellrod3* (top), |*DIV*|/*Ri* (middle), and *RTKE* (bottom)] and Mountain Wave Turbulence (MWT) diagnostics [right; *MWT3* (top), *MWT5* (middle), and *MWT12* (bottom)] at the 300 hPa level in the Global Graphical Turbulence Guidance (G-GTG) for the World Area Forecast System (WAFS) upgrade, derived from the 18-hr forecast of the Global Ensemble Forecast System (GEFS) model outputs on a 0.5 × 0.5 degree domain valid at 18 UTC 6 Jan 2016.

Given that underlying NWP model and the turbulence diagnostics are not perfect, the uncertainty in the forecasts should be taken into account (e.g., Gill and Buchanan 2014). In addition, turbulence in the free atmosphere occurs due to a combination of different generation mechanisms that are very hard to distinguish independently from the non-linear solution of the NWP model fields. Therefore, the multi-diagnostic ensemble gives better spread and takes into account possible uncertainties in the probabilistic turbulence forecast, although component diagnostics are not perfectly (ideally) independent of each other. To do this, at each grid point, we simply count how many EDR-scaled turbulence diagnostics exceed the EDR threshold of 0.22 $m^{2/3}$ s^{-1}, a value considered as a moderate-or-greater (MOG) turbulence intensity for mid-size aircraft (Sharman et al. 2014).

A probabilistic EDR forecast is calculated separately for the CAT and MWT. The maximum grid point by grid point probability forecast between the CAT and MWT are considered as the final probabilistic EDR forecast. Figure 2 shows a sample snapshot of the probabilistic EDR forecasts for CAT (upper), MWT (middle), and combined GTG (bottom) derived from the 18-hr GEFS forecast valid at 18 UTC 6 Jan 2016. In Figure 2, probabilistic GEFS GTG forecasts have higher values across the North Atlantic Ocean, near northwestern Africa, and the southern tip of Greenland. For users, this probabilistic forecast product can translate into a possibility of encountering MOG-level turbulence due to the different generation mechanisms within a given grid box.

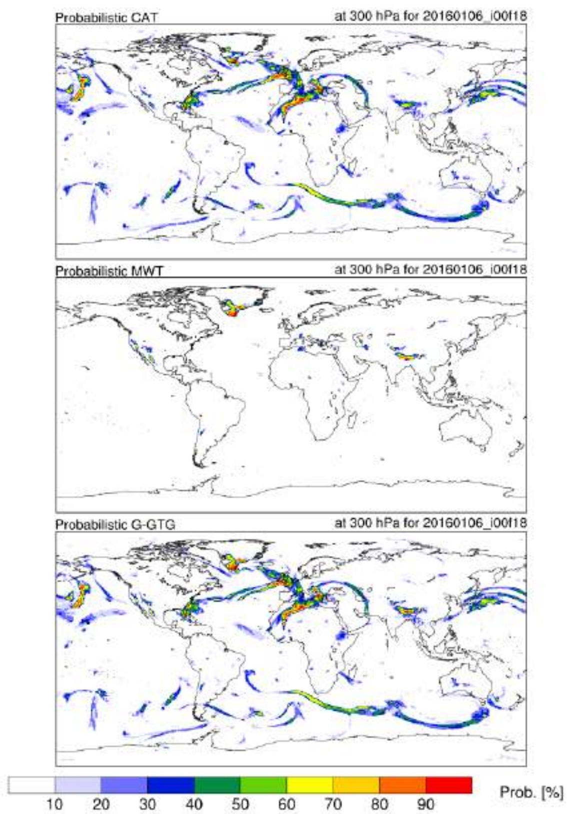


Figure 2. A snapshot of the probabilistic CAT (upper), MWT (middle), and max GEFS GTG (bottom) forecasts at 300 hPa, derived from 18-hr forecast of the GEFS model output on a 0.5 × 0.5 degree horizontal resolution domain valid at 18 UTC 6 Jan 2016.

2--Develop initial methodology to blend WAFC turbulence probability forecasts
For the operationally harmonized WAFS product between WAFC Washington and WAFC London, we apply the same GEFS-based EDR-scale GTG system with the same diagnostic selection to the Met Office Global and Regional Ensemble Prediction System (MOGREPS) on the same grid spacing as the

GEFS model. Figure 3 shows the deterministic EDR-scale CAT (left), MWT (center), and the maximum of CAT and MWT (right) forecasts from the GEFS (top) and MOGREPS (middle). The differences between the GEFS and MOGREPS (bottom), shown in Figure 3, shows only localized, small discrepancies between these two models. In general, the two EDR forecasts from the two different underlying NWP models have very similar patterns for this case as, large-scale upper-level flows in both models have similar structures (not shown).

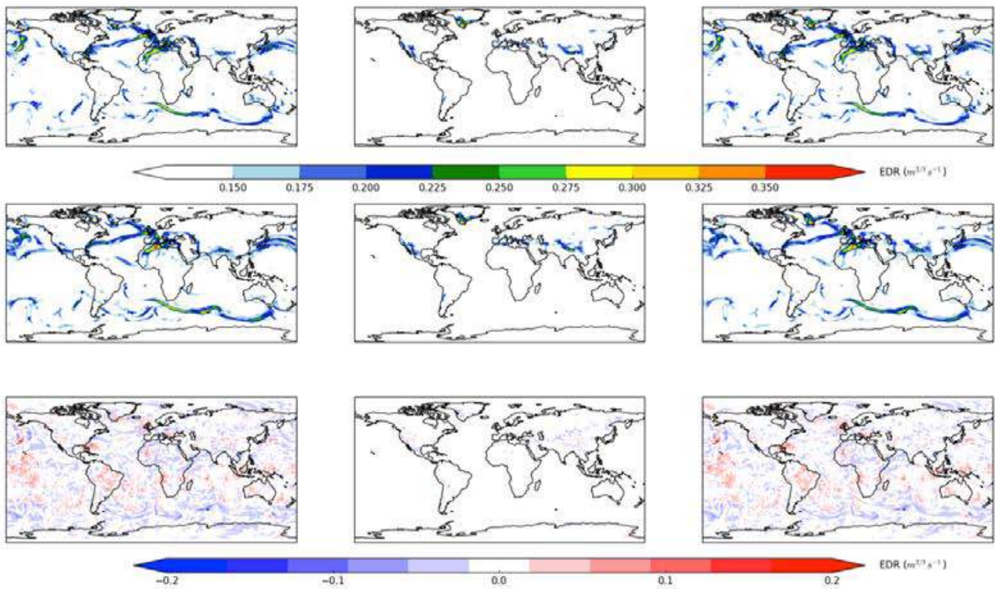


Figure 3. A snapshot of the CAT (left), MWT (center), and max G-GTG (right) EDR forecasts from the same combination of 15 CAT and 15 MWT individual diagnostics at 300 hPa, derived from 18-hr forecasts of the GEFS (upper) and MOGREPS (middle), and their difference (GEFS – MOGREPS) (bottom) on 0.5 × 0.5 degree domain, both valid at 18 UTC 6 Jan 2016.

Finally, in Figure 4, EDR forecasts from both WAFC Washington (GEFS-based) and WAFC London (MOGREPS-based) are blended by taking the maximum of the probabilistic EDR forecasts. This will give a consistent and harmonized en-route turbulence forecast for the WAFS users all over the world.

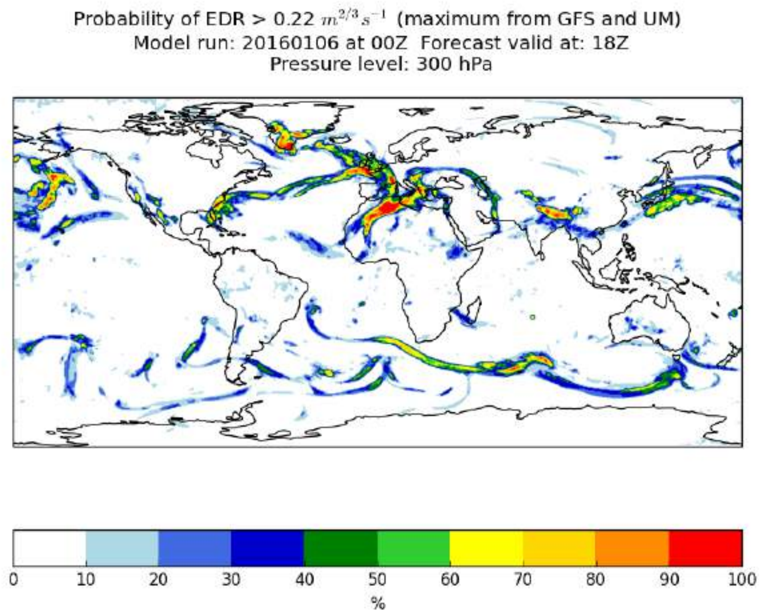


Figure 4**.** A snapshot of the blended maximum EDR probabilistic forecasts from the GEFS-based G-GTG and MOGREPS-based G-GTG 18-hr forecasts valid at 18 UTC 6 Jan 2016.

Figure 5 shows a case study of the comparison of the current WAFS CAT product (left) with the final blended deterministic EDR (middle) and probabilistic EDR (right) forecasts. The figure is zoomed in on the North Atlantic flight corridor, which is one of the busiest flight corridors in the world. During this period, there are numerous MOG-level turbulence reports over Southern Greenland. As shown in contours of sea level pressure (SLP) in Figure 5, cyclonic flow associated with a low pressure system produces easterly winds at the surface over Southern Greenland. This generates a vertically propagating large amplitude mountain wave, and a subsequent break down at the critical level at which there is a reversal of the background with height, from easterly to westerly. This case, as well as other cases under the similar synoptic pattern (not shown), are very well predicted by the blended deterministic and probabilistic GTG forecasts, whereas the current WAFS forecast misses the MWT events over the southern tip of Greenland (left panel).

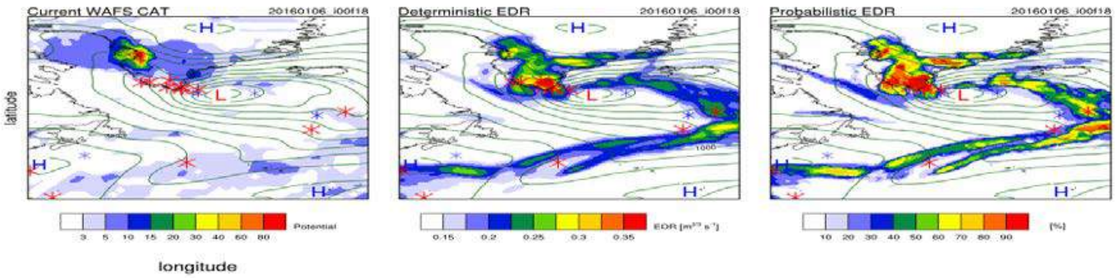
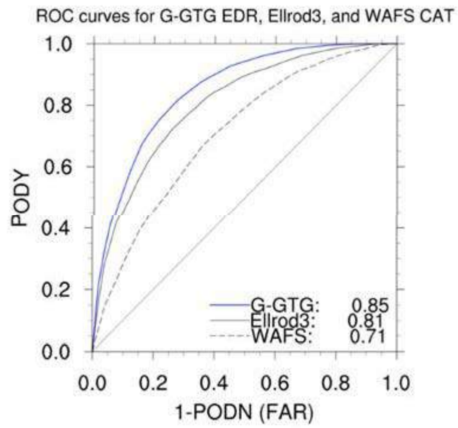


Figure 5. A snapshot of the current WAFS CAT potential (left), the blended maximum deterministic EDR (middle), and probabilistic EDR (right) with sea-level pressure (SLP; contour with 8 hPa interval), from the GEFS-based GTG and MOGREPS-based GTG valid at 18 UTC 6 Jan 2016, focusing on the North Atlantic flight corridor. In situ PIREPs (moderate-or-greater; red stars, and null; blue stars) reported around ±1-hr time window around this time is depicted.

3--Evaluations of the enhanced GEFS GTG product against observed EDR data

For the evaluation of the deterministic EDR forecasts, the Probability of Detection (POD) is “yes” for MOG-level turbulence events (EDR > 0.22 $m^{1/3} s^{-1}$) and “no” for null turbulence events (EDR < 0.01 $m^{1/3} s^{-1}$). These are calculated by constructing the Relative Operating Characteristics (ROC) curves as used in several previous studies (e.g., Ellrod and Knox 2010; Kim et al. 2011; Sharman and Pearson 2017). Figure 6 (left) shows the resulting ROC curves with their Area Under Curve (AUC) skill score (lower right) for the final GEFS-based G-GTG EDR forecast (blue curve) and the single best CAT diagnostic (*Ellrod3*). For comparison, the current WAFS CAT product is also evaluated using the same in situ EDR data. The important message here is that the new GEFS GTG EDR forecast provides significant improvement over the current WAFS CAT product due to the incorporation of improved diagnostics such as the Ellrod3 index, better resolution, and the inclusion of a specific MWT component as shown in the case study in Figure 5.



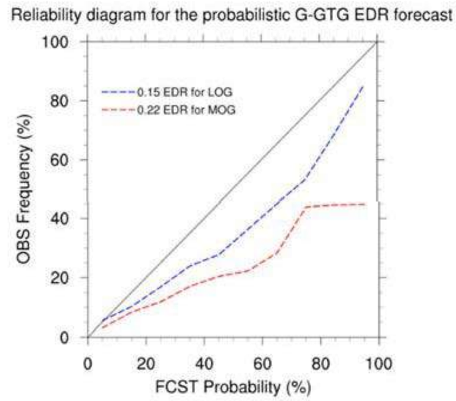


Figure 6. (left) Statistical performance as indicated by Relative Operating Characteristics (ROC) curves for the GEFS GTG forecast (solid blue curve) the single best CAT diagnostic (*Ellrod3*; solid black curve), and the current WAFS CAT (dashed black curve) with the Area Under Curve (AUC) skill scores (lower right), derived from 6-month period (2015.10 – 2016.3) of 18-hr GEFS forecast data. (right) Statistical reliability lines (dashed colored lines) for the probabilistic GEFS GTG EDR forecasts for Moderate-Or-Greater (MOG; EDR > 0.22 $m^{1/3}s^{-1}$; red line) and Light-Or-Greater (LOG; EDR > 0.15 $m^{1/3}s^{-1}$; blue line)-level turbulence using 6-month period of 18-hr GEFS forecast data and in situ EDR observation data. The perfect reliability line (black solid diagonal line) is also depicted in the plot.

In addition, the probabilistic GEFS GTG forecast is evaluated using the reliability diagram calculating the agreement of forecast probabilities with the actual occurrences in the same observed EDR data. Figure 6 (right) shows the reliability diagram for the GEFS-based probabilistic EDR forecasts for MOG (EDR > 0.22 $m^{1/3} s^{-1}$; red line) and Light-Or-Greater (LOG; EDR > 0.15 $m^{1/3} s^{-1}$; blue line) level turbulence. Here, the probability forecast can be translated into a chance of encountering a turbulent eddy due to the different CAT and MWT mechanisms in a given background condition in a grid box area. The reliability line that is closest to the perfect line (diagonal solid black line) is considered a better probability forecast. In Fig. 6 (right), as the EDR threshold for the probabilistic forecast increases from 0.15 (LOG) to 0.22 (MOG), fewer samples occur that correspond to the higher probability forecasts (>75%). This drops the reliability lines (red line) below the diagonal. In this study, the system is more reliable at predicting LOG-level turbulence than MOG-level, which is likely due to the lack of observation data for MOG-level turbulence and the lack of spread of the GEFS in the short (18-hr) forecast time frame.

4--Publish probabilistic forecast techniques and blending methodology in scientific papers and conferences

For the next generation version of the WAFS turbulence forecasts, we produced a probabilistic EDR forecast from the multi-diagnostic ensemble method by counting the number of the 15 CAT and 15 MWT diagnostics that exceeded a certain EDR threshold, derived from the GEFS model outputs. Those were shown to provide a considerably superior statistical performance than the current WAFS CAT and better performance than the best single turbulence diagnostic when verified against a 6-month period of global in situ EDR observation data. Reliability tests of the probabilistic EDR forecast against the same in situ EDR data showed that the system is more reliable at predicting LOG turbulence (i.e. EDR > 0.15 $m^{2/3} s^{-1}$) than MOG turbulence (i.e. EDR > 0.22 $m^{2/3} s^{-1}$) in this study but suffers from over-forecasting. It is likely related to the lack of observation data and global NWP ensemble spread in a short-term (18-hr) forecast. The results are very well documented in several scientific journal and international conferences as stated in the project publications.

Publications:

Avey, S., S. Alvidrez, S. Lack, A. Cross, J. Kankiewicz, and R. Bastholm, 2018: Guidance on Optimally Presenting Probabilistic Ceiling & Visibility Forecasts for the Aviation Community. *Sixth Aviation, Range, and Aerospace Meteorology Special Symposium*, Austin, TX, Amer. Met. Soc., 2.2. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper331035.html)

Kankiewicz, J.A., S. Avey, S. Lack, and A. Cross, 2018: Current and Future Efforts Using 3-D Cloud Fraction for Aviation Forecasting. *Sixth Aviation, Range, and Aerospace Meteorology Special Symposium*, Austin, TX, Amer. Met. Soc., 353.

Kim, J.-H., R. D. Sharman, M. Strahan, J. W. Scheck, C. Bartholomew, J. C. H. Cheung, P. Buchanan, and N. Gait, 2018: Global Graphical Turbulence Guidance (G-GTG) for World Area Forecast System (WAFS), *Bull. Am. Meteor. Soc.,* In revision.

Kim, J.-H., D. Kim, M. Strahan, R. D. Sharman, P. D. Williams, H.-Y. Chun, and Y.-J. Kim, 2018: Impact of Large-Scale Variability on Trans-Oceanic Flights during the Strong NAO and ENSO Phases, *Geophys. Res. Lett.*, In revision.

Kim, J.-H., R. D. Sharman, C. Batholomew, M. Strahan, J. W. Scheck, J. C. H. Cheung, and P. Buchnan, 2018: Global Graphical Turbulence Guidance (G-GTG) for World Area Forecast System (WAFS) Upgrade, *Eighth Conference on Transition of Research to Operations*, Austin, TX, Amer. Meteor. Soc., 6.6. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper331578.html)

Kim, J.-H., R. D. Sharman, J. Brown, S. Benjamin, S. H. Park, and J. Klemp, 2018: Impact of Hybrid Vertical Coordinate to the WRF RAP-based Upper-Level Turbulence Forecast, *Eighth Conference on Transition of Research to Operations (R2O)*, Austin, TX, Amer. Meteor. Soc., 14B.4. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper331661.html)

Kim, Jung-Hoon, M. Strahan, and R. D. Sharman, 2017: Integrated Wind and Turbulence Forecasts for Automated Flight Route Planning, WMO Aeronautical Meteorology Scientific Conference (AMSC) 2017, Meteo France, Toulouse, France, Session 2.4.

Kim, Jung-Hoon, M. Strahan, and R. D. Sharman, 2017: Impact of Large-Scale Climate Variability to Long-Haul Flight Route, WMO Aeronautical Meteorology Scientific Conference (AMSC) 2017, Meteo France, Toulouse, France, Session 3.1.

Lee, D.-B., H.-Y. Chun, J.-H. Kim, and R. D. Sharman, 2018: Development of the Global Korean Aviation Turbulence Guidance system (G-KTG) using the Global Data Assimilation and Prediction System (GDAPS) of Korea Meteorological Administration (KMA), *Sixth Aviation, Range, and Aerospace Meteorology Special Symposium*, Austin, TX, Amer. Meteor. Soc., 330.

Pettegrew, B. P.**,** D. L. Sims, H. Y. Chuang, J. W. Scheck, and M. Strahan, 2018: Enhancing FAA/NWS Research-to-Operations to Support Global and Domestic Missions through the Unified Post Processor, *Eighth Conference on Transition of Research to Operations*, Austin, TX, Amer. Meteor. Soc., 275.

Pettegrew, B. P., A. Terborg and C. B. Entwistle, 2018: GLM Evaluation Updates on Total Lightning Use in the Aviation Weather Testbed and Aviation Weather Center, *Eighth Conference on Transition of Research to Operations*, Austin, TX, Amer. Meteor. Soc., 764.

Terborg, A**.** and B. P. Pettegrew, 2018: Flying into a New Era of Advanced Satellite Observations: Transitioning GOES-16 Utility for Aviation Forecasting into Aviation Weather Center Operations, *Eighth Conference on Transition of Research to Operations*, Austin, TX, Amer. Meteor. Soc., 5.3. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper334405.html)

CLIMATE-WEATHER PROCESSES

Research focusing on using numerical models and environmental data, including satellite observations, to understand processes that are important to creating environmental changes on weather and short-term climate timescales (minutes to months) and the two-way interactions between weather systems and regional climate.

PROJECT TITLE: Enhancing NIDIS Drought Monitoring and Early Warning in the Upper Colorado River Basin

PRINCIPAL INVESTIGATOR: Nolan Doesken

RESEARCH TEAM: Rebecca Bolinger, Peter Goble, Noah Newman, Zach Schwalbe, Henry Reges, Julian Turner, Nolan Doesken

NOAA TECHNICAL CONTACT: Veva Deheza, Executive Director, Elizabeth Weight, Regional Coordinator, Sandy McClellan, Budget Analyst, NIDIS Program Office, Boulder, CO

NOAA RESEARCH TEAM: Elizabeth Weight, Regional Drought Information Coordinator, Christina Stone, Communications Coordinator, Kathryn Bevington, Website Content and Development Coordinator NIDIS Program Office, Boulder, CO

FISCAL YEAR FUNDING: $161,192

PROJECT OBJECTIVES:

1--Continue to provide and improve weekly drought assessment services.
2--Incorporate and promote the new "Evaporative Demand Drought Index" (EDDI)
3--Assess and incorporate soil moisture monitoring capabilities as a means of enhancing drought early warning.
4--Continue efforts to better engage key representatives (National Weather Service, U.S. Bureau of Reclamation, State Engineers Offices and local River Commissioners, etc.) from the UCRB and surrounding regions in effective drought monitoring, early warning and coordination. In particular, identify effective partners in WY and UT.

PROJECT ACCOMPLISHMENTS:

The first few months of the reporting period were also the final few months of work on this project, which officially wrapped up on June 30, 2017.

As part of Objective 1, we continued to provide weekly assessments of drought conditions over the Upper Colorado River Basin, and began expanding our coverage to the Intermountain West region in preparation of our next statement of work (the Intermountain West: Wyoming, Utah, Colorado, Arizona, New Mexico). We also increased frequency of our webinars to biweekly during the spring and early summer as snowpack began melting and runoff increased.

As part of Objective 2, we continued to promote the use of the EDDI product through our assessments and webinars. EDDI information now regularly updates on our weekly assessment website, and Peter

Goble provides interpretation of the updated graphics on the webinars. EDDI is one of the indicators we now rely on for making recommendations of changes to drought depiction with the U.S. Drought Monitor.

As part of Objective 3, the spring of 2017 marked the official launch of CoCoRaHS soil moisture. Peter revised previously written protocol based on feedback from alpha testers in the warm season of 2016. Peter presented on the launch of CoCoRaHS soil moisture to WERA 1012 at the YMCA of the Rockies, and at the Marena, Oklahoma in situ Soil Sensor Testbed (MOISST) conference in Norman Oklahoma in May of 2017. He has maintained an active presence in the emerging National Soil Moisture Network, which aims to pool weather station, satellite, and modeling resources to improve the monitoring of soil moisture across the United States.

In May 2017, Nolan, Becky, Peter, and Noah traveled to northeast Colorado with the USDA Climate Hub Director and met with Colorado State University Extension. The purpose of this trip was to learn more about local farming practices and gain a better understanding of how drought and climate variability play a role in the state's agriculture. This trip was also important in meeting the goals of Objective 4 by collaborating and coordinating with regional representatives. Peter and Becky also met with regional representatives at the U.S. Drought Monitor Forum in April 2017.

<u>Timeframe July 1, 2017 – March 31, 2018</u>

PROJECT TITLE: Enhancing NIDIS Drought Monitoring and Early Warning in the Intermountain West

PRINCIPAL INVESTIGATORS: Nolan Doesken (retired August 2017), Russ Schumacher (as new Director of the Colorado Climate Center)

RESEARCH TEAM: Rebecca Bolinger, Peter Goble, Noah Newman, Zach Schwalbe, Henry Reges, Julian Turner, Nolan Doesken

NOAA TECHNICAL CONTACT: Veva Deheza, Executive Director, Elizabeth Weight, Regional Coordinator, Sandy McClellan, Budget Analyst, NIDIS Program Office, Boulder, CO

NOAA RESEARCH TEAM: Elizabeth Weight, Regional Drought Information Coordinator, Christina Stone, Communications Coordinator, Kathryn Bevington, Website Content and Development Coordinator NIDIS Program Office, Boulder, CO

PROJECT OBJECTIVES:

1--Engagement with Broad User Community: we seek to build upon and maintain relationships with the community of stakeholders, decision makers, and other experts within the Intermountain West who have an interest in drought.
2--Improving Partnerships and Collaboration: we aim to improve existing partnerships and develop strategies for regular collaboration to improve drought awareness, early warning, and preparedness across the region.
3--Data Enhancement and Product Development: Successful drought monitoring and early warning starts with adequate data and products that experts rely on to identify indicators and triggers.

PROJECT ACCOMPLISHMENTS:

[Objective 1] The entire NIDIS team continues to provide weekly assessments, archiving them on our website, and give monthly webinars to our stakeholders. Additionally, we have successfully expanded all our products to include the entire Intermountain West region (Wyoming, Utah, Colorado, Arizona, New Mexico).

A new effort in engaging the broad user community has been tested through the "Digital Drought Short" summary series. Both Peter and Becky have experimented with videos through YouTube and Facebook to provide up-to-date drought information and summaries for the Intermountain West. These digital shorts have had some success, and we will continue to test different methods of communication delivery and gage what has the largest reach and most attentive audiences. In addition to our own videography, we have worked closely with Anne Manning (Colorado State University SOURCE) to produce more professional videos. Our first web-based tutorial was filmed in February 2018, where Becky and Peter discuss the importance of snowpack in drought monitoring and our drought monitoring operations at the Colorado Climate Center.

Since the beginning of 2018, our drought monitoring efforts have placed a heavier emphasis on impacts reported from local experts. Becky, Peter, and Zach have increased communication efforts with Colorado State University Extension and USDA's Farm Service Agency directors to better understand conditions on-the-ground where drought is emerging and intensifying. We've also introduced an Impacts Reports section on our weekly assessment website.

[Objective 2] As drought begins to emerge in our region, Becky, Peter, and Zach have successfully collaborated with experts from Wyoming, Utah, and New Mexico in accurately depicting drought conditions across state borders. Additionally, Russ and Nolan partnered with the Colorado Water Center and the Colorado Water Institute to provide drought information to CSU Extension upon the activation of the Extension Drought Task Force.

We have also been working closely with state officials and other experts to update Colorado's State Drought Response and Mitigation plan. Russ, Becky, and Peter have met with Colorado Water Conservation Board, private consulting firms, state representatives from federal agencies (including USDA, USBR, NOAA), local water resource managers, and others. One of the key components of the updated drought response plan is to identify and assess various triggers and thresholds for better drought early warning and preparedness.

Henry has traveled to Arizona and Utah to meet with representatives at several National Weather Service offices. He is working with each office to get them better engaged with CoCoRaHS and condition monitoring. It has also provided the entire team with additional contacts necessary for improving collaboration.

Most of our NIDIS team met with Western Water Assessment and the NIDIS Program Office in February 2018 to give updates on our current projects and discuss methods for improving our collaborative efforts and communications with the user community.

[Objective 3] Becky has been working on precipitation forecasts that will serve as one part of the drought outlook products. The goal of these precipitation projections is to give an idea of how hard it would be to make up precipitation deficits before the end of the water year. This work is highlighting the relative importance (or lack thereof) of wintertime precipitation as part of the entire water year's accumulations.

Last summer, Becky also rolled out the North American Multi-Model Ensemble Tool for Colorado. This tool, located on our main website, provides 6-month forecasts of precipitation and temperature for each climate division in Colorado. The forecasted variable is easily comparable to long-term normals, so can be quickly interpreted for climate variability (and drought) purposes. The next step will be to expand this product over the Intermountain West.

In January 2018, Peter presented research he has done, analyzing evapotranspiration (ET) estimates that are used for EDDI, simplified estimates using PRISM data, and ET from our own CoAgMET sites. This work is essential in learning what products best represent ET over the IMW region, and serves as the building blocks for our own ET mapping product over the IMW. Peter is currently working on an

Executive Summary and Press Release of his findings to disseminate to stakeholders and other researchers in the drought community.

[Meets Multiple Objectives] CoCoRaHS Condition Monitoring maps have officially been rolled out, and have been a great source of information for the drought monitoring community. One of our deliverables for this project was to solicit reports from volunteers in Colorado and New Mexico when their county went to D2 on the U.S. Drought Monitor. This has been an effort we were able to implement in early 2018 and have had success. The Condition Monitoring maps show large increases of volunteer participation from both states after solicitations were emailed. These maps and subsequent reports have been heavily accessed and utilized by the drought community, including the U.S. Drought Monitor authors.

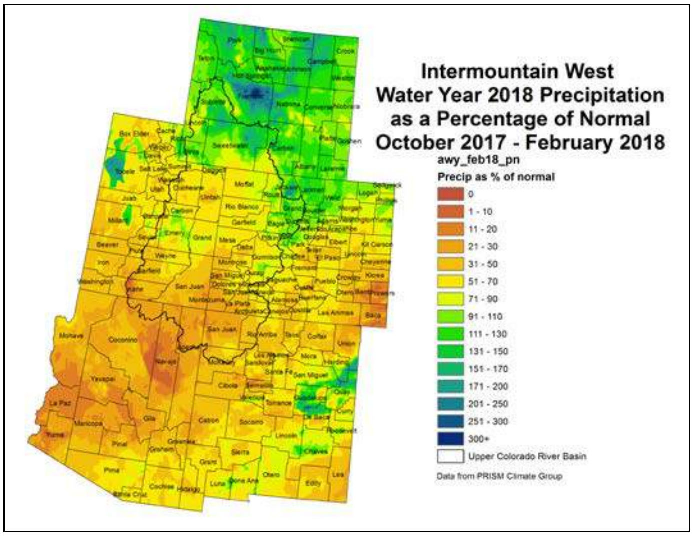


Figure 1. Our data products, water-year-to-date precipitation in this example, were expanded to cover the entire Intermountain West Region.

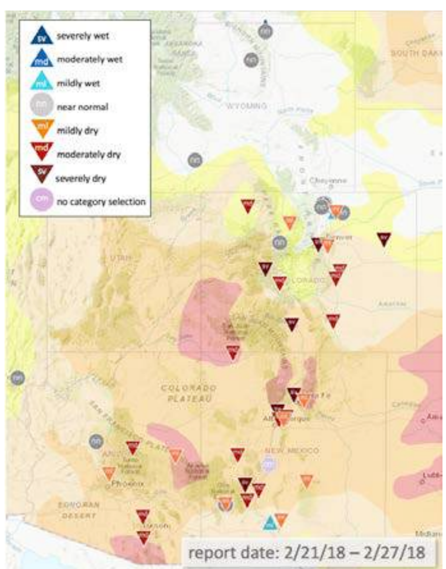


Figure 2. A sample screenshot of the CoCoRaHS Condition Monitoring map over the Intermountain West. Reports are represented by triangles or circles, and background contours show the current U.S. Drought Monitor depiction.

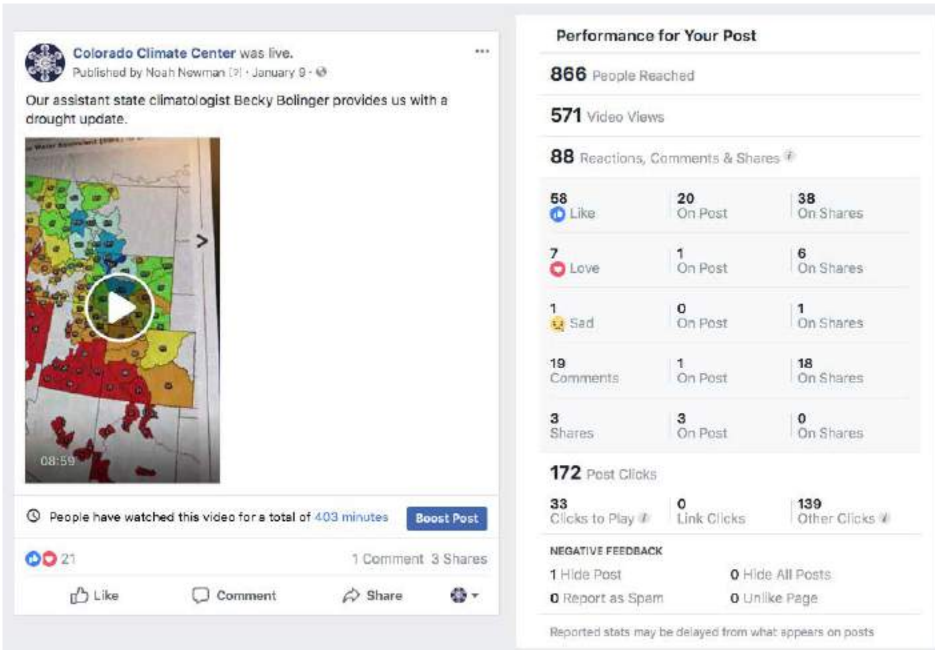


Figure 3. Details on one of our “Digital Drought Short” summary series, which was recorded via Facebook Live. While the live audience was small, we had good participation after.

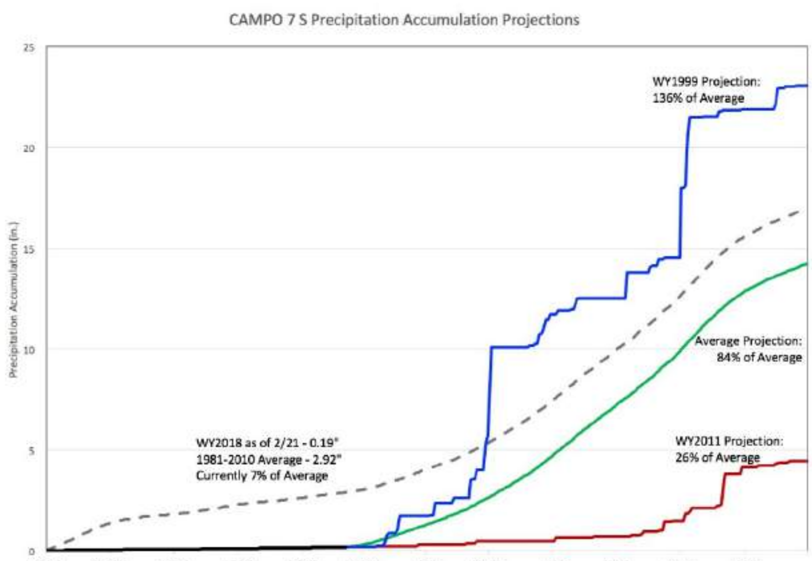


Figure 4. A precipitation projection graph for Campo, Colorado. The station is currently showing much drier than average conditions. But the projection shows that near average precipitation for the rest of the water year would bring the station closer to average.

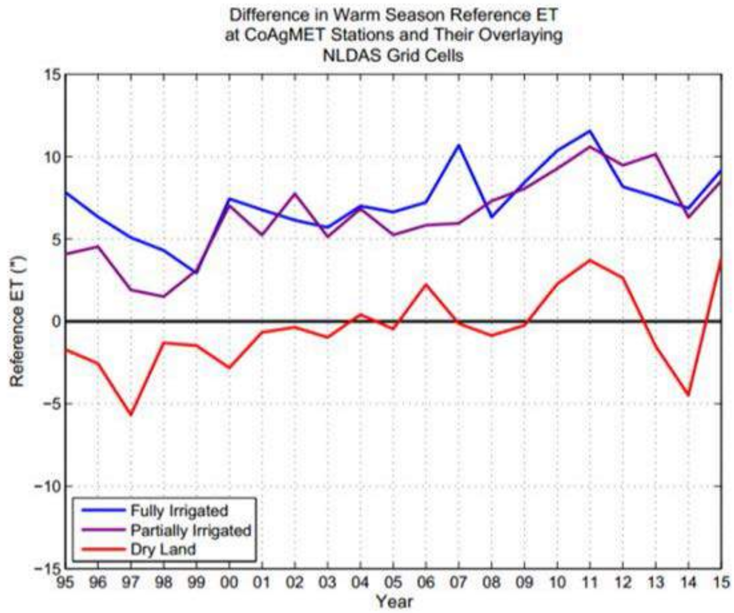


Figure 5. Differences in warm season reference evapotranspiration between CoAgMET stations and nearby NLDAS grid cells (which are used as inputs to the EDDI product).

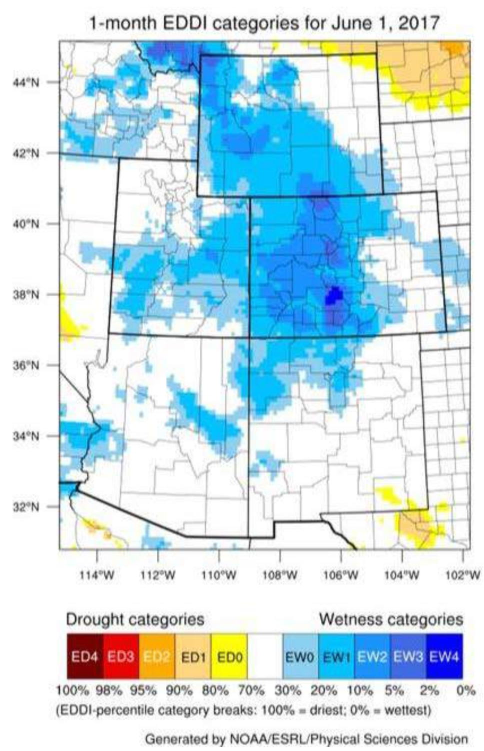


Figure 6. Incorporation of the new EDDI product over the Intermountain West into our weekly assessment products.

Publications:

**links to all presentations/publications can be found at http://climate.colostate.edu/pubs.html

Bolinger, Becky, 2017: Drought Monitoring Efforts as Part of the NIDIS Intermountain West DEWS**.** U.S. Drought Monitor Forum, Keystone, South Dakota - April 4, 2017

Goble, Peter, 2017: CoCoRaHS and the Drought Impact Reporter. U.S. Drought Monitor Forum, Keystone, South Dakota - April 4, 2017

Goble, Peter, 2017: Evaluating Differences between Measure and Modeled Potential Evapotranspiration in the State of Colorado. 23rd Conference on Applied Climatology, June 2017, Asheville, North Carolina.

Goble, Peter, 2017: The Launch of CoCoRaHS Soil Moisture. MOISST Workshop: Integrating Diverse Sources of Soil Moisture Information, Stillwater, OK - May 23, 2017

Goble, Peter, 2018: Evaporative Demand. Measurements, Models, and Methods. 32nd Conference on Hydrology Poster Session, AMS Annual Meeting, January 2018, Austin, Texas.

Goble, P., and Nolan Doesken, 2017. Colorado's Climate and Forests: An Update on Snowpack's Developing Relationship with Climate Change and the El Niño Oscillation. Colorado Water, Newsletter of the Water Center of Colorado State University, vol. 34, 2 (Mar/Apr), pp. 18-21.

Lackstrom, K and Coauthors, 2017. CoCoRaHS Observers Contribute to "Condition Monitoring" in the Carolinas: A New Initiative Addresses Needs for Drought Impacts Information. Bull. Amer. Meteor. Soc. doi:10.1175/BAMS-D-16-0306.1. (coauthors include Nolan Doesken, Henry Reges, Julian Turner)

PROJECT TITLE: Hydrometeorological and Water Resources Research

PRINCIPAL INVESTIGATOR: V. Chandrasekar, Christian Kummerow

RESEARCH TEAM: Lynn E Johnson, and Jungho Kim, CIRA Post-Doc, Colorado State University Department of Electrical and Computer Engineering

NOAA TECHNICAL CONTACT: Rob Cifelli (NOAA/OAR/ESRL/PSD/HMA)

FISCAL YEAR FUNDING: $98,529

PROJECT OBJECTIVES:

1--Hydrologic Research and Applications Development
Objective: Provide expert guidance and consultation on hydrologic applications for the HMA Team.
2--Forecast-Based Operations Optimization (FBO-O) Project:
Objective: Improve precipitation and river flow forecasting to maximize water capture.
3--Russian River Tributaries Water Budget Project:
Objective: Develop a hydrologic water budget model that estimates historical (unimpaired), current (impaired) and future flow conditions of selected Russian River tributaries.
4--San Francisco Bay Coastal Flooding Forecast Project

Objective: Demonstrate the interoperability of the USGS CoSMoS and NOAA DHM prediction models, and application of these for coastal flooding mitigation planning and prototyping for real-time flood warning operations.
5--Advanced Quantitative Precipitation Information (AQPI) Project
Objective: Develop AQPI system to provide high resolution (space and time) forecasts of extreme weather events for the 9-county San Francisco Bay area.

PROJECT ACCOMPLISHMENTS:

1--Hydrologic Research and Applications Development
- Assisted in the design, coordination and development of hydrological modeling and water resources management applications for regional demonstrations with the Hydrometeorological Testbed (HMT) and NWS National Water Center (NWC).
- Provided guidance and leadership in carrying forward the hydrological research agenda defined by the HMA Team, including publication in technical reports, peer-reviewed journals, and conferences.
- Supported the HMA Team Leader in identifying and tracking candidate (and past) tools, techniques and knowledge transfers to NWS and key stakeholders.

2--Forecast-Based Operations Optimization (FBO-O) Project

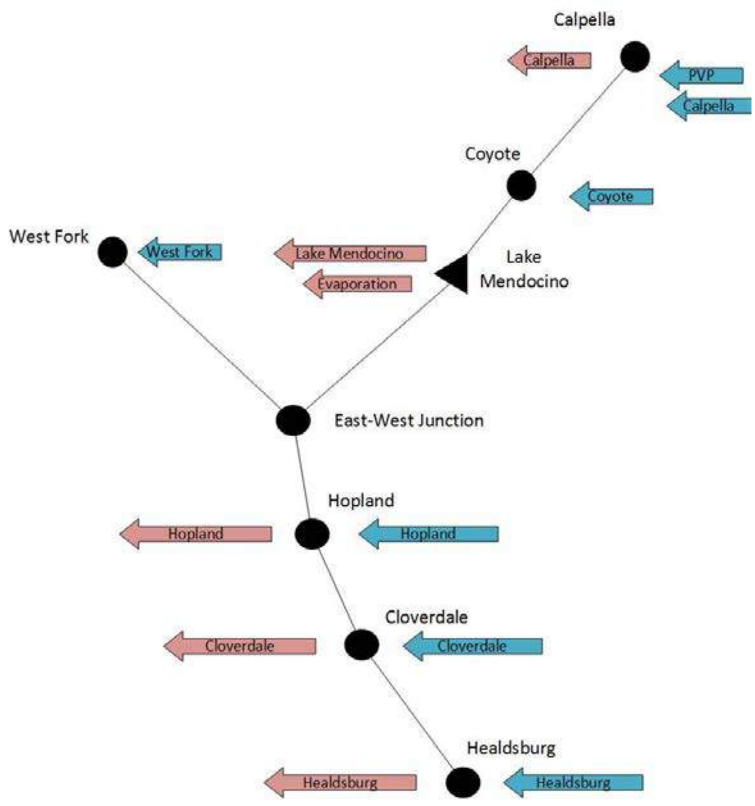


Figure 1. Network flow diagram of the monthly dynamic programming model based on the historical unimpaired flows.

--Work to date on this project has focused on setting up the framework for a dynamic programming optimization model for the Russian River basin using the generalized dynamic programming software package CSUDP developed at Colorado State University.

--Preliminary development of the CSUDP model has included programming of the logic for the Lake Mendocino operating rules, but underwent further refinement and adjustment through interaction with HEC and SCWA personnel.
--The next task is to link the CSUDP model with the HEC-WAT river basin simulation and analysis package, as well as incorporating SCWA water supply requirements.
--Presented highlights of project (oral) at ASCE EWRI Conference in Sacramento, CA in June 2017.

3--Russian River Tributaries Water Budget Project

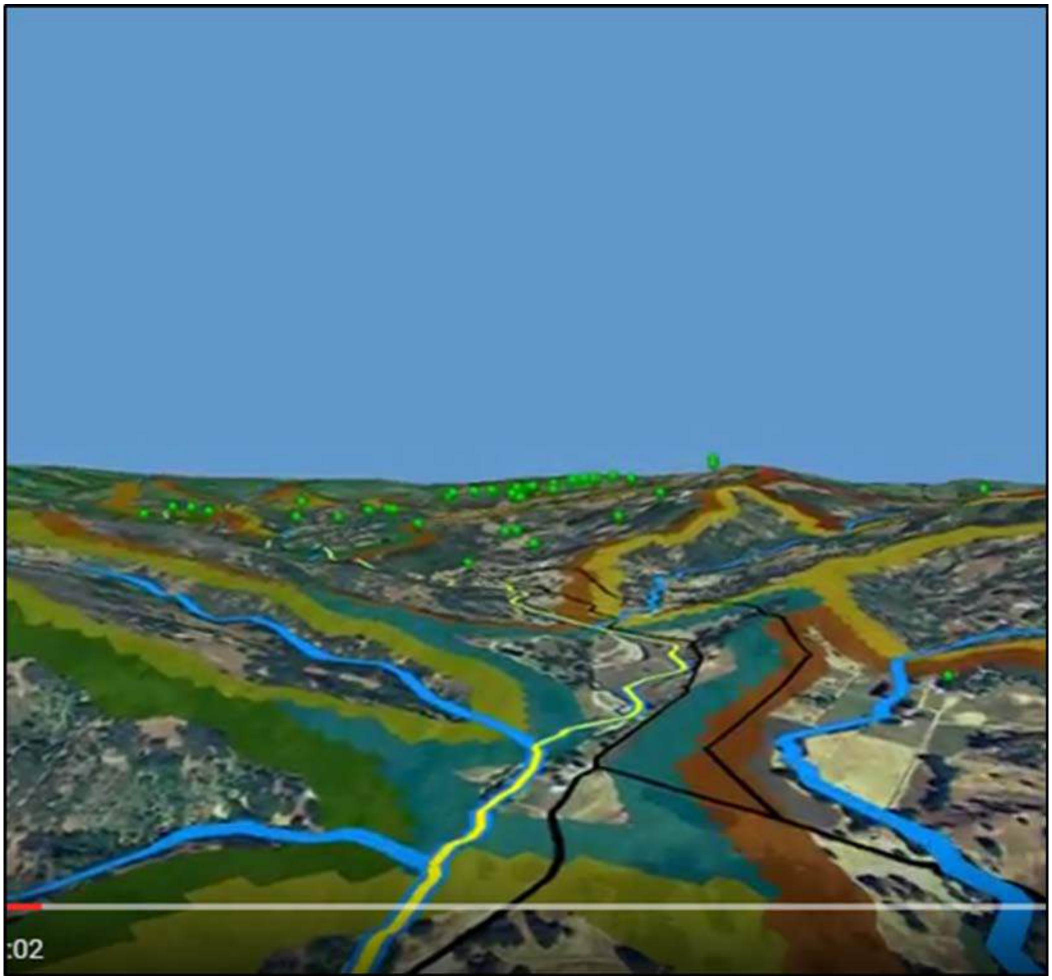


Figure 2. Watershed visualization of Feliz Creek fisheries habitat portrays flow levels along stream reaches.

--A hydrologic water budget model has been developed for the Feliz Creek watershed within the Russian River basin by combining the RDHM streamflow simulation model with the GIS-based Geo-MODSIM network streamflow model.
--A web-based interface has been developed for the dissemination of information to project stakeholders.

4--San Francisco Bay Coastal Flooding Forecast Project

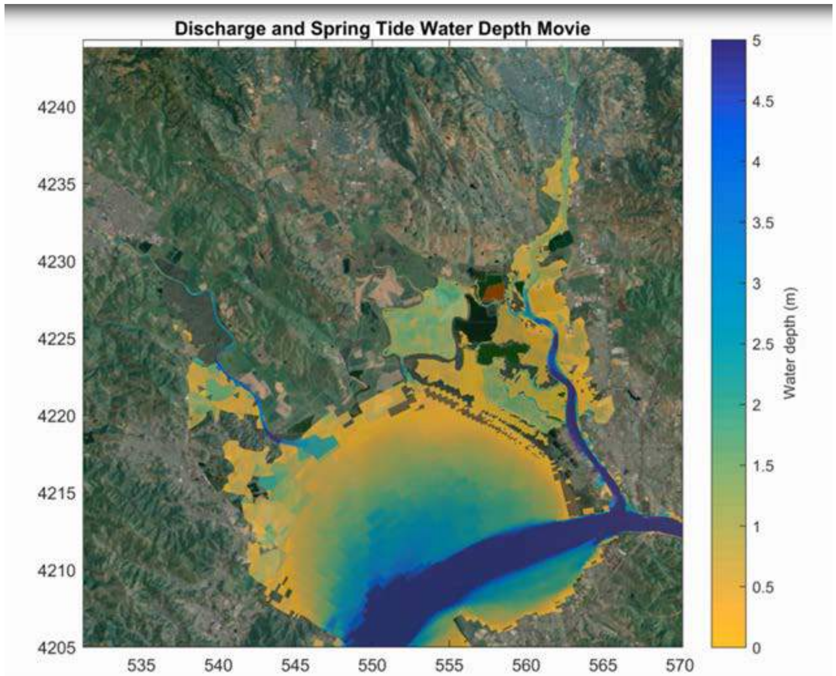


Figure 3. Coastal Flood Inundation Mapping for Napa River Estuary.

--Napa River fluvial runoff scenarios generated and provided as input to the CoSMoS coastal storm surge inundation model.
--CoSMoS simulation of SF Bay storm surge scenarios with Napa River fluvial inflows.
--Animation of coastal storm surge and river inflow flood inundation time series.
--Design of table-top exercise for coastal/fluvial flood simulation exercise to be held with California DWR and local emergency response agencies.
--Presented highlights (oral) of project at AMS98 Conference in Austin, TX in January 2018.

5) Advanced Quantitative Precipitation Information (AQPI) Project for SF Bay Area

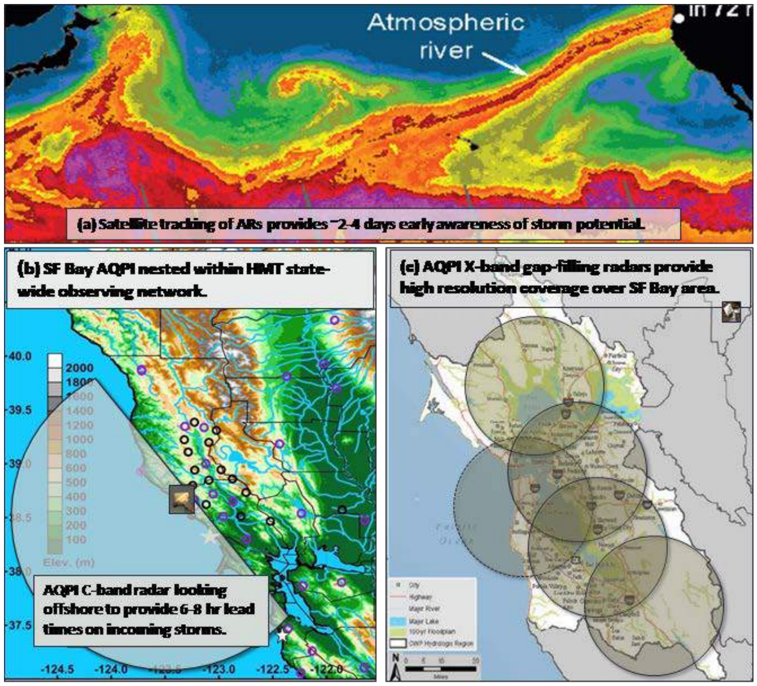


Figure 4. AQPI system involves (a) satellite detection and tracking of atmospheric river events over the Pacific Ocean, (b) C-band weather radar will look offshore at incoming storms, and (c) x-band radars will provide coverage over the SF Bay area.

--AQPI contract funded by the California Dept. Water Resources for $19M was finalized October 1, 2017.
--Now work has begun with engagement with SF Bay stakeholders to identify requirements for AQPI information products.
--Proposal to NOAA Natl Ocean Service IOOS was prepared on “San Francisco Bay Integrated Flood Forecasting Project” to obtain supplemental funding (3 yrs., $880,000) for AQPI project. Proposal not submitted due to short time frame to secure endorsement letters from NOS and NWS Office of Water Prediction.

Publications:

Finzi Hart, J., L. Johnson, L. Herdman, J. Kim, R. Martyr-Koller, R. Cifelli, P. Barnard, L. Erickson, and V. Chandrasekar, 2018: Assessment of Information Products for a Coupled Watershed–Coastal Flood Forecast Modeling System, *16th Symposium on the Coastal Environment,* Austin, TX, Amer. Meteor. Soc, 8.4. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper336220.html)

Halgren, J., L.E. Johnson, T. Coleman, and R. Cifelli, 2018: Assessment of Distributed Hydrological Model Products for Flash Flood Operations, *32nd Conference on Hydrology*, Austin, TX, Amer. Meteor. Soc.

Johnson, L. E., R. Cifelli and A. White, 2018: Benefits of an Advanced Quantitative Precipitation Information Systems. *Journ. Amer. Wat. Res. Assoc.* (JAWRA) Accepted.

Kim, J., L. E. Johnson, R. Cifelli, V. Chandrasekar, D. Gochis, J. L. McCreight, D. N. Yates, L.K. Read, T Flowers and B Cosgrove, 2017: Experiments with Interaction between the National Water Model and the Reservoir System Simulation Model: A Case Study of Russian River Basin, *Hydrology*, New Orleans, LA, Amer. Geophys. Union.

Kim, J., L. Herdman, L.E. Johnson, R. Martyr-Koller, R. Cifelli, P. Barnard, L. Erikson, J. Finzi Hart, and V. Chandrasekar, 2018: Integrated Flood Forecast Model (Hydro-CoSMoS) for San Francisco Bay, *32nd Conference on Hydrology*, Austin, TX, Amer. Meteor. Soc.

Viterbo, F., A.R. Thorstensen, R. Cifelli, M. Hughes, L.E. Johnson, D.J. Gochis, A.W. Wood, K. Nowak, and K. Dahm, 2017: National Water Model assessment for water management needs over the Western United States, *Hydrology*, New Orleans, LA, Amer. Geophys. Union.

Viterbo, F., A.R. Thorstensen, R. Cifelli, M. Hughes, L.E. Johnson, D.J. Gochis, A.W. Wood, K. Nowak, and K. Dahm, 2018: National Water Model Forecast Evaluation of Extreme Hydrometeorological Events over the Western United States, *32nd Conference on Hydrology*, Austin, TX, Amer. Meteor. Soc., 5.6. (Recorded Presentation available at:
https://ams.confex.com/ams/98Annual/webprogram/Paper334753.html)

PROJECT TITLE: Hydrometeorological and Water Resources Research

PRINCIPAL INVESTIGATOR(S) (CIRA/CSU PI): V. Chandrasekar

RESEARCH TEAM: Haonan Chen, Jungho Kim, Sounak Kumar Biswas

NOAA TECHNICAL CONTACT: Robert Cifelli, Physical Sciences Division, NOAA/Earth System Research Laboratory

NOAA RESEARCH TEAM: Robert Cifelli, Physical Sciences Division, NOAA/Earth System Research Laboratory

PROJECT OBJECTIVES:

1—Improving NEXRAD radar-based quantitative precipitation estimation (QPE) over complex terrain in the San Francisco Bay Area
2—Development of an integrated coastal flood forecasting model to demonstrate the interoperability of the USGS hydrodynamic model (CoSMoS) and the distributed hydrologic model for flood forecasting
3—Improvement of regulated streamflow forecasts by coupling National Water Model with a reservoir operation simulation model (HEC-ResSim)
4—Evaluation of the Mountain Mapper product generated by the Multi-radar Multi-sensor System (MRMS) over the Russian River Basin in California
5—Comparison of precipitation forecasts from NOAA's High Resolution Rapid Refresh (HRRR) model with polarimetric radar observations in the San Francisco Bay Area

PROJECT ACCOMPLISHMENTS:

<u>Project 1--Improving NEXRAD radar-based quantitative precipitation estimation (QPE) over complex terrain in the San Francisco Bay Area</u>

The San Francisco Bay Area is hosting two S-band WSR-88D radars, namely, KMUX and KDAX. However, in complex terrain like the Bay Area, it is still challenging to obtain an optimal rainfall algorithm for a given set of dual-polarization measurements. In addition, the accuracy of rain rate estimates is contingent on additional factors such as bright band contamination, vertical profile of reflectivity (VPR) correction, and partial beam blockages. This project aims to improve radar QPE for the Bay area using advanced dual-polarization rainfall methodologies. The benefit brought by the dual-polarization upgrade of operational radar network is assessed. This study also conducted a detailed comparison between the dual-polarization radar-derived rainfall products with various operational products from the NSSL's Multi-Radar/Multi-Sensor (MRMS) system. Quantitative evaluation of various rainfall products is achieved using rainfall measurements from a validation gauge network, which shows that the dual-polarization upgrade can produce better QPE.

Project 2--Development of an integrated coastal flood forecasting model to demonstrate the interoperability of the USGS hydrodynamic model (CoSMoS) and the distributed hydrologic model for flood forecasting

In this project, a prototype forecast system that couples watershed and oceanic models was developed to demonstrate capabilities for forecasting watershed and coastal flooding in this complex urban environment. This collaborative project involves linkage of the United States Geological Survey (USGS) Coastal Storm Modeling System (CoSMoS) with a National Weather Service (NWS) Distributed Hydrologic Models (DHM). A prototype for the Napa River basin and Napa Estuary was demonstrated at a "table-top exercise" held June 13, 2017 at California Department of Water Resources (CaDWR) office in Sacramento.

Project 3--Improvement of regulated streamflow forecasts by coupling National Water Model with a reservoir operation simulation model (HEC-ResSim)

This project intends to improve the representation of reservoir mass balance and storages in the operational NOAA National Water Model (NWM) through the implementation and evaluation of a new reservoir level data coupling scheme and new reservoir process representations. Primary accomplishments are as follows: (1) HEC-ResSim (reservoir operation system model) model developed by the USACE HEC and the Sonoma County Water Agency for the Russian River basin was reviewed. (2) natural flows and regulated flows from the NWM V.1.1 retrospective run in the Russian River basin was reviewed. (3) The HEC-ResSim model was modified to reflect NWM stream reaches and local inflows. (4) Lake Mendocino reservoir operations were simulated using NWM inflows, reservoir operations rules, and downstream main stem routing with NWM local inflows.

Project 4--Evaluation of the Mountain Mapper product generated by the Multi-radar Multi-sensor System (MRMS) over the Russian River Basin region in California.

The Mountain Mapper product from MRMS is used by the NWS California Nevada River Forecast Center (CNRFC) for forecast and flash flood warning in the western United States. In this project, the Mountain Mapper product is evaluated with the observations from rain gauges in the Russian River watershed operated by the NOAA Physical Science Division (PSD). These rain gauges are independent and are not used in the generation of the Mountain Mapper product. Precipitation data from the years 2015 to 2017 for the months of October to March are used for this project. For comparison purposes, the pixels corresponding to the PSD rain gauge locations are selected. Hourly rainfall accumulations as well as 24-hour or daily rainfall accumulations are compared. Statistical scores in terms of Normalized bias, Normalized Standard Error and Correlation Coefficient are computed. Probability distribution of low to high rainfall accumulations is also compared between selected rain gauges and Mountain Mapper product. Results indicate that the Mountain Mapper product shows better comparison with the rain gauges at low elevation than that of high elevations. This study also explored the accuracy of the Mountain Mapper product with respect to terrain, gauge locations, and storm characteristics.

Project 5--Comparison of precipitation forecasts from NOAA's High Resolution Rapid Refresh (HRRR) model with polarimetric radar observations in the San Francisco Bay Area

A continental-scale hourly updated assimilation and model forecast system, termed "Rapid Refresh" or "RAP" in short, has been developed in NOAA, in order to produce operational precipitation forecasts. Nowadays, the RAP system is one of the mainstream models running operationally in National Centers for Environmental Prediction (NCEP). As a complement of RAP, the 3km High-Resolution Rapid Refresh (HRRR) system is also updated hourly, but covering a smaller geographic domain. The HRRR system is primarily comprised of a numerical forecast model and an assimilation system to initialize that model. This project conducted a detailed comparison between precipitation forecasts from the HRRR model and various radar-based precipitation estimates. The performance of various rainfall products were evaluated using rainfall measurements from a gauge network. The performance of HRRR model-based precipitation forecasts as a function of forecast lead time was investigated, which is important for issuing flood watches and warnings as well as for a variety of water management activities in the Bay area.

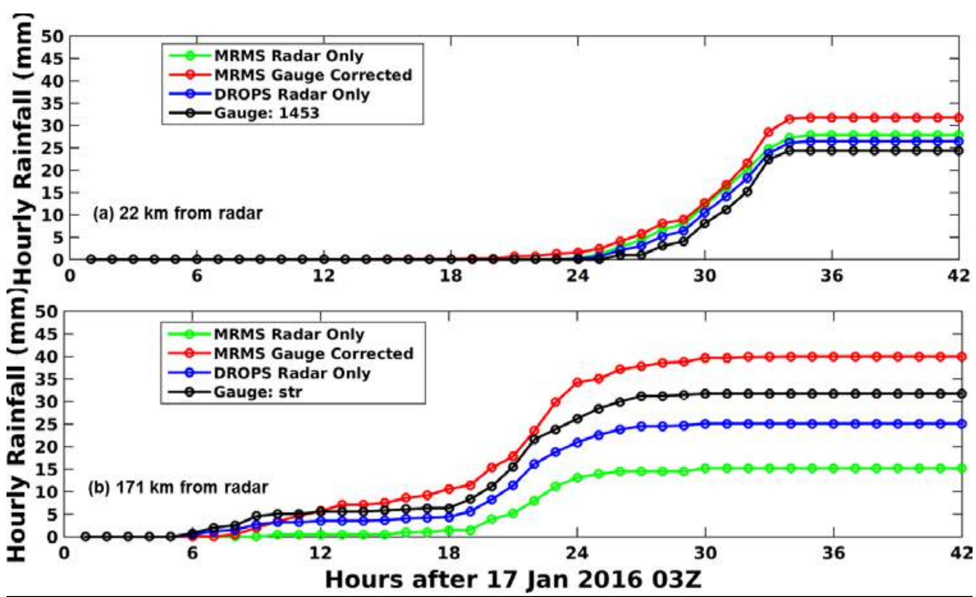


Figure 1. Radar derived precipitation estimates at two gauge locations (for Project 1).

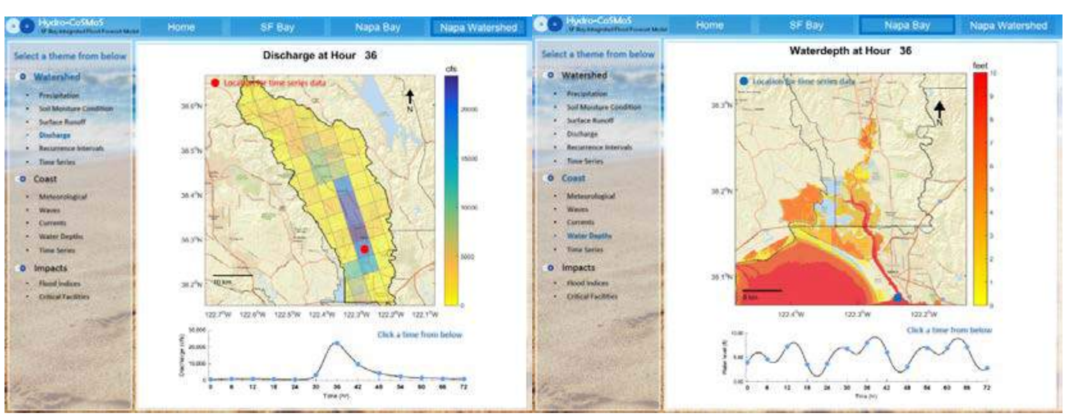


Figure 2. The integrated flood forecasting model with sample results: (a) example discharge in the watershed; (b) example water depth in the coast region (for Project 2).

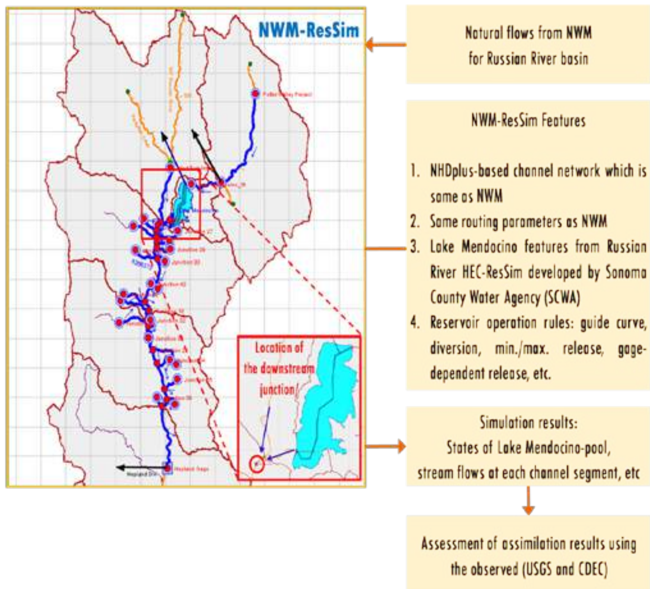


Figure 3. NWM-ResSim (a coupling scheme of National Water Model with HEC-ResSim) based on NHPplus channel network, NWM parameters for channel routing, and lake operations (for Project 3).

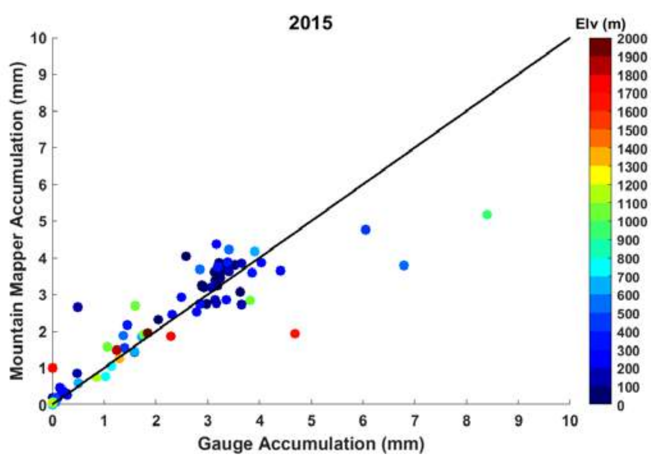


Figure 4. Scatter plot of Mountain Mapper accumulation vs Gauge accumulation based on elevation for year 2016 (for Project 4).

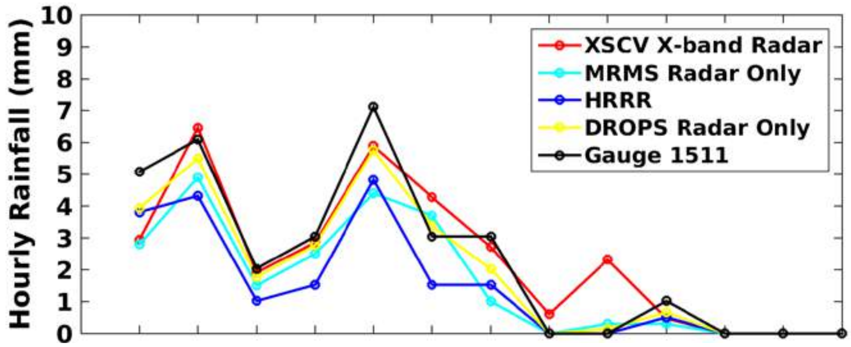


Figure 5. Radar and HRRR model-based rainfall products at sample gauge location (for Project 5).

Publications:

Biswas, S. K., Chandrasekar, V., Cifelli, R., Bytheway, J., 2018: Evaluation of the Mountain Mapper Product Generated by the Multi-Radar Multi-Sensor System (MRMS) over the Russian River Basin Region in California. American Meteorological Society 98th Annual Meeting, 32nd Conference on Hydrology. January, 2018, Austin, Texas, USA.

Chandrasekar, V., Chen, H., Petersen, W. A., Cifelli, R., 2017: High-Resolution Quantitative Precipitation Estimation and Nowcast Using Dual-Polarization Radar Network. 38th Conference on Radar Meteorology, Chicago, IL, August 28-September 1, 2017.

Chen, H., Chandrasekar, V., Cifelli, R., Xie, P., 2018: Improving Satellite-based Rainfall Retrievals by Incorporating High-Resolution Ground Radar Network Observations. the 98th AMS Annual Meeting, Austin, Texas, USA, Jan 7-11, 2018.

Cifelli, R., Chen, H., Chandrasekar, V., 2017: Comparison of Precipitation Forecasts from NOAA's High Resolution Rapid Refresh (HRRR) Model with Polarimetric Radar Observations in the San Francisco Bay Area. IEEE International Geoscience and Remote Sensing Symposium (IGARSS 2017), Fort Worth, Texas, July 23-28, 2017.

Cifelli, R., Chen, H., Chandrasekar, V., 2017: Improving Radar Quantitative Precipitation Estimation over Complex Terrain in the San Francisco Bay Area. American Geophysical Union Fall Meeting, New Orleans, Louisiana, Dec 11-15, 2017.

Cifelli, R., Chandrasekar, V., Chen, H., Johnson, L. E., 2018: High Resolution Radar Quantitative Precipitation Estimation in the San Francisco Bay Area: Rainfall Monitoring for the Urban Environment. J. Meteor. Soc. Japan, 96A, https://doi.org/10.2151/jmsj.2018-016.

Hart, J., Johnson, L., Herdmanm L., Kim, J., Martyr-Koller, R., Cifelli, R., Barnard, P., Erikson, L., Chandrasekar, V. 2018: Assessment of Information Products for a Coupled Watershed-Coastal Flood Forecast Modeling System. 2018 American Meteorological Society 98th Annual Meeting, 32nd Conference on Hydrology. January, 2018, Austin, Texas, USA.

Kim, J., L. Herdman, L.E. Johnson, T. Coleman, R. Cifelli, R. Martyr-Koller, J. Finzi-Hart, L. Erikson and P. Barnard 2017. San Francisco Bay Integrated Flood Forecasting Project - Summary Report. NOAA Technical Memorandum PSD-31X, NOAA Printing Office, Silver Spring, MD, 42

Kim, J., Johnson, L., Cifelli, R., Chandrasekar, V., Gochis, D., McCreight, J., Yates, D., Read, L., Flowers, T., and Cosgrove, B. 2017: Experiments with Interaction between the National Water Model and the Reservoir System Simulation Model: A Case Study of Russian River Basin. AGU Fall Meeting, New Orleans, LA, USA.

Kim, J., Chandrasekar, V., Cifelli, R., Johnson, L 2017: Coupling Fluvial and Oceanic Drivers in Flooding Forecasts for San Francisco Bay. 2017 UCOWR/NIWR Annual Conference “Water in a Changing Environment. June 2017, Fort Collins, CO, USA.

Kim, J., Herdmanm L., Cifelli, R., Barnard, P., Erikson, L., Johnson, L., Chandrasekar, V. 2017: Coupling Fluvial and Oceanic Drivers in Flooding Forecasts using Multi/Radar Multi/Sensor Data for San Francisco Bay. Weather Radar and Hydrology Symposium, April, 2017, Seoul, South Korea.

Kim, J., Herdmanm L., Johnson, L., Martyr-Koller, R., Cifelli, R., Barnard, P., Erikson, L., Hart, J., Chandrasekar, V. 2018: Integrated Flood Forecast Model (Hydro-CoSMoS) for San Francisco Bay. 2018 American Meteorological Society 98th Annual Meeting, 32nd Conference on Hydrology. January, 2018, Austin, Texas, USA.

Martyr-Koller, R., Kim, J. 2018: How Does Sea-Level-Rise Influence tides, Coastal Storms, and River Flow Interactions? Insights from an Urbanized Estuary. EGU General Assembly 2018.

DATA DISTRIBUTION

Research focusing on identifying effective and efficient methods of quickly distributing and displaying very large sets of environmental and model data using data networks, using web map services, data compression algorithms, and other techniques.

PROJECT TITLE: CIRA Research Collaborations with the NWS Meteorological Development Lab on Virtual Laboratory, Innovation Web Portal, Impacts Catalog and AWIPS II Projects

PROJECT TITLE: CIRA Research Collaborations with the NWS Meteorological Development Lab

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Kenneth Sperow, John Crockett, Michael Giebler, Jason Levit, Jason Burks, Dan Gilmore, David Miller, Michael Coulman, Geoff Wagner, Paul Roebber, David Clark

NOAA TECHNICAL CONTACT: Stephan Smith (NOAA/NWS/OSTI/MDL)

NOAA RESEARCH TEAM: NOAA/NWS/OSTI/MDL: Mamoudou Ba, Lingyan Xin, Matthew Davis, John Schattel, Michael Churma, Tom Filiaggi, Matthew Peroutka, David Ruth, Steve Olson, Jung-Sun Im, Kenneth Howard (NSSL), Ryan Solomon (NOAA/NWS/AWC), Michael Pavolonis (NOAA/NESDIS)

FISCAL YEAR FUNDING: $1,372,422

PROJECT OBJECTIVES:

Virtual Lab (VLab) https://vlab.ncep.noaa.gov
The NWS has created a service and IT framework that enables NOAA, in particular the NWS, and its partners to share ideas, collaborate, engage in software development, and conduct applied research from anywhere.
The project's objectives are the following:
1--Reduce the time and cost of transitions of NWS field innovations to enterprise operations;
2--Minimize redundancy and leverage complementary, yet physically separated, skill sets;
3--Forge scientific and technical solutions based on a broad, diverse consensus; and
4--Promote a NOAA/NWS culture based on collaboration and trust.

AWIPS II
AWIPS is an open source, service oriented architecture (SOA) that the National Weather Service uses for interrogation/display, forecast preparation and dissemination of weather data and products.
MDL and CIRA provide technical leadership to the AWIPS Program Office. Additionally, we develop new AWIPS applications and enhance existing applications. AWIPS II uses many technologies (JAVA, Camel, Hibernate, Python, JMS, JMX, etc.) that are new to the MDL and the NWS. In order for the MDL to be in a position to add value, they need people who have a working understanding of these technologies. Also MDL needs to be able to provide technical assistance in the form of software development expertise to assist in the shaping of the evolving AWIPS architecture.

AutoNowCaster (ANC)
Originally developed by the Research Applications Laboratory at the National Center for Atmospheric Research, ANC nowcasts convective initiation.
The project's objectives are the following:
1--Transition ANC to operations, and provide third-tier support for it in operations

2--Contribute to experiments designed to improve, better understand, or showcase ANC, and contribute to any associated publications or presentations
3--Where necessary or possible, correct or optimize ANC's software and streamline its configuration
4--Develop a more complete understanding of ANC's architecture and configuration, and document that understanding

Impacts Catalog / IRIS / iNWS / HazCollect Extended
The National Weather Service's Weather-Ready Nation Roadmap calls out the creation of a national Impacts Catalog, a system whereby the NWS can improve its Impact-based Decision Support Services to its core partners by providing those partners information regarding the impacts that relevant meteorological variables will have on those partners' operations.
The project's objectives are the following:
1--Provide leadership and technical expertise
2--Contribute to the engineering of the Impacts Catalog's software, including that of its framework system, IRIS, and its corollary systems, iNWS and HazCollectExtended

ProbSevere
Originally developed jointly by NOAA and the Cooperative Institute for Meteorological Satellite Studies at the University of Wisconsin in Madison, WI, ProbSevere nowcasts the probability that any given thunderstorm will produce severe weather.
The project's objectives are the following:
1--Provide leadership and technical expertise
2--Help transition ProbSevere to operations
3--Help facilitate the development of subject matter expertise in ProbSevere's scientific underpinnings for potential use in other NWS systems

Weather Information Statistical Post Processing System (WISPS)
WISPS is a new, community-based, statistical post-processing software system being designed by MDL. The scientific algorithms and workflow ideas of the current operational Model Output Statistics system, MOS-2000, will be the first statistical post-processing methods incorporated into WISPS. The WISPS Project is a 3-year effort to develop the framework that will take the inaugural version of WISPS to Technical Readiness Level 9 (i.e., operational implementation on NOAA's Weather and Climate Operational Supercomputing System, WCOSS) for some portion of the NWS' statistical postprocessing mission. The project will emphasize suitability for supercomputer operations, multiple statistical postprocessing methods, data formats that are self-describing and embrace widely-accepted standards, and software systems that are flexible, extensible, and shareable.
The project's objectives are the following:
1--Co-lead the development of WISPS with a team of experts provided by MDL.
2--Lead and oversee the process that gathers and documents requirements for WISPS.
3--Lead and oversee the investigation of useful pre-existing technologies that are suitable for WISPS.
4--Lead and oversee the design and development of data storage technologies and data modeling strategies for WISPS.

Statistical Post-processing of output from Numerical Weather Prediction (NWP) systems
It is difficult to overestimate the importance of StatPP guidance created by MDL. This includes output from MDL's signature Model Output Statistics (MOS) technique as well as the National Blend of Models (NBM). Together, they provide a set of next-generation foundational guidance products based on NWS and non-NWS model information. The techniques developed are intended to create an enduring process for the generation of guidance products for lead times extending from hours to two weeks.
The project's objectives are the following:
1--Work collaboratively and independently with MDL scientists to investigate and develop statistical post-processing and blending techniques for NBM.
2--Develop software and leverage existing algorithms that can derive variables needed to support the StatPP needs of the weather enterprise.
3--Develop, test, and document computer programs (primarily in Fortran and Python) and scripts necessary for data processing.

4--Work collaboratively with MDL scientists as they write documentation, create displays and maps, and prepare presentations.
5--Work collaboratively with MDL scientists who are implementing operational software on NOAA's various supercomputing platforms.

Extended Rip Current Prediction
The Climate Services Program of the NWS, in collaboration with the NWS Marine Program, engages user groups to investigate the NWS milestone "requirements for developing regional and local downscaling for extended rip current prediction to provide DSS for planning and management of coastal communities." Information gathered from the user groups, which includes coastal regions WFO forecasters, Marine and Climate Program Managers, National Park Rangers at beaches, lifeguards and the general public (for example, tourist, hotels, and beachgoers) indicates that there is a need to gather requirements for rip current prediction beyond 2 days. Users express the need for weather-to-climate scale outlooks (3-7 days and week 2) to support planning and preparedness. Additionally, investment is needed to develop skill, improve decision support services, and validate the current NOAA probabilistic rip current forecast model. CIRA has limited funding for this research with the following goals:
1--Identify components of a physical system that could provide a basis for an outlook for rip currents beyond the existing product suite;
2--Engage with partners to: 1) address user and stakeholder needs, and 2) formulate technical and scientific ideas for developing regional and local rip current outlooks.
3--Provide a report describing findings (draft and final report);
4--Provide monthly progress reports;
5--Present report to stakeholder at NWS Headquarters.

MDL Geospatial Data Services/Interactive Map Viewer
The Meteorological Development Laboratory (MDL) develops and implements techniques that generate products and services that enhance the value of NWS forecast products. Techniques emphasize information on forecast uncertainty that enhance decision making throughout the weather enterprise. Techniques also include data modeling, metadata, and web services that support NOAA's dissemination needs. Prototyping of promising techniques is done to identify those best for implementation. One area of focus includes geospatial data services that provide maximum flexibility for use by public customers and partners. Once developed and vigorously tested, these techniques are implemented in software on NWS operational platforms.

The project objects are:
1--Collaborate with MDL staff to develop and maintain systems to access quality operational and experimental NWS forecasts under two project areas: Modernized Product Generation and Delivery/Information Dissemination Program (IDP) and interactive Map Viewer.
2--Collaborate with MDL's staff to develop and visualize new products for the National Digital Forecast Database (NDFD) and the National Digital Guidance Database (NDGD).
3--Coordinate with NWS and non-NWS agencies on forecast guidance issues.

Local Climate Analysis Tool (LCAT)
LCAT is an online, interactive tool that will enable NWS forecasters and other registered users to conduct regional and local climate studies using station and reanalysis gridded data and various statistical techniques for climate analysis. LCAT will provides users with "best practice" climatological analysis techniques, saving time for the user and guaranteeing scientifically sound output. The analysis results could be used for Decision Support Services activities, to guide local decision makers in weather and climate-sensitive actions. LCAT augments current climate reference materials with information pertinent to the local/regional level as they apply to diverse variables appropriate to each locality. The LCAT studies allow users to supplement NOAA NWS climate forecasts with value-added information and increase expertise in impact of climate variability and change at local level. The LCAT outcomes will be also useful for guidance of governmental, economic, and business planning.
Project objectives include:
1--Provide direction and expertise to develop the existing LCAT program.

a----Establish a Science Advisory team to develop environmental intelligence for a range of applications, grid reanalysis capabilities and web interfaces.
2--Develop tools and services for LCAT.
a----Investigate RESTful API to expand the reach & utility LCAT provides.
b----Plan & implement 'sea ice' expansion to LCAT.
3--Develop new web interface for LCAT.

Web Services
The Meteorological Development Laboratory (MDL) continues to lead the way in data modeling and schema development for the International Civil Aviation Organization (ICAO) Weather eXchange Model for the US (IWXXM-US) and U.S Weather eXchange (USWX) model as well as the decoder and encoder software needed for the IWXXM-US and USWX products. MDL is also focused on the creation and modification of metadata records for these gridded and non-gridded weather products using ISO standards 19115-1, 19115-2 and 19139. However, it should be noted that the ISO standards are evolving and newly adopted changes are imminent. More recently, MDL has been brought on the OpenWIS program to provide technological development and enhancements to the OpenWIS web services software package.
Project objectives include:
1--Development of the aviation-focused gridded and non-gridded products metadata records.
2--Translation of these metadata records into any newly adopted ISO standards (e.g. ISO 19115-3).
3--Evaluation of discovery service options that can be used by IDP.
4--Software development for non-gridded product decoders and encoders for IDP.
5--Development and implementation of OpenWIS software improvements and enhancements in collaboration with partners, including NWS, FAA, DoD, NCAR and others.

PROJECT ACCOMPLISHMENTS:

VLab
Ken Sperow continues as the VLab technical lead, as well as the technical lead of the Virtual Lab Support Team (VLST). This team currently consists of 12 members to whom Ken provides support and training. Ken is not only the technical lead but also the deployment manager for VLab, overseeing and conducting all upgrades, security and feature updates within VLab. Under Ken Sperow and Stephan Smith's (the NOAA PI) leadership, the VLab continued to grow in importance and visibility within the NWS and NOAA again this year. The VLab is an essential and required component in the transition of research to operations for the NWS AWIPS. All AWIPS II development organizations must use VLab to check in, review, and verify AWIPS II code before it is included in the operational baseline.

VLDS Provides web-based services to help manage projects via issue tracking, source control sharing, code review, and continuous integration, VLab Development Services (VLDS) has grown by over 100% again this year to support over 1170 projects and 3610 developers. Multiple demos and consultations were made to development and operations groups covering VLab's capabilities and how they can be leveraged to address the group's needs. Additionally, staff worked with the NOAA CIO and Fisheries to allow the use of GitHub.com in combination with VLab. NOAA CIO sent out a policy update allowing NOAA to use GitHub.com.

Ken Sperow is the VLab expert, which includes providing guidance on Gerrit, Jenkins, Liferay, and Redmine, but also git expertise. He worked with NCEP EMC to transition all of the numerical modeling code to VLab, switching from svn to git. Ken provided in depth training sessions to NCEP EMC on use of git and VLab services.

Jason Burks and Ken Sperow continue to provide support to NOAA groups (OCLO, NASA SPoRT, and the Satellite group) developing reference material for use in the AWIPS Interactive Reference (AIR) tool, previously referred to as the Consolidate Reference Portlet. The AIR portlet enables users of VLab to easily enable material in VLab to be found by users in AWIPS looking for reference material on meteorological products. Jason Burks and Ken Sperow analyzed the performance of all of the components and worked to tune the system to operate more optimally. Jason implemented Google

Single Sign On within the Gerrit application of VLab. This makes it more convenient for users to log into the Gerrit system for code review.

Michael Giebler provided excellent support and development to the VLab this year. Additional enhancements were made to the NOAA Projects Registry. The Project Registry provides an interface for all of NOAA to enter project information into the VLab, enabling tracking of projects' transitions from research and development to operations, commercialization, and other uses. To date information for 560 projects have been entered into the repository. The NOAA Projects Registry is being considered as a replacement for the PDMS database which tracks additional metrics such as project milestones and project funding. Additional enhancements included the capture of project testbeds and validated mission requirements. Michael not only provided means for importing Ldap information into the VLCS portion of VLab, but also made additional improvements to VLCS including enhancements to the Subscription Manager portlet as well as sorting for the dynamic data list portlet.

Migration of VLCS to the most current Liferay software (Digital Experience - DXP) started in 2017 with full implementation in early 2018. This was a significant undertaking, requiring all VLab modifications (plugins, portlets, extensions, hooks, and themes) to be rewritten for Liferay DXP. Ken Sperow led the overall effort, but Jason Burks and Michael Giebler completed the heavy lifting and did an excellent job in migrating VLab's changes to DXP while continuing to support the production instance of DXP. Jason found and fixed two bugs within the Liferay code that VLab is built. The two bugs caused the VLab system to experience instability. One bug had a memory leak and other caused large amounts of CPU time to be used. Viable fixes were developed, tested and deployed leading to increased speed and stability of the VLCS system

Customer support and guidance is provided on the many facets of VLab. This includes setting up new communities and projects within VLab, import legacy data such as project management issues and code repositories, consultations with individuals and groups that provide guidance and assistance.

AWIPS II

Jason Burks and Ken Sperow Leading an effort to redesign the AWIPS II VLab Community. The current community has grown and is in need of restructuring to make it easier to find items. Jason participated in many software design reviews for the AWIPS II System.

Jason developed an AWIPS II Developer Training Course and is currently delivering the course to approximately 26 developers. The rest of the course will be completed in early 2018. Recordings from the training will be available on VLab.

Jason also developed several Dockerfiles to run the AWIPS architecture, including one that can be used to run the development environment. These docker images are being used in the AWIPS II developer training to facilitate fast spin-up of developer environment. He also created a fix for GOES-R incomplete frames issue in AWIPS II. The fix was delivered to version 18.1.1.

ANC

John Crockett continues to support the day-to-day running of ANC at the MDL, as well as maintain and update all of the documentation related to ANC. He modifies ANC applications in order to reduce overall CPU and disk usage, finding and fixing software bugs as needed.

John modified ANC so that it is able to ingest and process the new GOES East's (GOES 16's) data, and he made those changes available for inclusion in MRMS v11.5. He updated ANC's already existing boundary-related applications so that boundary processing can be done over a large domain, e.g., the CONUS, with fine resolution, e.g., 0.1 square degrees, and he also developed two new applications so that ANC can ingest and process surface boundary data published in CODSUS format by the Storm Prediction Center. He also reconfigured a test instance of ANC to use these new and updated applications so that nowcasts that incorporate boundary-related predictors in ANC could be saved for later comparison and analysis. In the past year, John updated the ANC sub-systems that implement the genetic algorithm used to auto-tune ANC's interest fields' weights.

Paul Roebber continued a research project to investigate how ANC's methodology for weighting its interest fields can be made adaptive, and John provided technical assistance as needed. Paul's research focused on applying more advanced data science techniques to the ANC likelihood fields. Using a newly developed version of evolutionary programming and data collected from June 11 through September 30, 2012, he was able to extend both the deterministic and probabilistic predictive capability of ANC. This was accomplished using a reduced set of likelihood fields as predictors (obtained via correlation analysis and physical reasoning) in combination with the ANC likelihood itself (using all the ANC likelihood predictors). The project's next steps include transforming this to an adaptive approach and calibrating the relative frequency of false alarms and hits to an acceptable operational balance.

John Crockett again assisted Taiwan's Central Weather Bureau (CWB) with its understanding and use of ANC. As part of this work, John traveled to Taipei, Taiwan, where he reconfigured the CWB's MDL-ANC system to ingest six meteorological variables from the CWB's version of the STMAS-WRF model, after which he configured the data flows needed to produce eight model-based predictors that are used by ANC's "mixed" regime. He experimented successfully with using Himawari-8 data as input to the CWB's MDL-ANC's version of NRL Monterey's cloud classification algorithm, and he successfully translated the results to ANC's MDV format. He answered any and all questions as they arose, and provided to the CWB's ANC team a list of recommendations for them to consider with respect to their use of ANC. Upon his return, John investigated and fixed problems remotely as the need arose.

From mid-May through mid-August, John trained a visitor from the CWB at the MDL in order to transfer knowledge regarding the entire ANC system. Starting from how to build, (re)configure, and run ANC through the scientific underpinnings of some of ANC's intermediate products, e.g., the predictor of vertical instability. The exchange was fruitfully two-way, as the trainee often posed questions that caused John Crockett to delve more deeply into ANC's software, one result of which was to determine that one application that had been being used was, in fact, unnecessary.

The paper previously submitted by John Crockett (with Mamoudou Ba, Lingyan Xin, and Stephan Smith) to *Weather and Forecasting*--"Evaluation of NCARs AutoNowCaster for Operational Application within the National Weather Service"--was published in vol. 32, no. 4 of that journal (10.1175/WAF-D-16-0173.1).

Impacts Catalog / IRIS / iNWS / HazCollect Extended
As Deputy Technical Lead of the project, John Crockett helped diagnose problems with the operational system and coordinated the mitigation efforts with Matthew Davis, the federal Technical Lead. John maintained the primary responsibility for the engineering and further development of the system's contact management application. He continued to take on responsibility for the (re-)engineering and further development of the system's data ingest applications. John began the re-engineering of the system's build, deployment, and startup processes in order to simplify them for NCO. As part of this, standardized the code to use Java 8, collected redundant code into common modules, standardized log file output, and implemented automatic connection retries to the IRIS database. As needed, he helped not only to coordinate and deploy operational system upgrades, but also to coordinate and effect operational system site failovers.

John participated in a three-day project Design and Development Conference at the NWS Training Center in Boulder, CO. He participated in, and sometimes led, weekly Development Team teleconferences and continued drafting project-wide, systems level documentation.

ProbSevere
As Project and Technical Lead of the project, John Crockett coordinated the creation and initial membership of the ProbSevere project within the VLab's Development Services, and coordinated the transfer of the ProbSevere software from the CIMSS GitLab to the VLab. While providing technical assistance, he also organized the transfer of ProbSevere training data to the MDL. He created and maintained overarching project design, development, and scheduling documentation then he presented the project's status at quarterly program reviews. Finally, John prepared a two-day set of project planning

and scheduling meetings at the Cooperative Institute for Mesoscale Meteorological Studies in Norman, OK. In Norman, he participated in two days of introductory ProbSevere Meetings.

WISPS

Jason Levit worked as the co-lead for the WISPS project through August of 2017, when he left CIRA for a position within the government as a branch chief at EMC. Unfortunately, because of budgetary uncertainties MDL decided not to fill this position at this time. Before leaving, Jason worked on the following for WISPS:

1--Continued development and continuous testing of data and metadata management software.
2--Continued development and integration of least squares regression software.
3--Provided support to NGGPS Working Group for Post-processing.
4--Submitted an abstract to AMS for oral presentation of an update for WISPS.

Statistical Post-processing of output from Numerical Weather Prediction (NWP) systems

Geoff Wagner conducted improvements to the Gridded MOS guidance system for the CONUS and Alaska domains to make improvements for public and private industry users and to meet the needs of the National Blend of Global models. To begin, he took the updated analysis software from the lead programmer and made changes to conform the software to the standards of NCEP Central Operations; and conducted additional testing and troubleshooting. Then, geospatial datasets were updated for CONUS and Alaska to cover an expanded grid area for analysis and packaged in MDL's TDLpack format. Fields included Unified Terrain, land/water definitions, and clipping masks. He added new stations to the analyses, most notably over 12,000 sites from the MADIS dataset were added to CONUS. Geoff made adjustments to analysis settings for most elements to improve the analysis and cover the new extents; including updating the radius scheme, generating new station pairs, changing the first guess field for many elements, and introducing additional dummy stations to leverage Direct Model Output (DMO) or Generalized Operator Equations (GOEs) where MOS forecasts are not available. Geoff also adjusted Alaska DMO and GOE processing to ingest higher resolution model data, thereby improving first guess fields. Finally, he conducted extensive reorganization of scripts to run groups of elements in parallel to offset the increase in runtimes for the larger grids.

Geoff Wagner completed updates to the Unified Terrain dataset to be shared between MDL gridded products (GMOS, EKDMOS, LAMP, NBM), AWIPS/GFE, and the URMA/RTMA analyses. This work included coordination with Brian Miretzky to test and decide on a suitable method to smooth the boundary between the terrain tiles provided by Alaska Region WFOs and the GMTED2010 topo data needed to fill the remainder of the full NDFD Alaska domain; the confirmed results were acceptable for URMA/RTMA group. Geoff collaborated with Raytheon/AWIPS group to develop a series of scripts to transition Unified Terrain fields for specific domains to AWIPS-suitable NetCDF files and delivered files for CONUS, Hawaii, and Puerto Rico (Alaska not included since WFO AWIPS was the source for the data). He packaged all Unified Terrain datasets for CONUS, Alaska, Puerto Rico, and Hawaii in GRIB2 and provided to RTMA/URMA team. Geoff also packaged all Unified Terrain datasets for CONUS, Alaska, Puerto Rico, and Hawaii in TDLpack and provided to MDL groups for gridded products.

Geoff Wagner performed general geospatial data support for National Blend of Models work which included generation of any required geospatial data for NBM use; primarily masks to clip Significant Wave Height model inputs and final output. He also began testing a new method to identify and match forecast features between model fields as a potential additional tool for later iterations of NBM. He began by writing prototype script to break an individual model forecast field down into distinct forecast features and began investigating objective ways to score and rank the similarity of features between two model fields.

Extended Rip Current Prediction

David Clark leads the feasibility study for extending 2-day rip current forecasts to 3-7 days, week to month timescales, and seasonal timescales. Specifically, David began by completing an assessment of the state of the operational NWS rip current model and the Dusek rip current model in development by NOS and NWS. He also investigated the timescales of the rip current models and model inputs, and their relevance to long term forecasts. He then reviewed scientific literature on the current state of wave forecasting (the principal input to rip current models) and ongoing developments for wave forecast models. David met with colleagues to discuss 7-14 day and seasonal wave forecasting, and wave prediction using dynamically downscaled model inputs. He collected, processed, and analyzed Wavewatch III validation data to assess forecast wave height errors in five regions of the U.S. coastline on 1-7 day timescales. Then, he propagated wave height input errors through the Dusek rip current model to find the resulting errors in rip current probability. During this time, he engaged with NOAA stakeholders to direct the course of this study, formulate ideas for rip forecast development, and discuss the details of NWS rip and nearshore wave prediction and finally delivered a progress report to stakeholders.

MDL Geospatial Data Services/Interactive Map Viewer
David Miller created a sliding histogram window feature for the 4-panel National Blend of Models (NBM) web map viewer. This histogram displays the color bin counts of various forecast weather elements and statistical output (such as bias) from image overlays covering NWS regions as well as for a specific WFO or RFC in each of the four display panels. This latter capability involved creating an image mask using a CWA or RFC shapefile which essentially cropped all parts of the image displayed on the NBM viewer outside that shapefile. While MapServer had this capability, David discovered that incorrect color counts were being returned for the histograms when using MapServer. Therefore, David had to create a scripts using the Geospatial Data Abstraction Library (GDAL) utilities so the correct color counts would be returned in addition to the cropped images. The histogram feature also displays relative frequency value of the color count bins when the user hovers over the histogram bars and allows a user to zoom in on those areas where counts are low, i.e. at the tails. This feature allows users to compare the different models' output in the viewer visually, especially the bias displays. As it impacted the new histogram feature, David corrected a problem in the NBM viewer code where the temperature color table object was being used for relative humidity instead.

David used his knowledge and expertise working with geospatial data transformation software on meteorological data to provide Adrienne Leptich of NWS New York WFO with detailed instructions on how to transform a NetCDF file created from AWIPS into a format that ArcGIS could render. Adrienne's goal was to create a Total Water Level grid based on the storm tide levels recorded from Extratropical Cyclone Sandy within AWIPS and see how ArcGIS did with creating an inundation map. Then she would compare the results from ArcGIS to the WFO's internal coastal flooding impacts catalog. The ultimate goal was to develop a visualization tool to assist with conveying inundation potential associated with extratropical cyclones. This was not only a WFO project, but also her Masters project. David's help paved the way for her to complete this project and also present it at the 2017 ESRI User Conference as well. Adrienne conveyed to David Ruth of MDL and Ross Dickman, the MIC at New York WFO: "I just wanted to send a note to express how grateful I am for the support he (David) has given me over the past few months. The field needs people like this. Hopefully this project will be something that can be implemented in the field in the future."

David provided an enhancement to the NBM web map viewer by allowing the user to drag and move the monthly statistics popup window of an element. Initially, the UI software that was being used to create this window would not allow for such capability due to event actions elsewhere preventing it. Upon investigation, David found this UI software was only being used for this window. As it was a fairly extensive library, he decided to use another UI software library to display this window and remove the present on from being loaded by the web browser. This other UI library was already being loaded (hence using less memory in the browser) and solved the move/drag issue with the popup window.

David Miller provided assistance to members of the MDL verification and NBM viewer development teams. He described how to georeference images and shapefiles for Alaska, Hawaii, and Puerto Rico as the verification team was unable to get the images to display in their verification system. As the MDL verification team would be adding River Forecast Centers' (RFC) QPF information to the verification database and also to the NBM viewer, David added RFC shapefiles to MapServer so the RFC outlines could be displayed. He assisted verification team member Dana Strom with his QPF Verification System (QPFVS) display viewer design using the mapping software library OpenLayers 4. Dana mentioned his thanks to David Ruth during a QPFVS display design review. David also provided assistance to team member Brad Diehl in determining which functions in the NBM viewer code could be moved into a common functions Javascript file. As many functions were either identical or very similar across region pages, any changes to those functions would have to be duplicated in each region's page. This made code maintenance difficult and also created the potential issue of changes being made to one region but missed in another. David singled out easy candidates and successfully created a common functions file, adding to it during the reporting period.

David investigated an issue reported by Jeremy Schultz at Boise WFO about one of their local web pages jumping to the place where it contains digital.weather.gov in an HTML5 iframe. This wasn't desirable for outside users since the headline was about the upcoming solar eclipse. Though the MDL team had not made any recent changes to digital.weather.gov, David was able to reproduce the problem. After a bit of research and testing, David passed along a solution where BOI's page would not initially load the digital.weather.gov page until its link was scrolled into view on the page by the user.

David updated the Alaska WFO shapefile used by the NBM Viewer when he discovered it was out of date. In addition, he fulfilled David Ruth's request to include the split portions of the Anchorage WFO (essentially west and east) as well as the combined Anchorage WFO shapefile when displayed in the histogram feature mentioned previously. David also corrected a zoom sync issue on the NBM Viewer where the image overlays were not displayed at the same zoom level as the map backgrounds at certain zoom settings.

David Miller successfully created four static prototype web mapping display pages for MDL's project to display Global Ensemble Forecast System fields from NCEP. First, David adapted code and image creation scripts obtained from NCAR's Ensemble display page. For the second prototype, he modified Dana Strom's QPFVS web mapping display as well as took advantage of a new version of MapServer which could display image overlays directly from GRIB files. The third prototype was a merging of the first two where image overlays for various weather elements were used but contours and wind barbs were still created by MapServer. Finally, David created the fourth prototype by adapting code from SPC's experimental HREF Ensemble Viewer and merging that with OpenLayers so the user can zoom and pan the image overlays as well as display contours and wind barbs, both of which were drawn within the browser by OpenLayers.

David made several enhancements and fixes to the operational NDFD Graphical Forecast display page, digital.weather.gov. He updated the page which provides the user with NDFD element definitions that contained the new Hazards HTML table. Then, David modified and updated the font file used for wind barbs so it correctly displayed Southern Hemisphere wind barbs on the NDFD Oceanic region web map display as well as added entries for Hawaii Tropical Cyclone threat grids. He made additions in the hazards table for new WWA entries so they would display in the viewer and updated the style to the revamped Warning, Watch, and Advisory (WWA) definitions web page as well as a few updated changes to the definitions page itself. David changed the point probe's popup window to use a previous version of NWS forecast click function as the new one would often time out with no response and also not work for Marine Zones. He also updated links in main digital.weather.gov pointing to MDL web addresses to point to ones that had been updated recently.

David Miller assumed responsibility for legacy NDFD Graphical Forecast page at graphical.weather.gov as MDL's Marc Saccucci took a post at NCEP's EMC (though Marc would still provide assistance). David was tested in this new capacity as MDL received an urgent NIDS trouble ticket where Excessive Heat Watches were being displayed on graphical.weather.gov instead of Areal Flood Watches. David found the error in a configuration file, tested a fix, and worked with NCO Support to apply the fix so the Areal Flood Watches (as well as a few other affected WWAs) displayed correctly in graphical.weather.gov.

In addition to support graphical.weather.gov, David Miller also assumed responsibility to provide support to NWS air quality displays and departments as necessary. The NWS HQ air quality contact recently asked if David could provide a color table for a new particle concentration scale they would be using soon. David provided several possibilities to them after examining the current ozone concentration scale and comparing to the new concentration scale.

At the request of David Ruth, David Miller provided fairly detailed explanation on retrieving NDFD graphics from NDFD's Web Map Service (WMS) to John Bender of Westrock, a paper and packaging company out of Georgia. David explained how John might be able to retrieve the GRIB files directly and import them into ArcGIS. John was trying to use the direct WMS tied in via ArcGIS, which unfortunately won't work due to how the NDFD's WMS is set up.

David Miller assisted MDL's Mike Allard in his efforts to create an Alaska page for Griddled LAMP. David had this same issue many years ago when creating NDFD images for data that crosses the dateline. David passed along his procedure for creating those images to Mike Allard.

LCAT
Michael Coulman focused on developing tools and services for LCAT. Specifically, Michael has provided direction and expertise to develop the existing LCAT program.
1--Ported LCAT from CentOS 6 to CentOS 7
a----Swapped out MySQL for MariaDB
b----Swapped out Apache for NGINX
c----Updated PHP to v. 5.4.16
d----Created patch for required source code changes
i------Created LCAT RPMs for both CentOS 6 & 7
ii------Created LCAT Docker containers for both CentOS 6 & 7
iii------Added LCAT test platform using Amazon Web Services Elastic Compute Cloud (AWS EC2)

Michael developed tools and services for LCAT, including planning and implementing a 'sea ice' expansion to LCAT.
1--Implemented CFS Reanalysis v. 1 data for Temperature, Ice thickness, & Ice cover
2--Implemented GUI selection of study area by bounding box or station
3--Implemented selection of all variants of OCNH data files
4--Planning expansion of CFS Reanalysis v. 1 variables
5--Planning addition of CFS Reanalysis v. 2 data

IDP Web Services
Unfortunately, funding for the IDP Web Services project ended at the end of August, 2017. Prior to defunding, Dan Gilmore modified metadata records based on FAA changes to PDD and necessary changes to IWXXM schema. He also created NDFD an OGC-compliant web service using timeSeriesML (TSML).

Publications:

Ba, Mamadou, L. Xin, J. Crockett, S. Smith, 2017: Evaluation of NCAR's AutoNowCaster for Operational Application within the National Weather Service. Wea. And Forecasting, **32**, 4, 1477 – 1490. https://doi.org/10.1175/WAF-D-16-0173.1

Sperow, K. and J. Burks, 2018: NOAA Virtual Lab (VLab Services*), 34th Conference on Environmental Information Processing Technologies,* Austin, TX, Amer. Meteor. Soc, 5A.5. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper337332.html)

PROJECT TITLE: CIRA Support to the JPSS Proving Ground and Risk Reduction Program: Integration of JPSS Experimental Products in AWIPS II through EPDT Code Sprints

PRINCIPAL INVESTIGATOR: Scott Longmore

RESEARCH TEAM: None

NOAA TECHNICAL CONTACT: Ed Mandel, NWS Systems Engineering Center Development Branch

NOAA RESEARCH TEAM: Debra Molenar, NOAA/NESDIS/STAR

FISCAL YEAR FUNDING: $0

PROJECT OBJECTIVE:

The project described answers two of the JPSS Proposal Initiatives, Innovation (#12), and Training (#13). The proposal described will allow JPSS to innovatively integrate its unique data into new and groundbreaking displays by leveraging EPDT's participants. The work performed will also broaden exposure of JPSS products to end-users by enabling their use in AWIPS II. These new and inventive displays will allow new investigations using JPSS products.

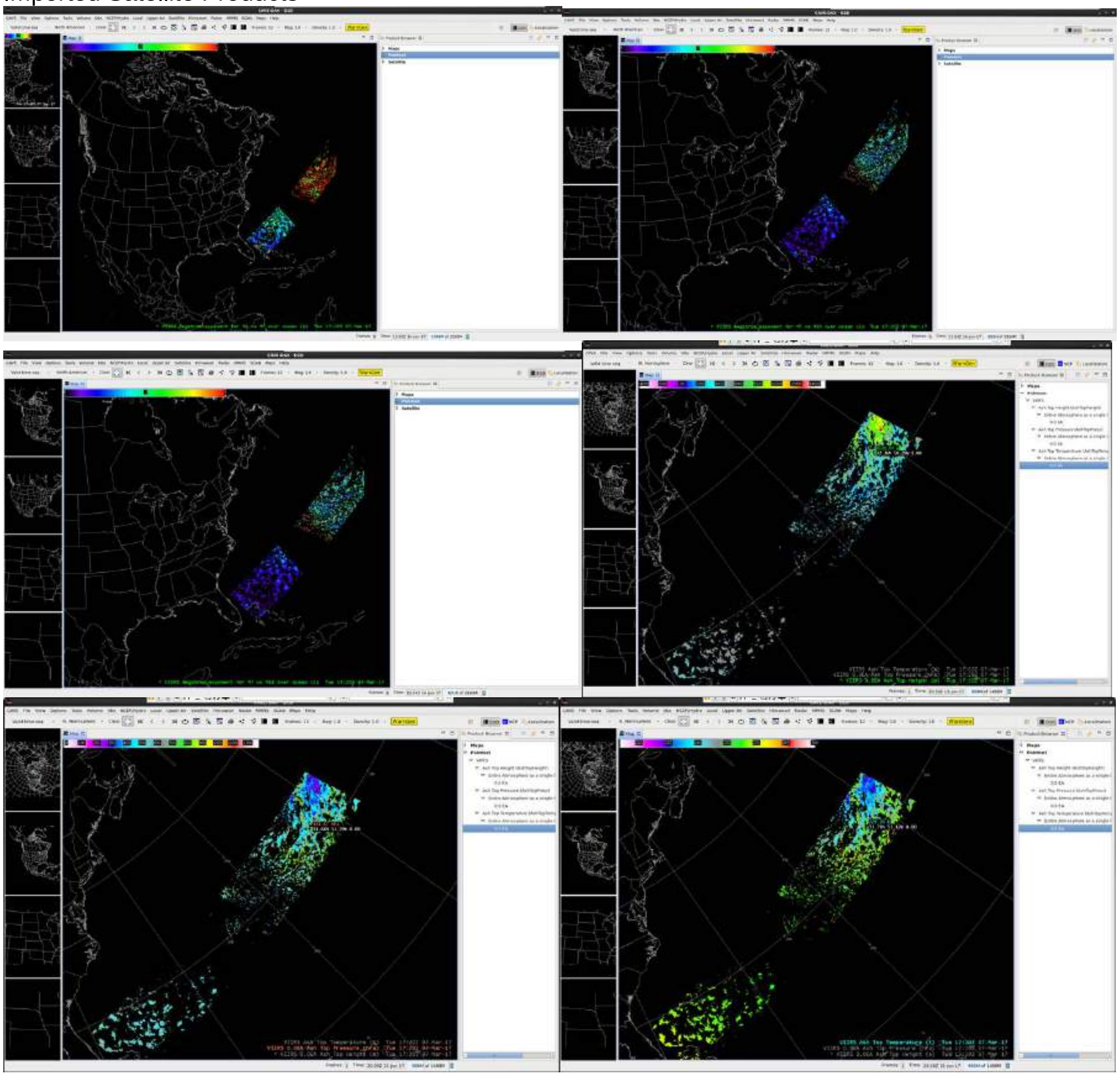
PROJECT ACCOMPLISHMENTS:

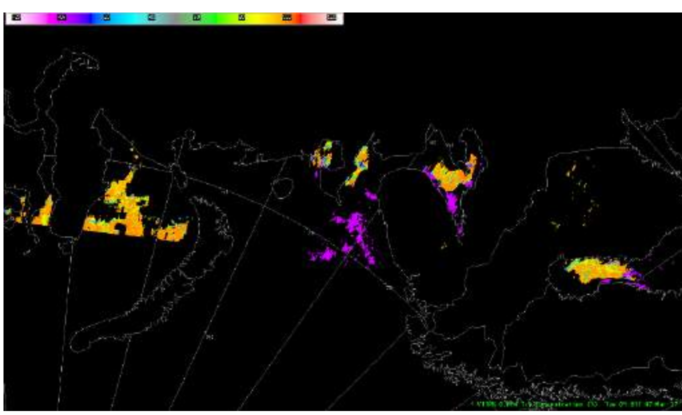
The Spring 2017 AWIPS II code sprint was held June 14-16, 2017 at CIRA/CSU in Fort Collins, Colorado. The purpose of the workshop was to develop ingest and display capabilities for new polar orbiting datasets that will be implemented in AWIPS II. Participants evaluated the AWIPS II Pointset and DBGeo plugins to determine the best implementation methodology for the products. It was determined that DBGeo needs additional optimization before it can be used in an operational environment. The NUCAPS display was also modified to distinguish between the operational and experimental NUCAPS products. Configuration files have been delivered to Lee Byerle for integration into the AWIPS II baseline.
The following participants attended:

Kevin McGrath (NASA/SPORT)
Evan Polster (CIRA/GSD)
Thao Pham (CIMMS)
Kevin Manross (CIRA/GSD)
Xianbao Jing (CIRA/GSD)
Matthew Comerford (NWS/SWPC)
Jorel Torres (CIRA/CSU)
Dan Bikos (CIRA/CSU)
Don Murray (CIRES - NOAA/ESRL/PSD)

The AWIPS II Spring 2017 code spring materials can be found on the Google Drive folder:
https://drive.google.com/open?id=0BwwuQpP7w6HZZHpoNE5sLUNkckk

Imported Satellite Products





Publications: None

PROJECT TITLE: EAR - Flow-following Finite-volume Icosahedral Model (FIM) Data Distribution Project

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Brian Jamison, Ning Wang, Ed Szoke

NOAA TECHNICAL CONTACT: Stanley Benjamin (OAR/ESRL/GSD)

NOAA RESEARCH TEAM: Jian-Wen Bao (OAR/ESRL/PSD), Mark Govett (OAR/ESRL/GSD/ATO)

FISCAL YEAR FUNDING (Total EAR): $4,834,735

PROJECT OBJECTIVES:

1--Generate graphics of output fields, creation and management of web sites for display of those graphics.
2--Create and manage graphics for public displays, including software for automatic real-time updates.

PROJECT ACCOMPLISHMENTS:

A web site for display of FIM model output https://fim.noaa.gov/FIM/ was updated and currently has 7 separate versions of FIM with up to 65 products available in 24 regions for perusal with 6-hourly forecasts going out to 14 days. Many regions use direct interpolation from the native icosahedral grid to a 0.125 degree global grid (approximately 14 km grid spacing).

A control and chemistry version of EMC's FV3 model were set up at GSD and those new graphics are available, as are graphics from the 0.25 degree EMC FV3.

A new set of FV3 graphics for regional domains is being created. They will be online for FV3 real time runs after they are examined and verified.

A new version of the FIM using HRRR physics was developed and graphics were added to the web page.

A coupled version of the FIM which produces subseasonal forecasts and weekly forecast anomalies was developed. New 5-panel graphics were created for this model and are available at https://fim.noaa.gov/FIMano/ .

Difference plots are generated and available, as are plots of forecast error. Cross sections are also being generated and are available at https://fim.noaa.gov/FIMxs/. Plot loops that show the progression of forecasts from model runs with the same valid time (dProg/dt) can be viewed at https://fim.noaa.gov/FIMdpdt/.

Workflows were set up to control all complementary FIM graphics, including differences, dProg/dt, GFS, and FV3, which speeds up output and helps prevent runaway processes.

A dual-monitor hallway display on the second floor of the David Skaggs Research Center (DSRC) shows FIM model graphics for public viewing. Currently, a montage loop of four output fields is displayed and updated regularly.

A large touchscreen kiosk monitor in the second floor atrium area currently has FIM graphic loops of 10-meter wind, precipitation and snowfall. New, larger, and more detailed images are created and updated specifically for the kiosk.

PROJECT TITLE: EAR – Forecast Impact and Quality Assessment

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Melissa Petty, Paul Hamer, Ken Fenton, Arlene Laing, Dana Mueller

NOAA TECHNICAL CONTACT: Michael Kraus (OAR/ESRL/GSD/EDS Chief)

NOAA RESEARCH TEAM: CIRES: Matt Wandishin, Geary Layne, Joan Hart, Michael Rabellino, Laura Melling

PROJECT OBJECTIVES:

The objectives of this project are to provide program management, scientific, and engineering support for the NOAA/OAR/ESRL/GSD/EDS/Forecast Impact and Quality Assessment Section (FIQAS), the primary activities of which are:
1--Scientific research and formal, impact-based product evaluations;
2--Technology development supporting product evaluation and decision support.

PROJECT ACCOMPLISHMENTS:

1--Scientific Research and Product Evaluation:
The primary sponsor for evaluation activities in 2017/18 was the FAA Aviation Weather Research Program (AWRP), for whom FIQAS serves as the Quality Assessment Product Development Team (QA PDT). The role of the QA PDT is to conduct independent evaluations of AWRP products as part of the formal AWRP Research to Operations process. In addition to evaluations performed for the FAA, in FIQAS also received funding in 2017/18 from GSD's Atmospheric Science for Renewable Energy (ASRE) Program to partner with Idaho National Laboratory (INL) and conduct an investigation into the use of weather forecast information for more effective transmission of electricity.

Accomplishments for evaluation activities include:
Completion of the Evaluation of the Icing Product Alaska - Diagnosis (IPA-D) Product:
IPA-D is a new diagnosis product for the detection of in-flight icing, developed by the In-flight Icing Product Development Team (IFI PDT) within NCAR's Research Applications Laboratory (RAL). The 2017/18 activities supporting the evaluation of IPA-D included completion of data processing and analysis of results and reporting of findings. In this assessment, IPA-D was compared to the baseline product currently used by the Alaskan Aviation Weather Unit (AAWU), the 0-hour forecast of the Forecast Icing Potential/Forecast Icing Severity (FIP/FIS) products. It was additionally compared to the IPA-Forecast (IPA-F) 2-hour short-term forecast. Overall findings were that IPA-D exhibited similar skill to the IPA-F 2-hour and FIP/FIS 0-hour algorithms-- while IPA-D's detection rate was lower compared to the other products, its false alarm rate was also lower, yielding similar overall skill. Results were presented to AWRP management, the IFI PDT, and the AAWU in August 2017, with a written report submitted later that month. Findings were presented to a Technical Review Panel (TRP) as input to their decision of whether IPA-D should continue to move forward in the transition process.

Completion of the Evaluation of the Global Graphical Turbulence Guidance (GTG-G) Product:
The GTG Global turbulence product, developed by NCAR's Turbulence PDT, is a global extension to the CONUS GTG forecast system. FIQAS performed an evaluation of GTG-G as part of its transition to operations. The 2017/18 activities supporting the evaluation of GTG-G included completion of assessment implementation, data collection and processing, analysis of results, and reporting of findings. Coordination with stakeholders-- which included the US and UK World Area Forecast Centers (WAFCs), AWRP, and the Turbulence PDT-- occurred throughout the evaluation. This evaluation was a focused assessment performing a comparison of GTG-G to the current World Area Forecast System (WAFS) turbulence forecast produced by the two WAFCs, using verification techniques and metrics aligned with those currently provided by the UK WAFC. Main findings were that GTG-G generally outperformed the

WAFS turbulence forecast. Performance improvements of GTG-G over WAFS varied by observation platform, which included in-situ Eddy Dissipation Rate observations and Pilot Reports. A more in-depth evaluation using additional flight-based verification techniques, with comparisons across GTG-G, WAFS turbulence, and GTG CONUS products, is planned for 2018/19.

Completion of the Evaluation of Ensemble Prediction of Oceanic Convective Hazards (EPOCH), Summer Period:
EPOCH is a global probabilistic forecast of oceanic convective hazards, developed by the Convective Weather (CW) PDT of NCAR/RAL. FIQAS is performing an assessment of EPOCH that spans two seasons of data: a summer period (June - Sept 2017) and a winter period (Dec 2017 - March 2018). The 2017/18 activities for the assessment resulted in completion of the evaluation for the summer period. Multiple sources of truth sets were investigated and used for the evaluation, including MRMS, European radar, various lightning sources, IMERG accumulated precipitation, and satellite-derived cloud top height and overshooting tops fields. Assessment activities for 2017/18 included code implementation, data collection for the assessment, data processing, analysis, and reporting of findings for the summer period. Assessment activities for the winter period will be completed later in 2018.

Preparation for Evaluation of Ceiling and Visibility (C&V) Analysis Products for Helicopter Emergency Medical Services (HEMS) Tool:
FAA AWRP has overseen the development of C&V Analysis and Forecast grids to be used as input to capabilities such as the Aviation Weather Center's (AWC) HEMS Tool. FIQAS is performing an evaluation of the Real Time Mesoscale Analysis (RTMA) and Localized Aviation Model Output Statistic (MOS) Program (LAMP) analysis products, as well as the National Ceiling and Visibility Analysis (NCVA) product currently incorporated into the HEMS Tool. Activities for 2017/18 supporting the evaluation included development of verification techniques, development and review of the verification plan, data collection for the cool season of the assessment period (Jan - Mar 2018), and preliminary implementation. The verification plan was presented to stakeholders for review and feedback. Stakeholders included AWC, AWRP, the NWS Model Development Laboratory (MDL), and NCEP's Environmental Modeling Center (EMC).

Completion of Evaluation of the High Resolution Rapid Refresh (HRRR) for Dynamic Transmission Line Ratings:
The power transmission community uses line ratings to determine the amount of current that can safely be passed through transmission lines. At present, line ratings are based on seasonal extreme weather values. FIQAS Partnered with Idaho National Laboratory (INL) to conduct an investigation of the gains in transmission line capacity that could be realized with dynamic line rating based on forecasts from the HRRR weather model. Activities included verification technique development, assessment implementation, data collection, processing, analysis of results, and reporting of findings. The evaluation involved an examination of the sensitivity of line ratings to certain weather variables, as well as an investigation of the use of the HRRR in determining line ratings. Main findings were that the transmission capacity could be potentially increased by up to 8% by leveraging short-term weather forecasts, without changes to existing infrastructure. Results were presented at a Dynamic Line Rating workshop hosted by INL, which included participants from a variety of organizations in the power transmission sector.

2--Technologies for Product Evaluation and Decision Support
Technology Development:
CIRA was responsible for application development in support of FIQAS activities, including FIQAS assessments as well as the development of technologies for external users. The primary sponsors for these activities in 2017/18 were FAA AWRP, NWS Aviation and Space Weather Services Branch (ASWSB), the NWS Office of Science and Technology Integration (OSTI), and OAR's Office of Weather and Air Quality.

Accomplishments include:
Verification and Requirements Monitoring Capability (VRMC):
The VRMC is a web-based application developed and maintained by FIQAS for AWRP. It provides ongoing verification metrics for operational AWRP turbulence and icing products as well as verification

capabilities to support FIQAS assessments performed as part of the operational transition process. Activities for 2017/18 included completion of assessment components to support the IPA-D and GTG-G assessments, and enhancements to the User Interface to support user export of the data backing the statistical plots. Upgrades to the monitoring component for the operational CONUS-based icing algorithms (Current/Forecast Icing Product; CIP/FIP) were also implemented.

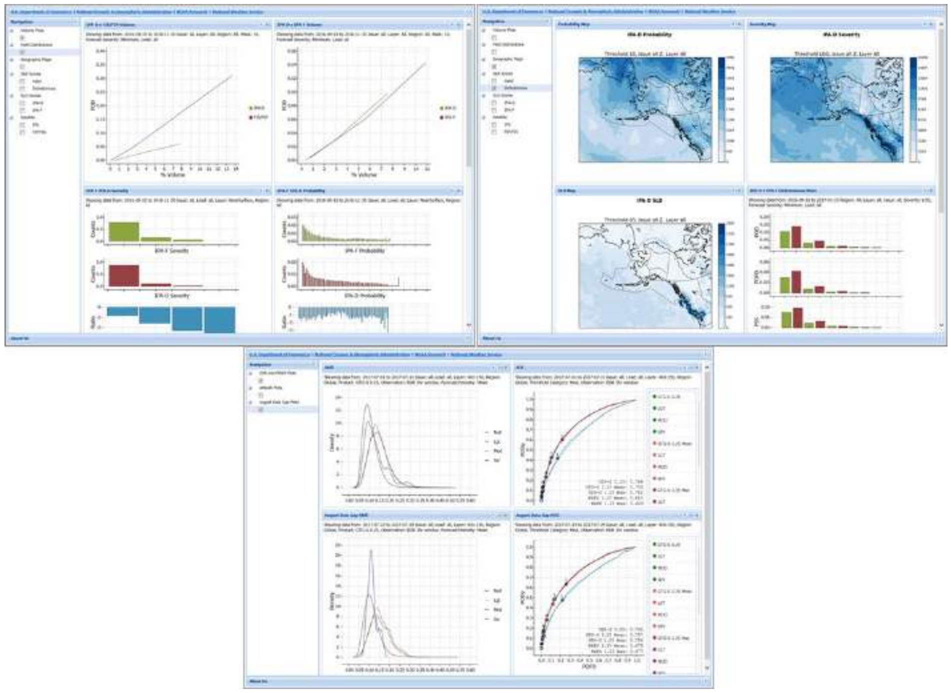


Figure 1. Multiple views of the VRMC IPA-D Assessment Component (top) and GTG-G Assessment Component (bottom).

CWSU Briefing and Verification Tool (CBVT):
NWS Center Weather Service Units (CWSUs) provide decision support services to regional FAA traffic management centers. The CWSU meteorologists provide forecasts to the FAA identifying weather events impactful to FAA operations, such as wind shifts necessitating a runway configuration change, or low cloud ceiling and visibility events. FIQAS was tasked with developing an automated verification tool for the NWS providing performance metrics for forecaster briefings for wind shift events and low cloud ceiling and visibility events. Capabilities to support verification of wind shift events were implemented in 2016/17, and technique development and implementation for ceiling and visibility events was completed in 2017/18. Operational hardening activities also occurred, in preparation for future possible implementation in NWS operations.

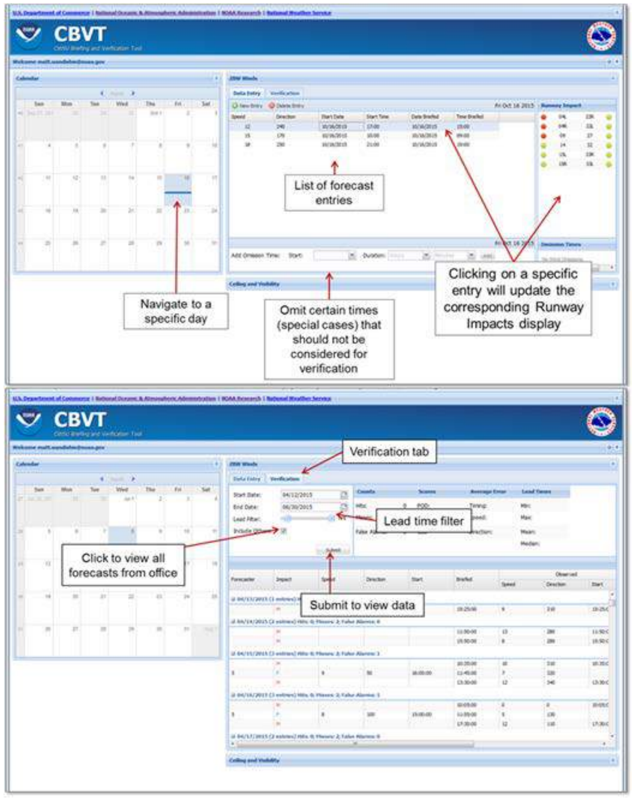


Figure 2. CBVT Briefing Entry (top) and Verification (bottom) pages.

TRACON (Terminal Radar Approach Control Facilities) Gate Forecast Verification Tool (TFVT): TRACON Approach and Departure gate forecasts are being produced by CWSUs to provide greater detail of convective occurrence with respect to TRACON activities. An automated, centralized version of this product has been developed by AWC to produce forecasts for a predefined set of CWSUs. FIQAS has developed an automated verification tool for the NWS to support ongoing monitoring of performance of AWC's automated forecast product. Activities for 2017/18 included coordination with AWC in preparation of the tool to incorporate forecaster modifications to the automated AWC forecast. Operational hardening activities also occurred, in preparation for future possible implementation in NWS operations.

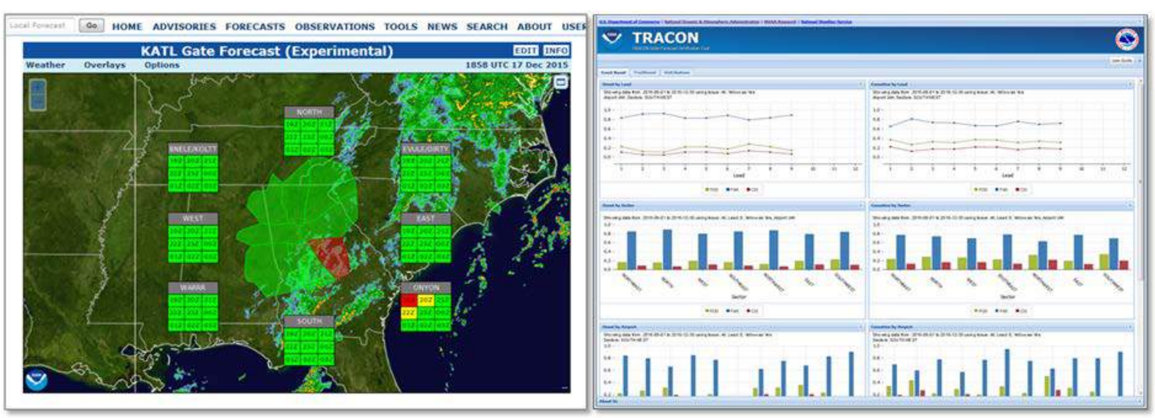


Figure 3. Example of TRACON Gate forecast (left) and TFVT web page (right).

Convective Weather Verification Service (CWVS):
The CWVS provides impact-based performance metrics for AWC's collaborative convective forecast product known as the Traffic Flow Management (TFM) Convective Forecast (TCF). Impact-based techniques measure TCF performance with respect to its ability to predict convection impactful to en route aviation operations. The tool was updated to include three variants of the product for inter-product comparison. This included updates both to the backend processing and the user interface. The tool is used by the NWS to regularly report TCF performance to stakeholders.

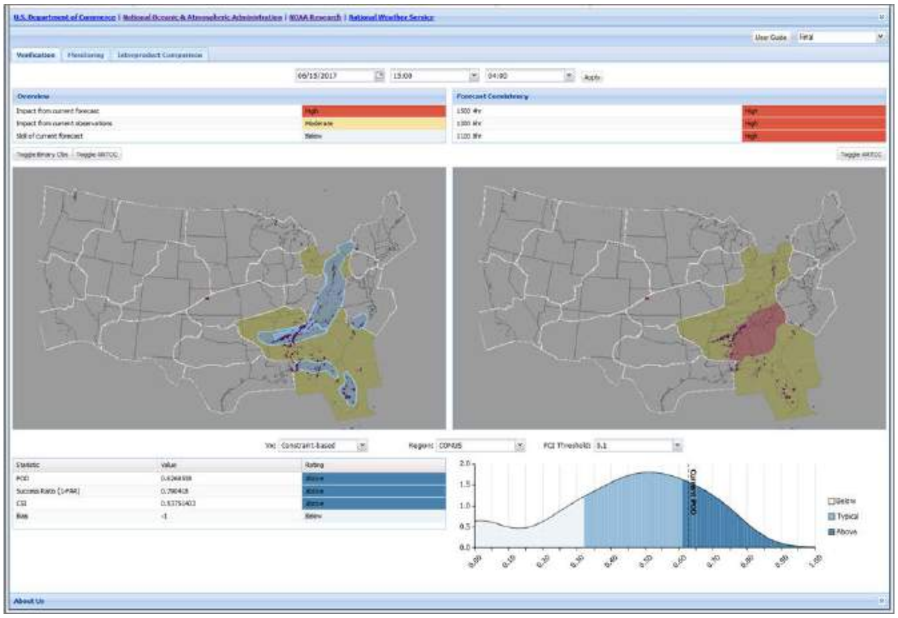


Figure 4. CWVS Main Page, including geographical comparisons of airspace constraints derived from TCF (left panel) and from observations (right panel).

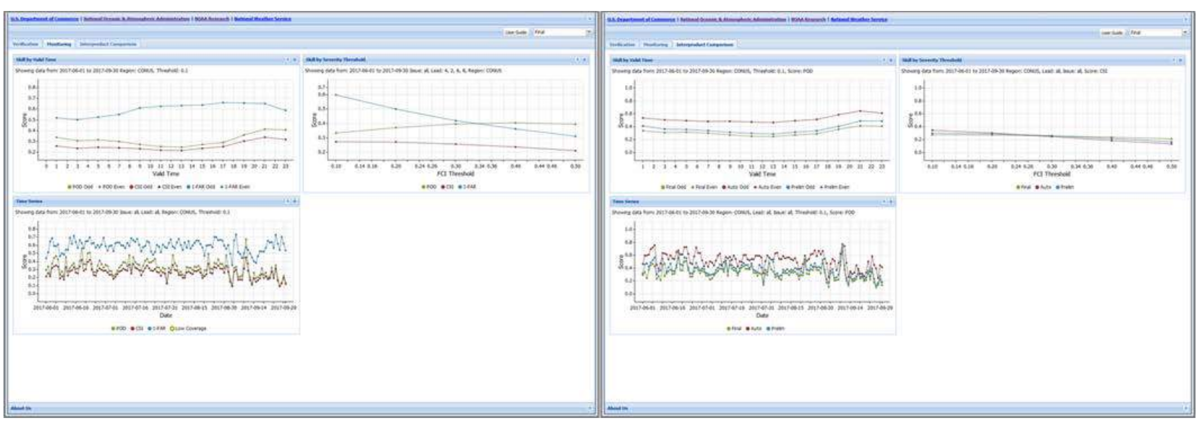


Figure 5. CWVS performance monitoring panels for a single TCF variant (left), and all three variants (right).

Integrated Support for Impacted air-Traffic Environments (INSITE):
INSITE is a web-based application developed for use in the NWS convective weather forecast process. It aligns with NWS Weather Ready Nation initiatives to provide Impact-based Decision Support Services by blending raw convective weather information with traffic data to highlight potential weather-related impacts to aviation operations. The targeted users for this tool include NWS forecasters-- AWC forecasters, National Aviation Meteorologists, and CWSU forecasters-- in support of their impact-based weather services to the FAA.

Activities for 2017/18 included a demonstration of INSITE Data Services, a capability to disseminate the constraint fields produced in INSITE in a format compatible with AWIPS. The demonstration included a collaboration with AWC's Aviation Weather Testbed (AWT), where constraint fields were disseminated to AWC, and AWC configured their Testbed AWIPS systems to display the constraints. Additionally, preparatory activities occurred to support transition of INSITE Data Services to NCEP's Weather and Climate Operational Supercomputer System (WCOSS), also a collaborative effort with AWC.

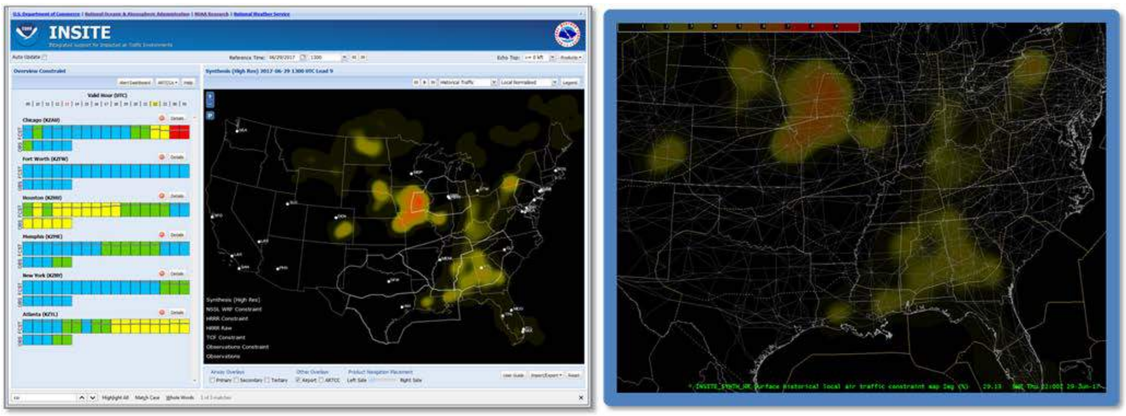


Figure 6. INSITE web application display of constraint fields (left), and same constraint field displayed in AWIPS.

PROJECT TITLE: EAR - Rapid Update Cycle (RUC) Rapid Refresh (RAP) and High-Resolution Rapid Refresh (HRRR) Models Project, Data Distribution and Visualization

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Brian Jamison, Ed Szoke

NOAA TECHNICAL CONTACT: Curtis Alexander (OAR/ESRL/GSD/ADB Chief)

NOAA RESEARCH TEAM: Stephen Weygandt (OAR/ESRL/GSD/ADB)

PROJECT OBJECTIVES:

Tasks for this project include:
--Creation and management of automated scripts that generate real-time graphics of output fields,
--Management of web sites for display of those graphics, and
--Management of graphics for hallway public displays.

PROJECT ACCOMPLISHMENTS:

Each of the web pages for RAP https://rapidrefresh.noaa.gov/RAP/, HRRR https://rapidrefresh.noaa.gov/hrrr/HRRR/ , and RUC https://ruc.noaa.gov/ruc/RUC/ have been refined with new developmental model versions, difference plots, better graphics and new fields.

The operational HRRR is run at The National Centers for Environmental Prediction (NCEP). GSD receives the data, and creates all graphics for GSD's HRRR web page, including all subdomains and soundings. The in-house HRRR was renamed HRRR Experimental (HRRRX) to distinguish it from the operational version.

Adjustments were made to HRRR to support extreme event forecasting including moving the Cleveland subdomain to southern California to aid fire forecasters. The total precipitation scale was changed to capture higher amounts and other details produced by hurricanes Harvey and Maria. The wind scale was updated to capture higher winds produced by hurricane Irma. The HRRR-Smoke model was revised to use initial output files which allow quicker graphics production. HRRRX and HRRR-Smoke differences were also created for evaluation.

The RAP version 4 and HRRR version 3 were released by The National Centers for Environmental Prediction (NCEP) and are received operationally at GSD. Graphics created from these models are displayed on GSD's RAP and HRRR web pages, along with difference plots for comparison.

GSD has developed a HRRR Ensemble forecast model (HRRRE) consisting of 9 members. The HRRRE is focused on severe storm forecasting. Graphics have been updated and improved for HRRRE and new products were added including CAPE, CIn, helicity, shear, precipitation and max hourly reflectivity.

A new HRRR model was developed with the domain centered over the Caribbean (https://rapidrefresh.noaa.gov/hrrr/CARIBBEAN) and features more coastline detail. This version was especially useful for forecasting and evaluation of hurricane Maria.

Many improvements and some new models were added to the graphics suites, including new subhourly versions of the HRRR Real-Time Mesoscale Analysis (RTMA). Graphics workflows were developed to handle all graphics production, which greatly improved speed and availability, and reduced the possibility of runaway processes that can hamper computer resources.

A dual-monitor hallway display on the second floor of the David Skaggs Research Center (DSRC) displays HRRR model graphics for public viewing. Currently, a montage loop of four output fields is regularly displayed and updated automatically.

A large touchscreen kiosk monitor in the second floor atrium area has been updated with new HRRR-Smoke near-surface smoke loops and an Alaska Sky Simulation product.

PROJECT TITLE: EAR – AWIPS I & AWIPS II Workstation Development

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: James Ramer, U Herb Grote, Evan Polster, Amenda Stanley, Yujun Guo, Kevin Manross, Nathan Hardin, Randy Pierce, Isidora Jankov

NOAA TECHNICAL CONTACT: Daniel Neitfield

NOAA RESEARCH TEAM: OAR/ESRL/GSD/EDS: Tracy Hansen, Thomas LeFebvre, Joseph Wakefield, Susan Williams, Vivian LeFebvre, Woody Roberts; CIRES: Chris Golden, Paul Schultz, Xiangbao Jing

PROJECT OBJECTIVES:

The ongoing objective of this program is to research and maintain AWIPS-related service solutions for researchers and operational field personnel using those solutions, as well as supporting the NWS in the future development and delivery of those solutions. AWIPS I is the original Advanced Weather Information Processing System used by the NWS Weather Forecast Offices (WFO) since the 1990's. AWIPS II (also known as A2) is the re-factored version of the AWIPS I system.

The long-term objective of this project is to develop a forecast workstation with advanced interactive display capabilities that includes inter-office and external collaboration, and integrates existing hazard services. The collaboration capability can improve forecast consistency between offices and permit better coordination with external partners.

PROJECT ACCOMPLISHMENTS:

AWIPS II Transition Task - Forecast Decision Support Environment - Ensemble Feature Migration
CIRA personnel furthered their effort on the "Ensemble Tool" project, in support of migrating Advanced Linux Processing System (ALPS) ensemble features into the AWIPS 2 Common AWIPS Visualization Environment (CAVE) workstation. The following was accomplished during the performance period:
-- Patches for general bug fixes;
-- Project support for task/issue tracking; source code management; code-review processes; continuous integration; personnel guidance and support.

AWIPS I and II Formatters Task
Funding for this project expired and was not renewed effective September 1, 2017.

AWIPS2 Hazard Services for Aviation
Continued progress toward initial operating capability was made in the past year regarding developing Hazard Services for Aviation functionality. This work is being conducted in order to develop a Common Aviation Platform within Hazard Services as a replacement for In-Flight products that the Meteorological Watch Offices (MWOs) currently produce in N-AWIPS and IC4D. Per the Statement of Work, the deliverables for the past year center on developing initial operating capability for the Convective SIGMET, International SIGMET, AIRMET, and Volcanic Ash Advisory for the three MWO offices (Alaska Aviation Weather Unit, Honolulu Weather Forecast Office, and the Aviation Weather Center).

The role of CIRA/GSD personnel in this project is to:
--Gather requirements based on feedback from the National Weather Service (NWS) partners (MWOs and NWS Headquarters).
--Conduct software design and code reviews with Raytheon and NWS partners.
--Develop AWIPS2 code and tools to demonstrate operational capability for the four aforementioned products.
--Demonstrate capability and gather feedback at relevant testbed experiments.

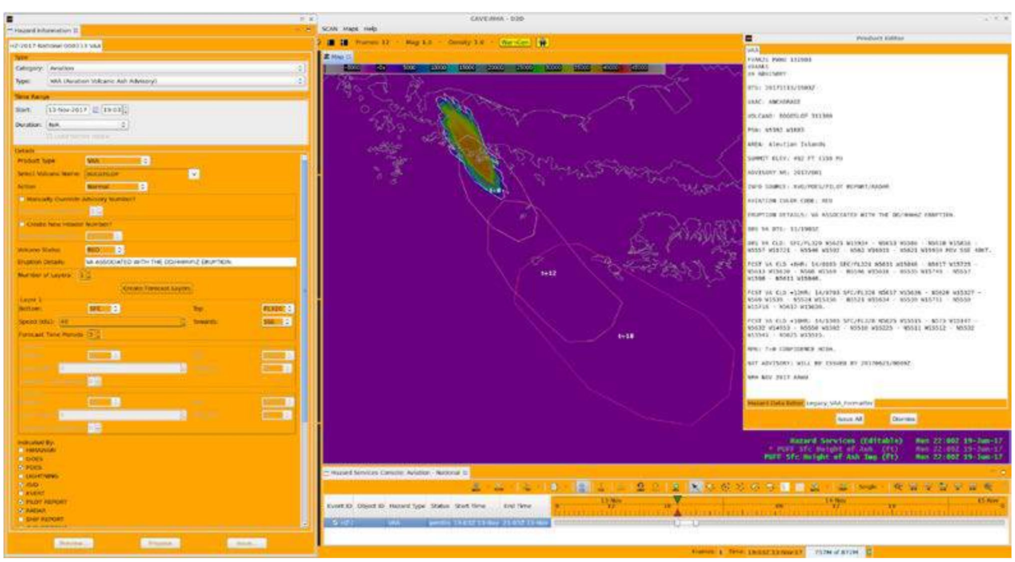


Figure 1. Sample Volcanic Ash Advisory using automated tool developed by CIRA/GSD.

A centerpiece of CIRA/GSD's development work for In-Flight capabilities is using partner input to develop automated tools that streamline the forecasting process. Figure 1 shows an example of this work, in which the user can generate a proposed Volcanic Ash Advisory using model input as a starting point. The tool also will automatically populate a variety of formatted products. This not only removes potential sources of human error, but also allows forecasters to quickly generate and issue products, thus allowing users to more quickly receive life-saving information.

The four products under development were demonstrated at the Arctic Testbed and Proving Ground in Anchorage, AK in July of 2017, and also at the Aviation Weather Testbed in Kansas City, MO in November of 2017. Partner and user feedback is fundamental is ensuring initial operating capability is accomplished. Additional feedback is scheduled at the Aviation Weather Testbed in August of 2018. Feedback gathered at this experiment will help further fine-tune development activities as this work is transitioned to operations.

AWIPS2 Hazard Services National Hurricane Center Storm Surge
In partnership with the National Hurricane Center's (NHC) Storm Surge Unit (SSU), CIRA/GSD personnel continued development work aimed at demonstrating the feasibility of generating, issuing, and disseminating hazardous information at the National Center level using Hazard Services.

This exploratory project investigated the benefits and challenges of replicating the existing workflow to generate the new Storm Surge Watch/Warning, which is currently constructed using the Graphical Forecast Editor (GFE). The high-resolution hazard is impeded by GFE's relatively coarse grid spacing (2.5 km). Hazard Services preserves the integrity of the underlying guidance (~100 meters). An example Storm Surge Warning can be seen in Figure 2.

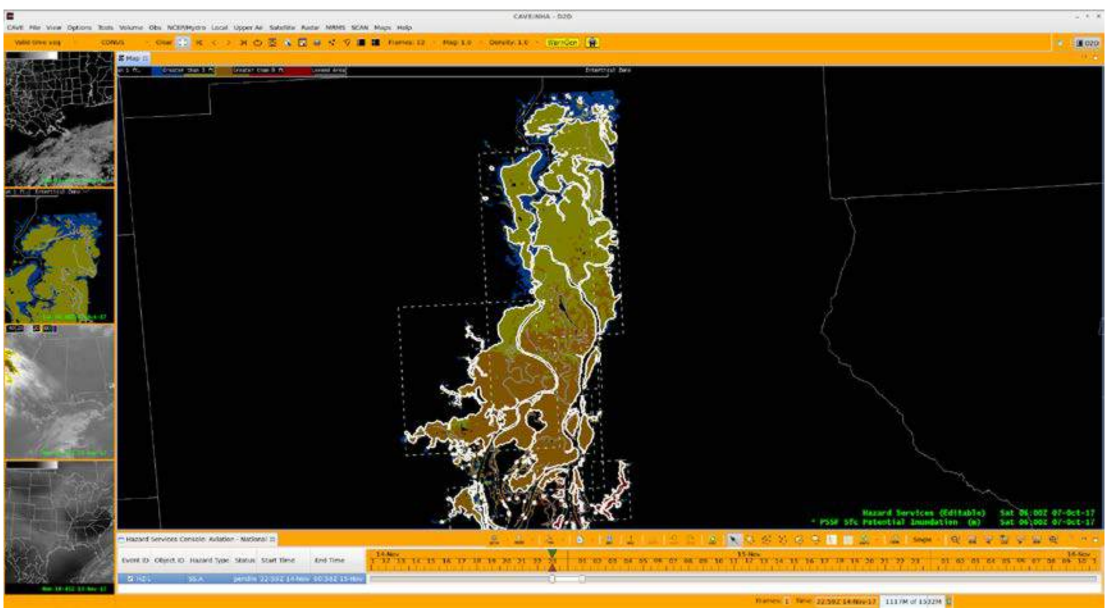


Figure 2. Hypothetical example of a Storm Surge Warning constructed in Hazard Services for Hurricane Nate, zoomed into Mobile Bay.

This output is created using a recommender that reads in probabilistic guidance created by SSU and suggests a first-guess proposed Storm Surge Watch/Warning. Using Hazard Services to create the watch/warning results in a more accurate hazard than one using the current workflow. The Hazard Services workflow also results in better consistency between operational products, thus improving communication between core partners. This new workflow was used to demonstrate operational feasibility during the landfall of Hurricane Nate in October of 2017.

AWIPS2 Hazard Services Initial Operating Capability
The initial field deployment of Hazard Services will be an instance focused on Hydrologic hazards called the Initial Operating Capability (IOC). A significant task for CIRA/GSD developers within the past year has been to support testing, documentation, and development of product formatting algorithms for the IOC. This work is funded by the National Weather Service. The role of CIRA/GSD in this tasking includes:
--Nearly sole responsibility for creating and maintaining documentation that explains how to customize Hazard Services to invoke functionality unique to an individual WFO.
--Along with partners in the Office of Hydrology and the Warning Decision Training Division, serving as an intermediary to help Raytheon developers understand and implement requirements expressed from forecasters in the field.
--Along with many NWS partners, participate in extensive operational testing of the IOC. This includes participating in formal testing at several NWS Regional Headquarters.
--Write and regularly perform formal regression tests focused on functional areas (as opposed to weather scenarios).
--Participate in the regular development process for Hazard Services IOC, almost exclusively python development focused on product formatting.

AWIPS2 Hazard Services Winter Weather Post-IOC
A significant task for CIRA/GSD developers within the past year has been to develop and implement the ability to recommend winter weather hazards in Hazard Services. This work is funded by the National Weather Service. GSD's role in this task include:
--Development of winter weather hazard type associated Metadata.
--Development and implementation of winter weather hazard criteria.
--Development and implementation of GFE grid based hazard recommender.
--Development of descriptor dictionary to hold qualifiers to be used in winter weather product headlines.
--Development of Zorro tool for hazard area mask to be integrated with recommended hazards.

The GFE Grid based hazard recommender takes existing hazard events as input. It reads relevant GFE weather element grids as described in the winter weather criteria, then uses the hazard criteria or logic to generate winter weather hazard events. The newly created events will be merged with existing hazard events. New and updated winter weather hazard events are the output from the Grid based recommender. Figure 3 illustrates how the grid based recommender fits in the console menu, how the hazard recommender dialogue looks like, and an example of the recommended event from running the hazard recommender. This work was completed by CIRA personnel, and is fundamental in incorporated winter weather hazard into the Hazard Services environment.

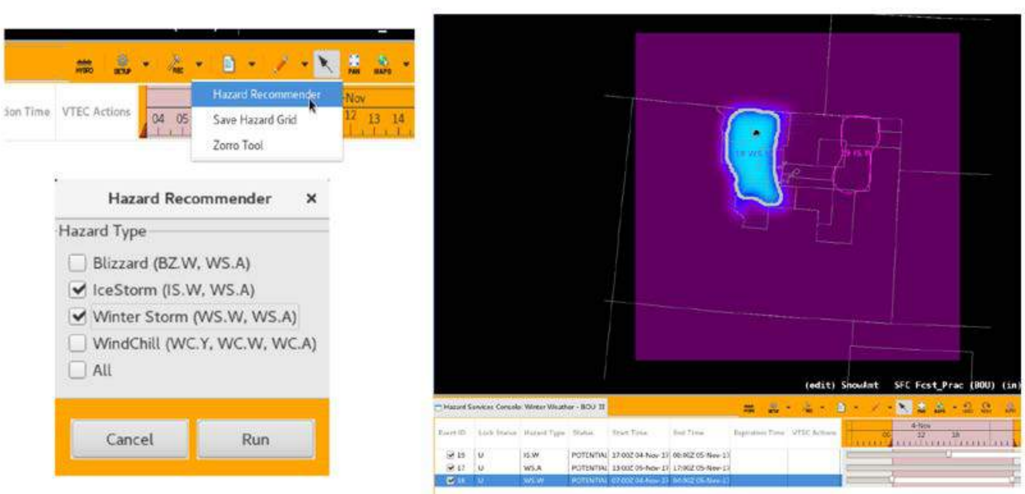


Figure 3. Grid based hazard recommender in the winter weather Hazard Services.

Probability of What (PHI into AWIPS2 Hazard Services)

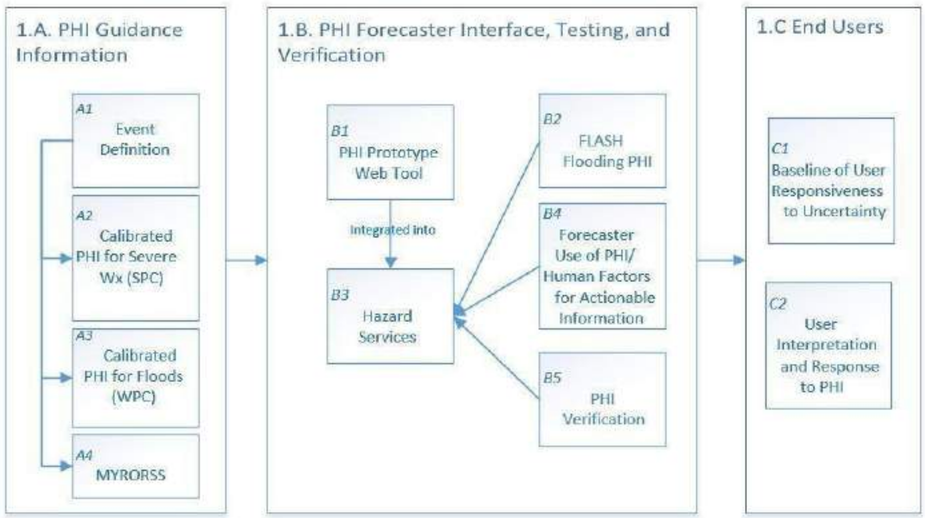


Figure 4. "Probability of What" concept map.

Forecasting a Continuum of Environmental Threats (FACETs) is a proposed next-generation severe weather watch and warning framework that is modern, flexible, and designed to communicate clear and simple hazardous weather information to serve the public. http://www.nssl.noaa.gov/projects/facets/ FACETs supports NOAA's Weather-Ready Nation initiative to build community resilience in the face of increasing vulnerability to extreme weather and water events.

This past year coincided with year three of three of the US Weather Research Program (USWRP) awarded funding to support the "Probability of What" - a collaborative effort between NSSL, WPC, SPC, GSD, University of Oklahoma, University of Akron. This Research to Operations effort is the first to implement the (FACETs) concept into the National Weather Service. A key aspect of implementing the various subtasks of this project to operations is leveraging the AWIPSII Hazard Services plugin as a conduit.

The specific focus of CIRA/GSD personnel has been task B3 (Figure 4): integrating the functionality of NSSL's Probabilistic Hazards Information (PHI) web prototype tool into Hazard Services. The "PHI into Hazard Services" work is the backbone of the FACETs initiative. The general PHI concept is that NWS forecasters, as well as objectively analyzed output, provide uncertainty information for impact weather in the form of a geospatial probabilistic grid that would be available to end users. The NSSL prototype functionality has several years of NWS forecaster and human factors expert input.

GSD is leveraging a branch of Hazard Services to implement the functionality of the NSSL prototype which would allow forecasters to analyze impact weather and produce PHI grids within AWIPS2.
During Year 3 of this task, we were able to accomplish the following:
--Joint Technology Transfer Initiative (JTTI) Funding was proposed and granted for FY18-20 to continue this development of Probabilistic Hazards Information into Hazard Services.
--This current task necessitates the use of AWIPS2 and also attempts to bridge the gap between the "watch" and the "warning" time and space scales. Currently National Centers (NC) are not using AWIPS2 in their operational workflow. Worked with WPC and SPC, primarily, to explore their needs for operations and the drawback of using AWIPS2. Attempting to assess how we can incorporate AWIPS2 into National Center workflow.
--Staff participated in Probability of What meetings in Norman, OK and the AMS Annual Meeting.
--Researchers presented on developments and findings at the AMS Annual Meeting and National Weather Association meetings.

--Testing was continued with forecasters and co-developers at the Hazardous Weather Testbed in Norman, OK.
--The human-algorithm-hybrid logic for forecaster interaction was revisited and refined.
--Staff implemented locking and ownership techniques for handling hazard events.
--Many refinements were made to the user-interface.
--Many improvements were made to data processing.

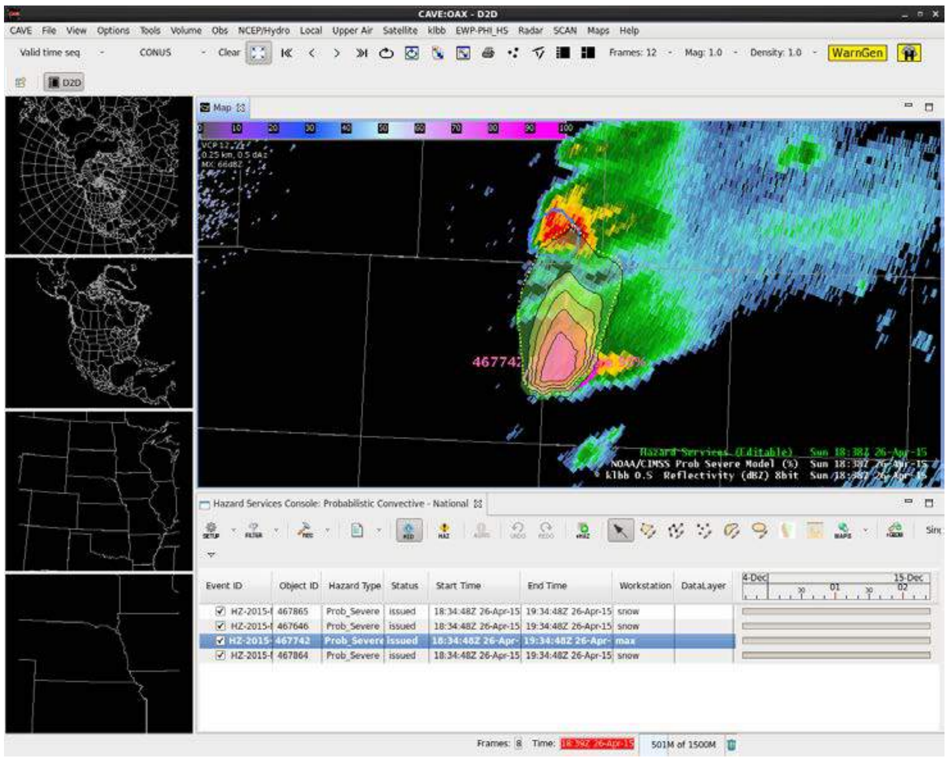


Figure 5. Illustration of upgrades to AWIPS2 Hazard Services to include first-guess fields and probabilistic information. (Left) Hazard Services “Hazard Event” created from CIMSS “ProbSevere” product as a first guess with preview swath displayed. (Right) Hazard Information Dialog box where user interacts with Hazard Event attributes such as object motion and probability trend. (Note: colors on right are correlated with the preview swath shown on the left)

Testing in the HWT is ongoing with our most mature system yet. The local forecaster who has participated in the “shakedown” week each of the past two years said “this system [in Year Three] is better, even on its worst day, than the system was last year on its best day”.

AWIPS II FxCAVE Project
The FxCAVE project is the name of the AWIPS II thin-client service/workstation in support of the National Interagency Fire Center. FxCAVE as a service solution is composed of the AWIPS II application (EDEX) servers and a pared-down version of the Common AWIPS Visualization Environment (CAVE) meteorological workstation, which has been rebranded to the Forecast eXperimental CAVE (FxCAVE). The FxCAVE mission includes providing:
--AWIPS II data services to remote and local users of FxCAVE.
--Maintenance and support of eleven (11) physical FxCAVE workstations at NIFC field offices.
--Maintenance of eight (8) FxCAVE virtual machine (VM) desktops workstations.
--Maintenance and support of research-regular production-based EDEX data servers.

Accomplishments:
--Initiated migration to AWIPS II 17.3.1.
--Supported Customers: These services include continual support of the National Interagency Fire Center (NIFC) and their satellite Geographic Area Coordination Center (GACC) offices, and the Chief Presidential Support Element in charge of the Executive Fleet at Andrews AFB.
--Authentication Server: Web-based HTTPS proxy server for secure remote connection to AWIPS II EDEX server.
--Product Data Monitor: Initial investigation into an improved product/data monitor. This web-based tool improves the ability for the support team to know when meteorological data is missing or late.

PROJECT TITLE: EAR - Meteorological Assimilation Data Ingest System (MADIS)

PRINCIPAL INVESTIGATORS: Sher Shranz, Bonny Strong

RESEARCH TEAM: Tom Kent, Leigh Cheatwood-Harris, Amenda Stanley, Glen Pankow

NOAA TECHNICAL CONTACT: Greg Pratt (OAR/ESRL/GSD/ATO)

NOAA RESEARCH TEAM: Leon Benjamin (CIRES), Gopa Padmanabhan (CIRES), Michael Vrencur (ACEINFO), Michael Leon (CIRES), Joanne Wade (CSG)

PROJECT OBJECTIVES:

MADIS is dedicated toward making value-added quality control data available for the purpose of improving weather forecasting. MADIS data helps to provide support for use in local weather warnings and products, data assimilation, numerical weather prediction, and the whole meteorological community in general. This is accomplished by partnerships with both federal and state government agencies, universities, airlines, private companies, and individual citizens.

Project Objectives:
--Continue to add new functionality and data sources to MADIS.
--Provide support to the user community.
--Continue to transition new and enhanced MADIS research to operations at NWS NCEP.

PROJECT ACCOMPLISHMENTS:

CIRA researchers continue working on a suite of research to operations tasks with varying degrees of completion. MADIS has or is in the process of integrating ASOS, IOOS, HAD, AFWS, CLARUS, SNOTEL, NGITWS, and NWS Data Delivery systems into MADIS IDP operations at NCO. New data providers were added, as well as an automated testing and implementation process to improve future release efficiency.

MADIS achieved Final Operating Capability (FOC) at the NWS National Centers for Environmental Prediction (NCEP) Central Operations (NCO) in Jan, 2015. The NCO facility is located in College Park, MD and is the center of operations with the new Integrated Dissemination Program (IDP) infrastructure for NOAA wide data dissemination. With a couple of new software releases in 2017 for the IDP, MADIS had some new high profile additions:

Automated Surface Observing System (ASOS) - A real-time connection for 1 minute ASOS data was established between the FAA operational data facilities and NWS-MADIS. This valuable and highly reliable data set is coveted by the WFOs for support in forecasting. MADIS is the only non-FAA entity getting this binary data in real time.

Integrated Ocean Observing System (IOOS) - MADIS began handling IOOS data with a new decoder developed in conjunction with some of the National Mesonet Program data providers. The MADIS decoder leveraged work done by the NMP partners. This included standardizing the CSV data and header formats so that future IOOS formatted data can be added quickly to the system due to the self-describing nature of the IOOS standard. Work is continuing through 2018 on the standards for the IOOS metadata for the NMP.

Clarus - A lot of work was done to integrate CLARUS into MADIS to transition Department of Transportation (DoT) data, metadata, and QC algorithms to operations at NCO. The CLARUS QC will be applied to data in addition to the MADIS QC. This work will continue through 2018.

Hydrometeorological Automated Data System (HADS) and Automated Flood Warning System (AFWS)- These very reliable and important hydro systems are being migrated into MADIS to achieve cost efficiencies and consolidation for NOAA. The HADS is a mission essential function that acquires, processes, and disseminates critical hydrological and meteorological data to the National Weather Service (NWS) Field Offices to protect life and property. The AFWS was added in 2013 to include ALERT, ALERT2, and IFLOWS hydro data into the HADS system. HADS produces tailored Standard Hydrometeorological Exchange Format (SHEF) text products for the River Forecast Centers (RFCs), Weather Forecast Offices (WFOs), and for National Centers for Environmental Prediction (NCEP) from GOES DCP data. HADS also processes the AFWS data to produce both SHEF encoded text products as well as Hydrologic Markup Language (HML) products. These products are disseminated through the NWS Telecommunications Gateway infrastructure. Additionally, HADS maintains a web site where GOES DCP meta-data and decoded data are made available to the NWS, HADS stakeholders, all levels of governments, as well as the general public. There has been a lot of progress to integrate these systems into MADIS and the complex nature of multiple databases, data clients, and web interfaces took a lot of effort and collaboration with many different groups within NWS.

NGITWS (NextGen IT Web Services) - The NextGen congressionally mandated requirement is to provide enhanced weather forecast information required for integration into an air traffic management system, using an Open Geospatial Consortium (OGC)-compliant net-centric weather information dissemination capability. This year efforts focused on the delivery of all Product Data Descriptions documents for all products listed in the NOAA/FAA Product Delivery List. The MADIS team created three OGC templates for this data delivery:
Web Coverage Service Data
Web Feature Service Data
Web Mapping Service Data

The MADIS team also worked on automating the creation of these PDD documents and to define a process that efficiently and cost effectively allows these documents to be maintained by NWS and incrementally improved as required. The definitions and processes the MADIS team created for PDD development can be used to handle all metadata creation and improvements and will be briefed to NWSHQ later this year.

NWS DATA DELIVERY - MADIS worked with Raytheon to reconfigure the MADIS Data Provider Agent for release to run at NCO. While waiting for NCO operational VMs to become available in, these DPA capabilities are hosted at GSD on MADIS systems that both NWS AWIPS test and operational systems can access.

PROJECT TITLE: EAR - Citizen Weather Observer Program (CWOP)

PRINCIPAL INVESTIGATORS: Sher Shranz, Bonny Strong

RESEARCH TEAM: Leigh Cheatwood-Harris and Tom Kent

NOAA TECHNICAL CONTACT: Greg Pratt (OAR/ESRL/GSD/ATO)

NOAA RESEARCH TEAM: Leon Benjamin (CIRES), Gopa Padmanabhan (CIRES), Michael Vrencur (ACEINFO)

PROJECT OBJECTIVES:

The Citizen Weather Observer Program (CWOP) database is maintained by the MADIS Staff. CIRA researchers administer the CWOP through database updates (adding new stations, removing stations no longer reporting data, and maintaining accurate site location information), interactions with CWOP members (answering questions and discussing suggestions, and investigating data ingest and dissemination issues), refreshing related web pages and documents, verifying that station listings and other reference data required by MADIS are complete and accurate, and confirming that routine backups of database and related files are performed. The CWOP is a public-private partnership with three main goals:
1--Collect weather data contributed by citizens
2--Make these data available for weather services and homeland security
3--Provide feedback to the data contributors so that they have the tools to check and improve their data quality.

There are currently 18935 active stations (citizen and ham radio operators) out of a total of 36973 stations in the CWOP database. CWOP members send their weather data via internet alone or internet-wireless combination to the findU (http://www.findu.com) server and then the data are sent from the findU server to the NOAA MADIS ingest server every five minutes. The data undergo quality checking and then are made available to users thru the MADIS distribution servers. CWOP is in the process of transitioning to operations within the NCO IDP MADIS system.

PROJECT ACCOMPLISHMENTS:

This past year the process of transitioning CWOP to run inside MADIS continued. More database procedures were enhanced through development and implementation of scripts to auto-correct missing and typographical errors in new member sign-up requests, and through introduction of automated site geographic location and elevation verification algorithms. Interactions occurred with users via email regarding site setup, data transmission issues, quality control and general meteorology. Various web-based documents and databases were updated on a daily, weekly or monthly basis depending on content, and statistics and other informational graphics revised and posted. These improvements were all done with the intent to mesh with the current and future work on standardization of MADIS metadata.

In 2017, there were approximately 1727 stations added to the database. Approximately 1100 revisions were made to site metadata. Adjustments include latitude, longitude and elevation changes in response to site moves, refinement of site location, and site status change (active to inactive, vice-versa).

PROJECT TITLE: EAR - Research Collaborations with Information and Technology Services

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Leslie Ewy, Patrick Hildreth, Robert Lipschutz, Richard Ryan, Amenda Stanley, and Jennifer Valdez

NOAA TECHNICAL CONTACT: Scott Nahman (OAR/ESRL/GSD/ITS Chief)

PROJECT OBJECTIVES:

CIRA researchers in the GSD Information and Technology Services (ITS) group develop and maintain systems that acquire, process, store, and distribute global meteorological data in support of weather analysis, modeling, and information systems projects throughout GSD. The CIRA team collaborates with ITS systems, networking and security specialists and numerous GSD researchers to provide reliable services that meet project requirements. The team works to improve and extend ITS data handling and monitoring capabilities to increase reliability, better utilize GSD resources, and provide additional services.

CIRA ITS staff also participate as team members of several projects within other GSD branches.

In addition, a CIRA researcher in the group serves as the ESRL/GSD Webmaster, implementing and maintaining a wide range of web-based services for the Division.

PROJECT ACCOMPLISHMENTS:

--GSD Central Facility - At the start of the year, the CIRA team completed the transition to operations for a virtual, six-host Central Facility Data (CFD) system. This multi-year effort enabled the decommissioning of the legacy physical cluster that had been in production since 2009. As shown in Figure 1, CFD is the keystone for a collection of systems running data acquisition, transport, processing, storage and distribution functions configured and managed by the CIRA ITS team. By the end of the year, these systems were handling over 4 TB of meteorological data daily, delivered to users within GSD and on the NOAA R&D High Performance Computing Systems (RDHPCS). Selected GSD data sets continued to be distributed to NOAA and non-NOAA users and collaborators through FTP, Local Data Manager (LDM) and web services established and maintained by the CIRA ITS team.

The CIRA team established ingest, processing and transport for a number of real-time data sets within the Central Facility and RDHPCS environments, including:
--GOES-16 imagery (selected ABI channels and sectors), GLM (lightning), and Level-2 (derived) products,
--VIIRS Fire and Smoke/Dust/Aerosol products from NESDIS, which involved establishing access methods for the NESDIS Product Distribution and Access (PDA) system,
--GFS NEMSIO initial conditions files from NCEP, various GDAS and GFS files from NCEP supporting the Hurricane Forecast Improvement Project (HFIP),
--Alaskan Weather Camera files,
--Alaskan Lightning data,
--Lightning data from Vaisala Corp.,
--Ceiling and Visibility data from AWC,
--RAPv4 and HRRRv3 parallel (pre-operational) data,
--FV3GFS data from NCEP/EMC and Theia,
--HRRR Ensemble (HRRRE) distribution to NCEP/WPC,
--CFS files from NCEP supporting the Subseasonal Forecast Experiment (SubX),
--RTMA_RU from NCEP,
--Numerous GSD model graphics files from jet and theia to the GSD web server, and
--Automatic dependent surveillance — contract (ADS-C) aircraft observations for GSD’s AMDAR data set.

To improve system monitoring and trend analysis for the Central Facility, CIRA staff established new methods for gathering and reporting data flow metrics on the CFD system. This capability will enable the group to monitor trends in data latency, data download rate, and LDM data queue heath.

The CIRA team also worked with ITS Systems Administrators to transition GSD's enterprise storage system for real-time data from its legacy platform to a new scalable storage system that will meet GSD requirements for the coming years.

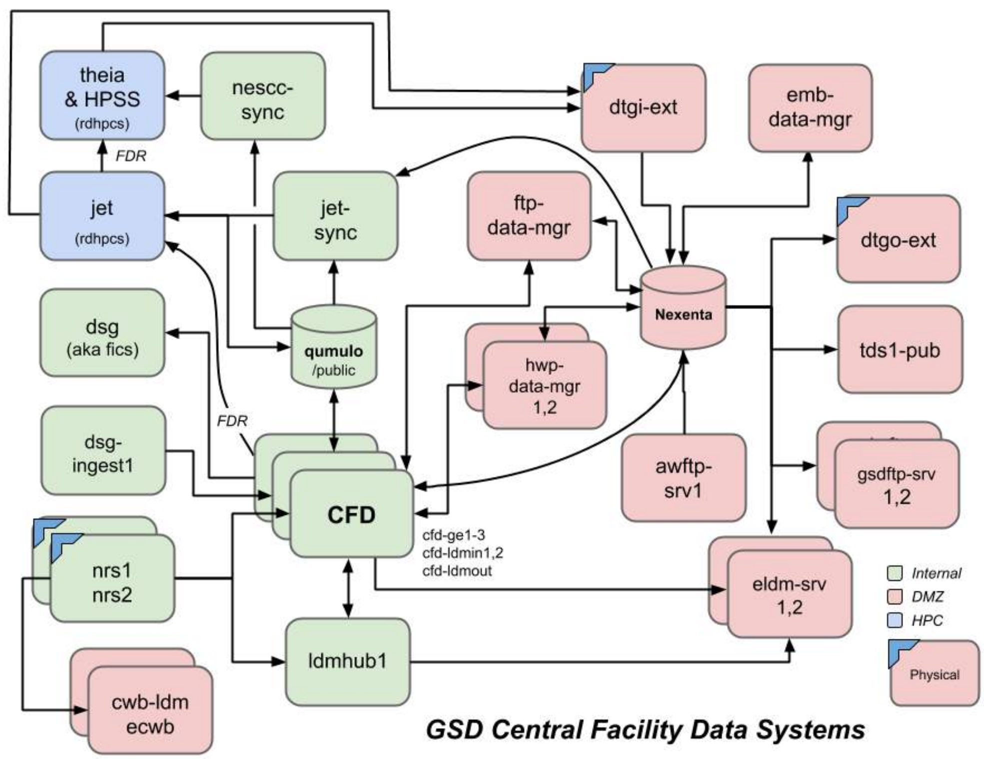


Figure 1. GSD Central Facility Data Systems with CIRA-managed data handling applications.

--MADIS (Meteorological Assimilation Data Ingest System) - The CIRA ITS team provided direct support to the MADIS project and was instrumental in enabling MADIS version 2.1.5 to achieve operational status within the NOAA Integrated Dissemination Program (IDP), thereby completing a NOAA Oceanic and Atmospheric Research (OAR) Operating Plan milestone. The effort included software developed by the CIRA group as part of the Hydrometeorological Automated Data System (HADS), Automated Flood Warning Systems (AFWS), and Snow Telemetry (SNOTEL) components.

--FXNet - The CIRA ITS team provided direct support to GSD's FXNet Fire Weather project by working with the FxCAVE team to support FXNet/FxCAVE fire weather customers via AWIPS2-based systems. This effort enabled AWIPS1-based systems to be decommissioned at the end of FY16.

--GSD Web Services - CIRA ITS team member Jennifer Valdez serves as GSD Webmaster, providing numerous services to GSD scientists, RDHPCS management, and external community members. Her notable activities for the period included:
--On-going work on re-design & reorganization of the GSD web site,
--Becoming an active member of the GSD IT Enterprise Group, which works on issues and guidance for IT-related projects, programs and tasks,
--Working on shutdown preparation, execution, and recovery of all GSD web sites during the government shutdown,

--Working with GSD scientists and developers to reduce the number of top-level websites managed by GSD, and
--Updating and maintaining scripts for the GSD Publications database.

PROJECT TITLE: EAR - Science On a Sphere® (SOS) Development

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Keith Searight, Steve Albers

NOAA TECHNICAL CONTACT: John Schneider (OAR/ESRL/GSD/ATO Chief)

NOAA RESEARCH TEAM: CIRES: Shilpi Gupta, Vincent Keller, Ian McGinnis, Stephen Kasica, Dr. Wen Wei (Tony) Liao

PROJECT OBJECTIVES:
1--Develop and enhance near-real-time and other global data sets for use at SOS sites
2--Provide software and technical support for existing SOS systems sites, new and proposed SOS installations, and travelling SOS exhibits that conduct scientific education and outreach
3--Plan and release new versions of the SOS system software with prioritized features
4--Research new technologies and configurations for future innovations in SOS

PROJECT ACCOMPLISHMENTS:

The Science on a Sphere® (SOS) Development project advances NOAA's crosscutting priority of promoting environmental literacy. SOS displays and animates global data sets in a spatially accurate and visually compelling way on a 6-foot diameter spherical screen. CIRA provides key technical leadership and developments to the SOS project, particularly research and implementation of effective controls and user interfaces for the system, new visualization techniques, and new data sets.

1--Near-real-time and other global data sets
The SOS development team continued to support the automated transfer of large volumes of near-real-time weather model and other datasets to SOS sites via private FTP. Recently collected statistics have documented a monthly average of 23 TB of SOS datasets downloaded. The SOS team also continued to collaborate with other scientific groups within and outside of NOAA to provide new compelling and impactful curated datasets for SOS audiences.

Dataset highlights for this reporting period included
--Continued maintaining up-to-date real-time datasets, including weather models (FIM, GFS), global weather satellites, earthquakes, fires, land surface temperatures, ocean color, snow and ice coverage, and drought risk.

--GOES-16 Tracks the Big Three. Three major tropical storms dominated the 2017 Atlantic Hurricane season: Harvey, Irma, and Maria. The Advanced Baseline Imager (ABI) on GOES-16 tracked these major storms. Geostationary Lightning Mapper (GLM) data is also featured.

--Sea Ice Extent: Sept. Only - 1979 - 2017. This very popular dataset was updated to go back to 1979 and up through 2017. September is specifically highlighted to show when the minimum sea ice extent is reached in the Arctic.

--Clouds with Precipitation - Real-time. At the request of SOS sites, two popular real-time weather observation datasets were combined by layering *Precipitation - Real-time* on top of *Clouds - Real-time* to provide an effective visualization to highlight weather events like the large 2017 hurricanes (see Figure 1).

--Exploring the Unknown Ocean. A new narrated movie, made for SOS, tells a fascinating story behind new ocean technologies, the people that operate them, the scientists who use them, and the discoveries they make together.

--TRAPPIST-1 Exoplanets. A planet that orbits a star outside the solar system is an exoplanet. TRAPPIST-1 is a dwarf star that has 7 Earth-sized planets orbiting it, which were detected using the La Silla Observatory in Chile and the Spitzer Space Telescope. This series of seven datasets show an artist's concept of what these Trappist exoplanets might look like.

--Paleoclimate Proxies. Yearly processes, such as trees growing and sediment collecting on the seafloor, are sensitive to changes in regional climate, allowing them to be used like natural thermometers. This new dataset shows the types and locations of these paleoclimate proxies around the world, helping viewers understand how scientists research the past.

--Population Accessibility to Cities. This dataset is useful for illustrating social science impacts related to high accessibility such as increased wealth, educational attainment, and utilization of healthcare, as well as the negative aspects of high accessibility such as easing resource extraction and thus amplifying environmental degradation.

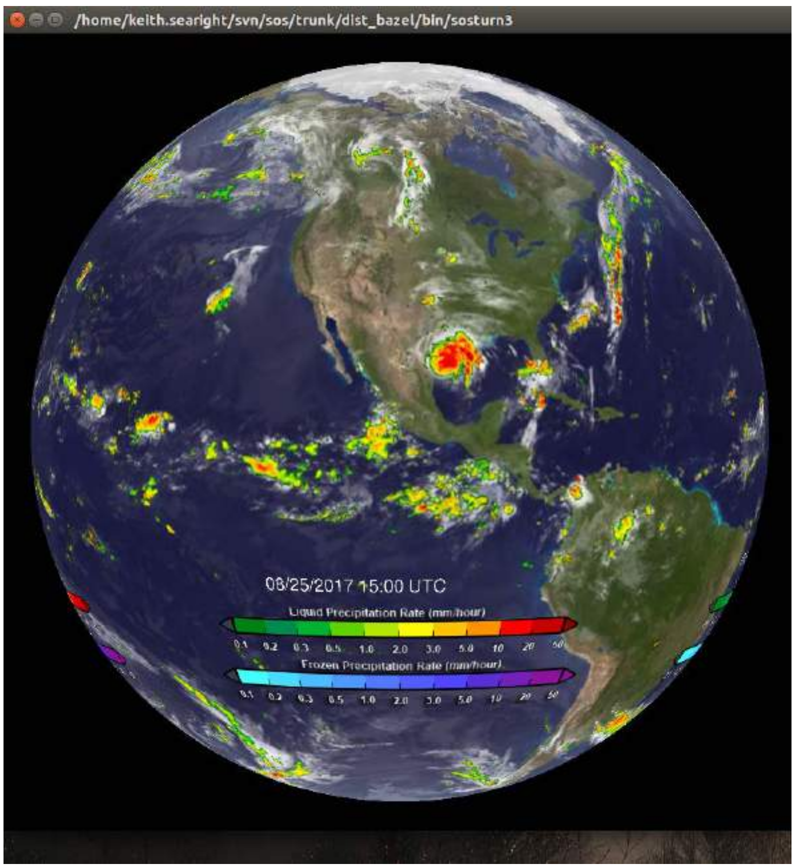


Figure 1. Clouds with Precipitation - Real-time dataset showing Hurricane Harvey.

2--Software and technical support for SOS systems; scientific education and outreach
The SOS team provided regular support to SOS sites by email, telephone, and occasionally in person. The issues handled included upgrades and solving problems with the SOS software, hardware, and equipment, finding and accessing datasets, and questions about operating the SOS system.

During this reporting period, new SOS systems were installed at venues worldwide, including Liberty Science Center (Jersey City, New Jersey), NOAA Center for Weather and Climate Prediction (College Park, Maryland), Morristown-Beard School (Morristown, New Jersey), Srikrishna Science Centre (Patna, Bihar, India), The Regional Science Centre, (Guwahati, India), Raman Science Center (Nagpur, India), Biodiversity Museum (Kerala, India), Kaihua Meteorological Bureau (Kaihua, China), Xuchang Technology Activity Center (Xuchang, China), Zhejiang Shaoxing Meteorological Administration (Shaoxing, China), and University of South Australia (Adelaide, Australia). The total number of SOS systems installed worldwide now exceeds 150, with a total viewership estimated at over 37M people annually.

Additionally, the largest ever Science On a Sphere® (SOS) was set up as part of a temporary exhibit called Climate Planet in Aarhus, Denmark, which was designated the European Capital of Culture in 2017. The 4-meter diameter sphere (Figure 2) was housed inside a temporary 24-meter spherical structure. A special SOS presentation about climate change was developed by the exhibit creators for the event.

Figure 2. Four-meter diameter SOS exhibit at Climate Planet, Aarhus, Denmark.

The SOS team played a major role in 8th Science On a Sphere® Users Collaborative Network Workshop, held at the Detroit Zoo, with over 100 attendees. The Boulder staff gave presentations and demonstrations on SOS topics, including What's New in the SOS Product Suite, SOS: Global to Local, SOS Visual Playlist Editor Tutorial, and SOS Product Suite: Feedback and Future Direction.

SOS staff also led a Girls & Science program at Denver Museum of Nature and Science and facilitated webinars for the SOS community on scientific content and use of SOS software. In the SOS Planet Theater at the NOAA Skaggs building in Boulder, SOS educational shows were viewed by an average of 470 visitors per month, with SOS staff conducting some of the presentations or providing technical backup to presenters when needed.

3--Plan and release new SOS capabilities
Under CIRA staff's leadership, the SOS team planned and executed two major software releases with many new features and capabilities. SOS v5.2 (Apr. 2017) and v5.3 (Feb. 2017) met all planned objectives on schedule.

Major highlights for version 5.2 included:
--New Text PIPs feature that allows beautiful and highly flexible display of text on the sphere using a large set of fonts, colors, and language support (Figure 3).
--Many improvements and fixes in the Visual Playlist Editor, including creation of Text PIPs, displaying dataset descriptions, and translation support for the SOS data catalog.
--New functionality in the SOS Remote App for Apple iOS, including individual display controls for picture-in-picture (PIP) graphics and new projector alignment options.
--A new graphical utility for controlling and reporting the status of SOS projectors.
--Enhanced documentation under the Support section of the SOS website, including more consistent formatting and printable PDFs available for the SOS manuals and guides.
--Extensive bug fixes and software improvements throughout all the SOS software applications.

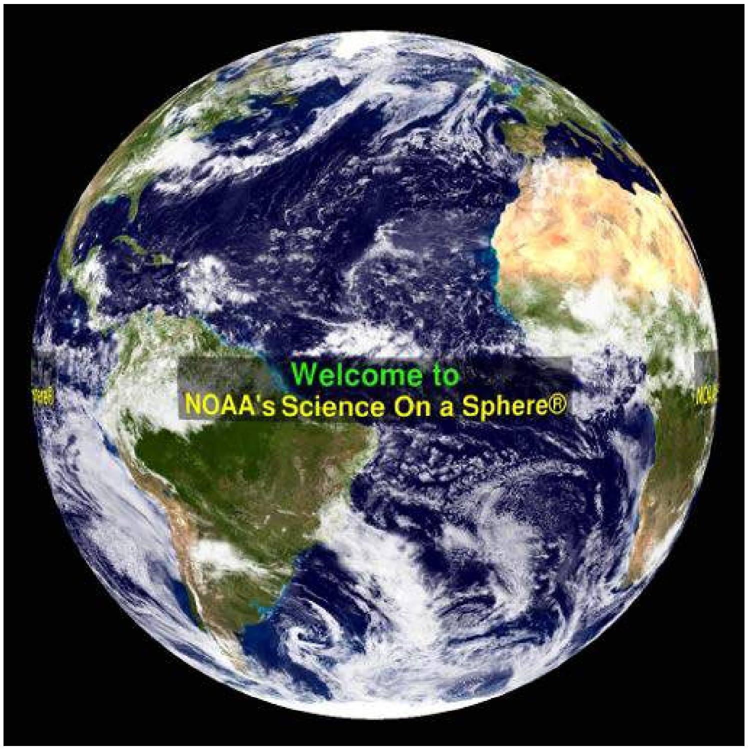


Figure 3. Text PIP feature to display of text using a large set of fonts, colors, and language support.

Major highlights for version 5.3 included:
--Improved Graphics: better display performance and all graphics elements (i.e., labels, annotations, pips, etc.) displayed in zoom magnifier and splitter sections (Figure 4).
--Spotlight Datasets: a new user interface in the Remote App that provides access to a handful of timely and compelling datasets that get updated periodically by the NOAA SOS Team (Figure 5).
--High resolution dataset downloads from a new FTP server for sites using 4K projectors.
--Stronger software security using a new Wibu CodeMeter dongle.
--Improved labels resolution with flexible customization options.
--Faster/cleaner Usage Statistics on the SOS website.
--Improvements in automated build and installation of the SOS applications.

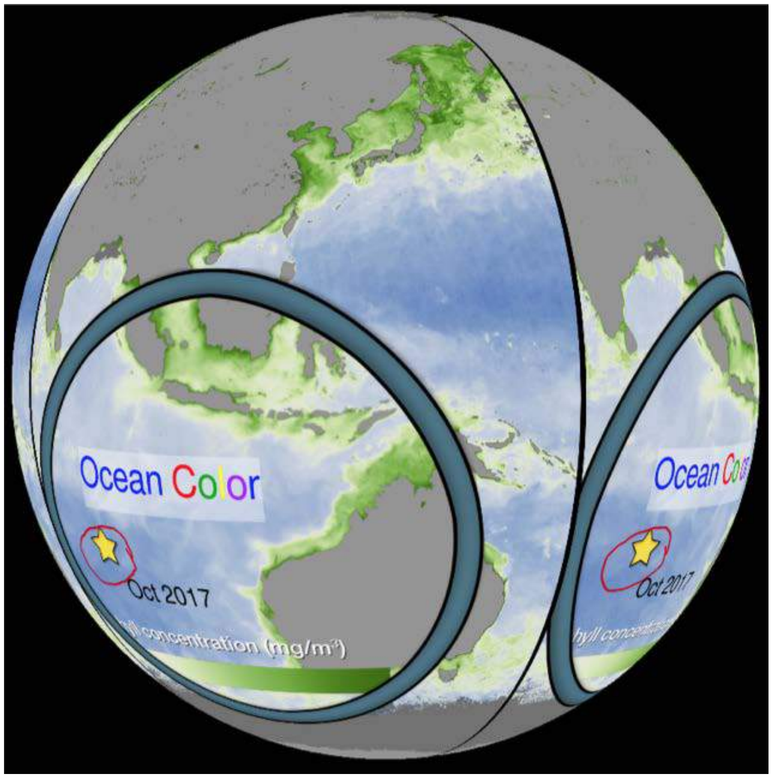


Figure 4. New feature to display all SOS graphics elements in the zoom magnifier and splitter sections.

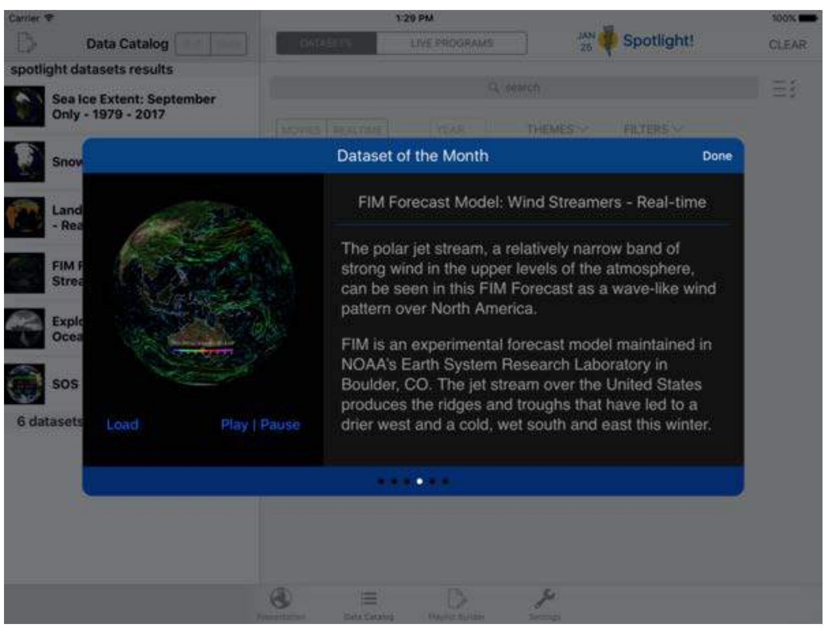


Figure 5. Spotlight Datasets: a new UI in the Remote App that accesses timely and compelling datasets.

4--Research new technologies and configurations for future innovations in SOS
To keep SOS exciting, relevant, and accessible to audiences, a number of new technical areas are now being evaluated for inclusion in future versions of SOS over the next year, including:
--Closed captioning and subtitles for narrated movies

--Augmented reality integration with the sphere
--Integration of SOS with external flat screen displays
--Picture-in-picture graphical elements that can move spatially on the globe
--Streamlining content creation processes for adding new datasets to the SOS catalog

PROJECT TITLE: EAR - TerraViz (also branded as SOS Explorer)

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Jeff Smith, Jebb Stewart

NOAA TECHNICAL CONTACT: John Schneider (OAR/ESRL/GSD/ATO Chief)

NOAA RESEARCH TEAM: Eric Hackathorn (OAR/ESRL/GSD/ATO), Jonathan Joyce (CIRES)

PROJECT OBJECTIVE:

Our objective is to create an easy-to-use Windows and Mac application that seamlessly combines and visualizes many types of 2D and 3D environmental data across time and from the bottom of the ocean through the atmosphere and into space.

SOS Explorer ™ (SOSx) uses the NOAA-developed Terraviz ™ visualization engine to create an interactive Earth for the flat screen and for virtual reality headsets like the Oculus Rift. This display can be projected on walls, computers, and large displays, providing teachers, students, and the public access to a library of selected Science On a Sphere ® datasets and movies, as well as 3D datasets designed specifically for SOSx. The visualizations show information provided by satellites, ground observations and computer models and rapidly animate through real-time global data. In addition, tools included in the application allow users to zoom into, probe, and graph the data, as well as add supplementary material including websites, videos, pictures, placemarks, 3D satellites and their orbits, immersive 360 degree “bubbles” that users can fly into.

SOSx Explorer also includes immersive 3D experiences such as ocean experience which teaches users about NOAA’s Okeanos Explorer ship and allows then to pilot an ROV to a coral reef. Moon Walk lets users walk on the Moon and experience low gravity physics. Tornado Experience, which also runs in virtual reality (VR) headsets, enables users to experience a tornado and learn about tornado safety.

NOAA Earth Information System (NEIS) advances this technology further by adding more controls to allow users to dynamically add and overlay multiple data layers from different data sources and explore a full 4D volume such as the isobaric levels of meteorological forecast models. Additionally, NEIS provides the ability to access remote data from a variety of standardized services.

Support for development has been provided by the NOAA National Environmental Satellite, Data, and Information Service (NESDIS), and the Science on a Sphere program.

PROJECT ACCOMPLISHMENTS:

Ongoing development and improvement to SOSx including the following:

Added virtual reality (VR) support for Oculus Rift. Developed a user interface using the Rift and Leap Motion controller to enable a user wearing the Rift to use his hands to rotate/zoom the Earth, search for datasets, fly into 360-degree immersive media bubbles, view legends, and operate other user interface windows/buttons.

Figure 1. Virtual Reality Setup for SOSx.

Expanded Tour Builder to support more sophisticated tour tasks, sub tours, edit new types of datasets, and edit the metadata in a graphical dataset editor. A tour is essentially a sequence of commands or ‘tour tasks’ (e.g., LoadDataset, FlyTo location on Earth, display a multiple choice question, display a web page, etc.) to be executed in sequence. Tour Builder enables customers such as NESDIS or museums to develop their own tours to run either autonomously or interactively. With Tour Builder, users can drag tour tasks onto a timeline, drag to reorder them, assign information to the attributes of each tour task, and select the Play menu option to immediately preview their tour within SOSx or NEIS.

Figure 2. Tour Builder for SOSx.

Developed Tornado Experience, an educational game included with SOSx, that places the player in a residential neighborhood about to be hit by a tornado. Tornado Experience works on 2 screens and also in virtual reality (the Oculus Rift) for a more immersive experience, and teaches tornado safety to players.

Figure 3. Screenshots from Tornado Experience.

NEIS was used to support presentations for various NESDIS scientists at both the American Geophysical Union Fall Meeting 2017 in San Francisco and the American Meteorological Society Annual Meeting in Austin, TX in January 2018.

Invited talks:

Jeff was invited to give a talk about SOSx and virtual reality (VR) at UCAR Software Engineering Assembly (SEA) on September 14, 2017.

Jeff was invited to give a talk on virtual reality and other emerging technologies at the University of Colorado Leed's School of Business on February 12, 2018.

EAR Publications:

Albers, S., D. Nietfeld, and Z. Toth, 2018: The Latest Nowcast: Improved Visibility, *Eighth Conference on Transition of Research to Operations*, Austin, TX, Amer. Meteor. Soc., 13B.3. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper335607.html)

Beck, J., I. Jankov, J. Wolff, M. Harrold, T. Hertneky, P. Skinner, and J. Brown, 2018: An Evaluation of Ensembles Available within the Community Leveraged Unified Ensemble (CLUE) during the Hazardous Weather Testbed (HWT). *25th Conference on Probability and Statistics*, Amer. Met. Soc., 5.6. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper334288.html)

Blake, B., J. Carley, T. Alcott, I. Jankov, M. Pyle, S. Perfater, and B. Albright, 2018: An Adaptive Approach for the Calculation of Ensemble Grid-Point Probabilities, *Wea. Forecasting,* Submitted.

Fenton, K., M. Wandishin, M. Petty, M. Marquis, T. McJunkin, A. Abboud, and J. Gentle, 2018: The Use of HRRR Forecasts in True Dynamic Line Rating, *Ninth Conference on Weather, Climate and the New Energy Economy*, Austin, TX, Amer. Met. Soc., 11.4. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper331345.html)

Govett, M, J. Rosinski, J. Middlecoff, T. Henderson, J. Lee, A. MacDonald, P. Madden, J. Schramm, and A. Duarte, 2016: Parallelization and Performance of the NIM Weather Model for CPU, GPU and MIC Processors. *Bull. Amer. Meteor. Soc*., **98,** 2201-2213. (https://doi.org/10.1175/BAMS-D-15-00278.1)

Hardin, N., D. Nietfield, T.L. Hansen, and Y. Guo, 2018: Hazard Services: Utilizing Recommenders to Create Hazardous Information, *34th Conference on Environmental Information Processing Technologies*, Austin, TX, Amer. Meteor. Soc., 1A.2. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper326206.html)

Jankov, I., J. Beck, J. Wolff, M. Harrold, J. Olson, T. Smirnova, C. Alexander, and J. Berner, 2018: Stochastic Parameter Perturbation in HRRR-Based Ensemble, *Mon. Wea. Rev*., submitted.

Jankov, I., J. Beck, J. Wolff, M. Harrold, G. Grell, J. Olson, T. Smirnova, J. Berner, C. Alexander, and S. Benjamin, 2018: Stochastic Approaches within a High-Resolution Rapid Refresh Ensemble. *Invited. 32nd Conference on Hydrology*, Austin, TX, Amer. Met. Soc., J53.1. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper335716.html)

Lin, H., S.S. Weygandt, S.G. Benjamin, and M. Hu, 2017: Satellite Radiance Data Assimilation within the Hourly Updated Rapid Refresh, Wea. Forecasting, **32,** 1273–1287, https://doi.org/10.1175/WAF-D-16-0215.1.

Lin, H., S.S. Weygandt, A.H. Lim, M. Hu, J.M. Brown, and S.G. Benjamin, 2017: Radiance Preprocessing for Assimilation in the Hourly Updating Rapid Refresh Mesoscale Model: A Study Using AIRS Data. Wea. Forecasting, **32,** 1781–1800, https://doi.org/10.1175/WAF-D-17-0028.1.

Lin, H., S. S. Weygandt, Y. Xie, M. Hu, C. R. Alexander, and S G. Benjamin, 2018: Satellite radiance data impact in RAP version 4. Proceedings, *Sixth AMS Symposium on the Joint Center for Satellite Data Assimilation (JCSDA)*, Austin, TX, Amer. Met. Soc., 3.1. Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper333887.html)

Petty, M., A. Terborg, P. Hamer, G. Layne, M. Wandishin, M. Rabellino, and M. Turpin, 2018: INSITE: IDSS for Aviation Weather. *34th Conference on Environmental Information Processing Technologies,* Austin, TX, Amer. Met. Soc., 2A.4. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper334353.html)

Petty, M., G. Layne, M. Wandishin, J. Hart, P. Hamer, and M. Rabellino, 2018: An Impact-Based Verification Approach for the TFM Convective Forecast (TCF). *Sixth Aviation, Range, and Aerospace Meteorology Special Symposium*, Austin, TX, Amer. Met. Soc. 361.

Stewart, J.Q., S. McNeil, S. Johnston, D. Hagerty, 2018: Scaling for Unknown Demand through the Use of Cloud Technology for the Eclipse of 2017, *34th Conference on Environmental Information Processing Technologies*, Austin, TX, Amer. Meteor. Soc, 6B.1. (Recorded Presentation Available at: https://ams.confex.com/ams/98Annual/webprogram/Paper337644.html)

PROJECT TITLE: Instructional Development and Learning Support for NOAA's OMAO's Chief Learning Officer (CLO), OMAO Kansas City, MO

Instructional Development and Learning

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Cari Kelly - October 16, 2017 to present

NOAA TECHNICAL CONTACT: Scott Tessmer (NOAA/OMAO/Chief Learning Officer)

FISCAL YEAR FUNDING: $41,140

PROJECT OBJECTIVE:

The objective of the Instructional Development and Learning project is to collaborate and support NOAA's Office of Marine and Aviation Operations (OMAO) Chief Learning Officer (CLO) with administration of the Commerce Learning Center (CLC) learning management system (LMS).
Cari Kelly joined the project on October 16, 2017.

1--NOAA OMAO Commerce Learning Center Administration
A major component of administration of the LMS is centered on the maintenance of OMAO staff records, generating reports for divisions, archiving historic training courses, and troubleshooting issues in the Cornerstone on Demand (CSOD) learning management system.

2--Resource and Administrative Support to the OMAO Learning Office and OMAO CLO
Resource support to the OMAO Learning Office and CLO includes developing training materials for instructor led training sessions, maintenance on the intranet, participation in research for procurement initiatives, and keeping the OMAO Training and Development calendar current with training opportunities.

3--Instructional Project Development
Developing training to meet the needs of the OMAO is a service that the OMAO Learning Office provides. The cost-benefit of online training will provide more opportunities to build courses in the future.

4--Training
Continued training online and at the National Weather Service Training Center (NWSTC) help to maintain knowledge and develop skills to better serve the Learning Office.

PROJECT ACCOMPLISHMENTS:

1-- NOAA OMAO Commerce Learning Center Administration

Historic data integration into the CLC continued from the previous year. Cari Kelly helped to complete the Small Boat Program data archiving and integration project to produce a current and accurate detail of annual and active instructor led training (ILT) events in the Commerce Learning Center as seen in Figure 1. Future Learning Coordinators (LCs) can easily add sessions in the three integral courses for the Small Boat Program (SBP) while the previous historic data is archived for reporting only purposes.

Events

(3 Results)

Event Name	Subjects	Vendor	Language(s)	Tentative Sessions	Approved Sessions	Completed Sessions	Evaluation	Options
NOAA Annual Small Boat Evaluation Course (SBP)	OMAO ... Small Boats	NOAA (NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION)	English (US)	0	1	0		
NOAA Small Boat Component Course (SBP)	OMAO ... Small Boats	OMAO	English (US)	0	2	30		
NOAA Small Boat Component Instructor Course (SBP)	NOAA OMAO ... Small Boats	NOAA (NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION)	English (US)	0	1	0		

Figure 1. 2017/2018 View of current/active SBP annual training events in the CLC. Before the project to archive outdated events, hundreds of items were visible to the LC/Admins when doing a basic search, making the CLC cumbersome and ineffective for data input by the Learning Coordinators.

We are currently working on a revision project for the Marine Operations Safety Program in the CLC, to develop effective data recall as was done for the SBP. Each OMAO division will benefit from this process because it creates a user friendly back-end for the learning coordinators to add ongoing and future training in a way that maximizes the CLC platform. The OMAO division LC's will become self-sufficient and the organization will be able to verify that the qualified personnel are staffed via a simple report. Training LC's on how to add sessions, rosters, run reports, and create learning assignments is ongoing.

Regular testing of processes in the CLC such as custom email development, running reports, and troubleshooting issues improves the functionality and user experience of the CLC. In addition, the mandatory training page has been revised (Figure 2), and a style sheet is in development to create a consistent 'branding' approach for the organization. This helps users find the information they need quickly, and invites them to explore more information. This project is ongoing.

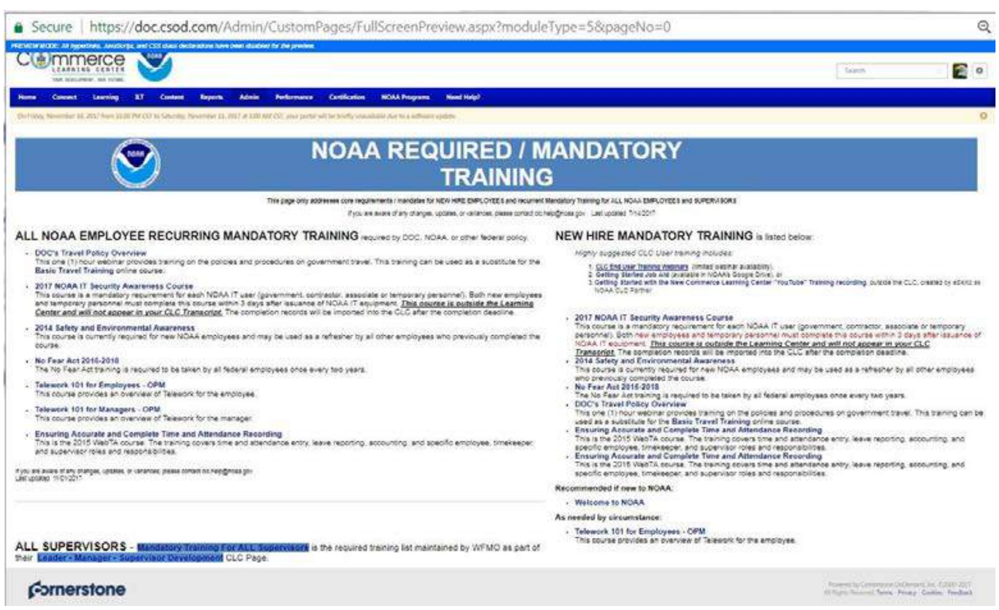


Figure 2A. Mandatory Training Custom Page in CLC Before Revision.

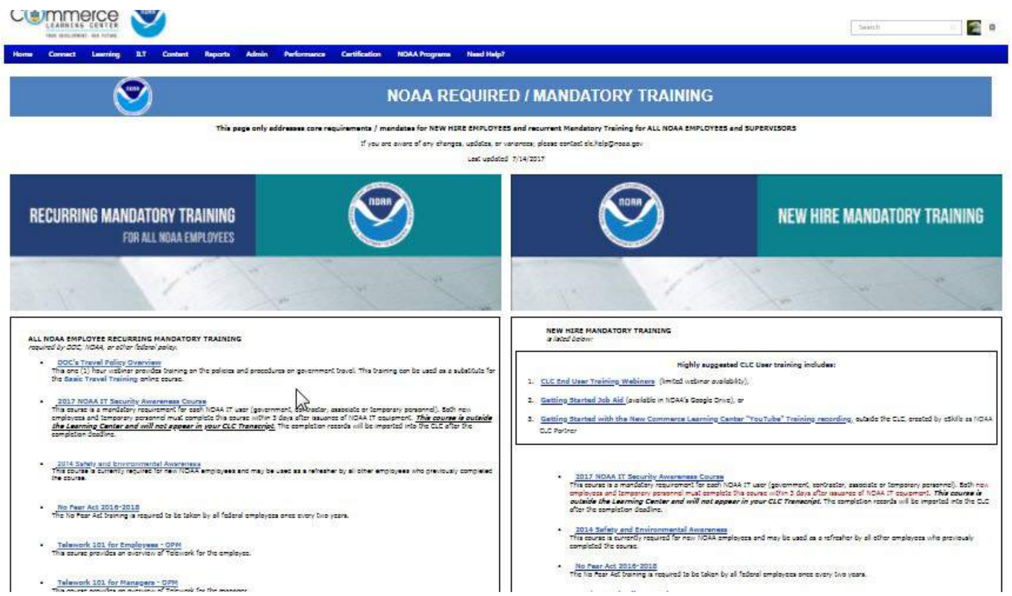


Figure 2B. NOAA Mandatory Training Custom Page After Revision. November 2017

Another responsibility of CLC Administration is working with divisions/departments to build curriculum for ongoing and new hire training. We worked with the Marine Operation Engineering department (EEB) to build a curriculum for IT Training Requirements. This was a fairly straight-forward build because it contained all online courses. We are working on a more complex curriculum that contains ILT's and offsite courses. This project is ongoing.

2--Resource Support to the OMAO Learning Office and CLO

The OMAO Learning Office CLO oversees learning, development, and training programs for OMAO employees. There are a variety of creative and administrative functions that the LMS Administrator executes to support the vision and mission of the Office.

The CLO facilitates two, week-long, face-to-face leadership training sessions. Accordingly, Cari Kelly created graphical training materials for the Mid-grade Leadership course to develop standardized practices throughout NOAA leadership.

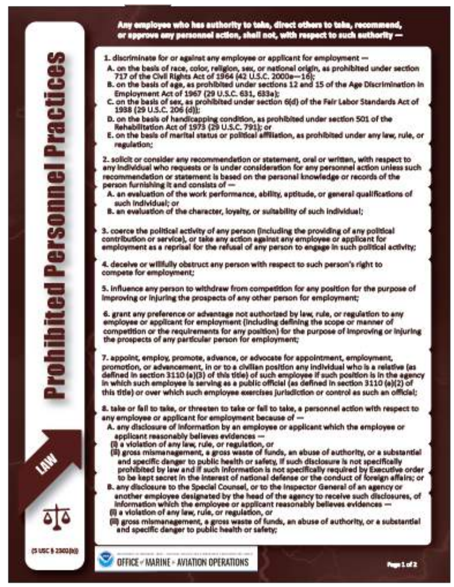


Figure 3. Print version of the Ethics posters developed for the Mid-Grade Leadership training. Larger poster versions were also created to mount on the wall during the class.

Cari Kelly assists in keeping the OMAO Learning Office intranet and training calendar up-to-date with training opportunities. The Learning Office will benefit from continued improvements to the intranet site to increase traffic and guide staff to learning opportunities. Also, research of hardware and software procurement options has led to new tools used by the OMAO Learning office and the National Weather Service Training Center.

3--Instructional Project Development

In collaboration with the Marine Operations and the Department of Census, the OMAO Learning Office is developing a training program for the newly developed ShipTA time management system for onboard personnel. Cari Kelly is building the online/onboard course using the adult learning principles of relevancy, practicality, and self-motivation. The course will respect the learners time by making the training to-the-point in a format that will be easy to navigate.

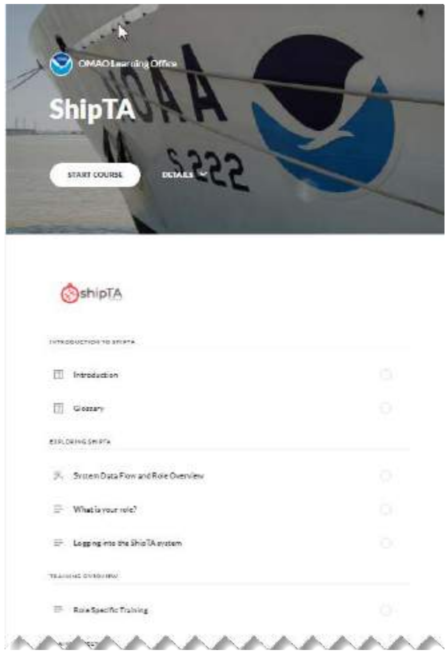


Figure 4. Start page of the ShipTA training built in Articulate 360.

This project is nearing completion, but a quick prototype was created to help the ShipTA project team to envision the training goal of the Learning Office (see Figure 4). We successfully guided the project from multiple, long, PowerPoint-based training focused on technicalities beyond the scope of the end user, to a concise training that will be engaging with positive transference to shorten the learning curve for employees to use the ShipTA program effectively.

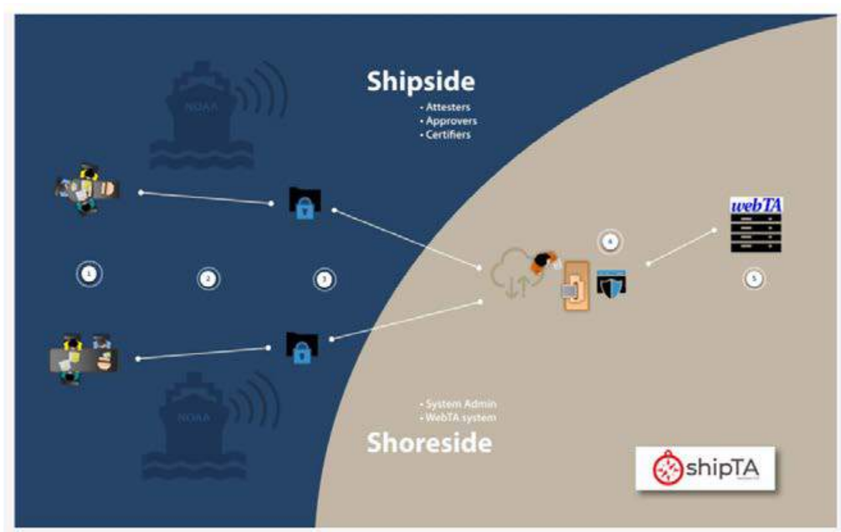


Figure 5. Custom graphic designed for the ShipTA training. This is an interactive graphic to show the Data Flow from ship to shore to process payroll for onboard personnel. Users click the button to learn about the process along from employee timesheet input to uploading the data to the payroll system shoreside.

4--Training Participation
--Cornerstone on Demand (CSOD) Administrator Core online training
--CSOD Learning Coordinator online training
--Writing and Grammar Basics - on-site (monthly)
--Articulate - intermediate and Advanced online training
--Instructional Design Overview - on-site (weekly)
--Cornerstone Success Center (CSC) online courses
--Participate in CLC team lead calls weekly

PROJECT TITLE: Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program (AWRP), and the NextGen Weather Program

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Daniel Vietor, Larry Greenwood, Bret Lucas, Brian Pettegrew, Robyn Tessmer

NOAA TECHNICAL CONTACT: Joshua Scheck (NOAA/NWS/AWC)

NOAA RESEARCH TEAM: Steven A. Lack (NOAA/NWS/AWC), Austin Cross (NOAA/NWS/AWC), Stephanie Avey (NOAA/NWS/AWC)

FISCAL YEAR FUNDING (Total Project): $2,184,938

PROJECT OBJECTIVES:

The Aviation Weather Center (AWC) Aviation Support Branch (ASB) is responsible for providing support to the research and operations processes, maintaining server and networking infrastructure, and supporting the www.aviationweather.gov website.

The primary goal of the ASB is to maintain the internal network, servers and workstations at the AWC to ensure continuity of operations. The 24x7 support is critical to AWC forecast and web operations. The ASB collaborates with the other National Center for Environmental Prediction (NCEP) centers and the National Weather Service (NWS) to provide data and research to operations support. The branch supports the research operations at the AWC, headed by a team of Technique Development Meteorologists (TDMs). This includes support for the Testbed (AWT) as well as support for AWRP. The AWRP products include Current and Forecast Icing Products (CIP/FIP), Graphical Turbulence Guidance (GTG), National Ceiling and Visibility Analysis (NCVA), and the National Convective Weather Diagnostic/Forecast (NCWD/F). The ASB also supports the AWC website which includes Aviation Digital Display Service (ADDS), World Area Forecast System (WAFS) Internet File service (WIFS) and the International Flight Folder Program (IFFDP).

As part of the CIRA effort, the ASB has close links to the research and development projects going on at the AWC. This includes:
--Supporting NextGen and AWRP,
--Providing better tools to decrease weather impacts to the National Airspace System (NAS) including efforts at the FAA Command Center and with the Traffic Flow Management (TFM) project,
--Providing direct support to the TDMs at the AWC for ongoing research projects including GOES-R, ensemble model diagnostics and product verification,
--Expanding collaboration efforts with the other testbeds within NOAA and the NWS focusing on R2O projects.

PROJECT ACCOMPLISHMENTS:

In the past year, efforts have been centered on six primary projects:
1--ADDS Lite
2--Aviation Clouds and Surface Forecasts
3--GFA Expansion
4--PIREP Submit Tool
5--Updates to HEMS Tool
6--Collaborative Research-to-Operations Enhancements and Support Activities

ADDS Lite
The aviationweather.gov website was moved from the NOAA Web Operations Center (WOC) to the NWS Integrated Dissemination Program (IDP) in 2015. The front-end web code and back-end processing was moved in its entirety, as-is, to IDP. A waiver was granted to allow ADDS to be deployed without going through the full IDP on-boarding process. This was done partly due to the short time cycle to get off the WOC due to security and support issues and partly because the complex back-end to ADDS could not be supported by IDP. After the website went live in November 2015, the lack of primary support from IDP and the inability to deploy a backup site to the IDP facility in Boulder, CO, resulted in much lower server reliability and increased down times from standard maintenance events.

The move was done under the assumption that the site would have to go through the on-boarding process. To get there, a new lighter, less complex back-end (ADDS Lite) had to be developed that could be supported directly by IDP. This included streamlining the back-end, reducing overhead, and replacing or updating scripts and processing software.

Work began in 2014 with an evaluation of the scripts to do data processing and generate imagery. It was determined that these scripts should be upgraded from their 1990's programming style, as in using C-shell and NCL, to more modern and flexible scripting languages such as Perl and Python using MatPlotLib and PyNGL. Second, to make data processing support easier, the bulk of the image processing would be moved to servers at AWC. In 2015, a couple of image generation servers were built at AWC in support of this move. Third, a set of standards for file naming and directory layout were established. This also consolidated the multiple components of the website into a single coherent file structure. The separation of the ADDS and AWC components would be eliminated. Finally, much of the ADDS overhead would be removed, mostly because it was not needed on a modern more reliable operating platform.

Much of this work was halted in 2015 when the site was moved to IDP but began again in 2016. By the end of 2016, most of the infrastructure and scripting was finalized. In 2017, new development and test servers were built at AWC and back-end code installed. The remaining work was to upgrade the web front-end to use the new directory layout and file names. This was also the opportunity to consolidate and update the web interface, fixing several issues that lingered from the deployment of the new website in March 2014 (Figure 1). This web development continued over the summer.

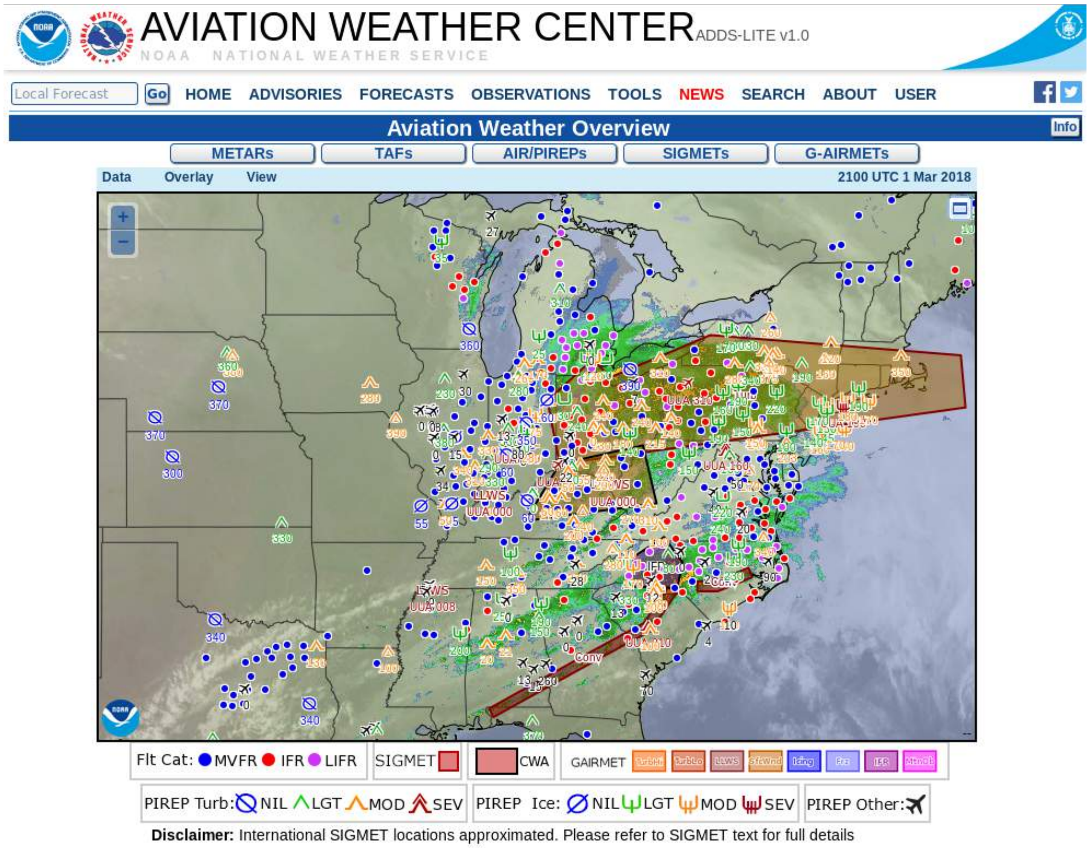


Figure 1. ADDS Lite upgrade to the web front-end.

In June, AWC worked with IDP during a three-week sprint to build out ADDS Lite servers in the development environments in both College Park, MD, and Boulder, CO. This is the first stage of the on-boarding process. Once the development environments have full functionality and are stable, the process of moving the code to production can begin. The months of August and September were spent on documentation, installation procedures, and troubleshooting guides. Version 1.0 of the ADDS Lite back-end and front-end code was delivered to IDP at the end of September.

Although the final schedule for on-boarding has not been set, the push is to get ADDS Lite on-boarded by the end of 2018 to have a functional backup site in Boulder. In the meantime, development on the web code continues including porting many of the ADDS Lite improvements back to the legacy website. This essentially merges the two code bases, eliminating the need to manage the two separately. Also, this allows various parts of the complex ADDS back-end to be eliminated, reducing support issues on the legacy site. As of early March, about half the ADDS Lite code has been deployed to production.

On a similar project, the testbed website at AWC (testbed.aviationweather.gov) is also being converted to ADDS Lite. By early March, most of the back-end has been implemented and work on converting the web front-end has begun. This project should be complete by late April 2018.

Aviation Clouds and Surface Forecasts

The text area forecast is a product AWC created for decades, originating over 50 years ago. However, the limitations of the area forecast restricted its use in the last decade. Today, better graphical products are available to aid pilots in deciding when and where to fly. In a joint decision by the FAA and NWS, the area forecast was discontinued in 2017.

There were two projects that made this transition possible. The first was the Graphical Forecast for Aviation Tool (GFA) that went operational in March 2017. The second was the generation of a set of static graphical products that provided critical forecast information to flight service. These graphics would be generated 6 times a day with forecasts every 3 hours out to 18 hours. The two graphics include:
Aviation Clouds Forecast
--Cloud coverage (scattered, broken, overcast) image
--Cloud layer information including cloud base, tops, layer information and whether there is high cirrus
--Icing and mountain obscuration AIRMETs

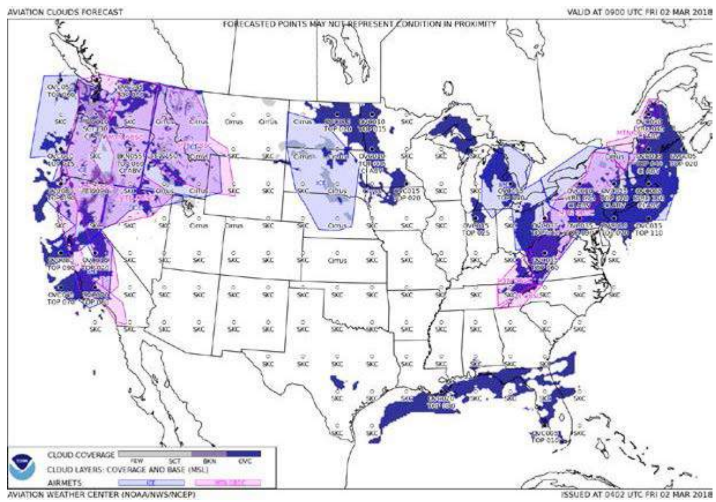


Figure 2. Sample Aviation Clouds Forecast.

Aviation Surface Forecast
--Visibility image showing reflecting values for marginal visual, instrument and low instrument weather conditions (MVFR, IFR, LIFR)
--Surface weather plotted as symbols and coloring for likelihood
--Surface winds
--IFR and surface wind AIRMETs

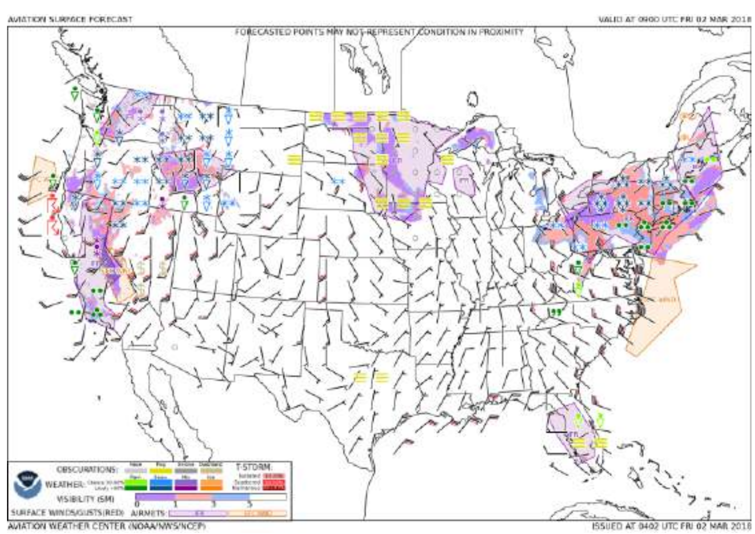


Figure 3. Sample Aviation Surface Forecast.

The development effort for these new products spanned three months from April to June with a final release to flight service in July. A three-month evaluation period followed with a couple of suggested enhancements made in late summer. The two forecast products went operational in early October. The text area forecast was discontinued in mid-October for the contiguous United States (CONUS) regions.

Graphical Forecast for Aviation Expansion Project

The original Graphical Forecast for Aviation (GFA) Tool went operational in March 2017. The original tool was developed for CONUS aviation operations with the intent of replacing the area forecast. This CONUS GFA does not replace the need for AWC to produce the area forecasts for the Gulf of Mexico and Caribbean areas. So to finally terminate all of the text area forecast, the GFA Tool will need to be expanded into these areas. Also, Hawaii, who generate their own area forecasts, is interested in terminating their forecast production if the GFA Tool could be expanded to their region.

In the summer of 2017, work began on a set of test products to expand the coverage area of the GFA Tool. This included:
--Surface wind and weather derived from the GFS model,
--A new cloud layer algorithm using the GFS model,
--Icing potential from the GFS post processor,
--Turbulence guidance from work AWC is doing to expand and calibrate the GTG algorithms for a global domain,
--Investigating OCONUS ceiling and visibility products from GFS or other source,
--Expanding radar coverage using MRMS

Although the GFA Tool was not adapted to use these new products, a prototype application was completed in September 2017 to assess the new graphics and lessons learned reported back to the FAA.

In early 2018, phase two of the project began with two goals. First, is to investigate alternatives to the GFS graphics used in phase one. The graphics will be produced using the expanded RAP model domain to provide products over the OCONUS areas. This will provide a seamless set of graphics since the GFA Tool already uses graphics from the RAP and will avoid the need to blend output from the GFS and RAP models. Second, this phase will incorporate the graphics into the GFA framework.

PIREP Submit Tool

The ability to submit Pilot Reports (PIREPs) from the aviationweather.gov website has been available for nearly a decade. But in 2014, the FAA tasked out AWC to expand the submission user base from airline dispatchers and air traffic control centers to the general aviation community. There were two tasks that needed to be completed to make this possible. First, the user interface needed to be updated and better quality control added to make sure users didn't put in incorrect information. The second is a user authorization system to make sure new users were qualified to submit PIREPs. These activities were completed in early 2017.

Once this new form went operational, the Airline Owners and Pilots Association (AOPA) followed with a set of recommendations to improve the tool. This mostly centered on the location entry but also added several more QC checks to the tool. A new version was released in May 2017.

The tool has become very popular as over 2500 PIREPs are submitted monthly through the AWC website. The tool has been expanded to enter PIREPs over the Pacific and now Alaska is starting to use the tool.

Updates to HEMS Tool

The Helicopter and Emergency Medical Service (HEMS) community is served by the HEMS Tool. This tool has been available on the website since 2015. User feedback on the tool has been very positive but there are two areas where improvement is needed.

First is surface observations. Meteorological Assimilation and Data Ingest System (MADIS) was added to the testbed version of HEMS in 2016 but these observations continue to be evaluated as to whether they add much to the tool (Figure 4). It was determined that most observations from networks of backyard weather stations probably don't provide the reliability and accuracy needed. But other mesonet observations can add value. There is also interest in expanding offshore observations for helicopter operations to oil rigs and search and rescue. Initial efforts to add buoy and Coastal Marine (CMAN) data are underway.

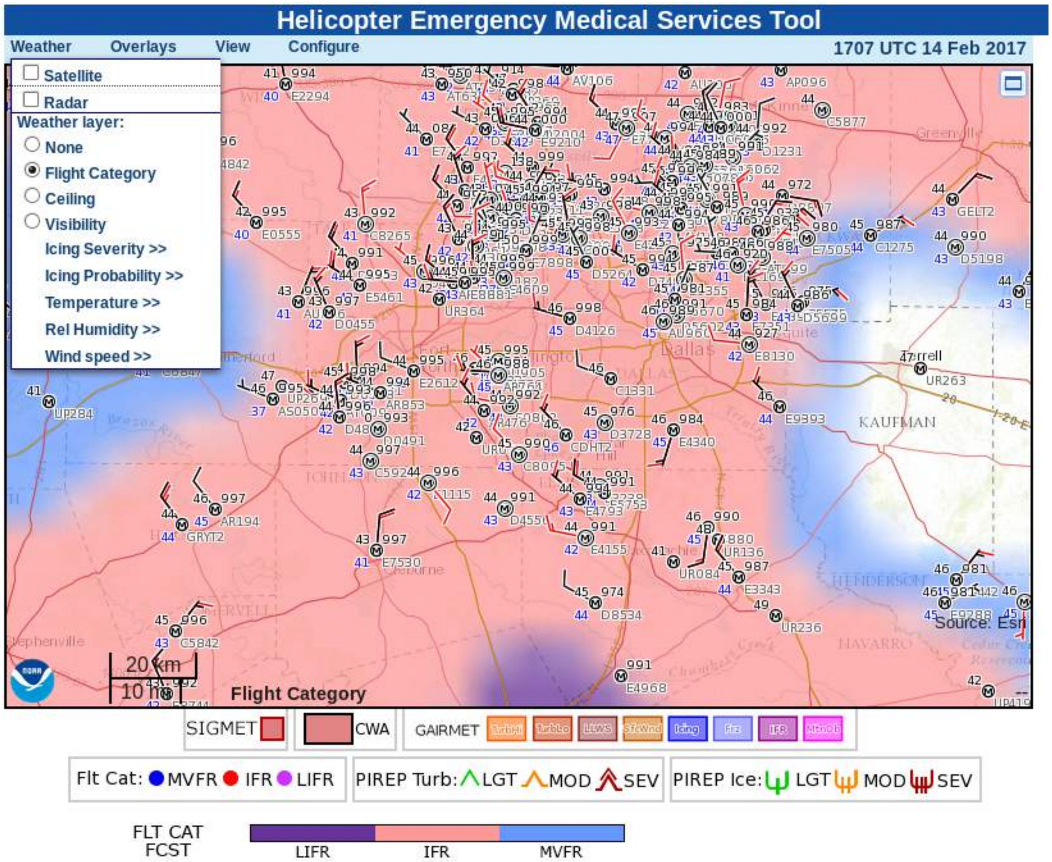


Figure 4. Example of MADIS surface observations over Dallas and Fort Worth overlaid on LAMP Flight Category data.

The second is improved ceiling and visibility data. Since helicopter operations are at low altitude, visibility is critical to prevent accidents. The production HEMS tool only provides data from the National Ceiling and Visibility Analysis (NCVA). The weakness of this product is that it's highly based off of surface observations and in many areas helicopters travel where there are no observations. So the NCVA product is unreliable. Also, it has no coverage over the oceans. Finally, short range forecasts are needed. AWC has been assessing the use of the Localized Aviation MOS Product (LAMP) data and Real Time Mesoscale Analysis (RTMA) to improve on the NCVA. Although RTMA is only an analysis, it provides better insight into data poor areas and covers oceanic areas where marine stratus could curtail helicopter operations. Even though LAMP has poorer resolution, it does provide a forecast product which could be helpful. The assessment period is nearing an end and a decision on what ceiling and visibility data will be incorporated into HEMS could be made by the end of 2018.

Collaborative Research-to-Operations Enhancements and Support Activities
R2O Enhancements and Migration
As AWC's role in fostering R2O, efforts have been made collaboratively with EMC, FAA, and NCAR to improve the production of such aviation algorithms such as Graphical Turbulence Guidance (GTG) and the Current/Forecast Icing Product (CIP/FIP).

The CIP/FIP products are still currently produced at the AWC, however, efforts have been made to migrate these processes to the Weather and Climate Operational Supercomputing System (WCOSS) in College Park, MD. Under AWRP sponsorship, AWC has collaborated with NCEP Central Operations (NCO) and NCAR to modify the current algorithm to fit within NCEP production standards. Over the course of 2017, the code base for FIP was successfully tested and installed onto the WCOSS developmental platform and is currently in the queue to be operationally installed in summer of 2018. Additionally, the CIP will follow suit later in 2018 as collaboration between AWC and NCAR continue in order to meet production standards.

The GTG was successfully migrated to WCOSS in 2015. However, as an effort to increase R2O efficiency, the AWC has lead a project collaborating with NCAR, FAA, and EMC to merge the current GTG production into the overall model post-processing (Figure 5). This will make R2O processes between NWS and the FAA more efficient by giving these algorithms access to the native model fields and attaching any algorithm improvement automatically to regular model upgrades. Post-processed fields of GTG are currently scheduled to be turned on with the upgraded RAP model in May of 2018. The AWC and EMC will evaluate the output before officially disseminating this output in early 2019.

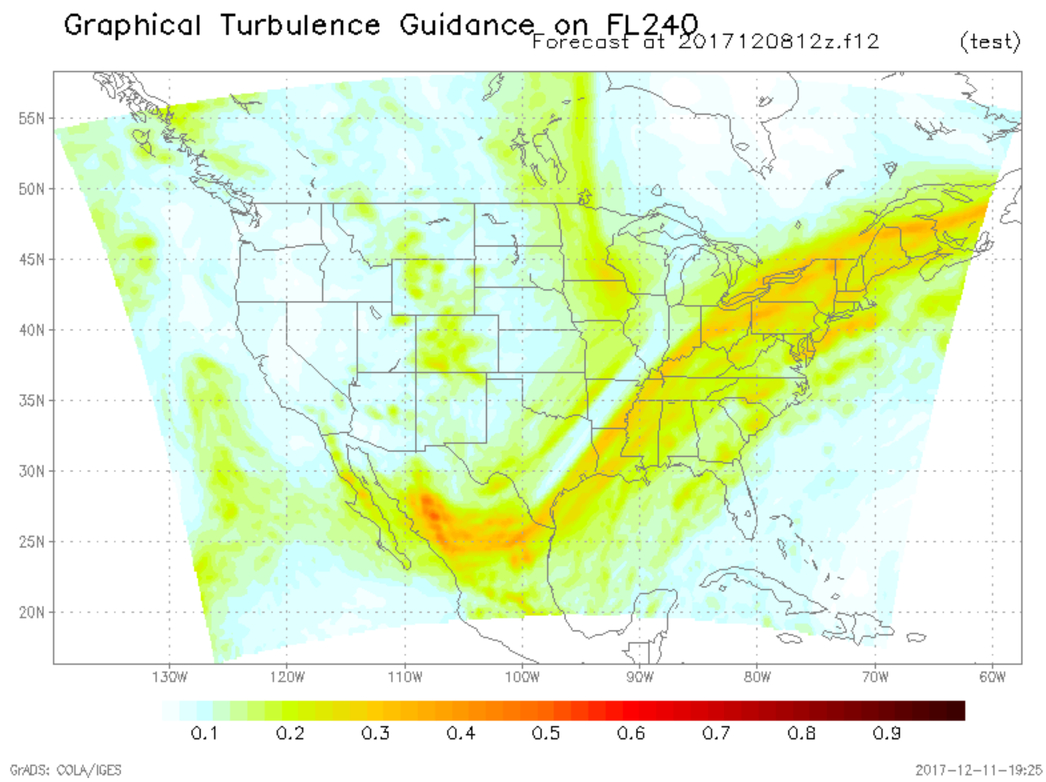


Figure 5. 12-hour forecast valid at 0000 UTC 20171209 at FL240 of the GTG output from a parallel version of the RAP Post Processing system.

Icing Product Alaska

In addition to aviation needs over the US, the AWT continues to support R2O activities that benefit Meteorological Watch Office (MWO) partner, the Alaska Aviation Weather Unit (AAWU). Developers at NCAR have extended the capabilities of FIP over the Alaska domain, called the Icing Product for Alaska (IPA) (Figure 6). Supported by FAA AWRP, the AWT has supported AAWU by sending them raw IPA output along with making these forecasts available through a secure webpage. The webpage was used by the FAA AWDE services in a user evaluation of IPA by pilots and other users in Alaska. Currently, the AWC and FAA are working towards a structured R2O process between the NWS and FAA and will begin demonstrating this on the IPA algorithm within the calendar year 2018.

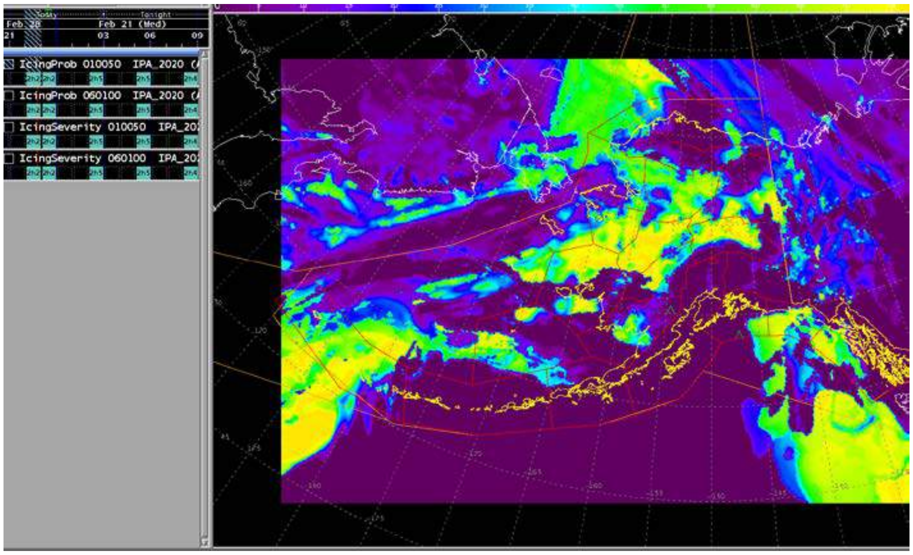


Figure 6. Icing Product Alaska - Forecast Icing Probability as currently displayed in IC4D, the product generation software used by AAWU.

Experimental WAFS Demonstration

The AWC also maintains a global responsibility as a World Area Forecast Centre (WAFC) as recognized by the International Civil Aviation Organization (ICAO). Aviation hazard forecasts are being enhanced as part of ICAO's Aviation System Block Upgrades (ASBU) for the Global Air Navigation Plan (GANP). One example is the global application of the GTG forecasting global turbulence in Eddy Dissipation Rate (EDR) units, as recognized as the official unit of turbulence observations by the ICAO (Figure 7). Also, icing forecasts are being converted to a categorical severity, using fewer colors than the previous icing potential forecast (Figure 8). The resolution will be enhanced from a 1.25° equal latitude and longitude grid to a 0.25° equal latitude and longitude grid. To support the transition of these forecasts for WAFC forecast users, AWT has developed a secure webpage demonstrating this global capability.

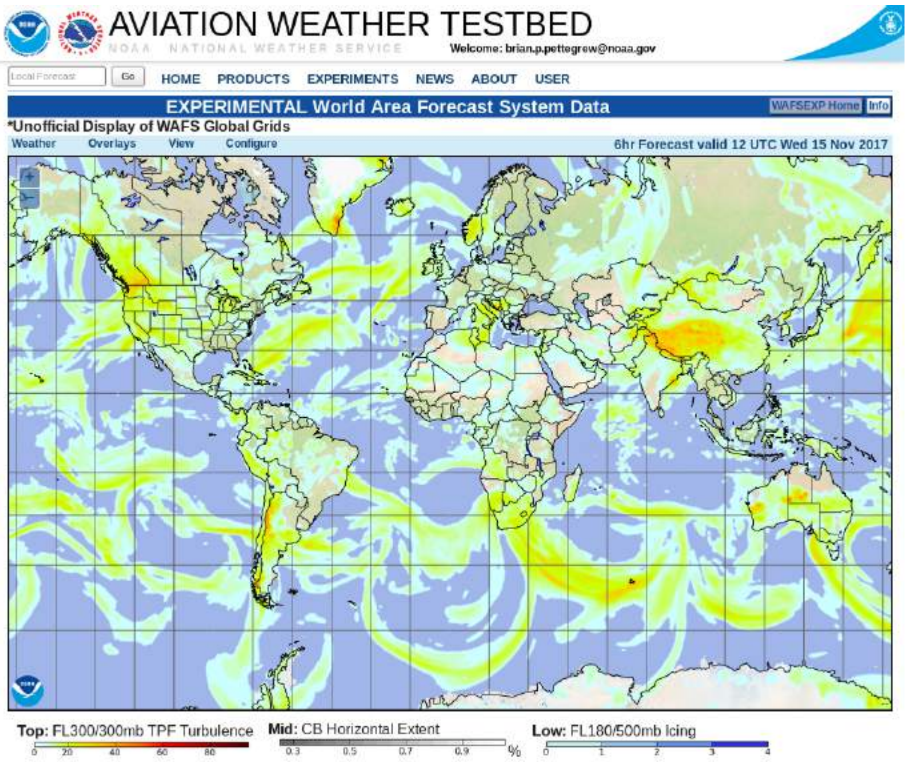


Figure 7. Experimental WAFS forecast of global GTG demonstrated on a secure AWT webpage.

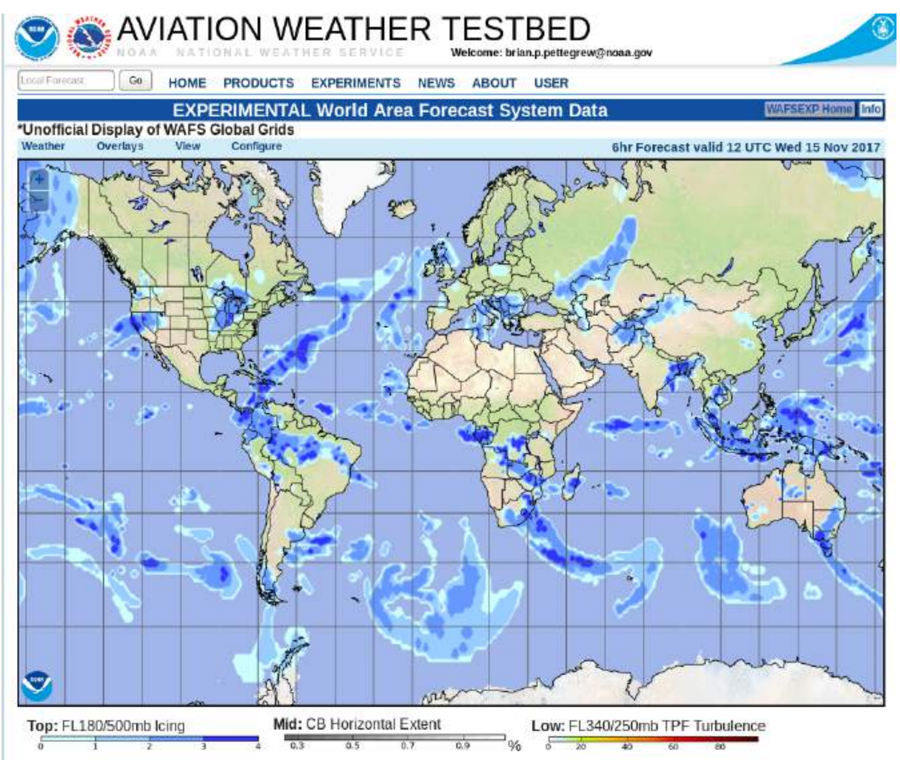


Figure 8. Experimental WAFS forecast of global Icing Severity demonstrated on a secure AWT webpage.

Graphical Turbulence Guidance - Nowcast
The AWT is supporting the transition of products that benefit forecaster and user capabilities in the area of impact based decision support. The Graphical Turbulence Guidance - Nowcast (GTGN) is a 15-minute nowcast product that infuses the nearest valid GTG forecast field and modifies it based on the presence of PIREPs, EDR observations, and the inclusion of Nexrad calculated EDR values, which is referred to as the Nexrad Turbulence Detection Algorithm (NTDA).

As part of the R2O effort, the AWT created a secure website for select users to access and evaluate the product. This was done in collaboration with FAA AWDE as part of a larger effort to determine the concept of operations in the aviation community.

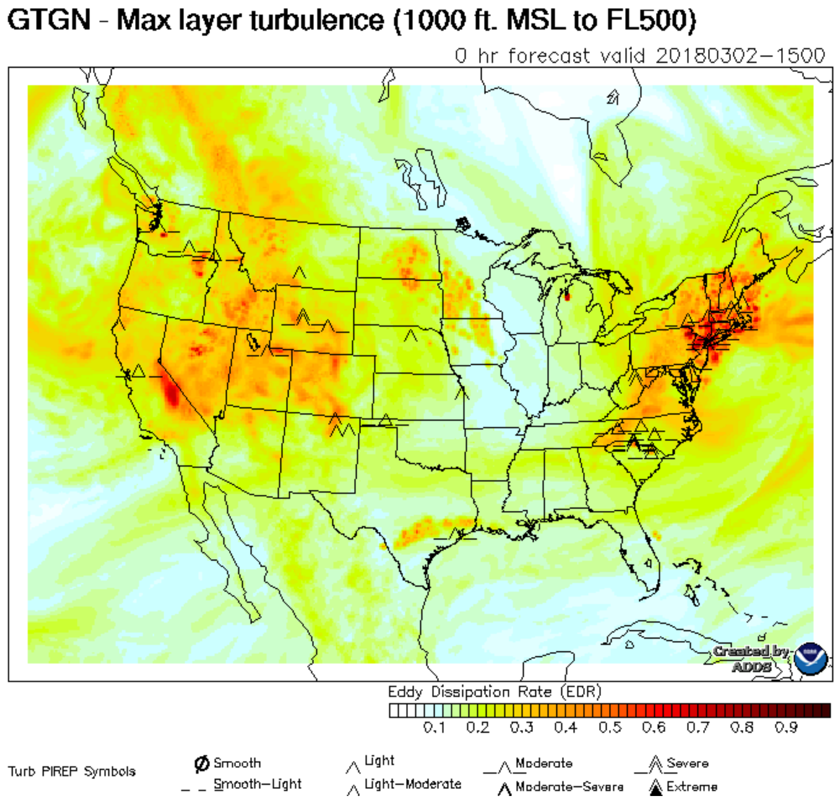


Figure 9. Experimental GTGN forecast over the CONUS demonstrated on a secure AWT webpage.

R2O processes demonstrated through the IPA product will be applied to the transition of the GTGN following calendar year 2018.

Other Accomplishments
GOES 16 - The GOES 13 satellite imagery was replaced with a new set of imagery from GOES 16. The global mosaics were upgraded in resolution from 10km to 4km. The CIP, which depends on global satellite imagery, was also updated to use the GOES-16 imagery to evaluate icing.
--Gate Forecast Tool - The user edit tool was opened up for evaluation. Feedback from several of the CWSUs was positive and work is being done to improve the editor capabilities based on their recommendations.
--TFM Convective Forecast (TCF) - A new archive page has been developed with enhanced features that can be used to quickly evaluate the forecasts. A verification product is being added to the page.

Presentations:

Pettegrew, B. P., 2017: Using Total Lightning to Support the Aviation Weather Center. 8th NOAA Testbeds and Proving Grounds Workshop, Kansas City MO, 25-26 April.

Vietor, D., 2017: AviationWeather.gov Update. EAA Airventure 2017, Oshkosh WI, 26-30 July.

Vietor, D., 2017: AviationWeather.gov Update. AOPA Fly-In 2017, Norman OK, 8-9 September.

Vietor, D. and J. W. Scheck, 2018: ADDS and PIREPs. Alaska Aviation Weather Workshop 2018, Anchorage AK, 5-6 February.

Vietor, D., 2018: HEMS Tool Status Update. US Helicopter Safety Team Infrastructure Summit, Washington DC, 14-15 February.

PROJECT TITLE: Research Collaboration at the NWS Aviation Weather Center (AWC) in Support of the Aviation Weather Testbed (AWT), Aviation Weather Research Program (AWRP), NextGen Weather Program.

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Lee Powell, Mick Ohrberg and Bret Sorensen

NOAA TECHNICAL CONTACT: Joshua Scheck

NOAA RESEARCH TEAM: Steven A. Lack (NOAA/NWS/AWC)

FISCAL YEAR FUNDING (Total Project): $2,184,938

PROJECT OBJECTIVE:

This research team is responsible for AWC's ground based satellite field and datacenter infrastructure with a primary mission of providing hardware platforms, virtual resources, technical expertise, and growth opportunities for research being done by fellow CIRA representatives in close collaboration with Federal liaisons. This three-person team is known as AWC's Datacenter Team. Geographically, responsibilities include the primary datacenter at the AWC in Kansas City, MO and a growing footprint to include the FAA's Air Traffic Control System Command Center (ATCSCC) in Warrenton, VA. This team supports disaster recovery exercises and facilities at Scott and Offutt Air Force Bases. This team's ultimate impact is realized when scientific improvements and breakthroughs are implemented in aviation weather prediction models. The Datacenter Team is instrumental in a product's research to operations (R2O) journey which is an intense procedure leveraging features and capabilities found in AWC's Aviation Weather Research Program (AWRP) and includes the Aviation Weather Testbed (AWT) and the center's web services platform.

The AWT at the AWC provides the infrastructure and facilities to develop, test, and evaluate new and emerging scientific techniques, products and services. The Datacenter Team falls into AWC's Aviation Support Branch (ASB) which collaborates with the other National Center for Environmental Prediction (NCEP) centers and the National Weather Service (NWS) to provide data and research for operational support. The (AWRP) products include Current and Forecasted Icing Products (CIP, FIP) and Graphical Turbulence Guidance (GTG). The ASB also supports AWC's web services which include the Aviation

Digital Data Service (ADDS), the World Area Forecast System (WAFS) Internet File service (WIFS) and the International Flight Folder Document Program (IFFDP). The Datacenter Team supports all these programs in addition to everyday and emergency operations at the AWC, ATCSCC and other partner facilities.

Milestones and projects shift yearly allowing the Datacenter Team to focus on specific areas of the IT infrastructure. This delivers modern IT management capabilities and standards-based infrastructure to reduce cost and increase efficiency. These projects along with milestones are set and monitored by CIRA personnel and AWC Management to ensure objectives are achieved in a timely fashion each year. The center utilizes weekly quad charts enabling visualization of progress and highlighting areas needing attention in order to achieve set goals. Yearly objectives do not always account for side projects or smaller research endeavors that may arise during the year. For the timeframe of April 1, 2017 – March 31, 2018 the team set the following goals:

Milestone	Completion Quarter
On time completion of seven NOAA8861 IT Security POA&Ms	3
Support AWT Summer Experiment	4
AWC RHEL 6 Conversion	2
AWC RHEL 7 Evaluation and Testing	4
Cisco 5585 Router Migration Planning	4
NetApp NFS and CIFS Backup Restructure	2
CAC Authentication Deployment to Linux	4
NAM Datacenter Network Migration Planning	3
Complete Audio/Visual Network Deployment	4

PROJECT ACCOMPLISHMENTS:

This year was focused on network and infrastructure security with some projects still in progress. A large undertaking every year is the annual accreditation and assessment of AWC's IT infrastructure and supporting environment. This is an audit following NIST 800-53 guidelines for medium systems. Findings were mitigated a quarter before the prescribed deadline. One finding from the Audit and Action Report (A&A) reflected a known issue within the routing infrastructure leading to a follow on project to supplant the NCO owned and operated Cisco 5585. Tremendous planning and testing in a development environment has taken place to ensure removal of the 5585 yields the least amount of downtime while letting AWC maintain a robust and reliable network. This same testing environment was also used to develop a plan to migrate the ATCSCC network supporting the National Aviation Meteorologist (NAM) datacenter infrastructure in Warrenton, VA, to a redundant 200 Mbps connection to the NCEP MPLS. This project is the culmination of over a year of planning and scheduling with NCEP Central Operations (NCO) and the Federal Aviation Administration (FAA).

Motivated by lack of support and the desire to develop with enhanced tools, migration from Red Hat Enterprise Linux 5 (RHEL5) to 6 was a big task this year. After this was successfully completed, the team undertook development with RHEL 7 to certify that security and operability met AWC standards. We plan to move forward with this operating system in 2018. Again, for security enhancement many weeks were taken to develop and implement Common Access Card (CAC) authentication into RHEL6 and 7 client workstations. The final component of this project was to implement a new security baseline, moving away from the United States Government Configuration Baseline (USGCB) and adopting Department of

Defense Security Technical Implementation Guides (STIG) as our new standard for Linux operating systems.

Support for AWT experiments this past year included technical assistance, testing and reliability enhancements to AWT equipment. Capitalizing on the foundation laid in previous years' projects allowed us to fully integrate audio/visual network and control surfaces deployed around AWC and the Operations floor, increasing the experiments' ability to disseminate information and enhance collaboration throughout the AWC. This was primarily possible due to the completion of the audio/visual system, the core of which is a full rack pictured in Figure 1. The processing power used to support AWT projects was also upgraded over the past year. We now provide 718 GHz of computer and 6.8 TB of memory to projects that support development and the AWT.

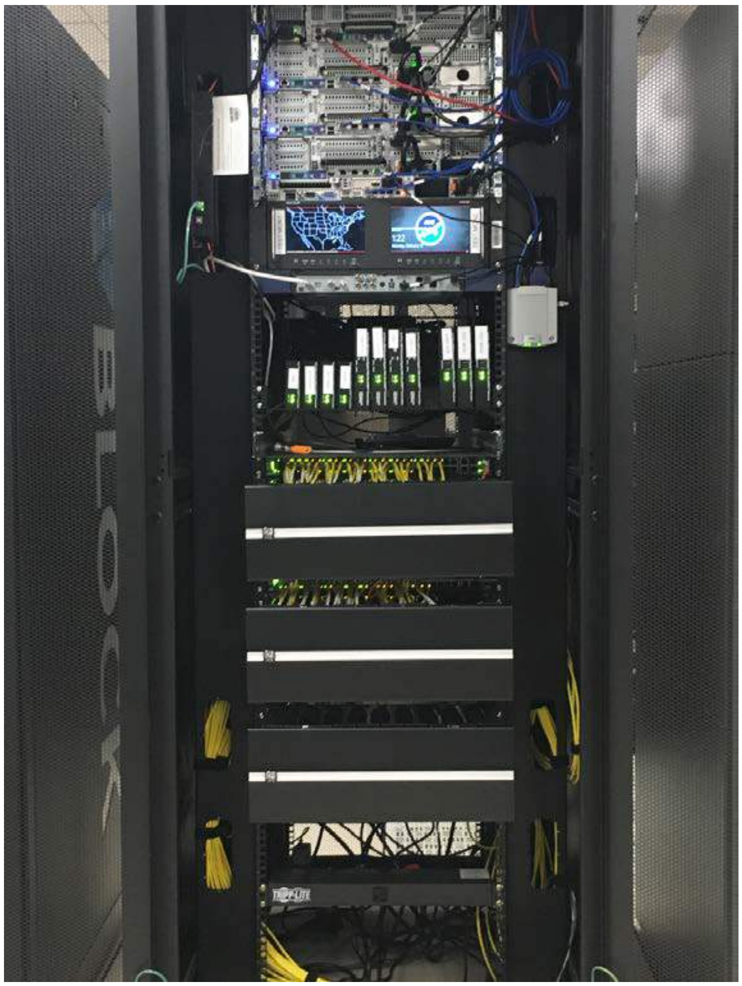


Figure 1. Central Rack for Audio/visual Network.

Additionally, local satellite work took place on the Geostationary Operational Environmental Satellites (GOES) Rebroadcast (GRB) and GOES antennas located at AWC. Multiple maintenance procedures were required to replace components that control these antennas, specifically within the In-Door Unit (IDU). The Datacenter Team replaced routers in the GRB racks in accordance with Harris' maintenance requests. As required the dishes were exercised quarterly to maintain proper lubrication and verify functionality; during one of these tests, a failed actuator was identified and repaired. Finally, with the retirement of GOES 13 at the end of 2017 the team started pulling feeds from GOES 15 by antennae redirection.

PROJECT TITLE: Research Collaboration at the NWS Aviation Weather Center in Support of the Aviation Weather Testbed, Aviation Weather Research Program, and the NextGen Weather Program

PROJECT TITLE: Aviation Weather Center Research to Operations

PRINCIPAL INVESTIGATOR: Sher Schranz, Bonny Strong

RESEARCH TEAM: Adam Kankiewicz, Amanda Terborg and Stephanie Avey

NOAA TECHNICAL CONTACT: Joshua Scheck (NWS/NCEP/AWC/ASB Branch Chief)

NOAA RESEARCH TEAM: Steve Lack and Austin Cross

PROJECT OBJECTIVES:

1--Clouds & Visibility (C&V)- GFA Expansion, Probabilistic C&V Display, C& V inclusion to NBM, AWT Cloud collaboration
2--Helicopter Emergency Medical Services (HEMS) - examination of NCVA replacement products
3--INtegrated Support for Impacted air Traffic Environments (INSIGHT) - development within both the AWIPS-2 and N-AWIPS frameworks

PROJECT ACCOMPLISHMENTS:

1--Clouds & Visibility (C&V)
Graphical Forecasts for Aviation (GFA) Expansion Effort
Coverage within the GFA is being expanded to provide Pacific Ocean, Caribbean and Gulf of Mexico coverage. We began work to implement 0.25 degree GFS and 13 km resolution extended RAP model data into current C&V GFA code to support the GFA expansion effort. This involved code development to replicate methodologies used with RAP model data within the current operational CONUS GFA. Output (C&V) grid variables needed for GFA expansion include sky cloud cover, visibility, ceiling height, and the resulting flight rules. An example of development output of the sky cloud cover from the GFS model (Figure 1) and RAP model (Figure 2) can be seen below. Additional work on this effort is focused on preserving the cloud common operating picture as much as possible between GFA elements (i.e., icing, convection, etc.).

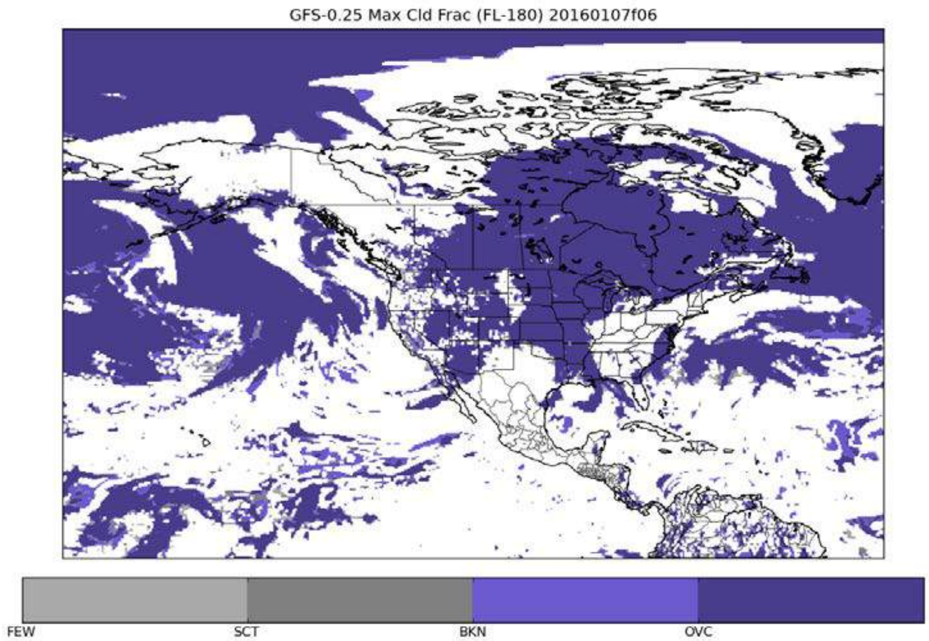


Figure 1. Sample GFA expansion coverage image of GFS model-derived sky cover

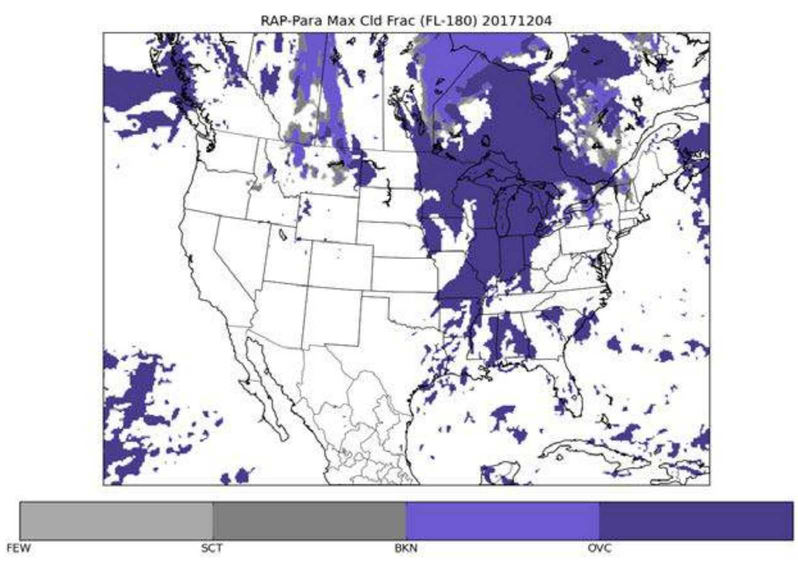


Figure 2. Sample GFA expansion coverage image of RAP model-derived sky cover

Probabilistic C&V Display Effort

Development work for probabilistic clouds and visibility (C&V) displays was done throughout the reporting period in close collaboration with the FAA's Aviation Weather Demonstration and Evaluation (AWDE) services team. This effort involved creating multiple sets of graphics as different ways to view probabilistic flight rule information from HREF model data. Several graphical iterations were done with feedback throughout from AWDE to arrive at final displays for the focus groups AWDE held in June 2017. An AWT website was developed for viewing the graphics from which AWDE can pull images for their storyboard presentation for end-user evaluations, and also for evaluation during the AWT 2017 Summer Experiment. An example of the HREF development graphics, and website presentation are shown below in Figures 3 & 4, respectively.

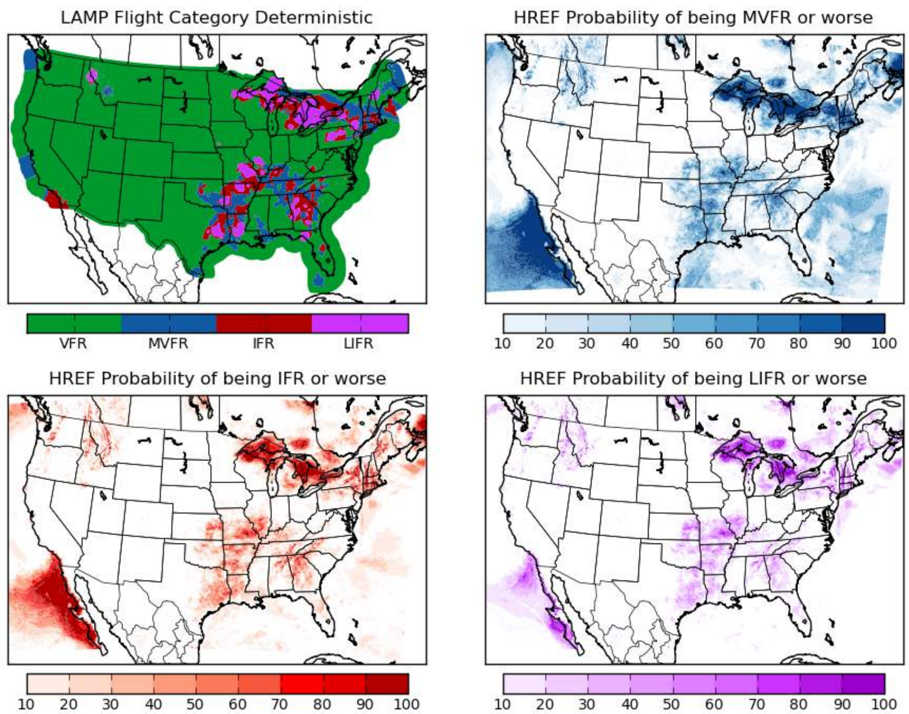


Figure 3. Comparison LAMP and HREF probabilistic forecast evaluation pages which AWDE used to evaluate how best to present probabilistic information to end users. Emphasis here is placed on worse than the current flight rule.

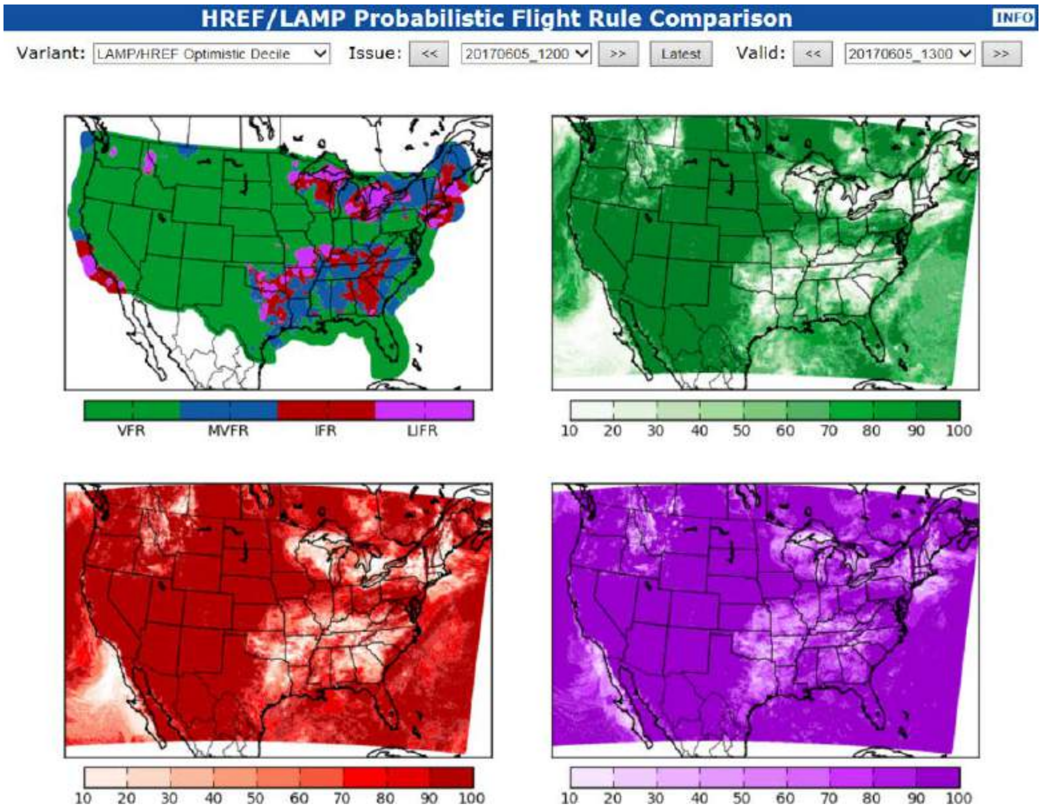


Figure 4. Comparison LAMP and HREF probabilistic forecast evaluation pages which AWDE used to evaluate how best to present probabilistic information to end users. Emphasis here is placed on better than the current flight rule.

Participant feedback was compiled from AWDE on probabilistic displays and developed into a final concept storyboard to deliver to FAA-AWRP (Task02 Mod15). The final concept design takes into account the preferences from end-user evaluations obtained by AWDE during focus groups as well as the AWT Summer Experiment. The future web-based platform will follow similar framework as the current GFA with capability to zoom in on areas of interest, move easily from product to product, and overlay current weather and airports/routes which would add value to the probabilistic information as well as aid in decision making. Example mock-up HREF-based screenshots are shown below in Figures 5 & 6, respectively.

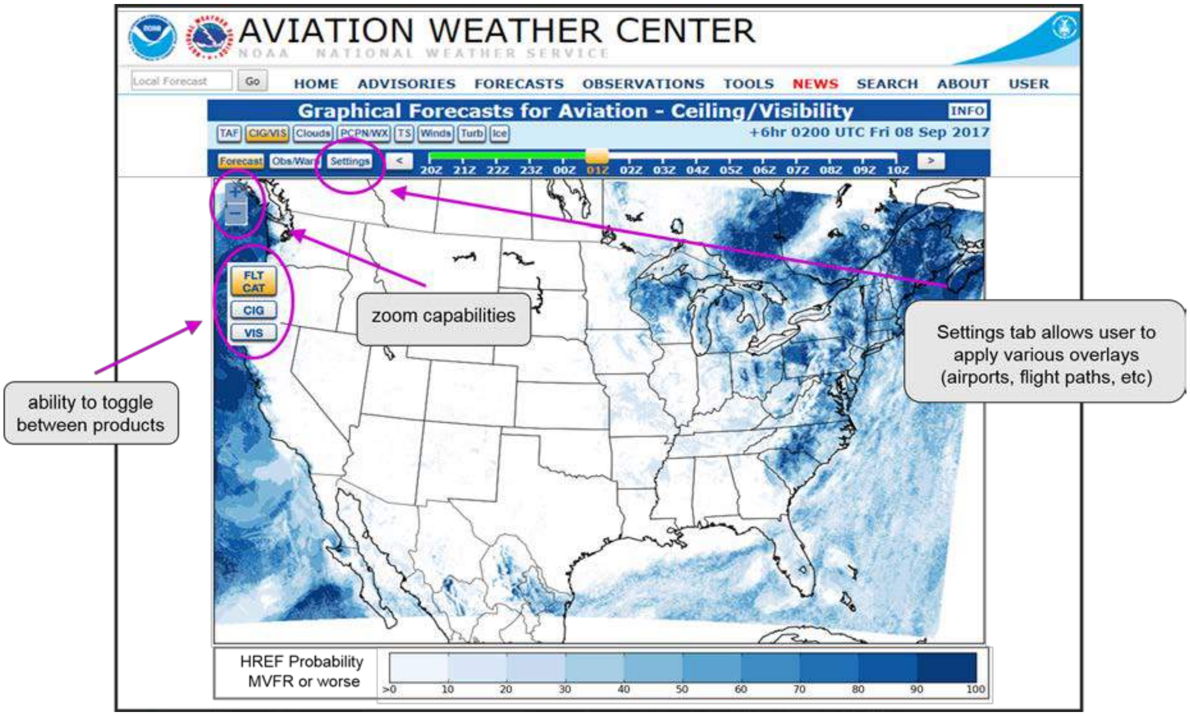


Figure 5. An example of the overall look of the probability product displayed in the GFA, meeting the preferences of the surveyed end-user. This highlights the combined probabilities of MVFR or worse conditions.

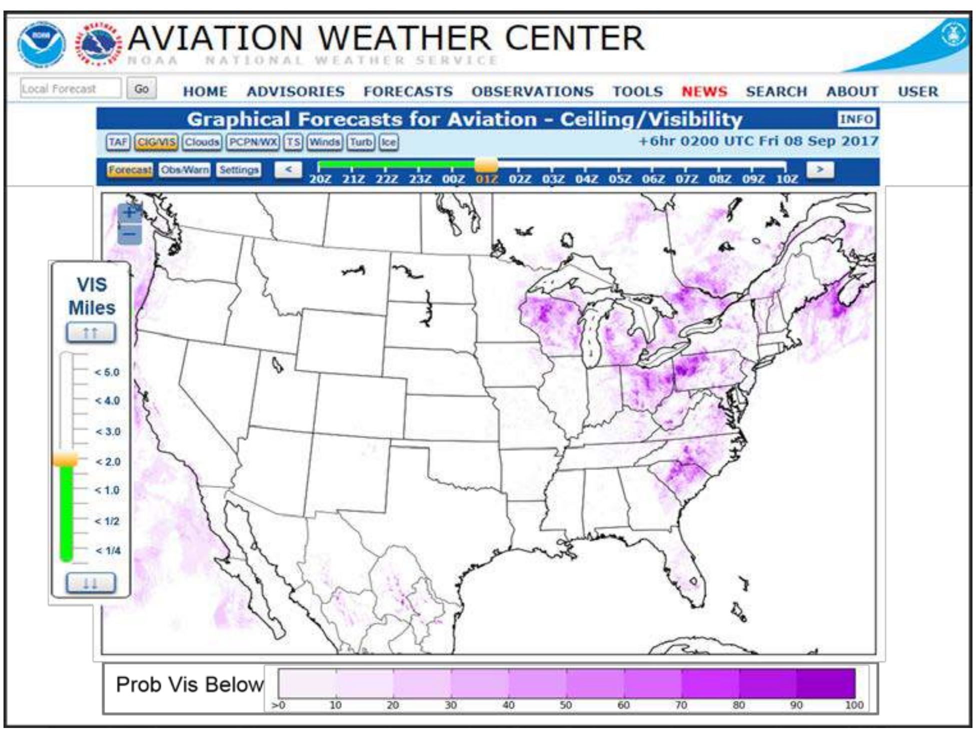


Figure 6. An example of what the probability of visibility might look like (based on user feedback), with a scroll bar to customize the various flight rule thresholds.

AWC Blended Mode Cloud Effort

The National Blend of Models (NBM) strives to blend numerical weather prediction (NWP) data with the end goal of creating a highly accurate and consistent gridded forecast. To best serve aviation interests, the NBM must expand its current ceiling and visibility forecasts to include cloud layers. This will support not only aviation weather enterprise partners, but also other service programs within the weather enterprise. The main challenge with blending forecast cloud layers is preserving discrete cloud layer details. NWP model 3-D cloud fields are the key to successful cloud layer forecasts; however, blending 3-D cloud fields without losing valuable cloud information is quite challenging. Figure 7 compares current 2-D NWP cloud results with a 3-D cross section of NWP cloud fraction. The vertical structure present in the 3-D cloud fraction cross section is crucial for deriving cloud layers needed for aviation C&V forecasting.

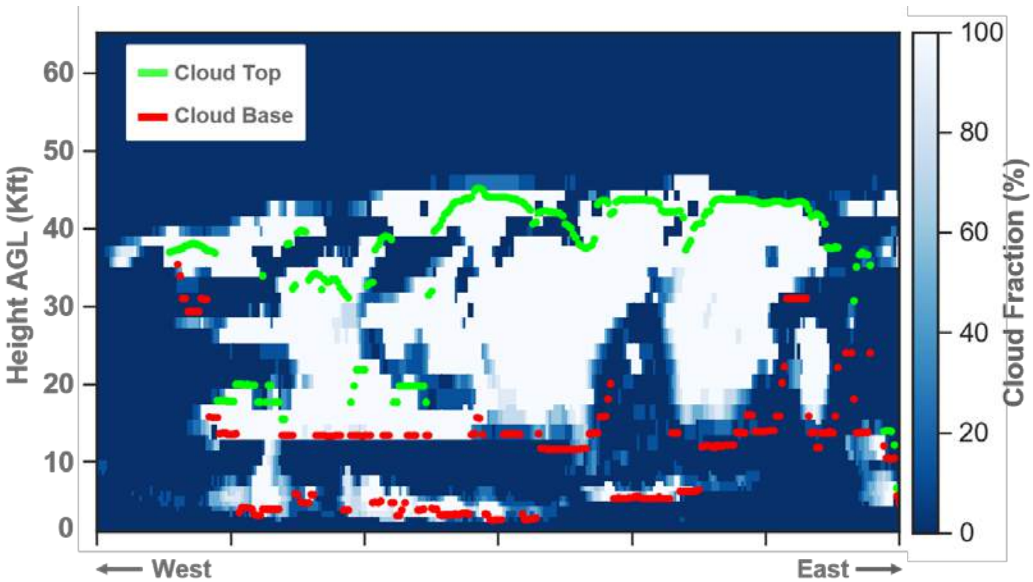


Figure 7. Example east-west cross section of the 2-D cloud base (red) and cloud top (green) fields from the HRRR model. The corresponding HRRR 3-D cloud fraction field is shown in the blue-to-white gradient field. Note the presence of several cloud layers which are not resolved in the current 2-D cloud base and cloud top NWP model fields.

Present C&V requirements for Weather Forecast Office (WFO) and AWC, including Graphical Forecasts for Aviation (GFA) and Terminal Aerodrome Forecast (TAF) needs, include the following:
Cloud ceiling height (BKN, OVC)
Cloud base height (FEW, SCT)
Presence of cirrus cloud
Cloud layer bases and tops
Cloud tops

To intelligently blend discrete 3-D cloud fraction, one must first determine the most prominent value therein, or the mode. The blended cloud mode methodology is illustrated in Figure 8. Application of the blended mode forecast methodology, including binning 3-D cloud fraction data into the different sky cover regimes (SKC, SCT, FEW, BKN, OVC), is shown to preserve discrete cloud details. Resulting blended mode model forecasts have been analyzed and satisfactorily demonstrated viability in meeting aviation weather needs.

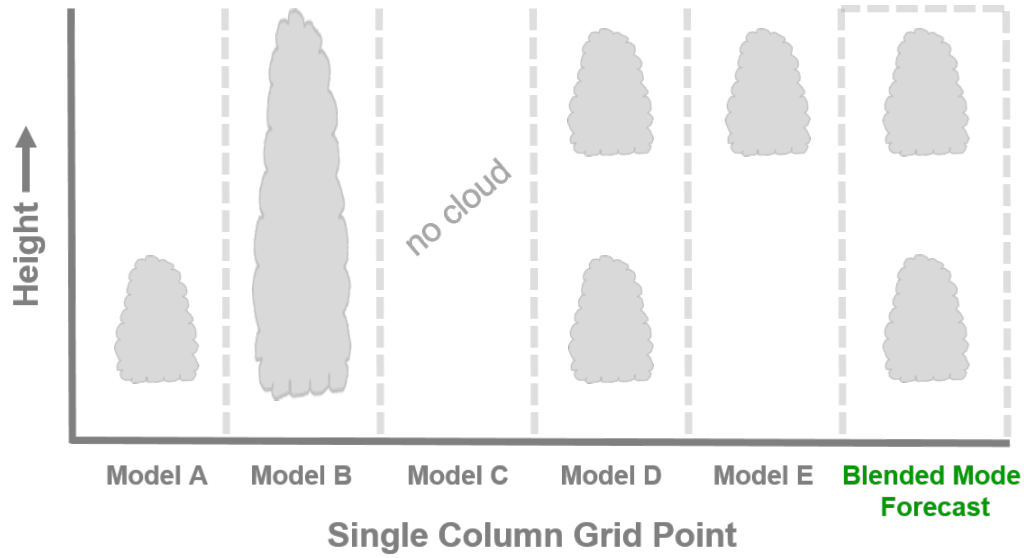


Figure 8. Schematic diagram of AWC blended mode forecast methodology. The goal is the dominant mode of the cloud layers present in a vertical cross section of NWP model cloud fraction forecasts.

To facilitate this effort, we have begun gathering hi-resolution model data feeds needed for aviation 3-D cloud C&V-project deliverables. NWP model data sourced include:
HRRR - hourly issuance, hourly leads out to 18 hour
NAM-Nest - 4x a day, hourly leads out to 48 hour
HIRESW-NMMB- 2x a day, hourly leads out to 48 hour
HIRESW-ARW- 2x a day, hourly leads out to 48 hour
HIRESW-ARWMEM2- 2x a day, hourly leads out to 48 hour

We worked with EMC and GSD to get hi-res model cloud fraction and cloud cover variables outputted on a common gridded grib2 data format to facilitate blended mode C&V forecasts. We then discretize the NWP cloud fraction data into sky cover bins to facilitate additional statistical mode processing. Sky cover bin ranges include the following:
SKC bin = 0 (Clear)
FEW bin > 0 to 31% Cloud Fraction
SCT bin > 31% to 57% Cloud Fraction
BKN bin > 57% to 99% Cloud Fraction
OVC bin > 99% Cloud Fraction

AWC blended cloud mode methodology is demonstrated on 3-D cloud fraction forecasts from the five high-resolution NWP models issued at 12 UTC on September 18, 2017. An overview of the weather conditions present during this time is shown in Figure 9. The focus of our forecast demonstration is the large cloud shield present over the Central United States. Figure 10 shows vertical North-South cross sections of the five high-resolution NWP model cloud fraction forecasts binned by sky cover. AWC blended mode model forecasting results are shown at the bottom of Figure 10 and are contrasted against the average binned sky cover cross section shown just above. Note that sharp cloud edge details are preserved, especially under BKN and OVC sky cover conditions, which are smoothed out and reduced to FEW and SCT sky coverage in the NWP forecast-averaged results. Some thinner lower cloud details are lost in the southern end of the mode cross section results due to the dominant mode being clear or partly cloudy. Additional blended NWP model cloud binning by flight rule and mode results are shown in Figures 11 & 12.

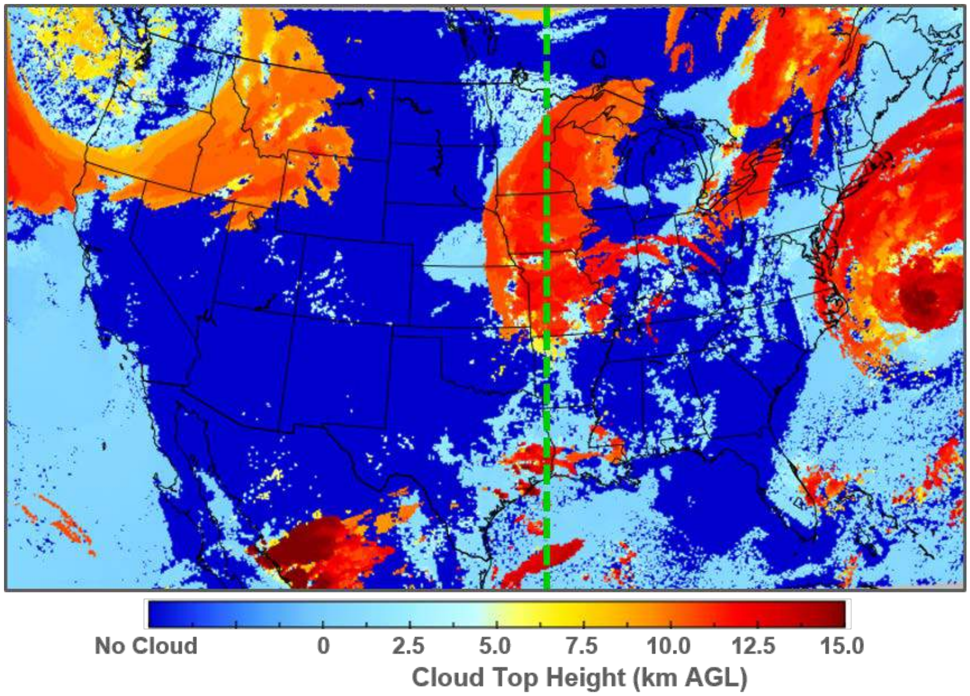


Figure 9. Cloud top heights from the NAM-Nest 6 hour ahead forecast issued at 12 UTC on 09.18.2017. The green dashed line indicates location of North-South cross section of forecast data referenced in Figure 10.

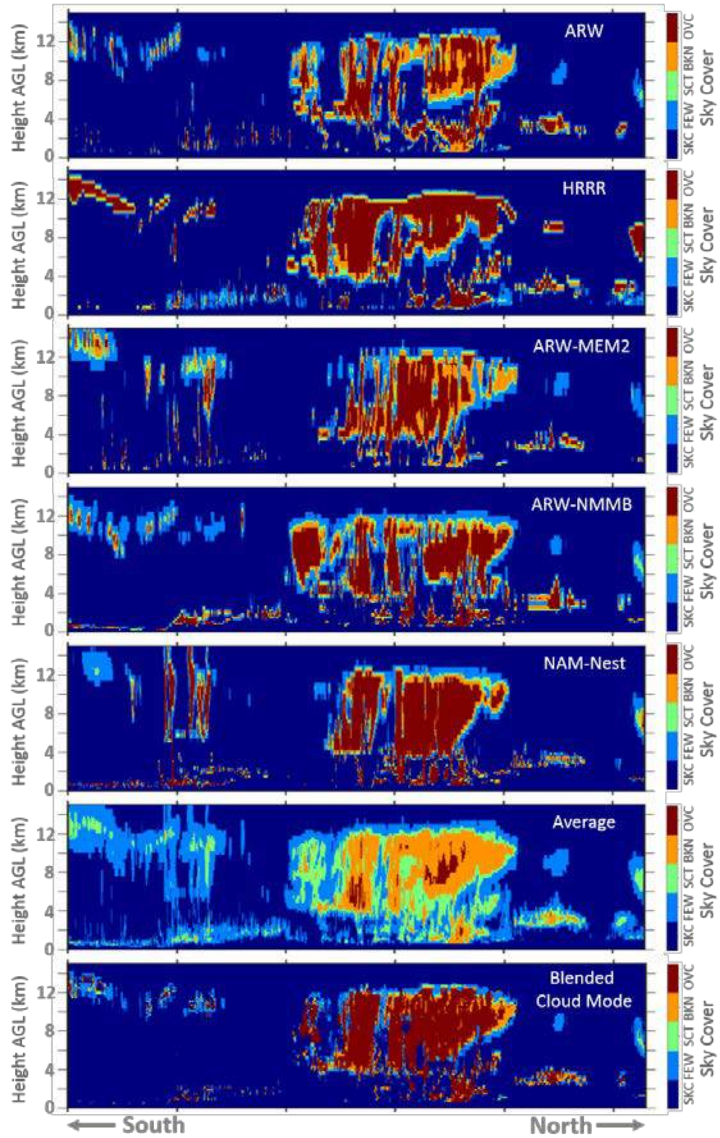


Figure 10. Example from recent blended mode cloud forecast work. North-South cross section (along N-S line shown in Figure 9) of five high-resolution NWP model cloud fraction binned by sky cover, average cloud cover and deterministic AWC blended mode cloud fraction results (bottom).

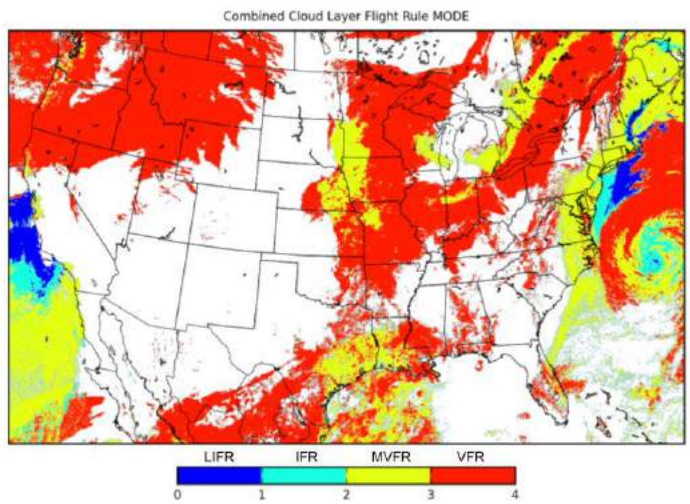


Figure 11. Example of Cloud Base Primary binning by flight rule. IFR/LIFR conditions are the most critical for aviation forecast needs.

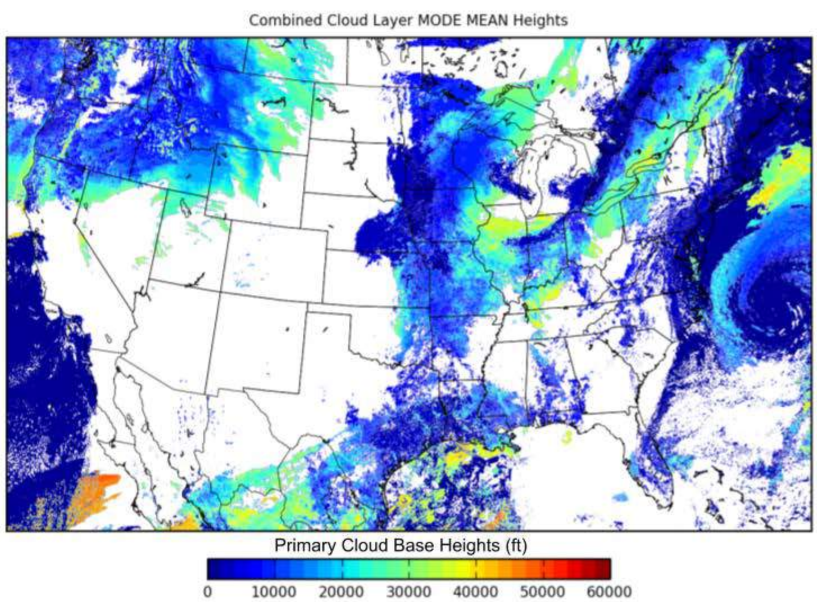


Figure 12. Example of NWP model blended mode Cloud Base Primary height results.

In summary, the AWC blended mode-based forecast model satisfactorily preserves 3-D cloud fraction details and promotes continuity between the various cloud forecast products needed to satisfy current and future FAA and NWS aviation weather requirements. Blended mode model cloud forecasts will continue to advance as improvements to cloud forecasts are incorporated into operational NWS models.

Near-term efforts include setting up a demonstration of blended model mode forecasts in the Aviation Weather Testbed for evaluation and fine-tuning. Blended model mode logic will also be tuned to preserve thin cloud layer forecasts during FEW and SCT sky cover conditions. Additional research will focus on improving blended model cloud forecasts below 3,000 ft. AGL where impacts to aviation are the greatest. AWC model blended mode cloud products will be demonstrated during the March 2018 AWT/OPG Winter Experiment where forecaster feedback will be used to evaluate and adjust current blended mode cloud products.

Long term efforts will focus on extending this work into the probabilistic cloud forecasting realm with the eventual goal of implementation into the NBM. This overall C&V task work will support us as we move forward with the concept of a fully-integrated field structure for clouds and visibility, eventually building consistency to support a common operating picture for cloud and ancillary aviation weather forecasts.

Collaboration in Support of a Common Operating Picture for Clouds and Visibility (AWT 2017 Summer Experiment Effort)
An important step toward creating a unified common operating picture for clouds and visibility (C&V) is producing collaboratively defined cloud and visibility grids through the National Weather Service (NWS) Digital Aviation Services (DAS). Once this is accomplished, the end result will be a consistent national grid of cloud and visibility in the National Digital Forecast Database (NDFD) to enhance the ability to provide decision support for end-users by driving forecasts including the Terminal Aerodrome Forecast (TAF) and the Graphical Airmen's Meteorological Information (G-AIRMET). In order to establish this process, work has been done toward the creation of a national C&V grid set in the DAS paradigm to populate first guess fields for the local NWS Weather Forecast Offices (WFO). WFO forecasters would then add in their local enhancements, resulting in a final aviation forecast that is both consistent and beneficial for all users.

To provide the best possible first guess C&V grids on the national level, improvements in how the Numerical Weather Prediction (NWP) models depict clouds is necessary. Current outputs of cloud base and ceiling height in the numerical models used at the NWS level involve post-processing of the cloud microphysics along with assumptions of relative humidity, precipitation, and boundary layer height. Cloud tops, however, are derived using the radiative transfer algorithm within the model infrastructure. This difference can lead to inconsistencies between the resultant cloud tops and ceilings reported in NWP forecasts. Scenarios with multi-layered clouds present are left unresolved in current cloud base and cloud top forecasts.

To combat these inconsistencies, NWP model developers are now providing three-dimensional (3-D) cloud fraction data on native vertical coordinate levels in their model output to provide a more accurate vertical structure of clouds. NOAA's Environmental Modeling Center (EMC) has incorporated 3-D cloud fraction output into the NAM12 and high-resolution NAMNest NWP forecasts. NOAA's Earth System Research Lab/Global Systems Division (ESRL/GSD) has done the same in their RAP, HRRR and HRRR-X NWP model outputs. By having a more complete representation of clouds in the vertical, AWC forecasters are able to accurately populate the C&V grids with cloud bases and sky cover derived from a common 3-D cloud dataset. Doing this on a national level will allow WFOs to move away from using their local tools to create these grids, and move toward a nationally collaborated C&V forecast.

Current TAF C&V Data Limitations
The current paradigm for C&V in Digital Aviation Services (DAS) is centered on WFO requirements to produce a TAF. These requirements include the need to complete primary cloud base, sky cover, visibility, and cloud ceiling forecast grids. Conditional grids for both cloud base and visibility, as well as a secondary cloud base grid, are also available for the forecaster to utilize for TAF creation. Once C&V grids supporting the final TAF forecast are completed, the forecaster can then use the TAF formatter, developed by GSD, to generate the familiar text strings end users are accustomed to seeing in the TAF.

Unfortunately, the current editable fields in DAS, combined with the TAF formatter, do not fully satisfy TAF reporting needs. Currently, only two cloud base options are possible, where up to three cloud bases can be reported in a TAF. For example, to create a TAF that reports "SCT BKN BKN" for multiple layers of sky cover, a forecaster would have to hand-edit the current production TAF to account for the additional layer of sky cover. Another shortfall of the current TAF framework is that it does not support all cloud coverage possibilities through the cloud layers. The current DAS paradigm does not account for the sky cover that corresponds to the secondary cloud base grid. Thus the TAF formatter must make some assumptions as to what this coverage is based solely on what is given in the primary sky cover grid, and does so by defaulting to one sky coverage category below what's currently reported for primary sky cover. If the primary sky coverage represents a cloud ceiling (i.e., BKN or OVC), the sky coverage is set to SCT. In certain instances, the forecaster may want to report an additional BKN or OVC layer which would have to be added in by hand after running the grids through the TAF formatter. By utilizing the new 3-D cloud fraction information from the NWP models and an additional editable sky cover field, one can now incorporate cloud layers, along with consistent cloud bases and tops, into improved C&V forecast products to support aviation forecast needs.

AWC C&V Software Development Processing Advancements

Current 3-D cloud fraction data processing methodology used by AWC developers starts from the surface and works up through the atmospheric column, identifying cloud layer fractions that exceed the various cloud cover thresholds for few (FEW >=0.125), scattered (SCT >=0.375), broken (BKN >=0.625), and overcast (OVC >=0.99) sky cover on grid point by grid point basis. If sky cover conditions are met for a cloud ceiling (i.e., BKN or OVC) in a given column, that height is reported as the primary cloud base, otherwise the primary cloud base is reported as the next significant cloud layer. The corresponding cloud fraction at the cloud base primary height is then used to populate the primary and secondary sky cover grids. The schematic diagram shown in Figure 13 further illustrates this logic.

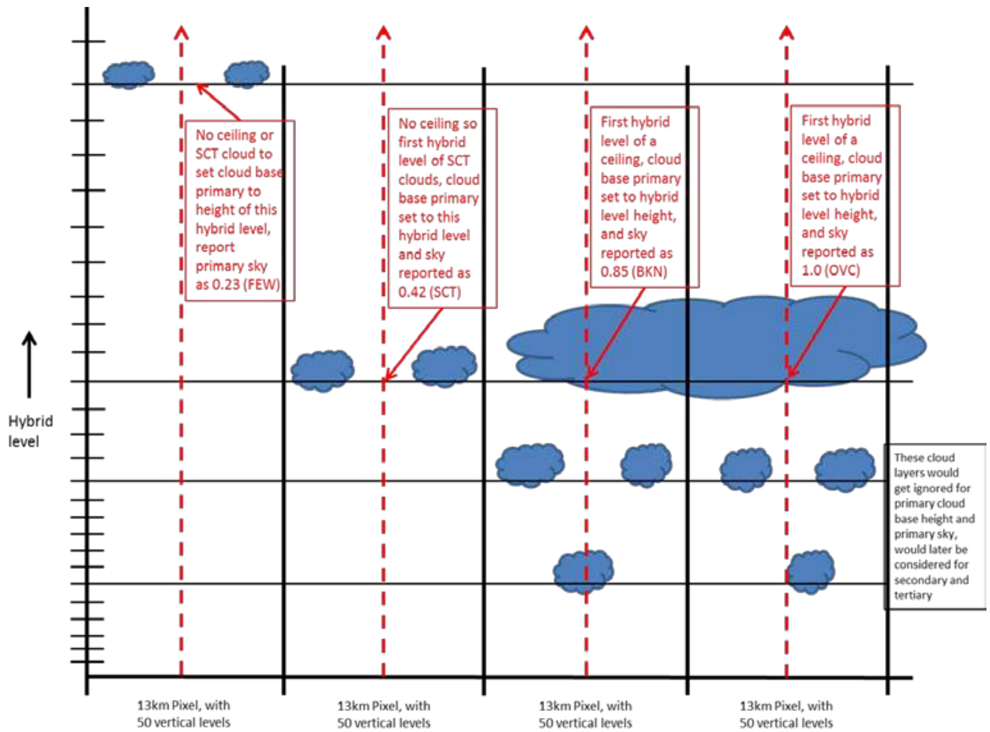


Figure 13. Schematic diagram illustrating the logic to get sky cover and primary cloud base from the surface up using the 3-D cloud fractions available in the model output. Cloud fields which include less than BKN sky cover under a cloud ceiling are currently ignored in the DAS primary sky cover grid (as observed in the two right columns of this schematic).

While this 3-D cloud fraction processing methodology can be computationally intense, it allows for a consistent cloud picture from base to top. Some early verification work of the resultant primary cloud base and sky cover grids has been done by comparing results against Real Time Mesoscale Analysis (RTMA) observations. This includes computing cloud ceiling grids from the combination of the AWC computed cloud base and sky cover fields and comparing with RTMA cloud ceiling, as well as comparing the resultant AWC primary sky with total sky cover from RTMA. An example of a cloud ceiling comparison between the AWC-NAM12 forecast versus the RTMA analysis valid at the same time can be seen in Figure 14. Here we observe similar, but smoother, AWC-derived cloud ceiling features as compared to RTMA cloud ceiling observations. This is due to the coarser, 12 km horizontal resolution of the NAM NWP model. Another example is shown in Figure 15 which compares the AWC-HRRR cloud base to corresponding RTMA cloud base analysis. Reasonable correlation is noted between the 2 hour ahead AWC-HRRR forecasts and resulting observations of primary cloud base.

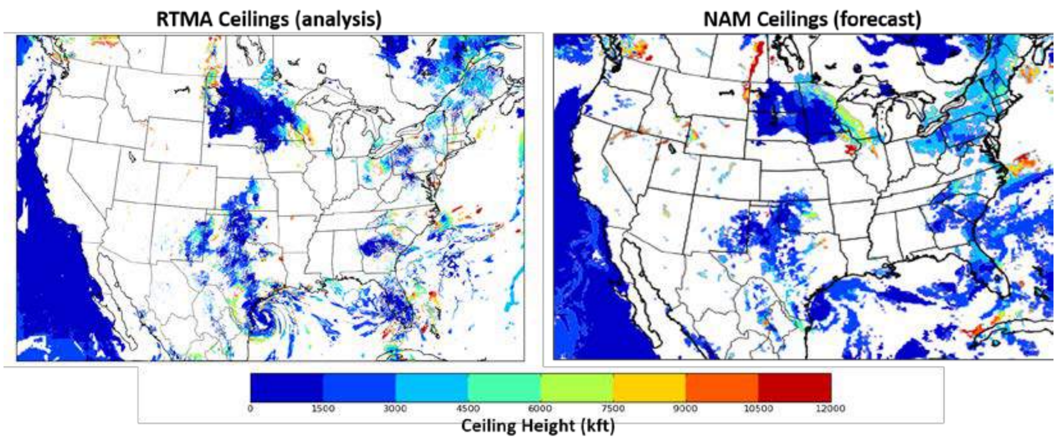


Figure 14. Cloud ceiling derived from the 3-D cloud fraction output from the NAM12 model 2 hour ahead forecast (right) compared with the RTMA analysis cloud ceiling (left) from 1700 UTC on August 25, 2017.

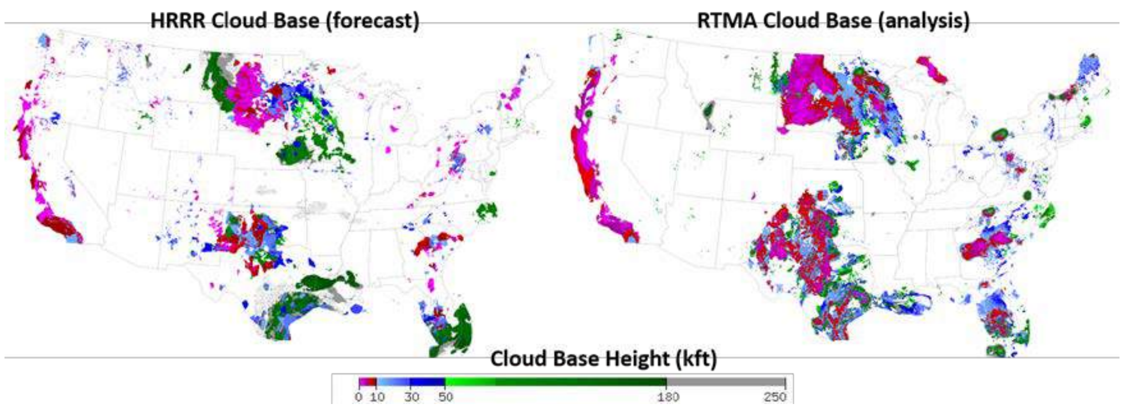


Figure 15. Cloud base derived from the 3-D cloud fraction output from the HRRR model (left) compared with the RTMA reported cloud ceiling (right) from 1800 UTC on August 25, 2017. The color table is consistent with the one currently used in DAS and corresponds to the aviation flight rules, with pink representing LIFR conditions with respect to cloud base.

This 3-D cloud fraction processing methodology was run on RAP, NAM, NAM Nest, and HRRR model output at AWC and used to populate the first-guess DAS Graphical Forecast Editor (GFE) grids evaluated during the 2017 AWT Summer Experiment. The goal here is to move toward a viable solution using this new 3-D cloud fraction methodology without adding significantly to workload, and still produce useful output for the end user. To this end, developers at AWC have conformed to a national grid paradigm that is consistent with the current WFO DAS paradigm, and added in an auto-populated secondary sky cover grid. This additional grid is designed to enable more flexibility, allowing the forecaster to edit coverage to derive a TAF with any mix of sky coverage (e.g., SCT, BKN, BKN, etc.), which is currently not possible in DAS without the forecaster making hand edits to the production TAF.

2017 Summer Experiment Collaboration C&V Grid Plans

The 2017 AWT Summer Experiment was a collaborative effort between the AWT, the NWS Operations Proving Ground (OPG), and the FAA's Aviation Weather Demonstration and Evaluation (AWDE) services group. Figure 16 shows participants on the first day of the 2017 AWT Summer Experiment. The experiment evaluated collaboration between AWC and local WFO forecasters through the passing and editing of the DAS grids using the Advanced Weather Interactive Processing System (AWIPS) GFE. Participants in the AWT created the national scale first-guess C&V grids, and then passed them along to OPG who simulated three different WFO offices editing the national grids on the local scale. This process simulated a collaborative forecast process between a national forecast center and the local WFO. The resulting final forecast grids from the OPG will then be representative of the common operating picture for clouds and visibility, from which all NWS C&V products and services could be informed.

Figure 16. 2018 Aviation Weather Testbed Summer Experiment kickoff picture and collaborative partners. NWS Director Dr. Louis Uccellini was in attendance (near right seated at table) on the starting day of the experiment.

The national scale grids will include the current DAS paradigm with the addition of a secondary sky cover grid, which represent the corresponding sky cover percentage of a given secondary cloud base deemed necessary by the forecaster for the aviation forecast. A smart tool (as illustrated in Figure 17) has been developed in GFE to easily fill this secondary sky cover grid based on the current TAF formatter logic, while keeping the workload associated with editing a grid to a minimum (a key goal). Then, if the forecaster so chooses, they can edit this new sky cover field as needed to produce the most accurate gridded area forecast and resultant point-derived TAFs.

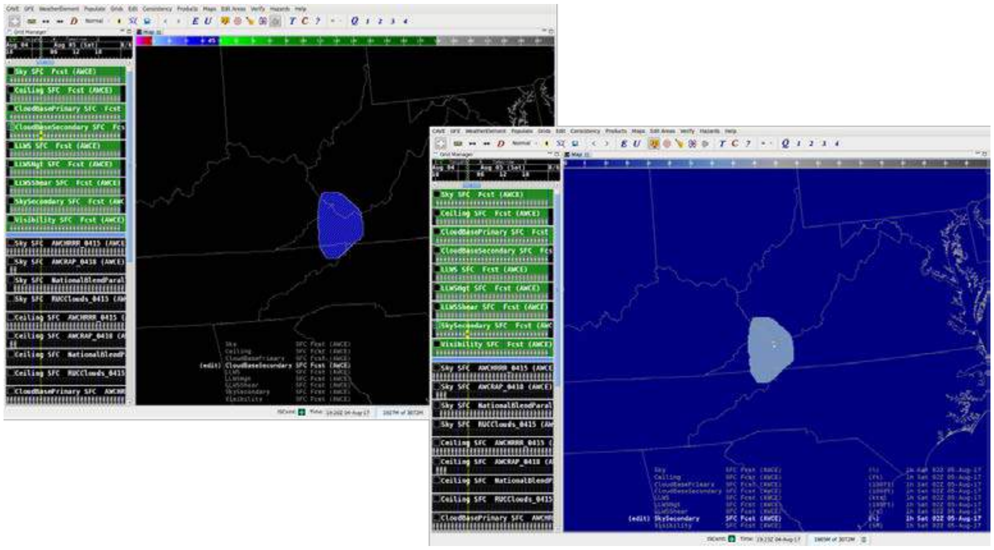


Figure 17. The secondary cloud base grid (left), and the resultant secondary sky cover grid (right) populated using the tool that assigns a percentage of sky cover based on the primary sky cover, and is consistent with the TAF formatter rules.

The national level C&V grids scrutinized during the 2017 Summer Experiment were divided into two halves, the East and the West, allowing participants to focus on one half of the CONUS each day of the experiment. An example of an Eastern US primary cloud base grid is shown in Figure 18. Given the challenge of forecasting accurately over such a large area, even just one half of CONUS, the AWDE team facilitated morning briefings for participating AWT forecasters highlighting areas of concern for aviation impacts, allowing for focused efforts on high-impact areas on the national level. The AWDE team was also remotely observing AWT forecaster methods at the various work desks, as well as evaluating the final C&V grids and published TAFs.

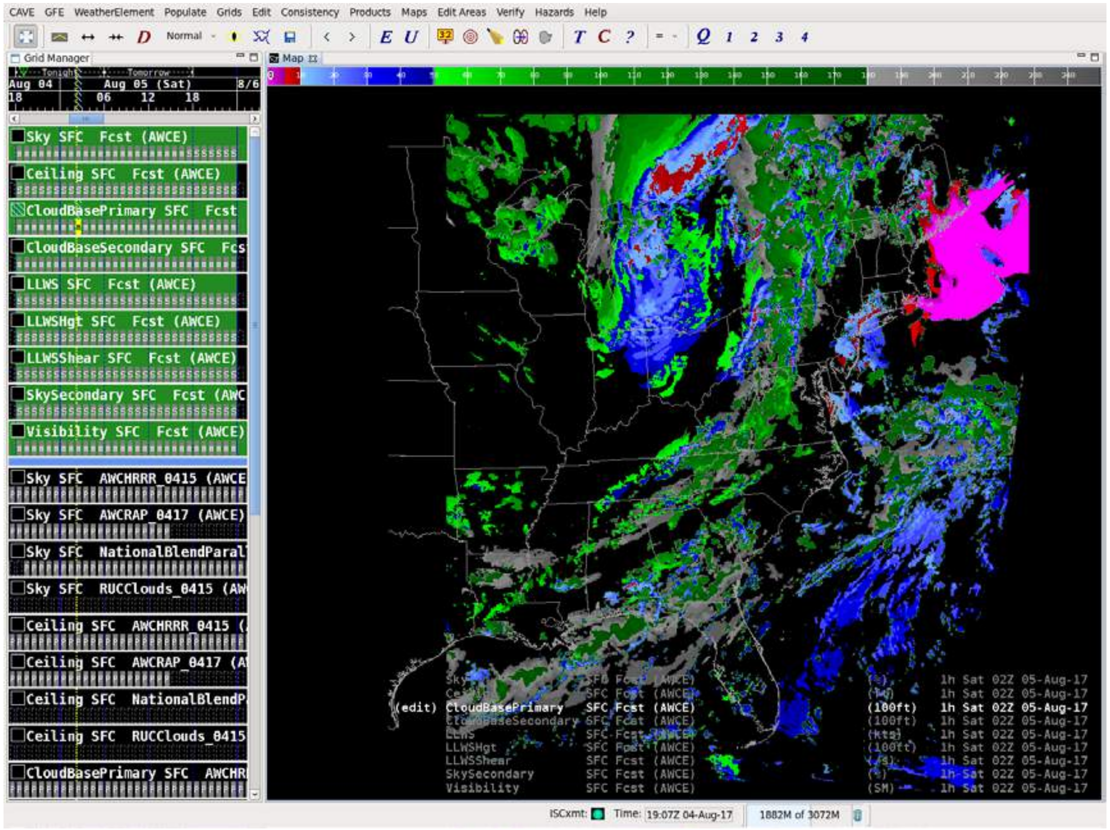


Figure 18. An example of the primary cloud base grid over the eastern half of the CONUS, which will be one of the two national grid focus areas targeted in the 2017 Summer Experiment.

The daily schedule of C&V grid creation and collaboration started on the national side (AWT) with forecasters evaluating current weather conditions and determining which AWC model derived sky cover and cloud bases had the best grasp of current conditions. Forecasters then made edits to the grids for a 0-30 hour ahead forecast to support the 18Z TAF reporting requirement. Figure 19 highlights possible WFO coverage options available for OPG participants. AWT forecasters on the national level had no prior knowledge of where the OPG simulated WFOs were, and focused their efforts on refining the C&V grids based on AWDE's input, and their overall feel for developing National Airspace System (NAS) impactful weather. Participants from OPG then visited the AWT for a briefing of what the national forecasters were looking at from a weather perspective, and learned how they were planning on populating their forecasted C&V grids. This interaction simulated how a national forecast center would collaborate with local WFOs to refine a forecast during impactful weather events before handing off their forecast C&V grids.

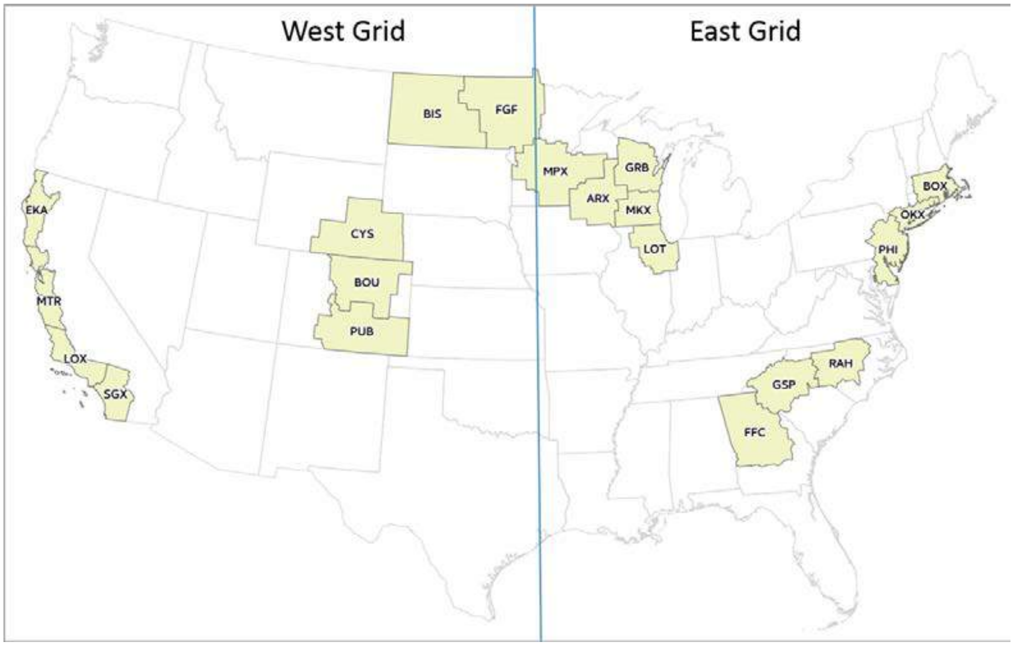


Figure 19. A map highlighting the possible WFOs that were pre-configured for the experiment that OPG simulated. The middle blue line denotes the east/west division of the CONUS grid. Three WFOs were selected for simulation purposes during each day of the 2017 Summer Experiment based on current NAS weather and technical concerns.

Once the AWT forecasters have edited and finalized their C&V forecast grids, they then were published and sent on to OPG to be enhanced and edited as needed on the local WFO scale. Another round of collaboration took place with the AWT and OPG participants so that simulated local WFO forecasters could ask questions of the national forecasters, and give some initial feedback on the starting C&V grids they were given. OPG participants then ran their final C&V grids through the TAF formatter, with the resultant TAFs compared with the operational TAFs issued from the same real-world WFOs. AWDE participants also had a chance to evaluate the final grids and TAFs and give their feedback from an end-user perspective.

Feedback and comments from the participants on all sides were collected throughout the two weeks, as well as during a final break-out session on the last day of each week during the experiment. AWC gathered valuable feedback throughout the successful 2017 Summer Experiment to better refine the process and collaboration of creating national C&V forecast grids that will support the goal of a common operating picture for aviation.

2--Helicopter Emergency Medical Services (HEMS) Project
The AWC is currently working on examining possible replacement products to the National Ceiling and Visibility Analysis (NCVA) in the Helicopter Emergency Medical Services (HEMS) tool. The tool is used to show weather conditions for short-distance and low-altitude flights that are common for the HEMS community. HEMS operators are highly sensitive to changing and/or adverse weather conditions and need weather information presented for non-weather experts quickly and effectively.

The NCVA product is derived solely from METAR point observations and therefore may, as a function of distance from a METAR, misrepresent actual conditions. Localized Aviation MOS Program (LAMP), Real-Time Mesoscale Analysis (RTMA), and RTMA - Rapidly Updating (RTMA-RU) ceiling and visibility products use NWP model data in addition to observations, and thus create a more robust analysis. These products are being evaluated as possible replacements for use in the HEMS tool. Examples of simultaneous NCVA (left), LAMP (center) and RTMA-RU (right) C&V analyses are shown in Figure 20 below.

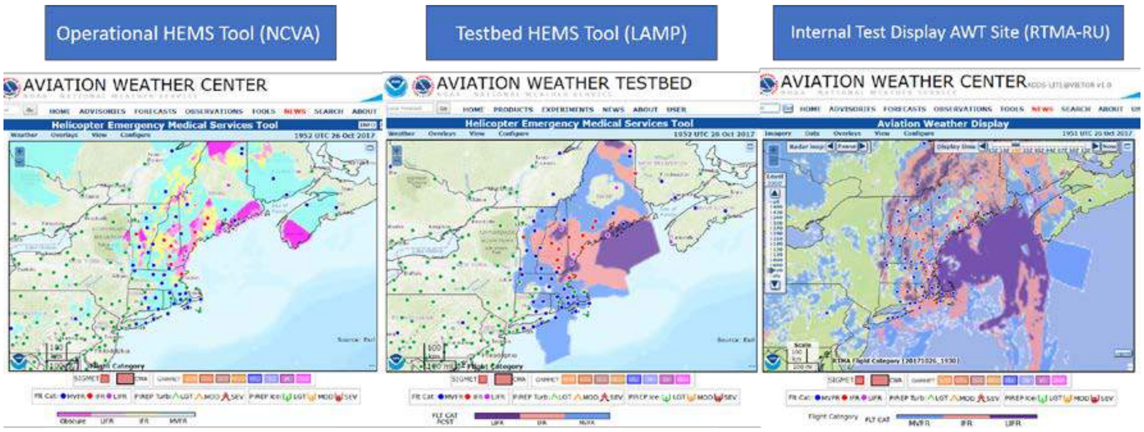


Figure 20. Examples of simultaneous NCVA (left), LAMP (center) and RTMA-RU (right) C&V analyses.

Before final implementation of a replacement C&V analysis product can be made within the HEMS tool, an in-depth evaluation of the products and how they are used by the HEMS community is required. Determining the quality of the products as well as how they are presented is a critical step toward reaching the end goal of improved C&V guidance within HEMS. The GSD QA group is leading this evaluation effort of the three C&V products to help determine which is most suited for HEMS Tool C&V analysis fields. AWC devised a plan for going forward with this evaluation that involves quality assurance of both products, end-user evaluations from the HEMS community on how the data is presented, and a framework to monitor latency of the products to ensure they are providing valuable information in a timely manner to meet the short-term needs of HEMS users.

Evaluation involved acquiring the latest parallel versions of RTMA and RU-RTMA which provides ceiling and visibility analysis every 15 minutes. Development work was done to create image displays for comparison of the RTMA (operational & parallel), Ru-Rtma (parallel), NCVA, LAMP, and MADIS observations of flight rules. The website was set up for evaluation during the AWT Summer Experiment, to gain feedback from end-users to help determine the final design of the HEMS Tool. Two sample website images are shown in Figures 21 & 22. AWC will continue to work with GSD to facilitate the overall HEMS C&V analysis QA effort. Additionally, AWC will facilitate HEMS website testing and evaluation on the AWT testbed website.

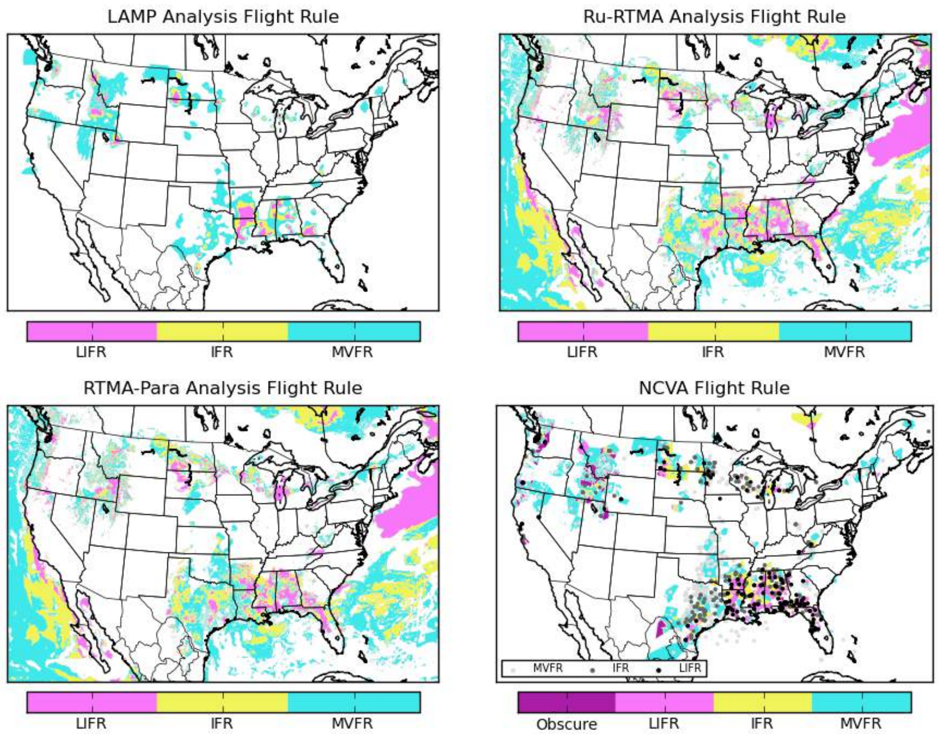


Figure 21. Example HEMS testbed images of LAMP (upper left), RTMA-RU (upper right), RTMA-Para (lower left) and NCVA (lower right) C&V analyses.

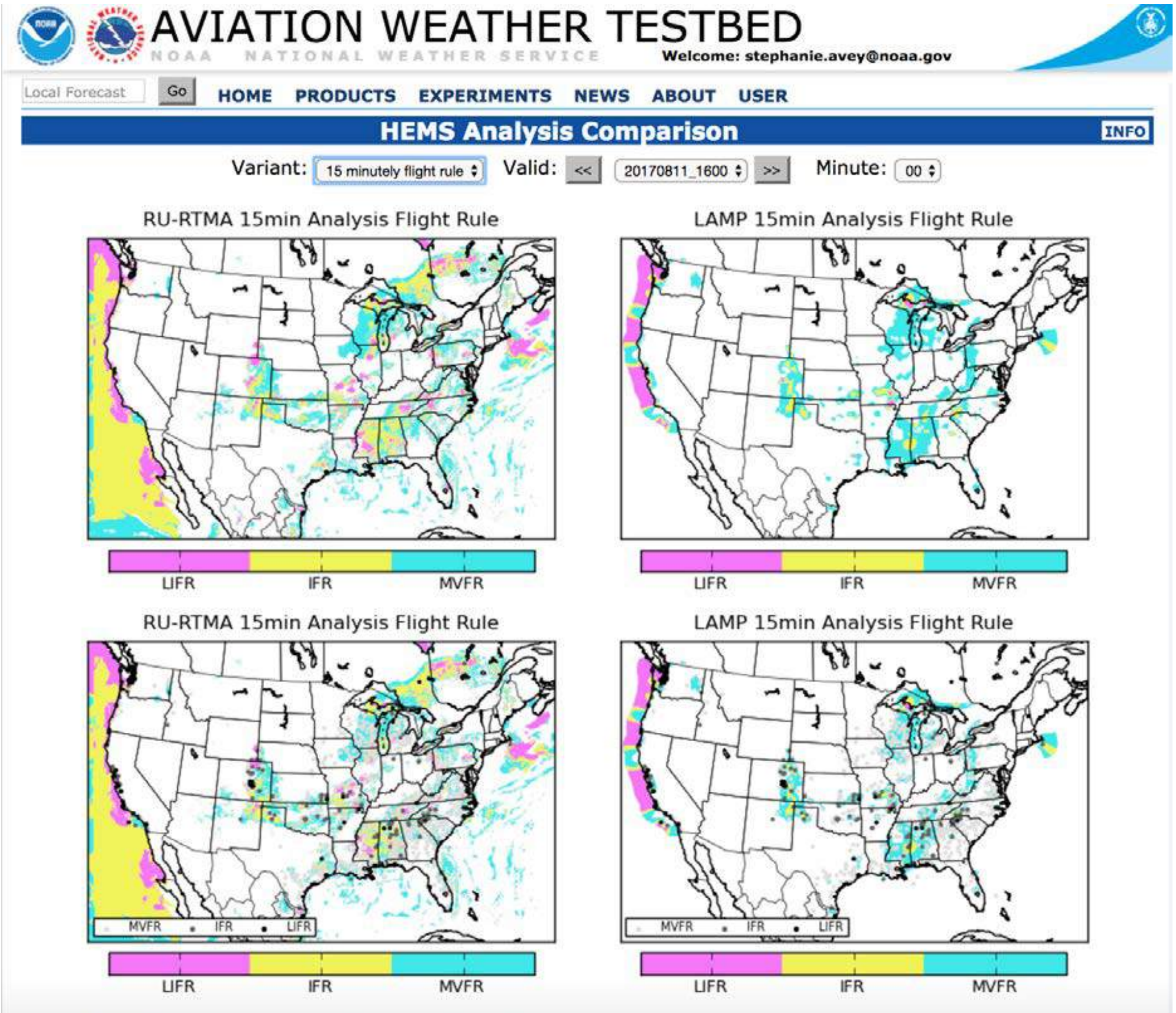


Figure 22. Example HEMS Page images of RTMA-RU (left column) and LAMP 15 minute analyses. Surface observations are overlaid on analysis data on the lower figures.

3--INtegrated Support for Impacted air Traffic Environments (INSIGHT)

INSITE is a prototype tool under development at NOAA's Global Systems Division (GSD) in the Earth System Research Laboratory (ESRL) of the Office of Oceanic and Atmospheric Research (OAR). The tool supports National Weather Service (NWS) operations for the convective weather forecast process by providing forecasters an interactive web-based application for identification of potential impacts or constraints to the National Airspace System (NAS) due to forecast convective weather. Figure 23 illustrates the overall INSITE concept for improving Aircraft Traffic Flow (ATF) management in a decision support framework.

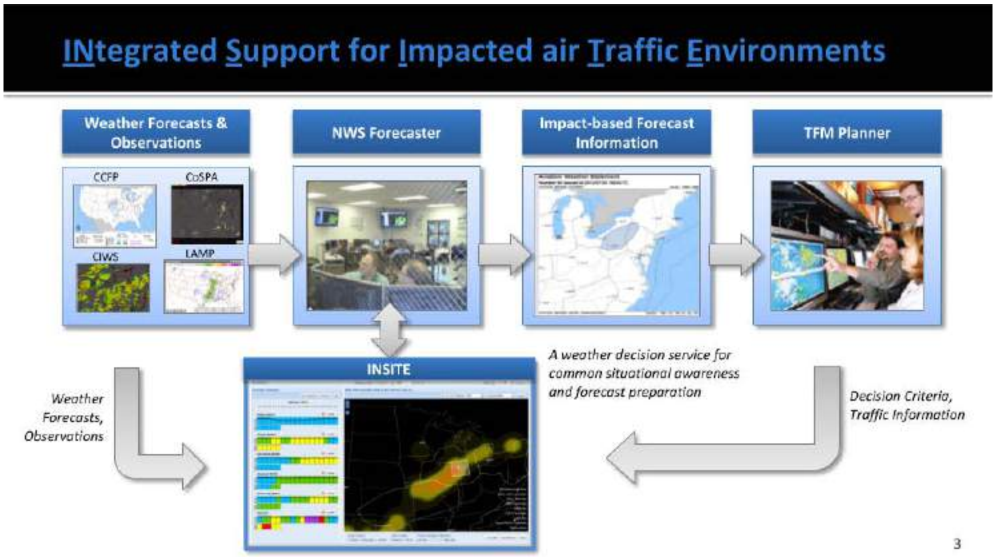


Figure 23. Conceptual diagram of how the various components of INSITE work together to improve aircraft traffic decision support efforts.

The AWC is working closely with GSD to begin INSITE development within both the AWIPS-2 and N-AWIPS frameworks. An example of the INSITE webpage is shown in Figure 24. Additional work also focused on finalizing INSITE configuration and setup in preparation for 2017 AWT Summer Experiment. Helpful feedback on INSITE was received from the 2017 AWT Summer Experiment participants.

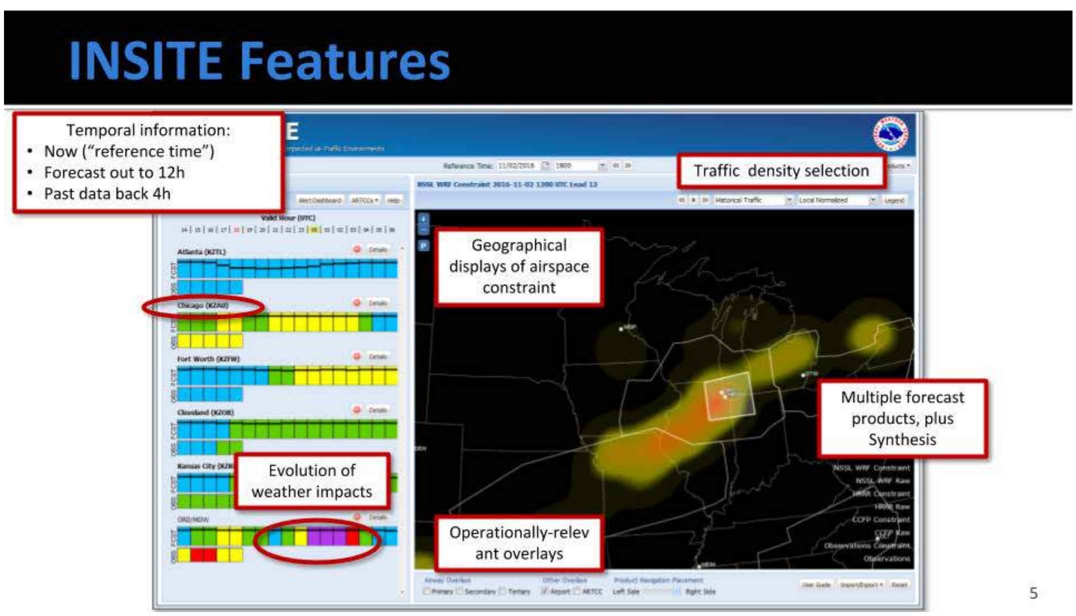


Figure 24. INSITE webpage screenshot with page highlights not in the red boxes.

INSITE migration to AWC operations was completed in the Fall of 2017. AWC worked with GSD and has completed and submitted INSITE Design Review for INSITE implementation into AWIPS-2 (as illustrated in Figure 25)

INSITE is currently available to NWS forecasters via web-based application (URL listed below).

https://www.esrl.noaa.gov/fiqas/tech/impact/insite/

2018 INSITE demonstration plans include an evaluation via AWC's Aviation Weather Testbed. Data dissemination of constraint fields to AWC and eventually to the CWSUs. Efforts will also focus on forecaster training on the 'heat map' displays within INSITE. An update on the INSITE project was co-presented by Amanda Terborg and Missy Petty (GSD) at the 2018 AMS Annual Meeting.

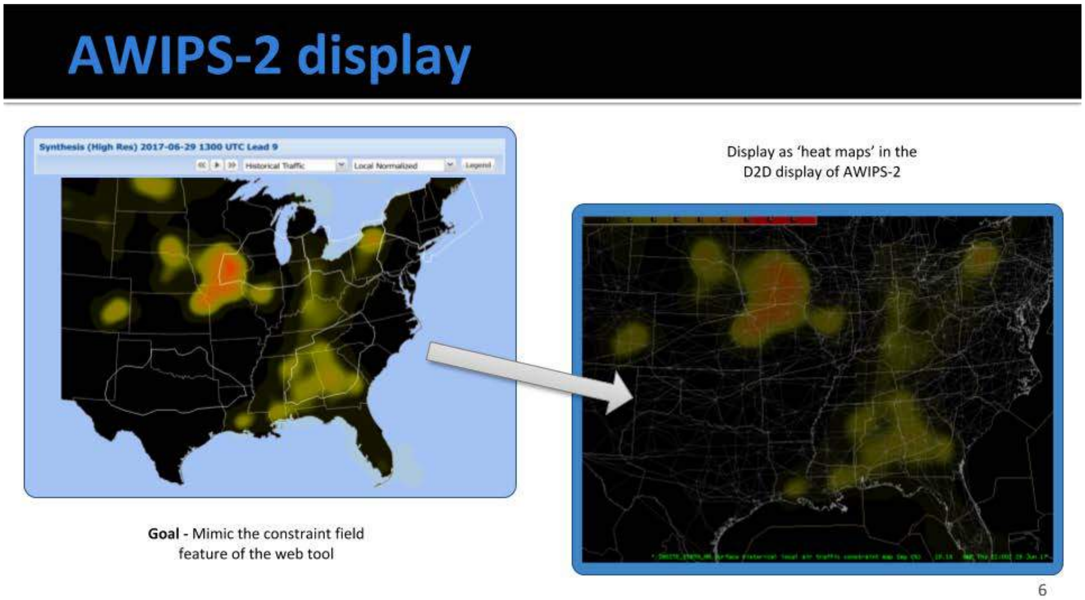


Figure 25. Example of INSITE webpage migration to AWIPS-2 efforts at AWC and GSD.

Publications:

Avey, S., S. Alvidrez, S. Lack, A. Cross, J. Kankiewicz, and R. Bastholm, 2018: Guidance on Optimally Presenting Probabilistic Ceiling & Visibility Forecasts for the Aviation Community. *Sixth Aviation, Range, and Aerospace Meteorology Special Symposium*, Austin, TX, Amer. Met. Soc., 2.2. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper331035.html)

Kankiewicz, J.A., S. Avey, S. Lack, and A. Cross, 2018: Current and Future Efforts Using 3-D Cloud Fraction for Aviation Forecasting. *Sixth Aviation, Range, and Aerospace Meteorology Special Symposium*, Austin, TX, Amer. Met. Soc., 353.

Kim, J.-H., R. D. Sharman, M. Strahan, J. W. Scheck, C. Bartholomew, J. C. H. Cheung, P. Buchanan, and N. Gait, 2018: Global Graphical Turbulence Guidance (G-GTG) for World Area Forecast System (WAFS), *Bull. Am. Meteor. Soc.,* In revision.

Kim, J.-H., D. Kim, M. Strahan, R. D. Sharman, P. D. Williams, H.-Y. Chun, and Y.-J. Kim, 2018: Impact of Large-Scale Variability on Trans-Oceanic Flights during the Strong NAO and ENSO Phases, *Geophys. Res. Lett.*, In revision.

Kim, J.-H., R. D. Sharman, C. Batholomew, M. Strahan, J. W. Scheck, J. C. H. Cheung, and P. Buchanan, 2018: Global Graphical Turbulence Guidance (G-GTG) for World Area Forecast System (WAFS) Upgrade, *Eighth Conference on Transition of Research to Operations*, Austin, TX, Amer. Meteor.

Soc., 6.6. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper331578.html)

Kim, J.-H., R. D. Sharman, J. Brown, S. Benjamin, S. H. Park, and J. Klemp, 2018: Impact of Hybrid Vertical Coordinate to the WRF RAP-based Upper-Level Turbulence Forecast, *Eighth Conference on Transition of Research to Operations (R2O)*, Austin, TX, Amer. Meteor. Soc., 14B.4. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper331661.html)

Kim, Jung-Hoon, M. Strahan, and R. D. Sharman, 2017: Integrated Wind and Turbulence Forecasts for Automated Flight Route Planning, WMO Aeronautical Meteorology Scientific Conference (AMSC) 2017, Meteo France, Toulouse, France, Session 2.4.

Kim, Jung-Hoon, M. Strahan, and R. D. Sharman, 2017: Impact of Large-Scale Climate Variability to Long-Haul Flight Route, WMO Aeronautical Meteorology Scientific Conference (AMSC) 2017, Meteo France, Toulouse, France, Session 3.1.

Lee, D.-B., H.-Y. Chun, J.-H. Kim, and R. D. Sharman, 2018: Development of the Global Korean Aviation Turbulence Guidance system (G-KTG) using the Global Data Assimilation and Prediction System (GDAPS) of Korea Meteorological Administration (KMA), *Sixth Aviation, Range, and Aerospace Meteorology Special Symposium*, Austin, TX, Amer. Meteor. Soc., 330.

Pettegrew, B. P., D. L. Sims, H. Y. Chuang, J. W. Scheck, and M. Strahan, 2018: Enhancing FAA/NWS Research-to-Operations to Support Global and Domestic Missions through the Unified Post Processor, *Eighth Conference on Transition of Research to Operations*, Austin, TX, Amer. Meteor. Soc., 275.

Pettegrew, B. P., A. Terborg and C. B. Entwistle, 2018: GLM Evaluation Updates on Total Lightning Use in the Aviation Weather Testbed and Aviation Weather Center, *Eighth Conference on Transition of Research to Operations*, Austin, TX, Amer. Meteor. Soc., 764.

Terborg, A. and B. P. Pettegrew, 2018: Flying into a New Era of Advanced Satellite Observations: Transitioning GOES-16 Utility for Aviation Forecasting into Aviation Weather Center Operations, Eighth Conference on Transition of Research to Operations, Austin, TX, Amer. Meteor. Soc., 5.3. (Recorded Presentation available at: https://ams.confex.com/ams/98Annual/webprogram/Paper334405.html)

PROJECT TITLE: Weather Satellite Data and Analysis Equipment and Support for Research Activities

PRINCIPAL INVESTIGATORS: Chris Kummerow / Michael Hiatt

RESEARCH TEAM: Michael Hiatt

NOAA TECHNICAL CONTACT:

NOAA RESEARCH TEAM:

FISCAL YEAR FUNDING: $75,000

PROJECT OBJECTIVES:

--Earthstation: Operations and maintenance for 5 antennas and associated telemetry, network, ingest, processing, distribution, and archive
--Data Collection: GOES GVAR from GOES-13/14/15, GOES GVAR special collections, GOES GRB from GOES-16, MSG via 7M DOMSAT system, and 22 project products via Internet

--Data Distribution and Archive: Online RAID storage
--Personnel Salary: Part time coverage for one Electrical Engineer

PROJECT ACCOMPLISHMENTS:

--All data sets collected, processed, cataloged, distributed, and archived at 99.9% level. Online archive now spans from 1987-2018 with approximately 850TB online data.
--2 large RAID NAS units added for additional storage
--3 processing servers upgraded, 1 repaired
--4Telemetry maintenance

Publications: None

MAJOR PUBLICATIONS/PRESENTATIONS MATRIX

	2013	2014	2015	2016	2017
CI Lead Author	23 Peer Reviewed 98 Non-peer Reviewed	28 Peer Reviewed 13 Non-peer Reviewed	30 Peer Reviewed 5 Non-peer Reviewed	57 Peer Reviewed 19 Non-peer Reviewed	97 Peer Reviewed 55 Non-peer Reviewed
NOAA Lead Author	28 Peer Reviewed 40 Non-peer Reviewed	21 Peer Reviewed 17 Non-peer Reviewed	35 Peer Reviewed 0 Non-peer Reviewed	43 Peer Reviewed 20 Non-peer Reviewed	35 Peer Reviewed 19 Non-peer Reviewed
Other Lead Author	31 Peer Reviewed 33 Non-peer Reviewed	51 Peer Reviewed 5 Non-peer Reviewed	34 Peer Reviewed 6 Non-Peer Reviewed	41 Peer Reviewed 17 Non-peer Reviewed	60 Peer Reviewed 32 Non-peer Reviewed

CIRA EMPLOYEE MATRIX

CIRA Personnel					
Category	**Number**	**None**	**B.S.**	**M.S.**	**PhD.**
Research Scientist	22	0	0	0	22
Visiting Scientist	0	0	0	0	0
Postdoctoral Fellow	4	0	0	0	4
Research Support Staff	70	3	21	35	11
Administrative	4	0	1	3	0
Total (≥ 50% support)	100	3	22	38	37
Undergraduate Students	3	1	2	0	0
Graduate Students	13	0	3	10	0
Employees that receive < 50% NOAA Funding (not including students)	71	4	15	21	31
		ESRL	**MDL**	**AWC**	**NESDIS**
Located at Lab (name of lab)	85	50	10	12	13
Obtained NOAA employment within the last year	3				

Other Agency Awards 2017/18
(Sorted by Awarding Agency)

	Title	Lead NOAA Collaborator	Awarding Agency	Fiscal Year Funding
Connell	CIRA Support to Building Regional Climate Capacity in the Caribbean	No	Caribbean Institute for Meteorology & Hydrology	$0
Miller	Advanced Algorithm Development for Next-Generation Satellite Systems	No	Department of Defense NRL	$0
Miller (Zupanski)	Advancing Littoral Zone Aerosol Prediction via Holistic Studies in Regime-dependent Flows	No	Department of Defense	$223,106
Liston	Changes in Climate and Its Effect on Timing of Snowmelt and Intensity Duration Frequency Curves	No	Department of Defense	$115,620
Hand	Assistance for Creation of Interactive Tools and Other Outreach Products to Enhance the Public Understanding of Air Quality Degradation on Natural Resources in US Fish and Wildlife Refuges	No	FWS	$170,214
Miller	CIRA Data Processing Center Support for the CloudSat Mission	No	JPL	$220,519
O'Dell	OCO-3	No	JPL	$90,000
Schumacher, A.	Joint Typhoon Warning Center	No	JTWC	$0
Kummerow	On the Implementation and Application of Cloud Analysis and Nowcasting (CAN) System to Support the International Collaborative Experiments for Pyeongchang 2018 Winter Olympic and Paralympic Games	No	KMA	$0
Baker	A Global High-resolution Atmospheric Data Assimilation System for Carbon Flux Monitoring and Verification	No	NASA	$71,807
Baker	GEOS-Carb II: Delivering Carbon Flux and Concentration Products Based on the GEOS Modeling System	No	NASA	$35,295

Other Agency Awards 2017/18
(Sorted by Awarding Agency)

	Title	Lead NOAA Collaborator	Awarding Agency	Fiscal Year Funding
Liston	Snow on Sea Ice: Data Fusion Using Remote Sensing and Modeling	No	NASA	$0
Musgrave	Utilization of Hurricane Specific, Global Precipitation Measurement-based Precipitation and Latent Heat Retrievals to Improve Operational Forecasts of Rapidly Intensifying Hurricane Events	No	NASA	$93,750
O'Dell	A Data Record of the Cloudy Boundary Layer	No	NASA	$46,537
O'Dell	Atmospheric Carbon Transport America (ACT-America)	No	NASA	$90,575
O'Dell	Enhancing OCO-2's Observational Capabilities Under Partly and Fully Cloudy Con	No	NASA	$33,381
O'Dell	Orbiting Carbon Observatory (OCO-2) Task	No	NASA	$50,000
O'Dell	Tackling Aerosol and CO2 Uncertainties through the Synergistic Use of MODIS and OCO-2 Observations	No	NASA	$40,000
O'Dell	Tackling Aerosol and CO2 Uncertainties through the Synergistic Use of MODIS and OCO-2 Observations	No	NASA	$325,280
Schranz	Using Earth Observations to Assess the Socioeconomic Impact of Human Decision Making During the Suppression of a Wildland Fire	No	NASA	$0
Schranz	Wildland Fire Behavior and Risk Forecasting	No	NASA	$0
Schuh (w/OU Lead)	Improved Parameterization of Carbon Cycle Models Across Scales Using OCO-2 Measurements of XCO2 and SIF	No	NASA	$0
Zupanski	Advancing Coupled Land-atmosphere Modeling with the NASA-unified WRF via Process Studies and Satellite-scale Data Assimilation	No	NASA	$0
Baker	GOES-CARB: A Framework for Monitoring Carbon Concentrations and Fluxes	No	NASA (via Pawson)	$0

Other Agency Awards 2017/18
(Sorted by Awarding Agency)

	Title	Lead NOAA Collaborator	Awarding Agency	Fiscal Year Funding
Apodaca	R2OTransition of the GOES-R GLM Lightning Assimilation Capacity in GSI for Use in the NCEP GDAS	No	NCAR/DTC	$11,116
Liston	CIRA Subcontract for "InterDisciplinary Study of Arctic Sea Ice Changes and Impacts for the Society (ID Arctic)"	No	NPI	$0
Hand	Assistance for Visibility Data Analysis and Image Display Techniques	No	NPS	$906,382
McClure	Data Warehouse for Air Quality Modeling in the Oil and Gas Regions of Wyoming, Utah, and Colorado	No	NPS	$486,897
Miller	Addressing Naval METOC Challenges via a New Era of Advanced Environmental Satellite Technology	No	NRL	$40,000
Chirokova	Conversion of CIRA's AMSU-based Wind Retrieval Algorithm into a Real-time Pre-operational NRL SSMIS Application	No	NRL	$0
Liston	Collaborative Research: Nutritional Landscapes of Arctic Caribou	No	NSF	$0
Liston	Collaborative Research: Snow, Wind and Time: Understanding Snow Redistribution and Its Effects on Sea Ice Mass Balance	No	NSF	$0
Fletcher	Establishing Links Between Atmospheric Dynamics and Non-Gaussian Distributions and Quantifying Their Effects on Numerical Weather Prediction	No	NSF	$674,937
Lu	Investigating Feedbacks Between Vegetation, Aerosol and Cloud Processes Using Observations and a Unified Regional Climate Model	No	NSF	$213,451
Fletcher	Regional, Seasonal and Large Dynamical Scale Based Covariance and Humidity Control Variable Transform Implementation into NAVDAS-AR	No	ONR	$20,000
O'Dell	geoCARB	No	OU (NASA)	$119,711

Other Agency Awards 2017/18
(Sorted by Awarding Agency)

Miller	Advancing Littoral Zone Aerosol Prediction via Holistic Studies in Regime-dependent Flows	No	ONR/MURI	$882,841
Baker	Atmospheric Carbon and Transport Study – America (ACT – America)	No	Penn State Univ (NASA)	$214,101
Schuh, Ogle	Quantification of the Regional Impact of Terrestrial Processes on the Carbon Cycle Using Atmospheric Inversions	No	Penn State (NASA)	$0
Chandra	Design and Development of AQPI System	No	Sonoma County Water Agency	$2,294,053
Johnson/ Labadie	Improve Precipitation and River Flow Forecasting to Maximize Water Capture for Fisheries	No	Sonoma County Water Agency	$0
Liston	Blending Fine-scale Terrestrial Snow Information with Coarse-scale Remote Sensing Data Using Inferential and Modeling Methods	No	UAF	$0
Liston	Bridging the Snow-Sea Ice Gap: A Snow on Sea Ice Assimilation System for the Arctic	No	University of Colorado/ NSIDC	$61,301
Schranz	Improving Fire-Management Decision Making through Advanced Modeling and Forecasting of Fire-Weather Interactions, Smoke Dispersion, Fire Danger, Large-Fire Ignition Probabilities and the Development	No	USDA-USFS	$192,037
Connell	Tasks Related to Technical Support of the WMO-GGMS Virtual Lab for Education and Training	No	WMO	$65,000

NOAA PROJECTS BY TITLE

COMPETITIVE PROJECTS

1—Accounting for Non-Gaussianity in the Background Error Distributions Associated with Cloud-related Variables (microwave radiances and hydrometeors) in Hybrid Data Assimilation for Convective-scale Prediction (NA16OAR4590233) (Fiscal Year Funding: $0)

2—Aerosol Size Distribution and Composition Evolution During FIREX Activities: Closure Analyses and Climate Impacts (NA17OAR4310001) (Fiscal Year Funding: $82,689)

3--Assessment of Distributed Hydrological Modeling for NWS Flash Flood Operations (NA15OAR4590152) (Fiscal Year Funding: $0)

4—Assimilation of Lake and Reservoir Levels into the WRF-Hydro National Water Model to Improve Operational Hydrologic Predictions (NA16OAR4590237) (Fiscal Year Funding: $0)

5--Collaborative Research: Assessing Oceanic Predictability Sources for MJO Propagation (NA16OAR4310094) (Fiscal Year Funding: $132,835)

6—Comparison of Model Versus Observationally-driven Water Vapor Profiles for Forecasting Heavy Precipitation Events (NA17OAR4590121) (Fiscal Year Funding: $133,844)

7--Development of a Framework for Process-oriented Diagnosis of Global Models (NA15OAR4310099) (Fiscal Year Funding: $85,179)

8—Evaluating Stochastic Physics Approaches Physics Approaches within Select Convection Allowing Model (CAM) Members Included in the Community Leveraged Unified Ensemble (VCLUE) during the Hazardous Weather Testbed (HWT) Spring Experiment (NA17OAR4590118) (Fiscal Year Funding $51,790)

9—Following Emissions from Non-traditional Oil and Gas Development through Their Impact on Tropospheric Ozone (NA14OAR4310148) (Fiscal Year Funding: $0)

10—Forecasting North Pacific Blocking and Atmospheric River Probabilities: Sensitivity to Model Physics and the MJO (NA16OAR4310064) (Fiscal Year Funding: $209,451)

11—Implementation and Testing of Lognormal Humidity and Cloud-related Control Variables for the NCEP GSI Hybrid EnVar Assimilation Scheme (NA16NWS4680012) (Fiscal Year Funding: $199,811)

12—Improvement and Implementation of the Probability-based Microwave Ring Rapid Intensification Index for NHC/JTWC Forecast Basins (NA15OAR4590200) (Fiscal Year Funding: $0)

13--Improvement to the Tropical Cyclone Genesis Index (TCGI) (NA15OAR4590202) (Fiscal Year Funding: $0)

14--Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models (NA15OAR4590204) (Fiscal Year Funding: $0)

15—Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors (NA17OAR4590138) (Fiscal Year Funding: $144,896)

16—Improving CarbonTracker Flux Estimates for North America Using Carbonyl Sulfide (OCS) (NA13OAR4310080) (Fiscal Year Funding: $0)

17—Improving Probabilistic Forecasts of Extreme Rainfall through Intelligent Processing of High-resolution Ensemble Predictions (NA16OAR4590238) (Fiscal Year Funding: $0)

18—Improving Understanding and Prediction of Concurrent Tornadoes and Flash floods with Numerical Models and VORTEX-SE Observations (NA16OAR4590215) (Fiscal Year Funding: $0)

19--Investigating the Underlying Mechanisms and Predictability of the MJO – NAM Linkage During Boreal Winter in the NMME Phase-2 Model Suite (NA16OAR4310090) (Fiscal Year Funding: $22,019)

20—Modeling the Complex and Dynamic Evolution of Organic Aerosol in Biomass Burning Plumes (NA17OAR431003) (Fiscal Year Funding: $83,552)

21—Multi-disciplinary Investigation of Concurrent Tornadoes and Flash Floods in the Southeastern US (NA15OAR4590233) (Fiscal Year Funding: $0)

22—Near-field Characterization of Biomass Burning Plumes (NA17OAR4310010) (Fiscal Year Funding: $93,504)

23--Observational Constraints on the Mechanisms that Control Size- and Chemistry-resolved Aerosol Fluxes Over a Colorado Forest (NA14OAR4310141) (Fiscal Year Funding: $0)

24--Quantifying Stochastic Forcing at Convective Scales (NA16OAR4590230) (Fiscal Year Funding: $0)

25--Research to Advance Climate and Earth System Models Collaborative Research: A CPT for Improving Turbulence and Cloud Processes in the NCEP Global Models (NA13OAR4310103) (Fiscal Year Funding: $0)

26--Towards Assimilation of Satellite, Aircraft, and Other Upper-Air CO2 Data into CarbonTracker (NA13OAR4310077) (Fiscal Year Funding: $0)

27--Use of the Ocean-Land-Atmosphere Model (OLAM) with Cloud System-Resolving Refined Local Mesh to Study MJO Initiation (NA13OAR4310163) (Fiscal Year Funding: $0)

28—Use of the Stochastic-dynamic Approach in a Single Dynamic-Core Storm-Scale Ensemble for Improved Spread and Reliability of QPF and Surface Variables (NA17OAR4590181) (Fiscal Year Funding: $199,582)

PROJECT TITLE: Accounting for Non-Gaussianity in the Background Error Distributions Associated with Cloud-related Variables (microwave-radiances and hydrometeors) in Hybrid Data Assimilation for Convective-scale Prediction

PRINCIPAL INVESTIGATOR(S): Dr. Karina Apodaca (CSU/CIRA at NOAA/OAR/AOML/HRD) and Dr. Steven J. Fletcher (CSU/CIRA)

RESEARCH TEAM: N/A

NOAA TECHNICAL CONTACT: Emily Liu NOAA/NWS/NCEP/EMC and John Derber NOAA/NWS/NCEP/EMC

NOAA RESEARCH TEAM: Dr. Stephen Weygandt NOAA/ESRL/GSD/ADB and Dr. Haidao Lin CSU/CIRA at NOAA/ESRL/GSD/ADB

FISCAL YEAR FUNDING: $0

PROJECT OBJECTIVES:

As a way to address the non-Gaussian behavior of cloud variables we proposed to implement the "Lognormal and Mixed-Distribution" formulation (Fletcher and Zupanski, 2006, 2007, Fletcher, 2017).

The overarching project objective is to further develop to the GSI data assimilation system via the incorporation of a lognormal and a mixed lognormal-Gaussian representation of background error statistics for humidity and hydrometeor control variables applicable to microwave radiance assimilation and to enhance the NWS capability to forecast high-impact weather that occurs at convective scales. Specifically, the project contributes to these goals by:

--Developing the infrastructure for non-Gaussian statistics in the background error (BE) components (background error covariance matrix [**B**-matrix] and background and observational terms of the incremental cost function) within the GSI system

--Implementing a tool for an improved first-guess of cloud-related fields

--Developing the methodology and guidelines for implementing and applying the lognormal and mixed lognormal-Gaussian distribution approach for the background errors in data assimilation cycling experiments

PROJECT ACCOMPLISHMENTS:

--The PI gave a presentation to NOAA/OAR and NOAA/NWS representatives outlining the details of a path to operations plan that was well received. A NOAA/NWS representative highlighted the frequent interaction between the PI and the NCEP/EMC POC's keeping the project on track for a potential operational implementation

--We started the development efforts to the GSI-hybrid system by adding two new cost functions (*J*) within the variational solver, a lognormal *J* that includes multiplicative (ratios) increments and a mixed lognormal-Gaussian *J* that includes both multiplicative and additive increments for the simultaneous assimilation of observations that yield Gaussian and non-Gaussian error distributions

--This application will be beneficial to the assimilation of microwave radiances; current operational MW sensors and planned (JPSS/ATMS - Hidao Lin)

--Furthermore, Minimization requires a Tangent Linear (TL) and an Adjoint (AD) of the observation operators

--For the TL we are working on the development of a Geometric Tangent Linear Model for the multiplicative increment mentioned above

--For linearization of the observational component we will calculate the observational Jacobians with respect to the natural logarithm of cloud control variables

Technical details:

• GSI source code changes/additions:

- control2state.f90
- state2control.f90
- gsimod.F90
- crtm_interfase.f90
- setuprad.f90
- intrad.f90
- stprad.f90
- new LOCAL control variables (CV) for each log of the hydrometeors (no need for new CV)

--Fixed files: new **B**-matrix lookup table (rap_berror_stats_global)

--Scripts: two new logical controls for the new cost functions in the gsiparm.anl.sh &SETUP namelist: use_nong_lcost, use_nong_mcost

--As of now, we are modeling a new a static **B**-matrix for Gaussian and lognormal cloud control variables with GEN_BE_V2.0 (Barker et al. 2004, Descombes et al. 2015) by following the NMC method.

--Generation of a new regional background error statistics look up table (rap_berror_stats_global)

--The calculation of this new **B**-matrix has been done by reading cloud background fields from RAP+HRRR time-lagged forecasts which covers the northern hemisphere (Figure 1)

--New modeling of **B**-matrix with source code modifications for lognormal cloud control variables and calculation of regression coefficients for the following: log(q) balanced with unbalanced temperature and surface pressure and log(q_cloud), log(q_ice), log(q_rain), and log(q_snow) balanced with log(q)

--New length-scale calculations to determine the horizontal and vertical impact of observations

--For testing and evaluation of the added capability, we conducted two experiments in the initial GEN_BE_V2.0 **B**-matrix calculations, a control experiment (CNTRL with standard Gaussian statistics) and one with the added capability (LOG_CV with lognormal statistics for specific humidity and cloud hydrometeors)

--Preliminary results show that Greatest impact is seen in the physical transform (Figure 2), with enhanced balance (horizontal and vertical cross-correlations) in the LOG_CV experiment (vertical cross correlations shown, only)

--Differences in the horizontal and vertical transforms between CNTRL and LOG_CV, but not a great impact of the lognormal CV representation on the horizontal and vertical (Figure 2)

--GEN_BE_V2.0 uses a Gaussian PDF in the calculation of length scales. We plan to do additional source code modifications by adding a lognormal PDF for length scale calculations (planned) could improve overall results

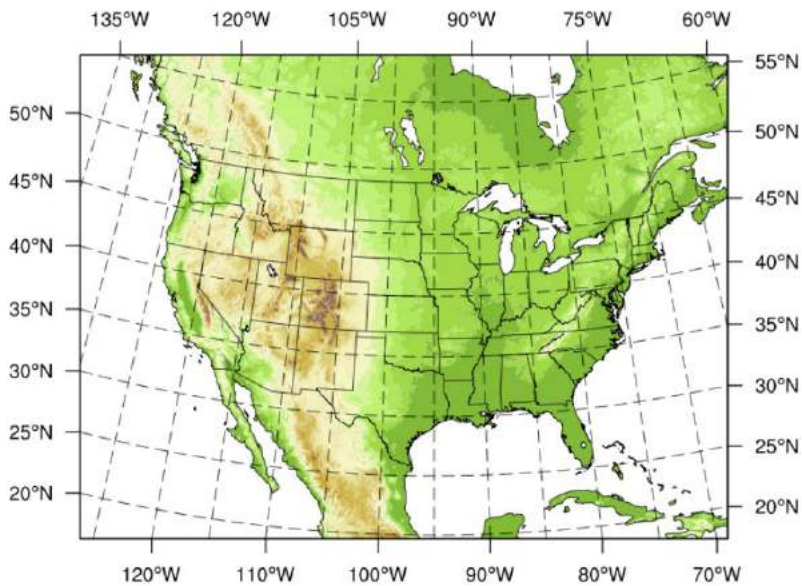


Figure 1. Domain for modeling of a new B-matrix for Gaussian and lognormal cloud hydrometeor control variables from RAP+HRRR time-lagged forecasts using the NMC method

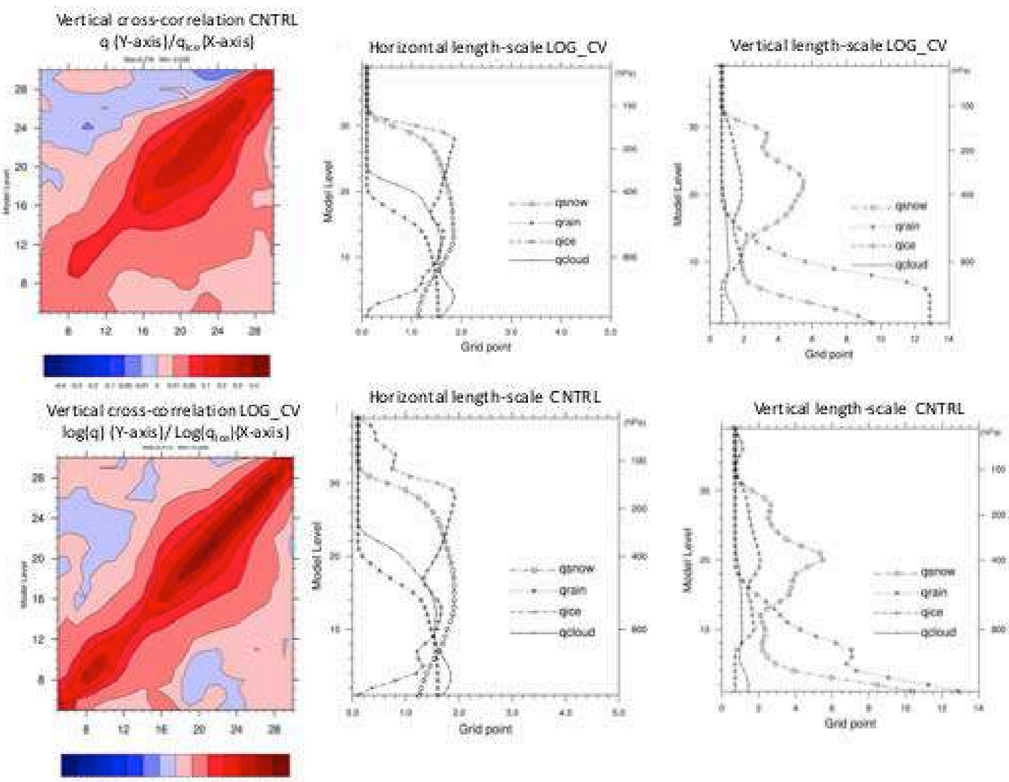


Figure 2. Top and bottom left: physical transform (vertical) for ice hydrometeors for the CNTRL and LOG_CV experiments respectively, with improved physical balance. Top and bottom middle: horizontal length-scale calculations for four hydrometeor species. Top and bottom right: vertical length-scale calculations for four hydrometeor species.

Publications:

Apodaca, K., S. J. Fletcher, 2017: Implementing non-Gaussian background error statistics for cloud-related control variables in the hybrid GSI for improved convective-scale assimilation and prediction. 7th WMO Symposium on Data Assimilation. Florianopolis, Brazil. September 11-15, 2017.

S. J. Fletcher S. and Apodaca K.: Implementing and Testing of a Lognormal-Based Humidity Control Variable for the NCEP GSI Hybrid EnVAR Assimilation Scheme. 22st Conference on Integrated Observing and Assimilation Systems for the Atmosphere, Oceans, and Land Surface. Data Assimilation: Advances in Methodologies IV. 98th Annual AMS Meeting, Austin, Texas. January 11, 2018.

PROJECT TITLE: Aerosol Size Distribution and Composition Evolution during FIREX Activities: Closure Analyses and Climate Impacts

PRINCIPAL INVESTIGATOR: Jeffrey Pierce

RESEARCH TEAM: Anna Hodshire, PhD student, Started July 1, 2017 (when project started)

NOAA TECHNICAL CONTACT: N/A

NOAA RESEARCH TEAM: N/A

PROJECT OBJECTIVES:

1--*Closure in FIREX lab studies*: We will quantify how various processes (e.g. OA formation/evaporation, coagulation, wall losses) contribute to changes in aerosol composition and size throughout FIREX laboratory studies from the Missoula fire lab (late 2016) and from the CU Boulder chamber (2017). This will be done through closure studies using the ASP smoke chemistry/physics model and the laboratory data.
2--*Closure in FIREX field studies*: We will quantify how these processes contribute to changes in aerosol composition and size throughout FIREX field studies (2018). This will be done through closure studies using the coupled SAM-ASP plume dispersion and chemistry model and the airborne measurements from the NOAA P-3.
3--*Comparison of lab and field data*: We will identify lab experiments where similar fuels were burned as in smoke plumes observed in the field, and we will determine if the evolution of the aerosol size distributions observed in the lab are consistent with the field. We will identify processes contributing to any differences (e.g. wall losses, dilution, concentrations).
4--*Regional and global modelling*: Through our closure studies, we will develop a parameterization of sub-grid aging of biomass-burning aerosol. We will test this parameterization in the GEOS-Chem-TOMAS global/regional aerosol microphysics model and quantify climate forcings.

PROJECT ACCOMPLISHMENTS:

As the data from FIREX lab students are currently being processed, and FIREX field studies are a year away, we have been focusing on theoretical studies of the biomass burning size distribution, constrained by the earlier FLAME studies.

At the start of this project year, we published Bian et al., 2017, “Secondary organic aerosol formation in biomass-burning plumes: Theoretical analysis of lab studies and ambient plumes” in ACP. This project started from funding from the Joint Fire Science Program, but achieved some of the goals of this work in understanding smoke particle evolution in chambers and in the ambient plume. We found that in chambers, vapor wall losses can suppress the much of the observed SOA formation, depending the rate of chemistry vs. wall losses. In ambient plumes, we find that under many circumstances primary OA evaporation nearly balances secondary OA formation, leading to little apparent change in OA, consistent with many field observations. However, the fire size greatly influences the dilution rates (small fires have plumes that dilute more quickly), such that we predicted net OA formation in plumes of large fires and net OA loss in plumes of small fires.

As part of this project, we are extending the work of Bian et al., 2017, which focused on bulk aerosol mass, to investigate size distribution changes. Figure 1 shows the isolated impacts of OA chemistry and coagulation on the size distribution. These simulations show how OA chemistry and coagulation both can greatly impact the evolving aerosol size distribution. Upcoming work will involve calculating the radiative impacts of the particles in these simulations.

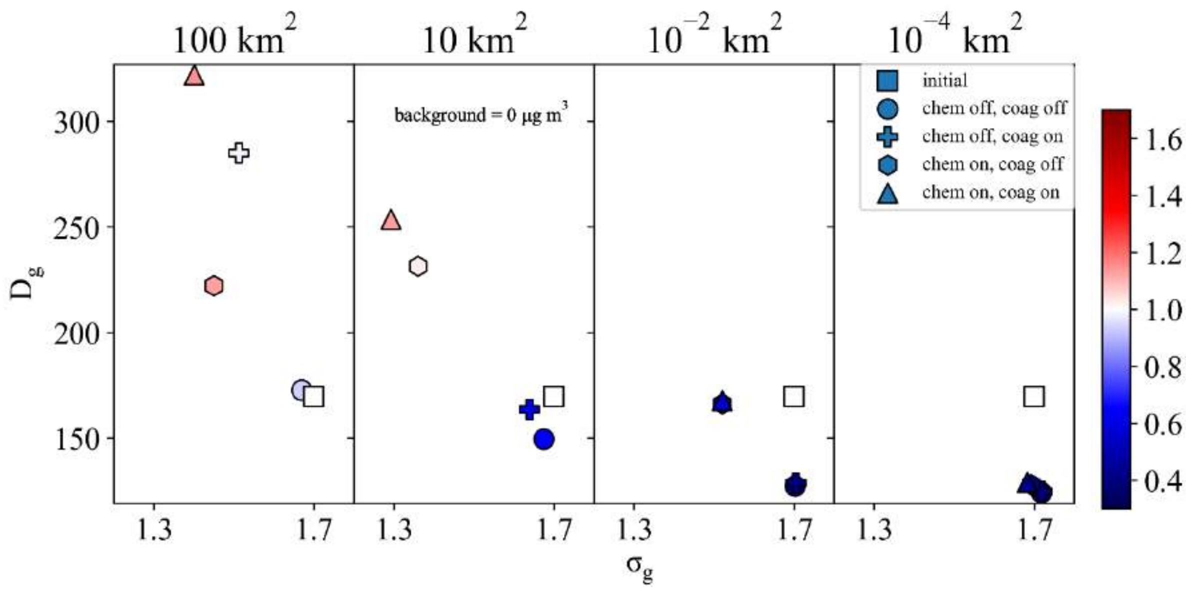


Figure 1. Evolution of median diameter and modal width for four different fire areas. These simulations assume no background aerosol. Colors show the ratio of final OA/CO to initial OA/CO.

PROJECT TITLE: Assessment of Distributed Hydrologic Modeling (DHM) for Flash Flood Operations

PRINCIPAL INVESTIGATOR: Lynn E. Johnson

RESEARCH TEAM: V. Chandrasekar, CIRA Fellow and Professor, and Jungho Kim, CIRA Post-Doc, Colorado State University Department of Electrical and Computer Engineering.

NOAA TECHNICAL CONTACT: Rob Cifelli (NOAA/OAR/ESRL/PSD/HMA)

NOAA RESEARCH TEAM: PSD Hydrometeorological Modeling and Applications Team

FISCAL YEAR FUNDING: $0

PROJECT OBJECTIVE: Assess distributed hydrological models for NWS flash flood forecast and warning operations.

PROJECT ACCOMPLISHMENTS:

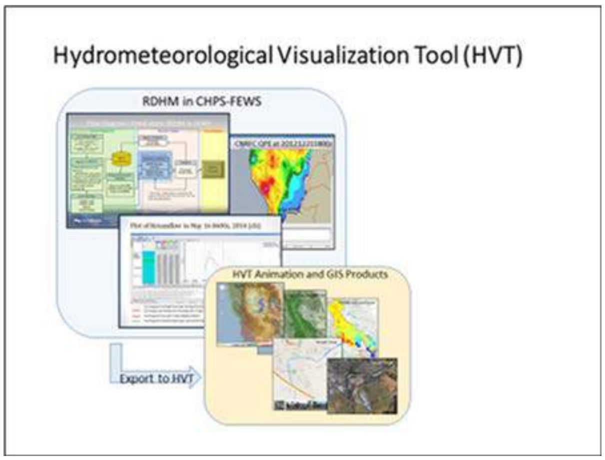


Figure 1. HVT web service provides interactive access to information on forecast flash flood levels and criticality, and flood impact features (e.g. bridge crossings).

--Implemented the Research Distributed Hydrological Model (RDHM) for the Russian and Napa River basins within the NWS Community Hydrologic Prediction System (CHPS) for near-real time data ingest and simulation capability.
--Developed a web mapping-based Hydrologic Visualization Tool (HVT) to include: threshold exceedance identifying criticality of flooding, at-risk road crossings, and locations of critical infrastructure.
--Conducted assessments with NWS WFO forecasters and other users for DHM forecast accuracy and usability for flash flood operations.
--Contract completed and final report prepared and submitted to FY2015 US Weather Research Program Hydrometeorology Testbed (HMT).
--Presented highlights of project (oral) at AMS98 Conference in Austin, TX in January 2018.

PROJECT TITLE: Assimilation of Lake and Reservoir Levels into the WRF-Hydro National Water Model

PRINCIPAL INVESTIGATOR: Lynn E. Johnson

RESEARCH TEAM: V. Chandrasekar, CIRA Fellow and Professor, and Jungho Kim, CIRA Post-Doc, Colorado State University Department of Electrical and Computer Engineering.

NOAA TECHNICAL CONTACT: Rob Cifelli (NOAA/OAR/ESRL/PSD/HMA)

NOAA RESEARCH TEAM: PSD Hydrometeorological Modeling and Applications Team (HMA)

FISCAL YEAR FUNDING: $0

PROJECT OBJECTIVES:

Improve the representation of reservoir mass balance and storages in the operational NOAA National Water Model (NWM).

PROJECT ACCOMPLISHMENTS:

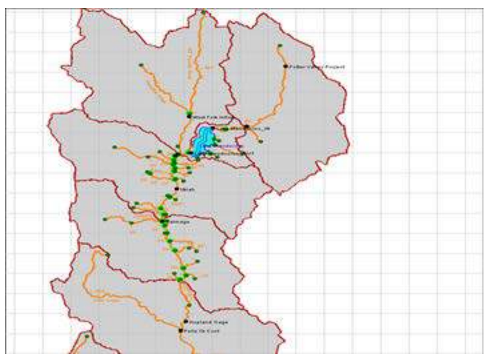


Figure 1. NWM Inflow Channel Network and Lake Mendocino in HEC- ResSim

--Interacted with NCAR project team to identify objectives and scope for case study on Russian River reservoir operations.
--Obtained updated reservoir simulation model (RESSIM) from USACE and Sonoma County Water Agency.
--Modified RESSIM model to accept local flow inputs from the National Water Model.
--Conducted RESSIM simulations with NWM local inflows.
--Developed concepts of operation for integration of reservoirs into the NWM.
--Presented highlights of project (poster) at AMS98 Conference in Austin, TX in January 2018.

Collaborative Research: Assessing Oceanic Predictability Sources for MJO Propagation
Progress Report

1. General information

Project title:	Collaborative Research: Assessing Oceanic Predictability Sources for Madden–Julian Oscillation Propagation
PI/co-PI names and institutions:	Charlotte DeMott (Colorado State University) and Nicholas Klingaman (University of Reading)
Report Year:	FY16, Year 1 Progress Report
Grant #:	NA16OAR4310094

2. Main goals of the project, as outlined in the funded proposal

Goal 1: Evaluate S2S database ensemble prediction skill for three types of Madden–Julian Oscillation (MJO) events—strong propagating, weak propagating, and eastward-decaying—with regards to atmospheric and oceanic precursor signals.

Goal 2: Test the roles of specific oceanic feedback processes for MJO prediction skill using coupled models with a demonstrated ability to simulate the MJO.

Goal 3: Adapt a set of MJO air–sea interaction diagnostics developed by the PIs for analysis of climate simulations to hindcast simulations.

3. Results and accomplishments

3.1. Progress towards MJO air–sea interaction diagnostics for S2S models

Efforts during the past six months have focused on several tasks geared toward assessing intraseasonal air–sea interactions in the S2S database.

- In April 2017, ECMWF released an updated set of Real-time Multivariate MJO (RMM) indices for all S2S models, which now covers all available re-forecast periods for each model (the previous version only covered the 1999-2009 common overlap period). Co-PI DeMott downloaded the ASCII-formatted data and consolidated it into a netCDF file (one file per modeling center). This reformatted data allows simpler searches for MJO criteria across the S2S database. The files have been uploaded to the NOAA MAPP S2S database where they are available to other MAPP-funded researchers.
- Co-PI DeMott acquired a 20 TB desktop RAID drive in May 2017 and began downloading data from the ECMWF S2S database. Modeling centers that employ atmosphere–ocean coupled forecast models and provided output variables needed for our diagnostics include BoM, CMA, CNRM, ECMWF, and NCEP. To date, all required fields have been downloaded, except for a subset of data

from ECMWF. In September 2017, an ECMWF tape containing their S2S reforecast data was damaged. Frederic Vitart of ECMWF is copying this data for us from the ECMWF in-house archive to a 4 TB drive. Co-PI Klingaman will either upload this data to CSU via a Google Drive folder, or deliver it Co-PI DeMott at the upcoming November 2017 6th International Monsoon Workshop in Singapore. This portion of the ECMWF re-forecast dataset is valuable to our project because it uses a 1° ocean model, and will allow an assessment of MJO forecast skill when compared to the current re-forecast dataset that uses 0.25° ocean resolution.

- Our evaluation of oceanic feedbacks and sources of predictability for the MJO will begin with a broad assessment of these processes in the ensemble-mean re-forecasts. To that end, we have computed ensemble means of all acquired surface variables. Skill metrics, such as pattern correlations with observed data, are being generated to quantify these effects.

3.2. Preparations for modeling studies

The overarching goal of our project is to assess oceanic sources of predictability on S2S scales. Specifically, we wish to understand how characteristics of the ocean state might contribute to the predictability of certain MJO events. Several oceanic processes are thought to regulate MJO convection. Warm SST anomalies associated with downwelling oceanic Rossby waves have been linked to initiation of MJO convection in the western Indian Ocean (*Webber et al.*, 2011; *Rydbeck and Jensen*, 2017). Persistent eastward or westward equatorial surface currents can enhance or reduce, respectively, surface fluxes and upper ocean mixing driven by MJO suppressed phase low-level easterly winds. These oceanic processes can regulate the SST response and potentially the amplitude of MJO convection (*Moum et al.*, 2016).

These processes, and a sampling of dates where they are observed, are summarized in the following table. All dates correspond to observed MJO events, and bold dates indicate events re-forecast by all modeling centers included in the S2S database. A reduced list of candidate cases for model sensitivity studies will be guided by the results of our forecast skill assessment for these cases.

Process	Dates observed
Downwelling oceanic Rossby waves	17 Jan 1996, 25 Jan 1997, **2 Feb 2003**, **15 Feb 2006**, **6 Feb 2010**, 19 Feb 2012
Persistent eastward equatorial surface currents	**17 Nov 2000**, **16 Nov 2001**, **7 Dec 2003**, 1 Nov 2012
Persistent westward equatorial surface currents	15 Jan 1993, 29 Mar 1997, **21 Jan 2002**, **25 Jan 2004 26 Jan 2009**, 24 Feb 2012
High-amplitude SST variability	TBD

Work performed in this section supports Project Goal 2, testing specific ocean feedback mechanisms to MJO propagation and forecast skill.

Co-PI Klingaman updated the MC-KPP ocean model coupling interface for compatibility with the latest configuration of the Met Office Unified Model (MetUM) atmospheric model, which the Met Office use for operational S2S forecasts and re-forecasts. This MetUM configuration, Global Atmosphere 7.0 (GA7), has shown improved MJO fidelity in both initialized (i.e., S2S) and climate configurations. This improved skill was demonstrated at a recent Met Office Tropical Convection Working Group meeting, which Co-PI Klingaman attended. We will use GA7 for our sensitivity studies; Co-PI Klingaman will also perform sensitivity experiments with GA7+MC-KPP in climate mode to understand the role of air–sea coupling in these changes, in a collaboration with Dr. Prince Xavier at the Met Office.

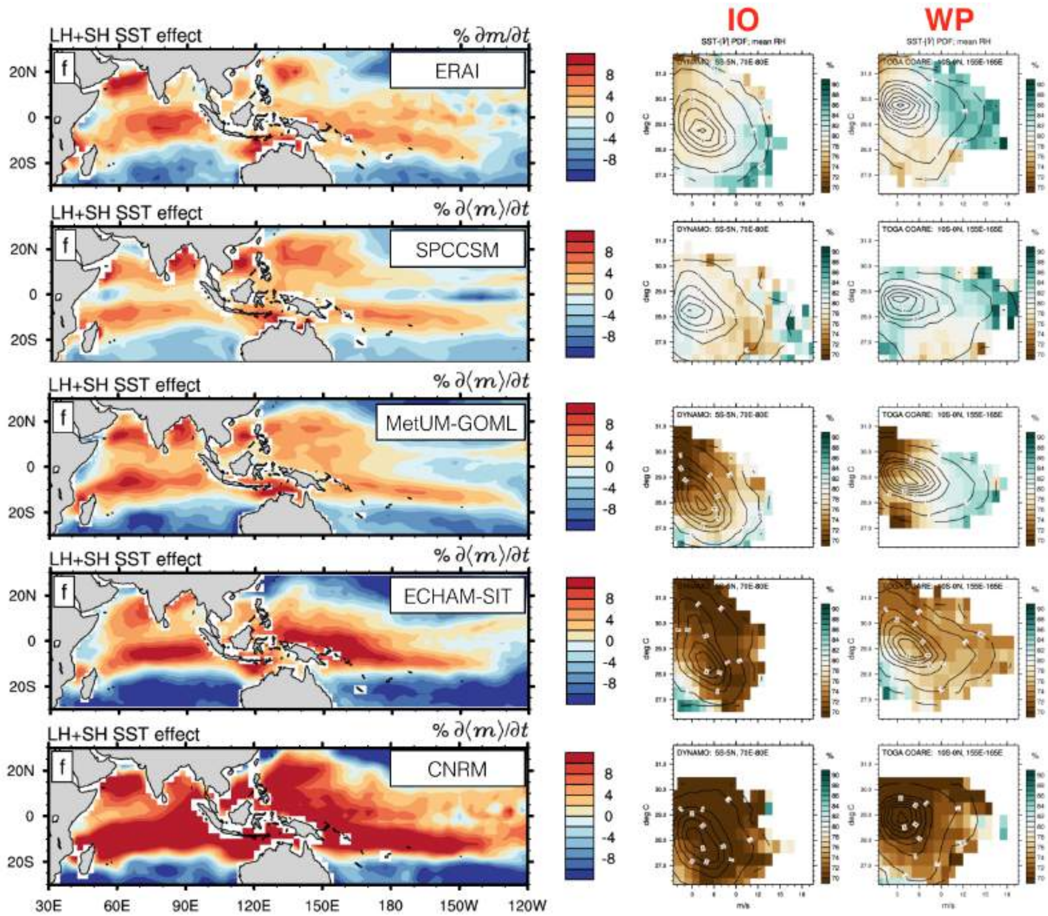


Figure 1: Left: Fraction of intraseasonal column integrated moist static energy ($\langle m \rangle$) tendency driven by SST fluctuations. Center and Right: Boundary layer relative humidity (shading) and frequency of occurence (contours) as a function of wind speed and SST for Indian Ocean and western Pacific Ocean locations, respectively.

3.3. Parsing ocean feedbacks into direct and indirect effects for MJO propagation

Work on our other funded projects and emerging findings based on S2S database analyses drive ongoing development of our air–sea interactions diagnostics package. Application of our diagnostics to a set of four coupled climate-length simulations reveals that exaggerated ocean feedback strength in some models is driven by a pervasive boundary-layer dry bias (Fig. 1. This dry bias inflates surface latent heat fluxes and SST variability, and leads to unreasonably large column moistening by surface fluxes in the most biased models (not shown). These analyses assess *direct* ocean feedbacks for MJO propagation.

Re-running each model as an atmosphere-only model driven with 31-day smoothed SSTs from the coupled simulation allows assessment of the indirect effects of ocean feedbacks on MJO propagation. Despite identical SST climatologies in each coupled–uncoupled pair, the composite MJO circulation anomalies in coupled models have stronger east-of-convection anomalous low-level easterlies (Fig. 2). Changes in the zonal extent and strength of the circulation anomalies are primarily driven by changes to the Kelvin wave part of the MJO wave structure. Preliminary analysis suggests that these circulation changes are supported by negative SST feedbacks to convection in the MJO suppressed phase that enhance long-wave cooling and moisture advection by the ensuing dry Rossby gyres (Kim 2014). Additionally, MJO convection in the Indian Ocean for coupled simulations exhibits a stronger peak on the Equator than in uncoupled simulations. This finding is consistent with direct ocean feedbacks on the convective anomaly (DeMott 2016), but may influence the intensity of the downstream Kelvin wave response. These differences represent *indirect* ocean feedbacks for MJO propagation.

In light of these findings, as well as recent work by *Kim et al.* (2016); *Gonzalez and Jiang* (2017) and *Wang and Lee* (2017), we have added the following elements to our diagnostics package, to better understand direct and indirect ocean feedbacks to MJO propagation:

- **Direct:** Boundary layer humidity variations throughout MJO lifecycle, as shown in Fig. 1.
- **Direct:** Indian Ocean equatorial rainfall "peakedness."
- **Indirect:** Rossby/Kelvin wave wind intensity index (*Wang and Lee*, 2017).
- **Indirect:** Warm Pool zonal and meridional mean moisture gradients (**?**)

We will use our improved Understanding of the direct and indirect oceanic influence on MJO propagation gleaned from these climate length simulations in our analysis of S2S model output by relatimg SST skill, ocean feedback strength, and indirect measures of feedback strength to MJO forecast skill.

This background analysis supports Project Goals 1 and 2 (i.e., evaluating models in the S2S database, testing specific ocean feedback processes) in that it provides a foundation for understanding the processes that enhance or hinder a model's ability to simulate MJO propagation.

3.4. Application of air–sea interaction diagnostics to a CFSv2 climate simulation.

Our participation in NOAA MAPP S2S Task Force meetings and monthly webinars has fostered interactions with other research groups focused on topics similar to ours. One outcome of these interactions was the opportunity to test our air–sea interactions diagnostics on CFSv2 model output. Fellow MAPP project members Arun Kumar, JieShun Zhu, and Wanqiu Wang provided output from a CFSv2 climate-length simulation using a relaxed Arakawa-Schubert cumulus parameterization, which simulates a reasonably good MJO (*Zhu et al.*, 2017). Our diagnosis of ocean feedback strength in the CFSv2 revealed:

- Contrary to many coupled models, CFSv2 exhibits a warm SST bias throughout the Warm Pool.
- CFSv2 exhibits a weak dry bias in boundary layer humidity.
- CFSv2 exhibits a positive bias in intraseasonal SST variability, the result of larger-than-observed surface cooling by surface turbulent and longwave radiative fluxes.
- The exaggerated SST variability leads to larger-than-observed surface latent heat flux projections onto column-integrated moist statice energy. This indicates that ocean coupling in this version of CFSv2 plays an overly important role for the maintenance of MJO convection across the Warm Pool.

Our diagnosis of ocean feedbacks in CFSv2 contributes to a growing body of evidence that the mechanisms for improved MJO propagation in coupled models are highly model dependent.

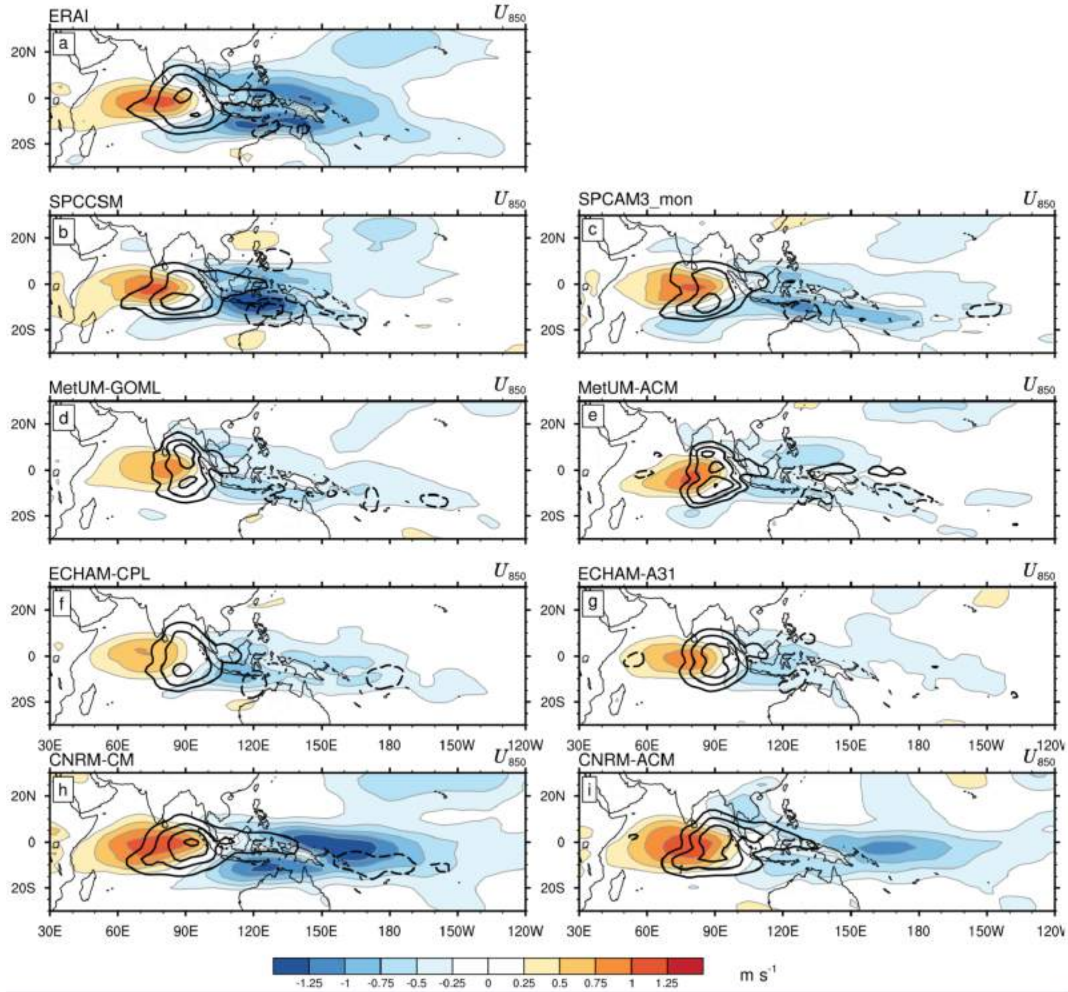


Figure 2: Composite zonal wind anomalies at 850 hPa (shading; [m s^{-1}]/[mm day^{-1}]) and rainfall (contoured every 0.5 [mm day^{-1}]/[mm day^{-1}]) regressed onto eastern Indian Ocean rainfall. Right: Reanalysis and coupled simulations; Left: Uncoupled simulations. All units are normalized by Indian Ocean heating.

4. Highlights of Accomplishments

Highlights from the second six months of Year 1 include:

1. Acquisition of data needed to assess ocean feedback strength in S2S models.
2. Repackaging of RMM indices for simpler analysis.
3. Additions to air–sea interaction diagnostics package to better discriminate direct and indirect ocean feedbacks to MJO propagation.
4. Updates to MC-KPP ocean model to support coupling to MetUM atmosphere with improved MJO
5. Analysis of intraseasonal ocean feedbacks in CFSv2.

5. Transitions to Applications

None.

6. Publications from the Project

DeMott, C. A., B. O. Wolding, E. D. Maloney, and D. A. Randall: Atmospheric contributions to MJO decay over the Maritime Continent. In final revision for *J. Geophys. Res. Atmos*.

DeMott, C. A., B. O. Wolding, D. Baranowski, D. Halkides, N. P. Klingaman, and E. D. Maloney: The shape of MJO heating in the Indian Ocean: Relationship to ocean feedback mechanisms. In preparation for J. Geophys. Res. Atmos. This paper will be finalized for submission pending acceptance of the above.

7. PI Contact Information

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8. Budget for Coming Year

8.1. CSU Budget

Item	Year 1 (July 16–June 17)		Year 2 (July 17–June 18)	
	Spend	Notes	Spend	Notes
DeMott salary and fringe	$44,687	5.15 months	$58,594	6.4 months
TBN Post-doc salary and fringe	$0	Post-doc not hired yet	$0	not hired yet
Supplies	$100	poster charges	$0	
Travel	$2,079	WGNE S2S Systematic Errors Workshop / MAPP S2S Task Force Kickoff, Palisades, NY	$6,605	WGNE S2S Systematic Errors Workshop / MAPP S2S Task Force Kickoff, Palisades, NY; Visit to Reading UK Oct 2017; AGU Dec 2017
Other Direct Costs - Network Charges	$206		$269	
Indirect Costs	$14,121	30% indirect rate	$19,640	30% indirect rate
Total projected spending	$61,193		$85,108	

Total projected spending through end of Year 2: $146,301
Total unspent funds at End of Year 2: $114,359

8.2. University of Reading Budget

Item	Year 1 (July 16–June 17)		Year 2 (July 17–June 18)	
	Spend	Notes	Spend	Notes
Klingaman salary and fringe	$0	Provided at no cost	$0	Provided at no cost
TBN Post-doc salary and fringe	$0	Post-doc not hired yet	$0	Post-doc not hired yet
Travel	$0		$0	
Indirect Costs	$0		$0	
Total projected spending	$0		$0	

Total projected spending through end of Year 2: $0
Total unspent funds at End of Year 2: $79,910
Note: Delays in availability of required HPC resources and selection of case studies have resulted in delays to project expenditure at Reading. We anticipate spending the full project funding in Year 3, for support with running and analyzing hindcast simulations, following identification of case studies.

9. Future Work

In the next six-month work period we will:

- Conduct a broad survey of Warm Pool SST anomaly forecast skill as a function of RMM phase.
- Apply our air–sea interaction diagnostics to S2S model output to reveal ocean feedback strength in member models. This will include an assessment of MJO circulation changes with forecast lead time and will leverage our understanding of indirect ocean feedbacks to MJO propagation gleaned from other funded studies.
- Prepare a manuscript describing our findings.
- Begin model experiments to diagnose specific ocean feedback mechanisms in select MJO events.

References

Gonzalez, A. O., and X. Jiang (2017), Winter mean lower tropospheric moisture over the maritime continent as a climate model diagnostic metric for the propagation of the madden-julian oscillation, *Geophysical Research Letters*, *44*(5), 2588–2596, 2016GL072430.

Kim, H.-M., D. Kim, F. Vitart, V. E. Toma, J.-S. Kug, and P. J. Webster (2016), MJO propagation across the maritime continent in the ECMWF ensemble prediction system, *Journal of Climate*, *29*(11), 3973–3988, doi:10.1175/jcli-d-15-0862.1.

Moum, J. N., K. Pujiana, R.-C. Lien, and W. D. Smyth (2016), Ocean feedback to pulses of the madden–julian oscillation in the equatorial indian ocean, *Nature Communications*, *7*, 13,203, doi:10.1038/ncomms13203.

Rydbeck, A. V., and T. G. Jensen (2017), Oceanic impetus for convective onset of the madden–julian oscillation in the western indian ocean, *Journal of Climate*, *30*(11), 4299–4316, doi:10.1175/jcli-d-16-0595.1.

Wang, B., and S.-S. Lee (2017), MJO propagation shaped by zonal asymmetric structures: Results from 24 GCM simulations, *Journal of Climate*, *30*(19), 7933–7952, doi:10.1175/jcli-d-16-0873.1.

Webber, B. G. M., A. J. Matthews, K. J. Heywood, and D. P. Stevens (2011), Ocean rossby waves as a triggering mechanism for primary madden-julian events, *Quarterly Journal of the Royal Meteorological Society*, *138*(663), 514–527, doi:10.1002/qj.936.

Zhu, J., W. Wang, and A. Kumar (2017), Simulations of MJO propagation across the maritime continent: Impacts of SST feedback, *Journal of Climate*, *30*(5), 1689–1704, doi:10.1175/jcli-d-16-0367.1.

COVER PAGE

National Oceanic and Atmospheric Administration
Office of Weather and Air Quality
Hydrometeorology Testbed

Federal Grant Number Assigned by Agency: NA17OAR4590121

Project Title: Comparison of Model Versus Observationally-Driven Water Vapor Profiles for Forecasting Heavy Precipitation Events

Principal Investigator Name: John M. Forsythe
970-491-8589; john.forsythe@colostate.edu

Submission Date: January 29, 2018

Cooperative Institute for Research in the Atmosphere
Colorado State University
West Laporte Avenue
Fort Collins, CO 80523-1375

Project/Grant Period (07/01/17 - 06/30/19)

Reporting Period End Date: December 31, 2017

Report Term or Frequency (semi-annual)

Final Annual Report? No

1. ACCOMPLISHMENTS

This reporting period (July 1 – December 31, 2017) saw the kickoff of the project and development of initial products. The project is on schedule and on budget. The project timetable is shown in Table 1, and the reporting period covers Year 1 Q1 and Q2. Tasks due for completion (model ingest and LPW calculation) have been completed. Model ingest, decoding and LPW calculation have been completed.

Table 1 *Activities and Key Milestones*	**Status as of 12/31/17**	**YEAR 1**				**YEAR 2**			
		Q1	**Q2**	**Q3**	**Q4**	**Q1**	**Q2**	**Q3**	**Q4**
Ingest and decode GFS and RAP analysis and forecast files at CIRA	Completed.	X							
Calculate LPW from model fields	Completed.	X	X						
Develop initial difference products	In progress		X	X	X				
Distribute products to WPC and partner WFO's in AWIPS format	In progress			X	X	X	X	X	X
Meet forecasters and present training at WPC	Not yet started.			X				X	
Revise difference products based on forecaster feedback	Not yet started				X	X	X	X	
Semi-annual report	Completed.		X		X		X		X
Submit journal paper, nominal title: "Model water vapor diagnostics for forecasting heavy precipitation"	Not yet started.								X

A new 12 core server was purchased and brought online in November 2017. This machine is now ingesting GFS and ALPW data and processing near-realtime water vapor difference fields every six hours.

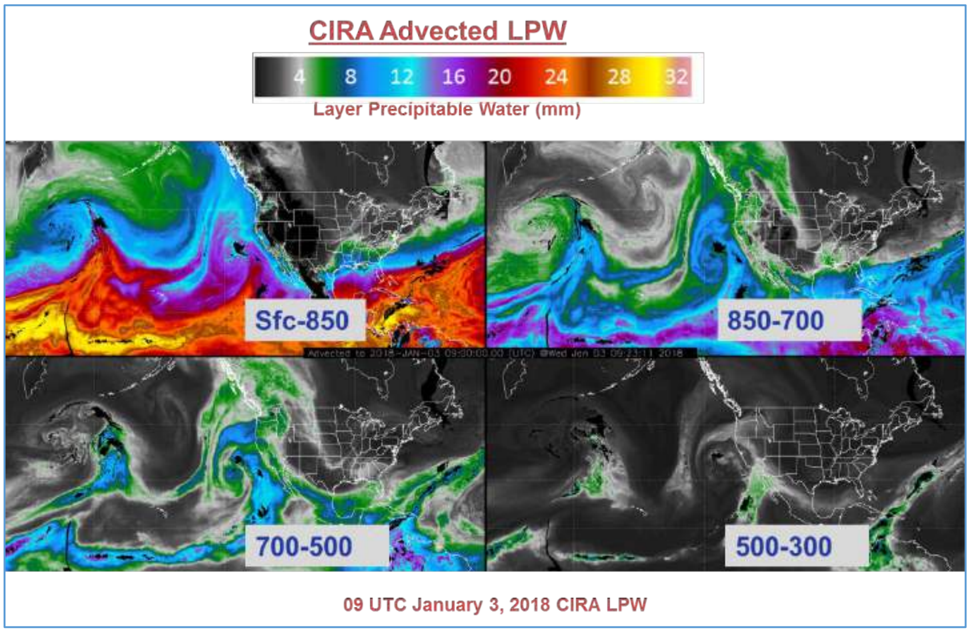
Initial difference products have been created, and are being distributed to two near-realtime websites:

http://cat.cira.colostate.edu/HMT/HMT_Main.htm as maps
http://cat.cira.colostate.edu/HMT/HMT_Histogram_alt.htm as histograms.

The top priority work in progress is to format the difference maps in AWIPS-2 format and begin distribution to WPC and NWS partners (EAX, TWC, BGM). This requires modifying the CIRA DPEAS software system in the McIDAS output routine to scale the difference results. This task is expected to be completed in February. At the AMS Annual Meeting in January, a planning meeting for the Flash Flood and Intense Rainfall (FFaIR) experiment was held. Ben Albright of WPC is the POC for the new difference maps, he indicated AWIPS-2 format is preferable.

2. PRODUCTS

Examples of the products developed in this project are shown in Figures 1 – 3. In Figure 1, the CIRA Advected LPW (ALPW) for the four layers (sfc-850, 850-700, 700-500 and 500-300) is shown, along with the PW at the same time derived from the GFS model (0.5° resolution product).



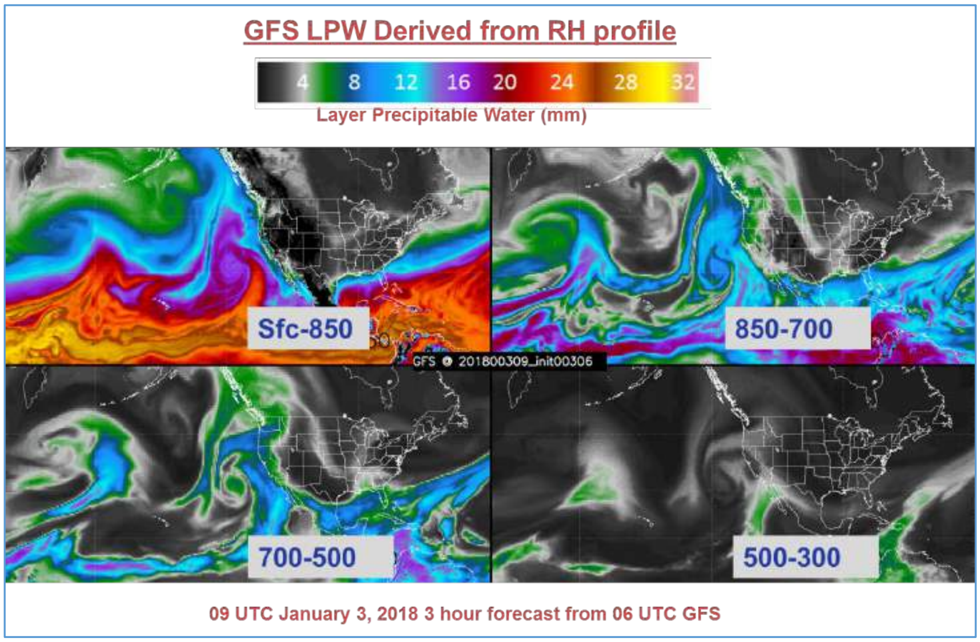


Figure 1: (Top) CIRA Advected LPW for four layers and (bottom) LPW derived from GFS for 09 UTC 3 January 2018.

The GFS LPW required integration of the relative humidity and temperature profile to create LPW, as LPW is not supplied with the model fields. Teten's formula is used to compute the saturation vapor pressure with respect to water.

The main products to be created in this product are model moisture difference fields. The first versions of these are shown in Figures 2 and 3.

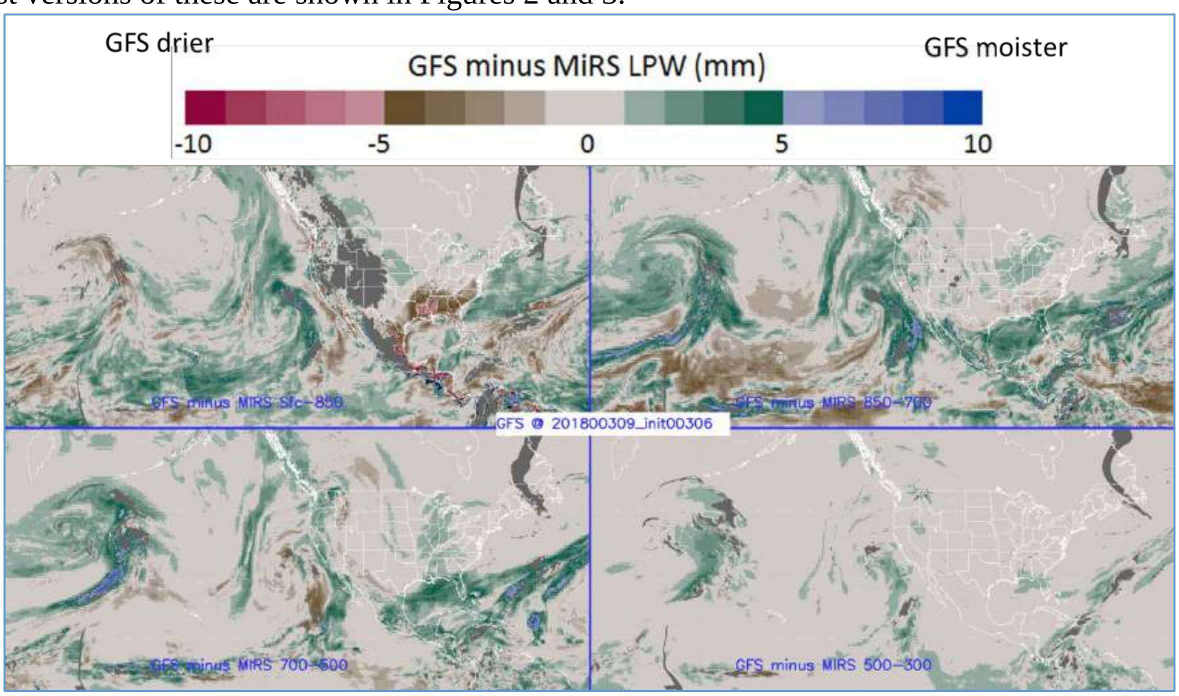


Figure 2: LPW difference product for the four layers shown in Fig. 1 for 09 UTC 3 January 2018.

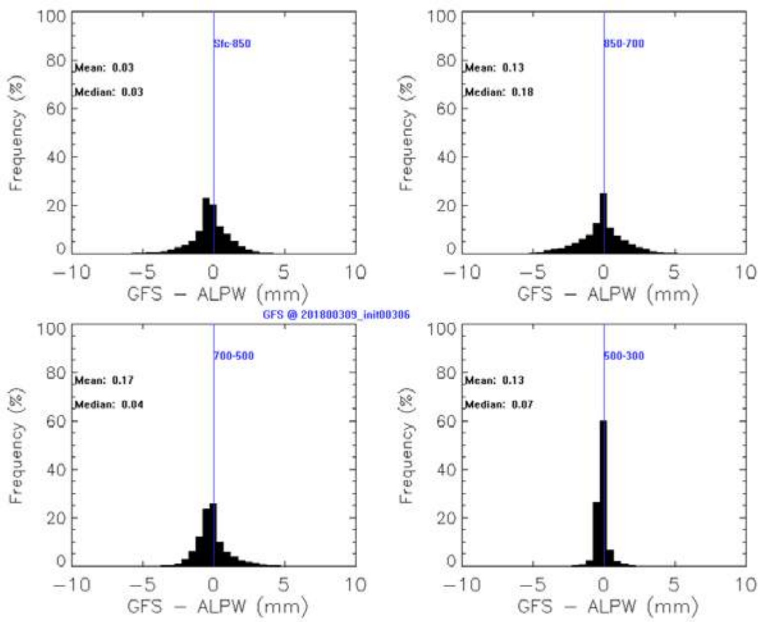


Figure 3: Histogram of differences for the four layers shown in Fig. 2.

Figure 2 shows the difference (mm) between GFS LPW and the ALPW at 09 UTC 3 January 2018 for the four layers. The histogram of differences across the domain are shown in Figure 3. Figure 2 in particular reveals interesting structure and feedback from forecasters will be solicited on both the display and the meteorological impact. Most regions in Fig. 2 have less than 5 mm difference, but there are a few exceptions. In the 850 – 700 mb layer the system off Baja shows some blue colors indicating that the GFS maybe be too moist by over 5 mm in that layer. There are also some red areas in sfc-850 (e.g. east coast of Mexico) which are likely due to topography differences, this issue is being explored.

The histograms of differences look quite Gaussian with little bias. This is an encouraging first result as it indicates the integration methodology is not introducing a large bias.

Note that missing regions in Figs. 1 and 3 represent either precipitation-flagged retrievals which could not be advected or gaps in the polar orbiter coverage.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

The project team at CIRA is PI John Forsythe, with co-I's Andy Jones, Stan Kidder, Steven Fletcher, Dan Bikos and Ed Szoke. PI Forsythe has done the majority of the science coding this reporting period, while Kidder and Jones have worked on data ingest.

NOAA collaborators are Mark Klein (WPC), Andrew Orrison (WPC), Daniel Leins (NWS Tucson, AZ), Chris Gitro (NWS Kansas City MO), and Michael Jurewicz (NWS Binghamton NY). These collaborators will be engaged more in the next reporting period to critique and refine the results and display, and to ingest the difference product in AWIPS format.

4. IMPACT

It is too early to assess the impact of these products, but due to their expected connection to heavy precipitation and flood forecasting which cause loss of life and billions of dollars of damage in the U.S. each year it could be large.

5. CHANGES/PROBLEMS

There have been no major changes to the project. The successful launch of JPSS-1 (now NOAA-20) in November should provide more coverage in the ALPW product, which will reduce gaps due to the irregular temporal sampling of polar orbiting satellites. The ALPW product is created independently of this project, so any improvements in ALPW will benefit this HMT project.

6. SPECIAL REPORTING REQUIREMENTS

The project Readiness Level is currently assessed at Level 4, as a prototype is currently being created at CIRA in near-realtime. Once AWIPS-2 files are delivered to WPC and collaborators in the next reporting period, the Readiness Level will advance to 5.

A Test Plan and Transition Plan are included as separate attachments.

The project has been approved to participate in the FFaIR experiment in June and July 2018.

No other transitions to NOAA have occurred during this reporting period.

7. BUDGETARY INFORMATION

The project is on budget. A server was purchased in November 2017 and is performing well with near-realtime production.

8. PROJECT OUTCOMES

The expected outcome of this award is a technique to evaluate model moisture fields. This could provide forecasters additional warning time for high impact flooding events, such as occurred frequently in 2017 in the U.S. (Hurricane Harvey, Southern California flash floods).

Project Title: Development of a Framework for Process-Oriented Diagnosis of Global Models
Project Number: GC15-106 **(**NA15OAR4310099)
PIs: Eric D. Maloney (Colorado State University), Andrew Gettelman (NCAR), Yi Ming (GFDL), David Neelin (UCLA)
Report Type: Year 3 Report

Main Goals of the Project

A. Develop a common and extensible mechanism for rapid dissemination of process-oriented diagnostics across modeling centers

B. Development of model diagnostics related to tropical convection and tropical variability

C. Implementation of these critical diagnostics for tropical convection and its variability into the framework developed in A.

Results and Accomplishments

A. NOAA MAPP Model Diagnostics Task Force (MDTF) Activities

1. General Task Force Activities

The NOAA MAPP MDTF was initiated in Fall of 2015, led by chair Maloney, and co-chairs Gettelman, Ming, and Aiguo Dai. Regular telecons have been conducted on the first Monday of each month. The task force activities that have been initiated and are ongoing are described below.

2. NOAA MDTF Timeslice Experiments

Timeslice experiments have been completed with the NCAR and GFDL models to provide high time and space frequency resolution output to kick start task force diagnostics efforts. The specifications of this design are:

Timeslices of free running models
Specified SSTs: 1993-2012 with limited output, 2008-2012 with high frequency output

Models
NCAR (1 deg, possible short run of 0.25 deg)
GFDL (1 deg, possible short 0.5 deg run)

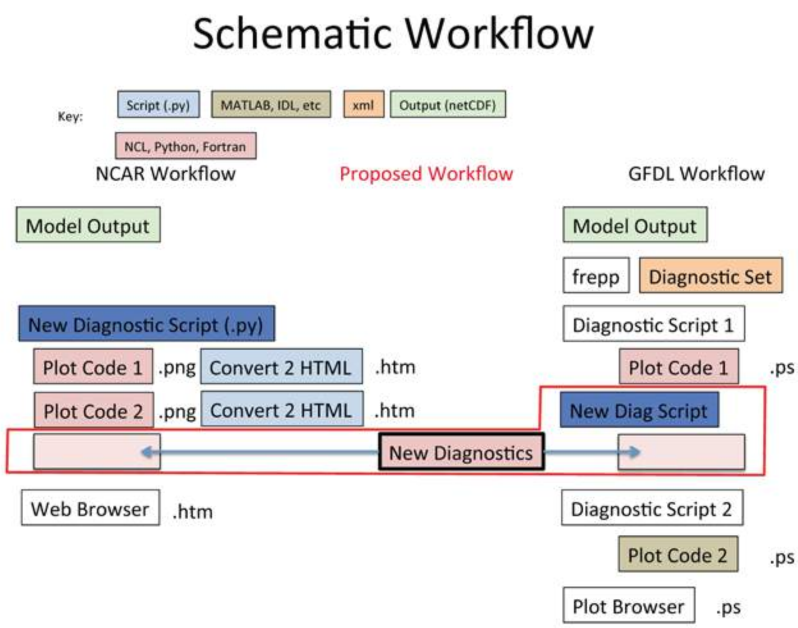
Output schemes
1. 20-year (1993-2012) simulation: Daily, a handful set of 2D variables
2. 5-year (2008-2012) sub period: 6-hourly, comprehensive list
3. 2-year (2011-2012) sub period: hourly, variables for diurnal cycle study

Both NCAR and GFDL have completed these experiments. These simulations are in the process of being posted to the Earth System Grid, and will be assigned their own DOI with the title of Model Diagnostics Task Force Timeslice Experiments. These experiments will form the basis for a MDTF diagnostics intercomparison and possible foundation for comprehensive manuscripts in future years.

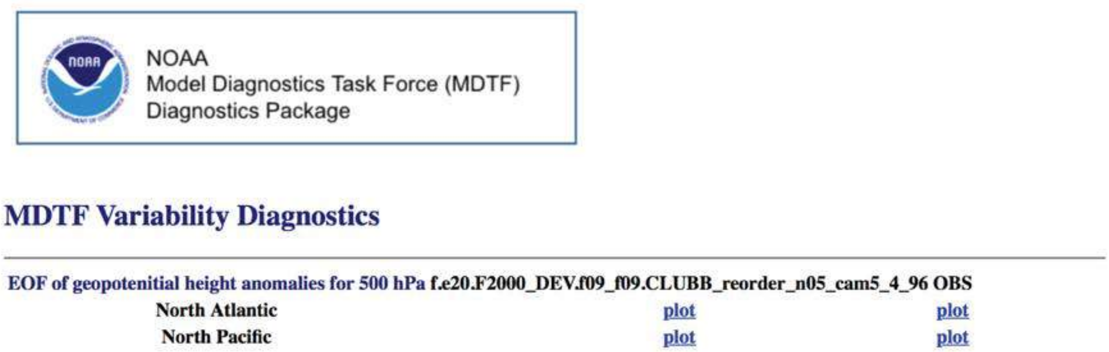
3. Implementation of convective onset diagnostics at GFDL and NCAR
Convective onset diagnostics developed by co-PI Neelin have been implemented at GFDL and NCAR, and serve as the initial test diagnostic for the diagnostic framework (discussed in 4 below). PI Ming at GFDL reports that this diagnostic suite is already being used as an important performance metric and is having a direct impact on model development at GFDL and efforts to freeze the next generation of the GFDL model for CMIP6. NCAR is also using the metrics in its CMIP6 model development activity that is currently wrapping up. Improvements to the diagnostics are discussed in section B.

4. Development of Diagnostics Software Framework/Application Programming Interface (API)
Based on discussions among our Type 1 team and the task force, and given input from others external to the task force including V. Balaji and Erik Mason at GFDL, and members of the WGCM community, we developed an initial Application Programming Interface (API), or guidance for use of diagnostics in the NCAR and GFDL workflows. A Python-based code infrastructure for implementation and output of these diagnostics has been developed. The basic structure uses a Python driver to call a series of diagnostic packages or modules to develop graphics and then output them to a common website. The resulting plots will be pulled together into common web pages by the driver (NCAR) or by the overall workflow (GFDL). The prototype shell script in Python works with diagnostics code developed in NCL, Python, Fortran or any other open source graphics package. The diagnostic modules has access to data structures and arguments from Python, and outputs a standard plot type (png) to a location where it can be used to construct web pages by the driver.

A schematic of the proposed GFDL and NCAR workflows is shown here:



The diagnostics website that will be populated by diagnostic results is shown here:



The convective onset diagnostics described in 3) have been successfully ported to this framework, providing an initial proof of concept on the ease of use of the framework.

5) Moist static energy budget subgroup
A subgroup of the MDTF is devoted to easing calculation of the vertically-integrated moist static energy (MSE) budgets in the GFDL, NCAR, and other models for storage efficiency and accuracy, and also for preventing duplication of efforts given the interest in such diagnostics on the part of several groups. PI Maloney is the point of contact with the modeling centers on such efforts. Ming Zhao at GFDL has been able to close the vertically-integrated MSE budget within

code and this closed budget has been applied for understanding the dynamics of the MJO in development versions of the GFDL model. This code will be made available for frozen versions of the CMIP6 implementation of the GFDL model for possible inclusion in timeslice experiments described above. Ming will present these results at the 2017 WGNE Systematic Errors Workshop. Jack Chen at NCAR has developed a novel technique to calculate the frozen MSE budget by defining frozen MSE as a new tracer variable and integrating the tracer transport equation, and is working with the NCAR model to develop in-code vertically-integrated budgets. Lessons learned from the efforts at GFDL to calculate the MSE budget will be translated to NCAR.

6) Session at 2016 AGU Meeting and other Meetings
A session on process-oriented diagnostics was conducted at the 2016 AGU meeting in San Francisco. PI Maloney submitted the proposal in April. This meeting served as a venue for a face-to-face meeting of the entire MDTF, who has a Monday evening dinner. Unfortunately, the PI Maloney has to cancel his trip to AGU because of an extended hospital visit, but the meeting among the rest of the TF members was nonetheless productive. The PIs on the Type 1 team also visited to GFDL in November in association with the WCRP Model Hierarchies workshop, and PI Maloney visited GFDL in February to give a seminar and have discussions with co-PI Ming and GFDL scientist Ming Zhao.

7) AMS Special Collection
A special collection on process-oriented diagnostics was submitted and accepted by AMS publications that reports on and synthesizes the work of our task force. The special collection description is included here: The special collection will span journals including *Bulletin of the American Meteorological Society (AMS)*, *Journal of Climate*, *Journal of the Atmospheric Sciences*, and *Journal of Hydrometeorology* devoted to process-oriented evaluation of climate and Earth system models. The Model Diagnostics Force (MDTF) of the NOAA Modeling, Analysis, Predictions, and Projections Program (MAPP) will organize this special collection. This special collection is motivated by community interest in moving beyond performance-oriented metrics toward process-oriented metrics of models, current efforts to develop the next generation of climate and Earth system models including those related to the Coupled Model Intercomparison Project (CMIP), and a need to link model development and evaluation efforts across modeling centers. Assessing processes in climate and Earth system models is essential for understanding model biases, identifying model error origins, and developing next-generation models.

The centerpiece of the special collection will consist of a comprehensive article in the *AMS Bulletin* that gives background on the concept of process-oriented model diagnosis, provides a partial summary of previous efforts at process-oriented diagnosis including both individual and organized efforts such as the European EMBRACE project, highlights key diagnostics developed by the MDTF, and describes an integrative process-oriented metrics framework serving multiple modeling centers that is being developed under the NOAA MAPP MDTF. Papers in *Journal of Climate*, *Journal of the Atmospheric Sciences*, and *Journal of Hydrometeorology* would provide the scientific details of specific process-oriented diagnostics accompany this core study. These papers detail studies not only by MDTF members, but also those contributed by the broader community.

8) 2017 WGNE Systematic Errors Workshop

The MDTF is co-organized the 5th WGNE workshop on systematic errors in weather and climate models to be held 19-23 June, 2017 in Montreal, Canada. A dedicated session on model metrics and diagnostics took place at this meeting, including a substantial number of contributions from the MDTF. The MDTF had a dedicated side meeting on June 23, part of which was held coincident with the WGNE MJO Task Force.

B. Research Activities

Improvement of the convective onset diagnostics and application to understanding convective physics (Kuo et al. 2017)

Previous work by various authors has pointed to the role of lower free-tropospheric humidity in affecting the onset of deep convection in the tropics. Empirical relationships between column water vapor (CWV) and precipitation have been inferred to result from these effects. Evidence from previous work has included deep-convective conditional instability calculations for entraining plumes, in which the lower free-tropospheric environment affects the onset of deep convection due to the differential impact on buoyancy of turbulent entrainment of dry versus moist air. The relationship between deep convection and water vapor is, however, a two-way interaction because convection also moistens the free troposphere. One might thus argue that the causality of the precipitation-water vapor relationship has not yet been fully established. Parameter perturbation experiments using the coupled Community Earth System Model (CESM) with high time-resolution output are analyzed for a set of statistics for the transition to deep convection, coordinated with observational diagnostics for GOAmazon and Tropical Western Pacific Atmospheric Radiation Measurement (ARM) sites. For low values of entrainment in the deep convective scheme, these statistics are radically altered and the observed pickup of precipitation with CWV is no longer seen. In addition to cementing the dominant direction of causality in the fast-timescale precipitation-CWV relationship, the results point to impacts of entrainment on the climatology. Because at low entrainment convection can fire before tropospheric moistening, the climatological values of relative humidity are lower than observed. These findings can be consequential to biases in simulated climate and to projections of climate change.

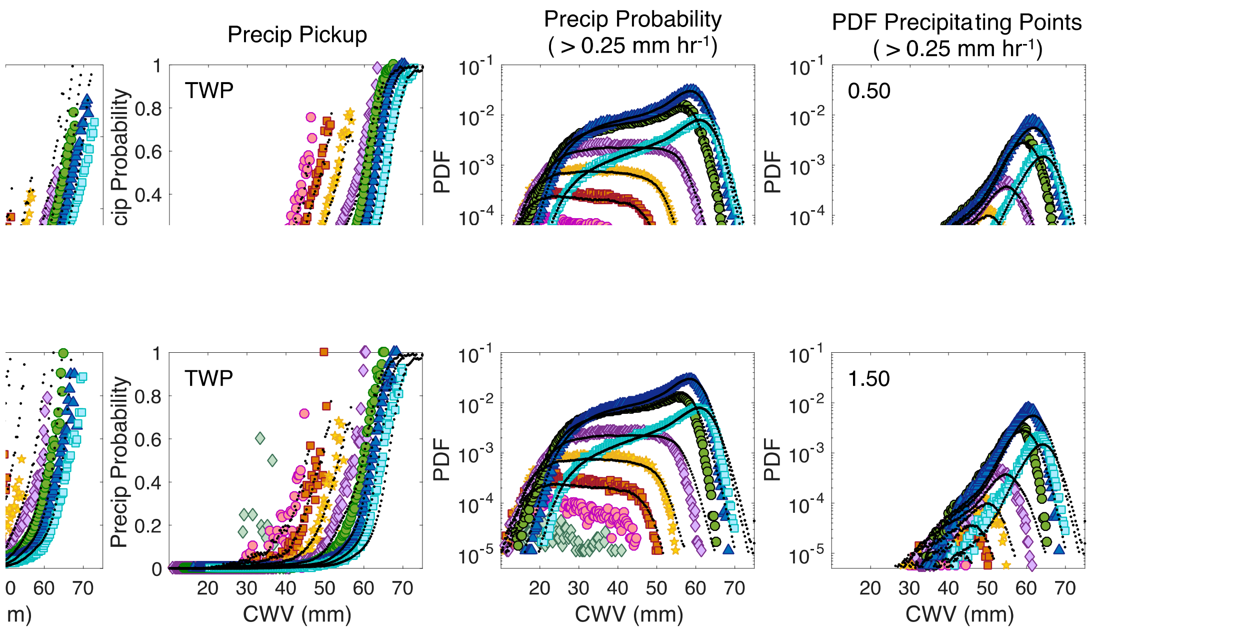


Figure 1. Resolution dependence of several convective onset statistics from TRMM Microwave Imager retrievals: (a)-(c) averaged to 0.5°; (d)-(f) averaged to 1.5°. The results from native 0.25° retrievals are overlaid in small black dots in each panel. (a) & (d) the pickup of precipitation (conditionally averaged by CWV and tropospheric average temperature); (b) & (e) probability of precipitation (larger than a threshold of 0.25 mm/hr); (c) & (f) the probability density function of precipitating points. (Analysis Y.H. Kuo & K. Schiro).

New weak temperature gradient diagnostics for the MJO applied to models (Wolding et al. 2016)

New process-oriented diagnostics using the concept of weak tropical temperature gradients are being developed and have been applied to understand the dynamics of the Madden-Julian oscillation in several climate models, and to understand their biases. These diagnostics can be applied in three dimensions, and extend the 2-D moist static energy budget diagnostics that have been used by the PI and collaborators over the last several years. These higher order diagnostics are being prepared for inclusion in the diagnostics packages of NCAR and GFDL, with the hope of broader application across a more extensive suite of models. We discuss some application of these diagnostics here to the Sp-CESM, although these have been also applied to other models such as the Ocean Land Atmosphere Model (OLAM).

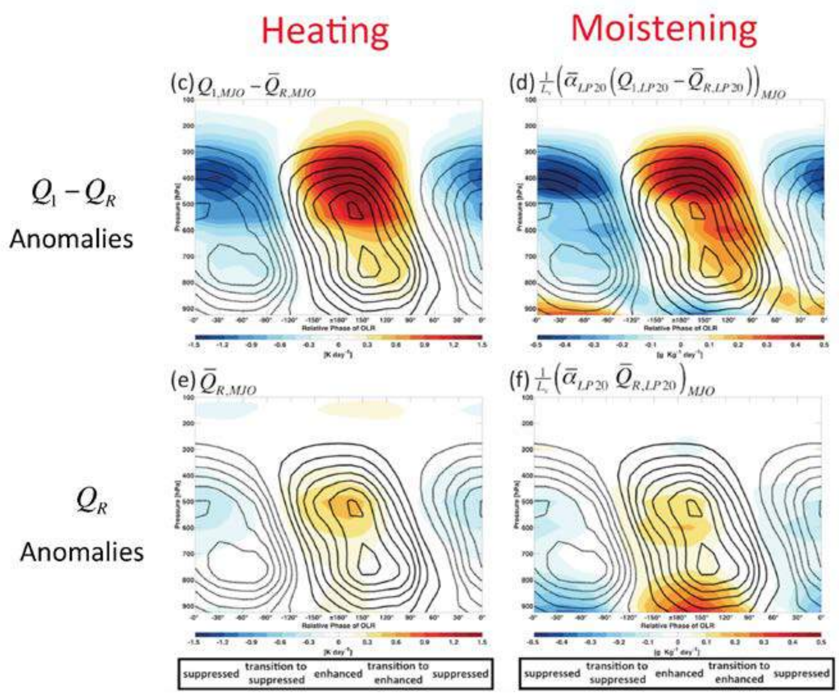


Figure 2. Composite vertical structure of condensational heating and radiative heating anomalies (left) and their moistening effect as determined through the assumption of WTG balance (right).

The collective effects of convection can influence large-scale circulations that, in turn, act to organize convective activity. Such scale interactions may play an important role in moisture-convection feedbacks thought to be important to both convective aggregation and the Madden-Julian Oscillation, yet such interactions are not fully understood. New diagnostics based on tropical weak temperature gradient (WTG) theory have begun to make this problem more tractable, and are leveraged in this study to analyze the relationship between various apparent heating processes and large-scale vertical moisture advection in SP-CESM. WTG theory provides a framework for accurately diagnosing intraseasonal variations in large-scale vertical motion from apparent heating, allowing large-scale vertical moisture advection to be decomposed into contributions from microphysical processes, subgrid scale eddy fluxes, and radiative heating. This approach is consistent with the column moist static energy (MSE) budget approach, and has the added benefit of allowing the vertical advection term of the column MSE budget to be quantitatively partitioned into contributions from the aforementioned apparent heating processes. This decomposition is used to show that the MJO is an instability strongly supported by radiative feedbacks (**Figure 2d**) and damped by horizontal advection, consistent with the findings of previous studies. Periods of low, moderate, and high MJO amplitude are compared, and it is shown that changes in the vertical structure of apparent heating do not play a dominant role in limiting the amplitude of the MJO in SP-CESM. Finally, a diagnostic approach to scale analysis of tropical dynamics is used to investigate how the governing dynamics of various phenomena differ throughout wavenumber-frequency space. Findings support previous studies that suggest the governing dynamics of the MJO differ from those of strongly divergent convectively coupled equatorial waves. This paper is published in the AGU journal *Advances in Modeling Earth Systems.*

Climate change and the Madden-Julian Oscillation: A vertically resolved weak temperature gradient analysis (Wolding et al. 2017)

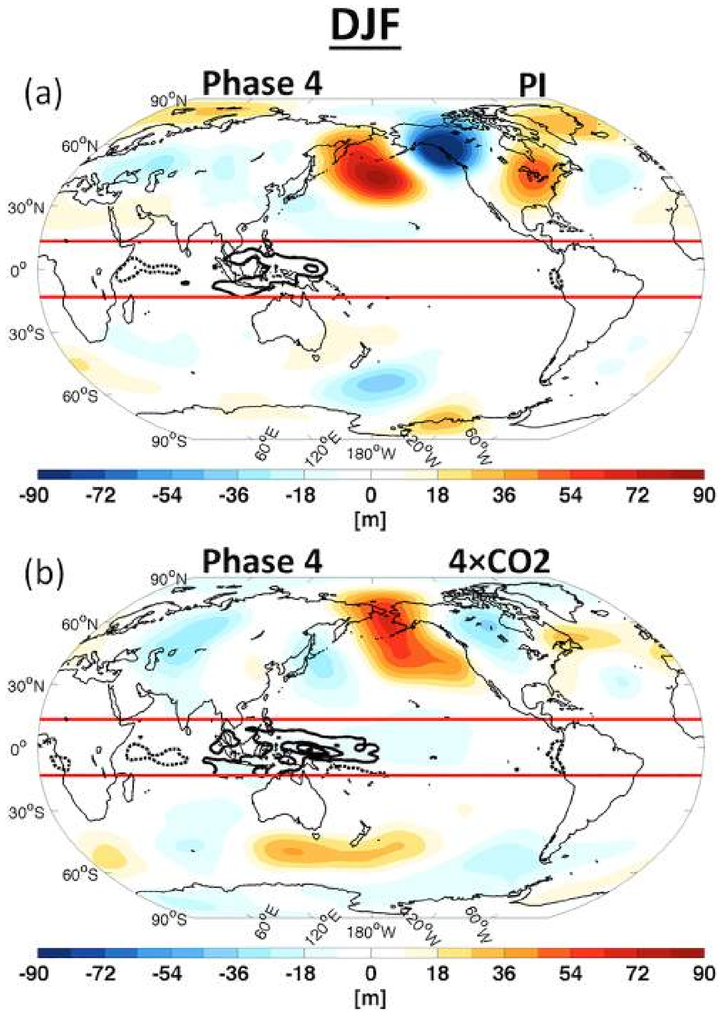


Figure 3. DJF phase 4 composites of 20–100 day band-pass filtered column-averaged apparent heating anomalies (contours) in the tropics, and 20–100 day band-pass filtered 525 hPa geopotential height anomalies (color shading) in the extratropics for the (a) pre-industrial and (b) 4×CO2 simulations. Red lines at 15°N and 15°S denote the boundaries used for tropical and extratropical averaging in the corresponding analysis. Solid and dashed contours correspond to positive and negative heating rates, respectively, contoured every 2 $K d^{-1}$ starting at ±1 $K d^{-1}$, with the 0 $K d^{-1}$ contour omitted.

WTG balance diagnostics are used to examine how changes in the moist thermodynamic structure of the tropics affect the MJO in two simulations of the Superparameterized Community Earth System Model (SP-CESM), one at preindustrial (PI) levels of CO_2 and one where CO_2 levels have been quadrupled (4×CO2). While MJO convective variability increases considerably in the 4×CO2 simulation, the dynamical response to this convective variability decreases. Increased MJO convective variability is shown to be a robust response to the steepening vertical moisture gradient, consistent with the findings of previous studies. The steepened vertical moisture gradient allows MJO convective heating to drive stronger variations in large-scale vertical moisture advection, supporting destabilization of the MJO. The decreased dynamical response to MJO convective variability is shown to be a consequence of increased static stability, which allows weaker variations in large-scale vertical velocity to produce sufficient adiabatic cooling to balance variations in MJO convective heating. This weakened dynamical response results in a considerable reduction of the MJO's ability to influence the extratropics, which is closely tied to the strength of its associated divergence. A composite lifecycle of the MJO was used to show that northern hemisphere extratropical 525 hPa geopotential height anomalies decreased by 27%

in the 4×CO2 simulation, despite a 22% increase in tropical convective heating associated with the MJO (**Figure 3**). Results of this study suggest that while MJO convective variability may increase in a warming climate, the MJO's role in "bridging weather and climate" in the extratropics may not.

Madden-Julian Oscillation Pacific teleconnections: The impact of the basic state and MJO representation in General Circulation Models (Henderson et al. 2017)

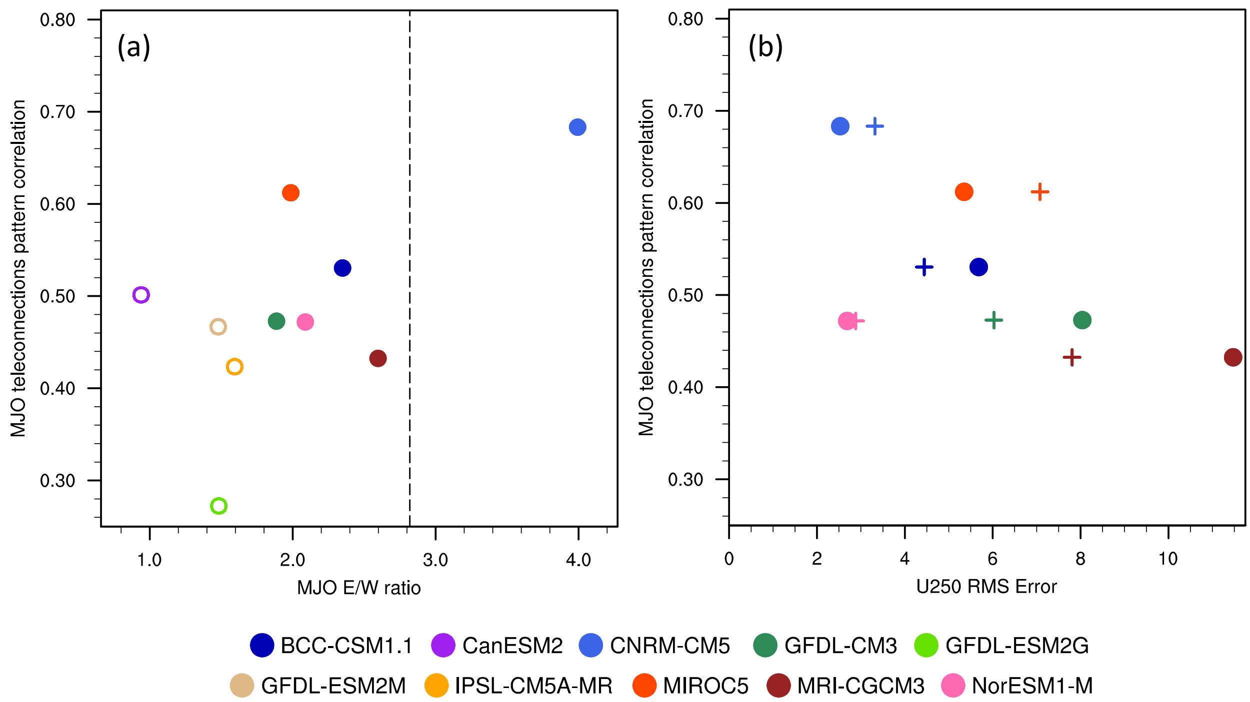


Figure 4. Teleconnection pattern correlation averaged for all MJO phases (y-axes) relative to the (a) MJO E/W ratio and (b) the 250-hPa mean zonal wind RMS error. In panel (a), the dashed line indicates the observed E/W ratio, and the open circles represent the poor MJO models. In panel (b), the plus signs show the model zonal wind RMS error over the full Pacific basin, while the filled circles indicate the longitudinal RMS error in the region of the subtropical jet.

Teleconnection patterns associated with the Madden-Julian Oscillation (MJO) significantly alter extratropical circulations, impacting weather and climate phenomena such as blocking, monsoons, the North Atlantic Oscillation, and the Pacific-North American pattern. However, the MJO has been extremely difficult to simulate in many General Circulation Models (GCMs), and many GCMs contain large biases in the background flow, presenting challenges to the simulation of MJO teleconnection patterns and associated extratropical impacts. In this study, the database from phase 5 of the Coupled Model Intercomparison Project (CMIP5) is used to assess the impact of model MJO and basic state quality on MJO teleconnection pattern quality, and a simple dry linear baroclinic model is employed to understand the results. Even in GCMs assessed to have good MJOs, large biases in the MJO teleconnection patterns are produced due to errors in the zonal extent of the Pacific subtropical jet. The horizontal structure of Indo-Pacific MJO heating in good MJO models is found to have modest impacts on the teleconnection pattern skill, in agreement with previous studies that have demonstrated little sensitivity to the location of tropical heating near the subtropical jet. However, MJO heating east of the Dateline can alter the teleconnection pathways over North America. Results show that GCMs with poor basic states can have equally low skill in reproducing the MJO teleconnection patterns as GCMs with poor MJO quality, suggesting that both the basic state and the MJO must be well represented in order to reproduce the correct teleconnection patterns (Figure 4).

Effects of the changing heating profile associated with melting layers in a climate model (Zhu et al. 2017)

This study investigates the impact of modifying the melting behaviour at the freezing level in the GA2.0 version of the Met Office UM. It finds that by allowing snow to melt over a greater depth, biases in rainfall over the Maritime Continent (MC) are improved, and there is an indication of benefits to the MJO.

This study uses moistening diagnostics under weak temperature gradient theory to explain how and why changes to the treatment of melting influence tropical rainfall biases. The modified melting experiment increases the lower tropospheric diabatic heating rate per unit column-integrated convective heating in the MC, which helps to increase lower tropospheric vertical moisture advection per unit column convective heating, making conditions more favorable for convection there. Changes of the opposite sense occur in tropical ocean regions of the west Pacific and Indian Ocean. Changes in lower tropospheric radiative heating per unit convection produced by the different treatment of melting are particularly influential in engendering mean precipitation changes between the experiments. Differences in precipitation in the MC region between the control and melting experiments and opposite changes in oceanic regions to the east and west are linked through changes in the Walker circulation, making it unclear which region is most influential for forcing the improvement in the pattern of precipitation biases. Sensitivity experiments that artificially enhance convection in one region through imposition of SST anomalies produce a negative precipitation response in the other region.

Fundamental Causes of Propagating and Non-propagating MJOs in models (Wang et al. 2017)

This study investigates the fundamental causes of differences in the Madden–Julian oscillation (MJO) eastward propagation among models that participated in a recent model intercomparison project. These models are categorized into good and poor groups characterized by prominent eastward propagation and non-propagation, respectively. Column-integrated moist static energy (MSE) budgets are diagnosed for the good and the poor models. It is found that a zonal asymmetry in the MSE tendency, characteristic of eastward MJO propagation, occurs in the good group, whereas such an asymmetry does not exist in the poor group. The difference arises mainly from anomalous vertical and horizontal MSE advection. The former is attributed to the zonal asymmetry of upper-midtropospheric vertical velocity anomalies acting on background MSE vertical gradient; the latter is mainly attributed to the asymmetric zonal distribution of low-tropospheric meridional wind anomalies advecting background MSE and moisture fields. Based on the diagnosis above, a new mechanism for MJO eastward propagation that emphasizes the second-baroclinic-mode vertical velocity is proposed. A set of atmospheric general circulation model experiments with prescribed diabatic heating profiles was conducted to investigate the causes of different anomalous circulations between the good and the poor models. The numerical experiments reveal that the presence of a stratiform heating at the rear of MJO convection is responsible for the zonal asymmetry of vertical velocity anomaly and is important to strengthening lower-tropospheric poleward flows to the east of MJO convection. Thus, a key to improving the poor models is to correctly reproduce the stratiform heating. The roles of Rossby and Kelvin wave components in MJO propagation are particularly discussed.

MJO Simulation in CMIP5 Climate Models: MJO Skill Metrics and Process-Oriented Diagnosis (Ahn et al. 2017)
The Madden-Julian Oscillation (MJO) simulation diagnostics developed by MJO Working Group and the process-oriented MJO simulation diagnostics developed by MJO Task Force are applied to 37 Coupled Model Intercomparison Project phase 5 (CMIP5) models in order to assess model skill in representing amplitude, period, and coherent eastward propagation of the MJO, and to establish a link between MJO simulation skill and parameterized physical processes. Process-oriented diagnostics include the Relative Humidity Composite based on Precipitation (RHCP), Normalized Gross Moist Stability (NGMS), and the Greenhouse Enhancement Factor (GEF). Numerous scalar metrics are developed to quantify the results. Most CMIP5 models underestimate MJO amplitude, especially when outgoing longwave radiation (OLR) is used in the evaluation, and exhibit too fast phase speed while lacking coherence between eastward propagation of precipitation/convection and the wind field. The RHCP-metric, indicative of the sensitivity of simulated convection to low-level environmental moisture, and the NGMS-metric, indicative of the efficiency of a convective atmosphere for exporting moist static energy out of the column, show robust correlations with a large number of MJO skill metrics. The GEF-metric, indicative of the strength of the column-integrated longwave radiative heating due to cloud-radiation interaction, is also correlated with the MJO skill metrics, but shows relatively lower correlations compared to the RHCP- and NGMS-metrics. Our results suggest that modifications to processes associated with moisture-convection coupling and the gross moist stability might be the most fruitful for improving simulations of the MJO. Though the GEF-metric exhibits lower correlations with the MJO skill metrics, the longwave radiation feedback is highly relevant for simulating the weak precipitation anomaly regime that may be important for the establishment of shallow convection and the transition to deep convection.

Dynamics-oriented diagnostics for the Madden-Julian Oscillation (Wang et al. 2018)
Realistic simulations of the Madden-Julian Oscillation (MJO) by global climate models (GCMs) remain a great challenge. To evaluate GCM simulations of the MJO, the U.S. CLIVAR MJO Working Group developed a standardized set of diagnostics, providing a comprehensive assessment of statistical properties of the MJO. Here, we develop a suite of complementary diagnostics that provide discrimination and assessment of MJO simulations based on the perception that the MJO propagation has characteristic dynamic and thermodynamic structures. The new dynamics-oriented diagnostics help to evaluate whether a model produces eastward propagating MJO for the right reasons. The diagnostics include (1) the horizontal structure of boundary layer moisture convergence (BLMC) that moistens the lower troposphere to the east of convection center; (2) the preluding eastward propagation of BLMC that leads the propagation of MJO precipitation by about 5 days; (3) the horizontal structure of 850 hPa zonal wind and its equatorial asymmetry (Kelvin easterly vs. Rossby westerly intensity); (4) the equatorial vertical longitudinal structure of equivalent potential temperature and convective instability index that

reflect the pre-moistening and pre-destabilization processes; (5) the equatorial vertical longitudinal distribution of diabatic heating that reflects the multi-cloud structure of the MJO; (6) the upper-level divergence that reflects the influence of stratiform cloud heating; and (7) the MJO available potential energy generation that reflects the amplification and propagation of MJO. The models that simulate better three-dimensional dynamic and thermodynamic structures of MJO generally reproduce better eastward propagations. This evaluation identifies a number of shortcomings in representing dynamical and heating processes relevant to the MJO simulation and reveals potential sources of the shortcomings.

A Unified Moisture Mode Framework for Seasonality of the Madden-Julian Oscillation (Jiang et al. 2018)

The Madden-Julian Oscillation (MJO) exhibits pronounced seasonality. While it is largely characterized by equatorially eastward propagation during the boreal winter, MJO convection undergoes marked poleward movement over the Asian monsoon region during summer, producing a significant modulation of monsoon rainfall. In classical MJO theories to interpret the distinct seasonality in MJO propagation features, the role of equatorial wave dynamics has been emphasized for its eastward propagation, whereas coupling between MJO convection and the mean monsoon flow is considered essential for its northward propagation. In this study, a unified physical mechanism based on the moisture mode framework is provided to interpret seasonality of MJO propagation characteristics. The process that was recently found to be critical for the eastward propagation of the winter MJO, i.e., moistening and drying due to horizontal advection of the lower-tropospheric mean moisture by MJO winds, is also shown to play a dominant role in the northward propagation of the summer MJO. The seasonal variations in the mean moisture pattern largely shape the distinct MJO propagation in different seasons. The critical role of the seasonal mean moisture pattern for MJO propagation is further supported by close association between model skill in representing MJO propagation and skill at producing the lower-tropospheric mean moisture pattern. This study thus pinpoints an important direction for climate model development for improved MJO representation during all seasons.

The impact of the Madden-Julian Oscillation on high-latitude winter blocking during El Niño-Southern Oscillation Events (Henderson and Maloney 2018)

Wintertime high-latitude blocking is associated with persistent changes in temperature and precipitation over much of the Northern Hemisphere. Studies have shown that the Madden-Julian Oscillation (MJO), the primary form of intraseasonal tropical variability, significantly modulates the frequency of high-latitude blocking through large-scale Rossby waves that alter the global circulation. However, the characteristics of MJO teleconnections are altered by the El Niño-Southern Oscillation (ENSO), which modifies the global flow on interannual timescales, suggesting that the MJO influence on blocking may depend on ENSO phase.

The characteristics of MJO Rossby waves and blocking during ENSO events are examined using composite analysis and a nonlinear baroclinic model. The ENSO phase-dependent teleconnection patterns are found to significantly impact Pacific and Atlantic high-latitude blocking. During El Niño, a significant persistent increase in Pacific and Atlantic blocking follows MJO RMM phase 7, characterized by anomalous enhanced tropical convection over the East Indian Ocean and suppressed west Pacific convection. The maximum Atlantic blocking increase is triple the climatological winter mean. Results suggest that the MJO provides the initial dipole anomaly associated with the Atlantic blocking increase, and transient eddy activity aids in its persistence. However, during La Niña significant blocking anomalies are primarily observed during the first half of an MJO event. Significant suppression of Pacific and Atlantic blocking follows RMM phase 3, when east Indian Ocean MJO convection is suppressed and west Pacific convection is enhanced. The physical basis for these results is explained.

C. Highlights of Accomplishments

- Accomplishments of the MDTF task force to date include:
  - Implementation of convective onset diagnostics into the GFDL and NCAR models
  - Development of a draft application programming interface to enable rapid dissemination of diagnostics across models,
  - Completion of simulations for timeslice experiments with the GFDL and NCAR models,
  - Closing the MSE budget in the GFDL model
  - Successful proposal for an AMS special collection on process-oriented diagnostics
  - A successful special session on diagnostics at the 2016 AGU meeting
- 3-D process oriented diagnostics to understand MJO moistening processes based on weak tropical temperature gradients have been developed and successfully applied to SP-CESM and other models. These diagnostics build on the 2D MSE budget diagnostics developed by the PI and collaborators
- Process-oriented diagnostics have been developed to document and understand reasons for poor MJO teleconnections in CMIP models
- Modeling results suggest that the MJO teleconnection to the extratropics may weaken in future climate

D. Publications From the Project

Kuo, Y.H., C. R. Mechoso and J. D. Neelin, 2017: Tropical convective onset statistics and establishing causality in the water vapor-precipitation relation. *J. Climate*, **74**, 915–931.

Henderson, S. A., E. D. Maloney, and S.-W. Son, 2017: Madden-Julian oscillation teleconnections: The impact of the basic state and MJO representation in general circulation models. *J. Climate*, **30**, 4567–4587.

Wolding, B. O., E. D. Maloney. S. A. Henderson, and M. Branson, 2016: Climate Change and the Madden-Julian Oscillation: A Vertically Resolved Weak Temperature Gradient Analysis. *J. Adv. Modeling Earth Sys*., **9**, doi:10.1002/2016MS000843.

Wolding, B. O, E. D. Maloney, and M. Branson, 2016: Vertically Resolved Weak Temperature Gradient Analysis of the Madden-Julian Oscillation in SP-CESM. J. Adv. Modeling. Earth. Sys., **8**, doi:10.1002/2016MS000724.

Zhu, H., E. Maloney, H. Hendon and R. Stratton, 2017: Effects of the changing heating profile associated with melting layers in a climate model. *Q. J. Royal. Met. Soc.*, **143**, 3110–3121.

Wang, L., T. Li, E. Maloney, and Bin Wang, 2017: Fundamental Causes of Propagating and Non-propagating MJOs in MJOTF/GASS models. *J. Climate*, **30**, 3743–3769.

Ahn, M.-S., D. Kim, K. Sperber, E. Maloney, D. Waliser, H. Hendon, 2017: MJO Simulation in CMIP5 Climate Models: MJO Skill Metrics and Process-Oriented Diagnosis. *Climate Dyn.*, **49**, 4023. https://doi.org/10.1007/s00382-017-3558-4.
Wang, B., S.-S. Lee, D. E. Waliser, C. Zhang, A. Sobel, E. Maloney, T. Li, X. Jiang, and K.-J. Ha, 2018: Dynamics-oriented diagnostics for the Madden-Julian Oscillation. *J. Climate*, in press.
Jiang, X., A. Adames, M. Zhao, D. Waliser, and E. Maloney, 2018: A unified moisture mode framework for seasonality of the Madden-Julian oscillation. *J. Climate*, in press.
Henderson, S. A., and E. D. Maloney, 2018: The impact of the Madden-Julian Oscillation on high-latitude winter blocking during El Niño-Southern oscillation events. *J. Climate*, accepted pending revision.

E. PIs Contact Information

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F. Budget for the Coming Year

The budget for the coming year is unchanged from that in the submitted proposal. We will be in a no-cost extension period for part of this period.

G. Future Work

The plan for future work includes that in the original proposal, although with the inclusion of significant extensions. Extensions of the originally proposed work include maintenance and possible expansion of the MDTF timeslice simulations, development of an in-code framework for calculation of the vertically-integrated MSE budget in the NCAR and GFDL models, and generation of an AMS special collection on process-oriented diagnostics, including a lead article in *BAMS*.

OAR Office of Weather and Air Quality (OWAQ)

NA17OAR4590118

Evaluating stochastic physics approaches within select Convection Allowing Model (CAM) members included in the Community Leveraged Unified Ensemble (CLUE) during the Hazardous Weather Testbed (HWT) Spring Experiment

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31 January 2018

Richard Fulton; Richard.Fulton@noaa.gov; 301-734-1289

Project/Grant Period: 1 July 2017, 30 June 2019

Reporting Period End Date: 31 December 2017

Semi-Annual Report

Final Annual Report? No

1. ACCOMPLISHMENTS

In the table below, the major proposed **goals, objectives, and tasks** of this project for year 1 are listed in the first column with a summary of the task activity during the period of performance (1 July – 31 December 2017) provided in the second column. The final column summarizes the percent completion to-date.

Proposed goals, objectives, and tasks	Task activity 1 July - 31 Dec 2017	Percent Completion
Collaborate with HWT staff to develop a test plan with explicit milestones ensuring a controlled set of configurations will be run during the 2018 HWT SFE to enable a meaningful comparison at the end of the experiment.	PI's have been participating in the HWT planning telecons to discuss collaboration with NSSL, SPC, and CAPS personnel. The test plan targeting work conducted under this project for HWT 2018 SFE will be finalized in mid-February 2018.	10% (On schedule; due 15 February 2018)
Work with NSSL staff prior to the start of the 2018 HWT SFE to transfer code and provide updated configurations with stochastic perturbation settings for inclusion in CLUE 2018 such that NSSL can coordinate and execute the real-time runs	DTC testing being leveraged by this project to inform the most promising stochastic configuration is underway. This will inform the decision on what configurations to transfer for use in CLUE 2018 during the HWT SFE. Current and previous testing has been discussed with our NSSL co-investigator and a final decision regarding the code base and configurations will be solidified by late February 2018.	10% (On schedule; due 28 February 2018)
Travel and participate in the 2018 HWT SFE; present background information on stochastic methods to educate participants and SPC forecasters on the techniques being employed;	Not yet underway.	0% (On schedule; due May 2018)
Collect CLUE 2018 model post-processed output in real-	Not yet underway.	0% (On schedule; due June 2018)

time during the experiment		
Conduct extended analysis on aggregated ensemble results over the 5-week 2018 HWT SFE period from several meaningful subsets of the full CLUE ensemble using a number of ensemble statistical approaches focused on large scale performance and severe weather applications. Conduct an aggregated assessment of the deterministic forecast performance for each of the ensemble members used in deliverable 3 over the 5-week period;	Preliminary results obtained from a small subset of cases during HWT 2017 SFE for three ensemble subsets run retrospectively after the experiment was over (including single, multi-, and stochastic physics) were analyzed; however, the results were not statistically robust. The verification workflow established on the NCAR HPC (Cheyenne) for the CLUE 2017 comparison will be used for processing and analyzing CLUE 2018 data.	5% (On schedule; due December 2018)
Inform decisions on future testing and development of stochastic approaches based on evaluation results from the 2018 HWT SFE	Not yet underway.	0% (On schedule; due February 2019)

As noted in the task activities above, the first six months of the project were focused on establishing a framework for future testing and remaining connected to other projects to leverage test results in preparation for informing NSSL colleagues of the most promising stochastic physics configuration to use for CLUE 2018. Future evaluation results of the full experiment will be presented as the opportunity arises. Further dissemination of work related to this project to the community will be a primary goal once additional results are available for analysis.

During the next reporting period (January – June 2018) the following activities will be conducted:

- Project staff will continue to participate in HWT planning teleconferences organized by HWT coordinators.
- A test plan with explicit milestones will be developed in collaboration with HWT colleagues to ensure a meaningful comparison of ensemble subsets at the end of the experiment
- Code, along with configurations enabling stochastic perturbations, will be transferred to NSSL staff for inclusion in CLUE 2018 such that NSSL can coordinate and execute the real-time runs
- Staff will travel and participate in the 2018 HWT SFE. While there, they will present background information on stochastic methods to educate participants and SPC forecasters on the techniques being employed.

- CLUE 2018 post-processed model output will be collected in real-time during the HWT 2018 SFE.

2. PRODUCTS

During the HWT 2017 SFE, configuration of the 2017 CLUE was planned to allow for a number of unique experiments that were designed to examine a number of issues immediately relevant to addressing a future NCEP/EMC operational CAM-based ensemble. The subsets of interest for this particular project include a multi-core ensemble [10 total members with 5 Weather Research and Forecasting – Advanced Research model (WRF-ARW) and 5 Non-hydrostatic Multiscale Model on the B-grid (NMMB) that also include initial and lateral boundary condition (IC/LBCs) perturbations], a single core ensemble (10 total WRF-ARW members with IC/LBC perturbations), and, the key ensemble subset for this project, the stochastic physics perturbation experiment with IC/LBC perturbations. With output from each of these three ensemble subsets an analysis can be conducted to investigate the performance of the stochastic ensemble and answer whether this type of ensemble design, which is easier to maintain and provides a better representation of the random component of forecast error, is able to perform equally or better than the mixed- or single-physics ensembles in terms of forecast skill and reliability.

Unfortunately, a number of ensemble members were unable to be run in real-time during the HWT 2017 SFE due to lack of computation resources. In addition, after processing of some of the initial data it was realized a bug in the Unified Post Processor (UPP) code had manifested itself with unrealistically large values of composite reflectivity. An attempt was made by National Severe Storms Laboratory (NSSL) and Center for Analysis and Prediction of Storms (CAPS) collaborators to fill in some gaps for a number of members that were not run in real-time as well as rerun the members with bad reflectivity data after the experiment was over. While additional data was made available in the Fall of 2017, it was ultimately a reduced number of cases for the ensemble subsets of interest. In particular, the CLUE members that employed stochastic perturbations are only available for five cycles.

During the first reporting period of the project (1 July – 31 December 2017), a verification workflow to calculate a number of deterministic and probabilistic statistics using the Model Evaluation Tools (MET) verification package for a subset of Community Leveraged Unified Ensemble (CLUE) members was established on the NCAR High Performance Computing (HPC) platform (Cheyenne). The available cycles for the three ensemble subsets of interested were then run through the verification workflow to ensure proper function. As a proof of concept, a few plots are provided using the available results to highlight a small sample of the future evaluation tools that will be used after HWT 2018. The example plots shown below should not be used to judge configuration performance at this time due to the relatively sample size, which does not provide statistically meaningful results at this time.

Details of the current state of the verification approaches in the workflow are provided in the following paragraphs. For deterministic members, traditional metrics were computed including Gilbert Skill Score (GSS) and Frequency Bias for accumulated precipitation and composite reflectivity (example shown in Figure 1) and bias-corrected root mean square error (BCRMSE) and mean error (bias) for surface temperature, dew point temperature, and wind speed. In addition, advanced spatial verification techniques, were applied to the accumulated precipitation and composite reflectivity fields using Method for Object-based Diagnostic Evaluation (MODE) and Fractions Skill Score (FSS). Figure 2 shows an example of output from MODE where attributes such as counts and location of identified forecast and observed objects can be compared to provide additional diagnostic information. Work is underway to also include verification of radar echo top to the suite of variables already established. The list of variables will continue to expand as the project matures.

There are also several ensemble verification methods used to assess the ensemble performance; the probabilistic metrics currently included in the workflow to evaluate to the same fields as the deterministic analysis include spread, Brier Score (BS), reliability diagrams, Receiver Operating Characteristic (ROC) curve, and rank histograms. Looking at a combination of these measures allows us to assess the properties of a probabilistic forecast in terms of reliability, resolution, and sharpness.

In addition to establishing the workflow, observational datasets were gathered, staged, and processed for use in the evaluation. For evaluation of accumulated precipitation and composite reflectivity, the Multi-Radar/Multi-Sensor (MRMS) local gauge bias-corrected radar quantitative precipitation estimation (QPE) and composite reflectivity analyses were used. The MRMS dataset is regridded to the CLUE model integration domain using budget interpolation for accumulated precipitation and nearest neighbor for composite reflectivity to allow for direct grid-to-grid comparisons. The evaluation is conducted on an hourly basis.

For conventional surface observations (temperature dew point temperature, and wind), Rapid Refresh (RAP) observation files in Binary Universal Form for the Representation of Meteorological Data (BUFR) format were acquired. Model forecasts are bilinearly interpolated to the observation locations for comparison.

The establishment of the verification workflow will allow for efficient processing of 2018 CLUE ensemble subsets when they become available in May/June 2018.

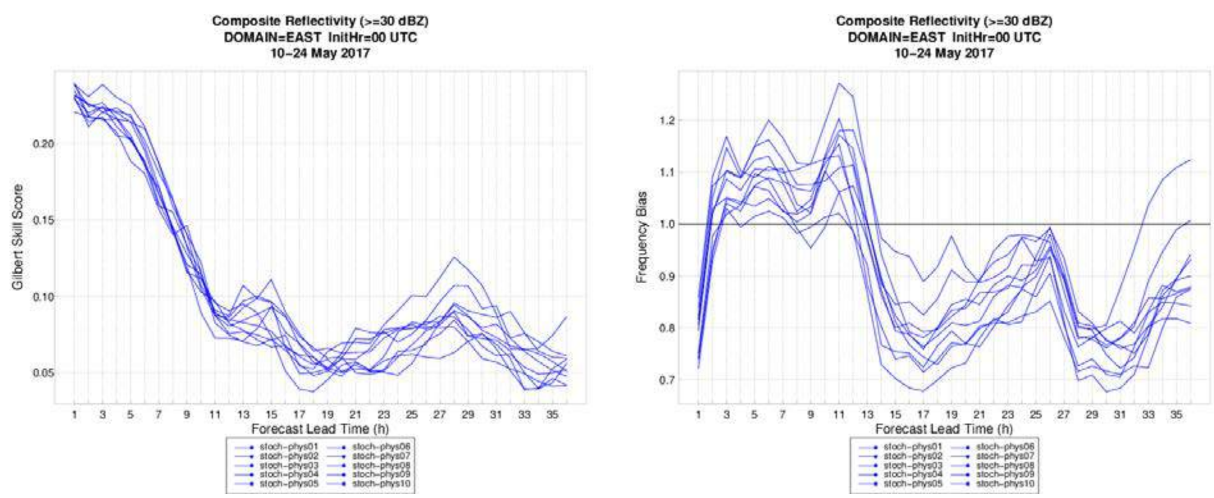


Figure 1.(a) Gilbert Skill Score (GSS) and (b) Frequency Bias for individual stochastic configurations (thin blue lines) as a function of lead time for all available cases initialized at 0000 UTC between 10-24 May 2017 over the eastern part of the CONUS for a simulated radar reflectivity threshold of >=30 dBZ.

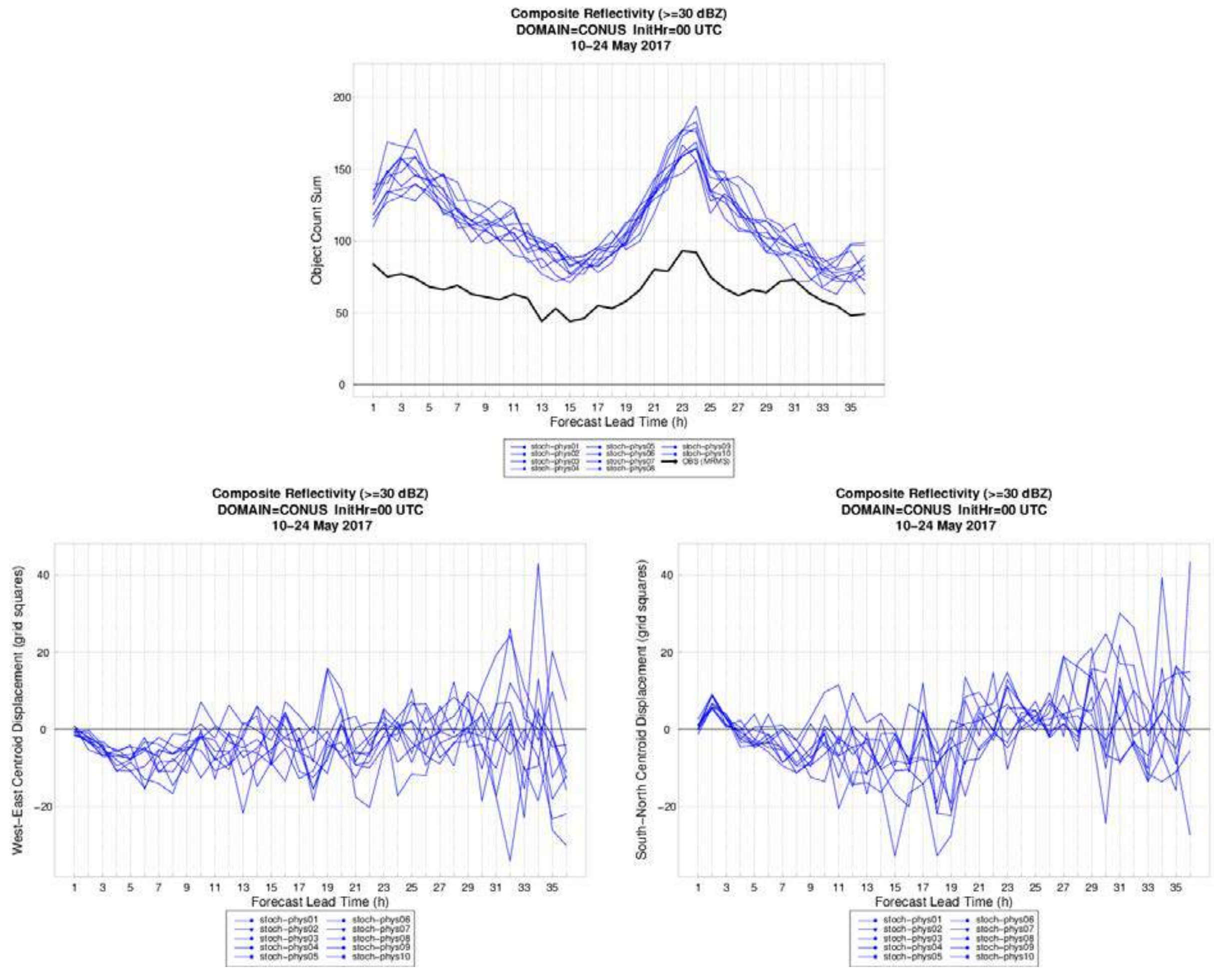


Figure 2. (a) Counts of MODE objects, (b) centroid displacement in the west (negative)/east (positive) direction, and (c) centroid displacement in the south (negative)/north (positive) direction for individual stochastic configurations (thin blue lines)as a function of lead time for all available cases initialized at 0000 UTC between 10-24 May 2017 over the eastern part of the CONUS for a simulated radar reflectivity threshold of >=30 dBZ. The observed object counts from the MRMS analysis is represented by the thick black line.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

During this performance period, Jamie Wolff and Michelle Harrold (both of NCAR), along with Jeff Beck and Isidora Jankov (both of CIRA) have worked on this project to accomplish the task related to establishing the verification workflow, gathering the data, and remaining aware of related activities that will inform future decisions for this work.

In addition, Adam Clark (NSSL) and Scott Dembek (CIMMS/NSSL) have been involved in running simulations (single and stochastic physics) in retrospective mode. Kevin Thomas (CAPS) has also conducted retrospective simulations (multi-physics) and has been leading the telecons for HWT 2018 planning.

Since the submission of the proposal, Joshua Hacker (Co-PI) has left NCAR and will no longer be participating on this project.

4. IMPACT

Due to the timing of the start of this project in relation to the HWT SFE, the full impact of this project has not been realized. As we prepare for the HWT 2018 SFE additional training and educational opportunities will present themselves during the experiment and at conferences/workshops after the experiment.

5. CHANGES/PROBLEMS

Due to the start of the project being pushed to 1 July 2017, the key deliverables for the project were rearranged to better align with milestones prior to and objectives during the HWT 2018 and 2019 SFEs during the two years of this project.

6. SPECIAL REPORTING REQUIREMENTS

At the current time, the project’s Readiness Level remains at a 6. Configurations will be recommended for testing in the HWT 2018 SFE for demonstration of stochastic physics perturbations in an CAM-based ensemble system

Also submitted during this reporting period are the Research to Operations Transition Plan and the test plan for the NOAA/OAR/OWAQ Testbed Projects.

7. BUDGETARY INFORMATION

There are no budget anomalies or concerns at this time.

8. PROJECT OUTCOMES

Project outcomes will be reporting as broad benefits to society are realized.

Annual Progress Report

Following emissions from Non-Traditional Oil and Gas Development Through their Impact on Tropospheric Ozone

Award Number: NA14OAR4310148
Principal Investigator: Dr. Emily V. Fischer
Institution: Colorado State University, Fort Collins, CO 80521
Co-investigators: Dr. Delphine K. Farmer, Dr. Chris Kummerow
Start Date: August 1, 2014
Period Covered: March 16, 2017 – May 30, 2018

I Project Statement

This project is focused on investigating how emissions from current oil and gas development are changing patterns of tropospheric ozone production at the local, continental and global scale. The proposed work tackles these scientific questions:
1. What are characteristic ozone production rates and efficiencies in air masses influenced by emissions from oil and gas production?
2. To what extent have emissions from oil and gas production impacted the extent of NO_x versus NMVOC limited ozone production?
3. Through which chemical pathways do emissions from oil and gas production propagate most efficiently to global ozone production?
4. How do emissions from this sector affect radiative forcing through perturbations to tropospheric ozone, methane, and remote aerosol formation?

II Accomplishments

Summary: Significant progress has been achieved during our no-cost extension including (A) publication of a manuscript focused on the impact of aged wildfire smoke on photochemistry in the Colorado Front Range based on observations of a major smoke event during our summer 2015 field campaign [*Lindaas et al*., 2017], (B) revision of a manuscript focused on the impact of different VOC sources on local ozone and organic nitrogen formation [*Emerson et al*., in prep], (C) preparation of a manuscript that documents spatial patterns in the emissions and observed atmospheric abundances of light alkanes over the U.S., and estimates the contribution of emissions from U.S. oil and gas industry to the observed patterns [*Tzompa-Sosa et al*., in prep], (D) preparation of a manuscript presenting a GEOS-Chem based analysis of the impact of the emissions of oil and gas on ozone and reactive nitrogen partitioning on a national scale [*Tzompa-Sosa et al*., in prep], (E) preparation of a manuscript that investigates the contribution of different VOC sources to high ozone abundances at BAO during summer 2015 [*Lindaas et al*., in prep], (F) submission of a manuscript on the seasonality, sources and sinks of C_1-C_5 alkyl nitrates in the Front Range [*Abeleira et al.*, in review], and (G) a preliminary investigation into the specific sources of oxygenated VOCs observed at BAO. We request an additional no-cost extension to this project to support the publication fees associated with the manuscripts that are underway.

(A) *Summary of Lindaas et al. [2017]*
This paper was opportunistic. We prioritized publication given the upcoming smoke-focused field campaigns. We observed two distinct periods where aged wildfire smoke impacted BAO during summer 2015: 6–10 July and 16–30 August. The smoke we observed at BAO was transported from the Pacific Northwest and Canada and it was several days old when it reached Colorado. This smoke also impacted the atmospheric column across much of the continental U.S. This paper

contrasts the smoke-free and smoke-impacted in situ observations from BAO during summer 2015. In addition to increases in carbon monoxide (CO) and particulate matter, the smoke impacted periods also showed elevated mixing ratios of peroxyacyl nitrates and several VOCs with atmospheric lifetimes longer than the transport timescale of the smoke. The data also showed that the abundance of short-lived alkenes were depressed during the smoke-impacted periods. During the two-week long August smoke-impacted period, NO_2 was also elevated during the morning and evening compared to the smoke-free periods. Given our measurement suite, we are unable to identify a mechanism associated with this increase, though it is statistically significant. There were six days during our study period where the maximum 8-hour average ozone at BAO was greater than 65 ppbv, and two of these days were smoke-impacted. We examined the relationship between ozone and temperature and found that for a given temperature, ozone mixing ratios were ~10 ppbv greater during the smoke-impacted periods. Enhancements in ozone during the August smoke-impacted period were also observed at two nearby sites located within Colorado, but outside the polluted Front Range urban corridor: Rocky Mountain National Park and the Arapahoe National Wildlife Refuge.

(B) *Summary of Emerson et al. [under revision]*
The topic of this paper has not substantially changed from the last report, but the paper is in revision in response to a series of reviews we received from the Journal of Geophysical Research.

(C) *Summary of Tzompa-Sosa et al. [in prep]*
This paper is nearly ready to submit to JGR. We use a nested GEOS-Chem simulation driven by EPA NEI 2011v6.3ek emissions with an assemblage of aircraft, surface and column observations to 1) document spatial patterns in the emissions and observed atmospheric abundances of light alkanes over the U.S., and 2) estimate the contribution of emissions from U.S. oil and gas industry to the observed patterns. The oil and gas sector in the EPA NEI 2011v6.3ek contributes > 80% of the total U.S. emissions of ethane (C_2H_6) and propane (C_3H_8), and emissions of these species are largest in the central U.S. Observed mixing ratios of C_2-C_5 alkanes also show enhancements over the central U.S. at altitudes below 2 km. A nested GEOS-Chem simulation under-predicts observed C_3H_8 mixing ratios in the boundary layer over several U.S. regions and the relative under-prediction is not consistent, suggesting that C_3H_8 emissions should be revisited. Our decision to consider only C_4-C_5 alkane emissions as a single lumped species produces a geographic distribution that largely matches observations. Due to the increasing importance of oil and gas emissions in the U.S., long-term measurements of C_2-C_5 alkanes are needed. We suggest monitoring of C_2-C_5 alkanes downwind of northeastern Colorado, eastern Texas/Louisiana, and Pennsylvania to capture changes in these source regions. The atmospheric chemistry modeling community should also evaluate whether chemical mechanisms that lump larger alkanes are sufficient to understand air quality issues in regions with large emissions of these species.

(D) *Summary of Tzompa-Sosa et al. [in prep]*
This paper is still in preparation, but will be submitted within the next six months. We expect the student leading this paper to defend her PhD over the summer. Again we use a nested GEOS-Chem simulation driven by EPA NEI 2011v6.3ek emissions to estimate the contribution of emissions from U.S. oil and gas industry to the abundance and production of important secondary species including ozone, peroxy acetyl nitrate, and several ketones. In summer, emissions from the oil and gas industry impact ozone most over the Central U.S. In the Front Range non-attainment area, the contribution is non-trivial. The instantaneous ozone enhancements driven by light alkanes from oil and gas development reach ~6 ppbv on summer afternoons. Emissions from this sector change NO_y partitioning by increasing PAN formation. The significance and location

of the impact varies substantially by season. Our results are consistent with the empirical evidence presented in *Lindaas et al.* [in prep], described next.

(E) *Summary of Lindaas et al. [in prep]*
This paper presents measurements of ozone and a suite of ozone precursors made at BAO during summer 2015. We employ an empirical analysis of acyl peroxy nitrates (APN) and a previously described positive matrix factorization of the VOCs (i.e. from Abeleira et al., [2017]) to investigate the contribution of different VOC sources to high ozone abundances at BAO. Based on the ratio of PPN to PAN, we find that anthropogenic VOC precursors dominate APN production when ozone is most elevated (Figure 1). Propane and larger alkanes, primarily from oil and natural gas emissions in the Colorado Front Range, drive these elevated PPN to PAN ratios during high ozone events. The percentage of OH reactivity associated with oil and gas emissions is also positively correlated with ozone and PPN/PAN (Figure 1). Idealized box model simulations are used to probe the chemical mechanisms for these observations. We find that VOC precursor mixtures dominated by oil and gas emissions likely create more abundant and more efficient peroxy radical intermediates compared to mixtures dominated by traffic or biogenic emissions.

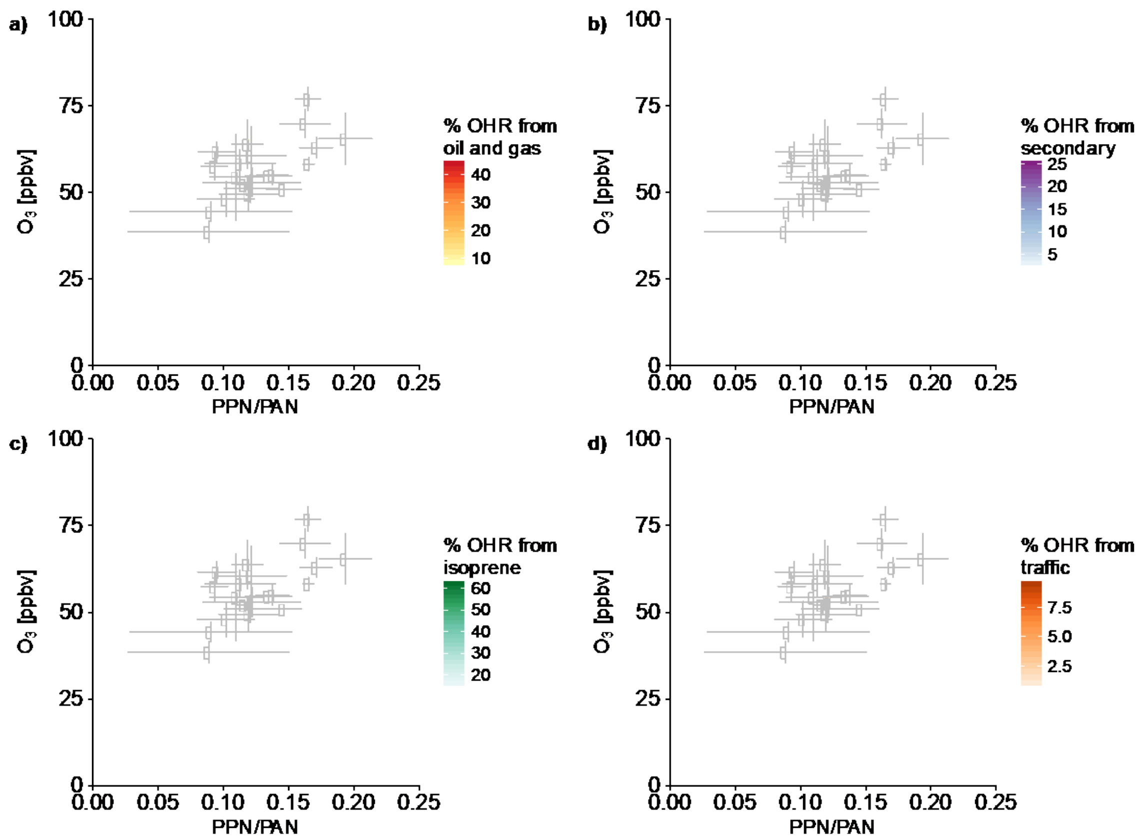


Figure 1. Afternoon (12PM – 6PM MDT) average ozone mixing ratios versus the ratio of PPN to PAN at BAO for each day during the study period. Error bars indicate +/- 1 standard deviation. Points are colored by a) the percentage of total calculated OH reactivity (OHR) from the oil and natural gas PMF factor, b) the percentage of total calculated OH reactivity from the secondary PMF factor, c) the percentage of total calculated OH reactivity from the biogenic PMF factor, which consists exclusively of isoprene, and d) the percentage of total calculated OH reactivity from the traffic PMF factor.

(F) *Summary of Abeleira et al., [in review]*
This paper describes an analysis of alkyl nitrate sources and sinks in a region with high precursor VOC concentrations due to substantial oil and natural gas emissions. We use three datasets to investigate C_1-C_5 alkyl nitrates derived from the short chain alkanes characteristic of the region: recent SONGNEX data from Spring 2015, SONGNEX data from Summer 2015 and data from the NACHTT campaign (Winter 2011). By combining our dataset with older, similar measurements, we find that while mixing ratios of the alkyl nitrates are similar across seasons, the strong diel variability apparent in the summer data highlighted photochemical sources and sinks of the species. We use ratios of the alkyl nitrate to parent hydrocarbon to investigate these sources and sinks, providing observational constraints on relevant branching ratios. We use detailed meteorological measurements from BAO to find nights during which meteorological conditions are stable in order to constrain dry deposition rates. We find that dry deposition is an important, through rarely considered, sink of these species.

(G) *Summary of Ongoing OVOC analysis*
We quantified three oxygenated VOCs (OVOCs) during our field campaigns at BAO: acetone, acetaldehyde, and methyl ethyl ketone (MEK). The summer data set was shortened to 5 weeks for the analysis presented here because aged wildfire smoke influenced the site during the last three weeks of the measurement campaign. *Abeleira et al.* [2017] found that these OVOCs accounted for almost a quarter of the total calculated OH reactivity yet the sources of these compounds were poorly reconstructed by the PMF analysis we completed. In summer 2017 we hosted a undergraduate intern supported by NSF and Colorado College, and he took a close look at the abundance of MEK to better understand the relationships between MEK and its known precursors as well as other OVOCs and secondary species. MEK can be directly emitted and it can be produced during the atmospheric oxidation of several different hydrocarbons (e.g. n-butane, 3-methyl hexane, i-pentane). We computed correlation coefficients for MEK and the other gases measured during this campaign. We found that the highest correlations during summer were between MEK and the alkyl nitrate species ($R > 0.4$). The other OVOC species were also positively correlated with MEK ($R = 0.43$-0.49, $p << 0.001$). Both spring and summer had elevated MEK with northerly and easterly winds ($p << 0.001$ for both seasons). We were able to identify several periods with clear MEK enhancements during periods of active photochemistry. Using box model simulations initialized with the suite of VOCs we measured, we believe that n-butane is the most important precursor for MEK in the NFRMA. We have identified periods of elevated MEK that do not occur during periods of active photochemistry.

III Plan for Requested Second No-Cost Extension Period
As discussed above, we have several manuscripts that are either in review or will be under review in the next few months. It is unlikely that all the publication costs will be incurred by July 2018, thus we request a second no-cost extension period.

IV Presentations and Accepted/Submitted Publications for this Period
Submitted/Accepted Publications:

Abeleira, A. A. and Farmer, D. K.: Summer ozone in the Northern Front Range Metropolitan Area: Weekend-weekday effects, temperature dependences and the impact of drought (2017), *Atmos. Chem. Phys.,.* 17, 6517-6529, https://doi.org/10.5194/acp-17-6517-2017.

Lindaas, J., Farmer, D. K., Pollack, I. B., Abeleira, A., Flocke, F., Roscioli, R., Herndon, S., and Fischer, E. V.: The impact of aged wildfire smoke on atmospheric composition and ozone in the

Colorado Front Range in summer 2015 (2017), *Atmos. Chem. Phys*., 17, 10691-10707, https://doi.org/10.5194/acp-17-10691-2017.

Abeleira, A. J., B. Sive, R. F. Swarthout, E. V. Fischer, Y. Zhou and D. K. Farmer (in review), Seasonality, sources and sinks of C_1-C_5 alkyl nitrates in the Front Range, *Elementa: Science of the Anthropocene.*

Presentations:

Farmer, D. K., Abeleira, A. J., Emerson, E. W., Fischer, E. V., Pollack, I. B., Zhou, Y., Lindaas, J., Sive, B., Herndon, S., Roscioli, R., Front Range Air Pollution and Photochemistry Experiment (FRAPPE) Science Meeting, *Impact of different VOC sources on organic nitrates, ozone and the* NO_y *budget at the BAO site*, Colorado Department of Public Health and Environment, Boulder, CO, United States. (May 3, 2017).

Tzompa-Sosa, Z., Henderson, B., Keller, C., Fischer, E. V., 8th International Geos-Chem Meeting, *Incorporating updated emissions of NEI 2011 v6.3 into GEOS-Chem*, Cambridge, MA, United States. (May 5, 2017).

Tzompa-Sosa, Z., Henderson, B., Travis, K., Keller, C. A., Fischer, E. V., 2017 International Emissions Inventory Conference – Applying Science and Streamlining Processes to Improve Inventories, *Atmospheric implications of light alkane emissions from the oil and natural gas sector*, Baltimore, MD, United States. (August 14, 2017).

Tzompa-Sosa, Z., Henderson, B., Travis, K., Keller, C. A., Fischer, E. V., Global Emissions Initiative (GEIA) Conference, *Evaluating updated light alkane emissions from the oil and natural gas industry in the U.S.*, Hamberg, N/A, Germany. (September 13, 2017).

Fischer, E. V., Tzompa Sosa, Z. A., Henderson, B., Travis, K., Keller, C., Sive, B. C., Herndon, S. C., Yacovitch, T. I., Mahieu, E., Franco, B., American Geophysical Union Annual Meeting, *Atmospheric implications of light alkane emissions from the U.S. oil and gas sector*, New Orleans, LA, United States. (December 14, 2017).

“Forecasting North Pacific Blocking and Atmospheric River Probabilities: Sensitivity to Model Physics and the MJO”: Progress Report Y2

1. General Information

Project Title: Forecasting North Pacific Blocking and Atmospheric River Probabilities: Sensitivity to Model Physics and the MJO
PI/co-PI names and institutions: PI Elizabeth Barnes (CSU) and Co-PI Eric Maloney (CSU)
Report Year (Progress Report Fiscal Year or Final Report): FY18
Grant #: NA16OAR4310064

2. Main goals of the project, as outlined in the funded proposal

The overarching aim of the proposed work is to quantify the extent to which east Pacific blocking and AR probabilities can be skillfully forecast at lead times of multiple weeks through their dynamical link with the MJO, including an explicit investigation of how AR prediction skill varies with a model’s ability to forecast the MJO. The work can be summarized by four main scientific goals:

A. Quantification of the predictability and prediction skill of North Pacific blocking and atmospheric river probabilities through knowledge of the MJO.
B. Assessment of the sensitivity of forecast skill to MJO skill and model setup: model physics, model resolution and forecast lead time.
C. Deliver a database of extreme events (i.e. atmospheric rivers and blocking) from the reanalysis and hindcast models
D. Deliver statistical forecast models of extremes (i.e. atmospheric rivers and blocking)

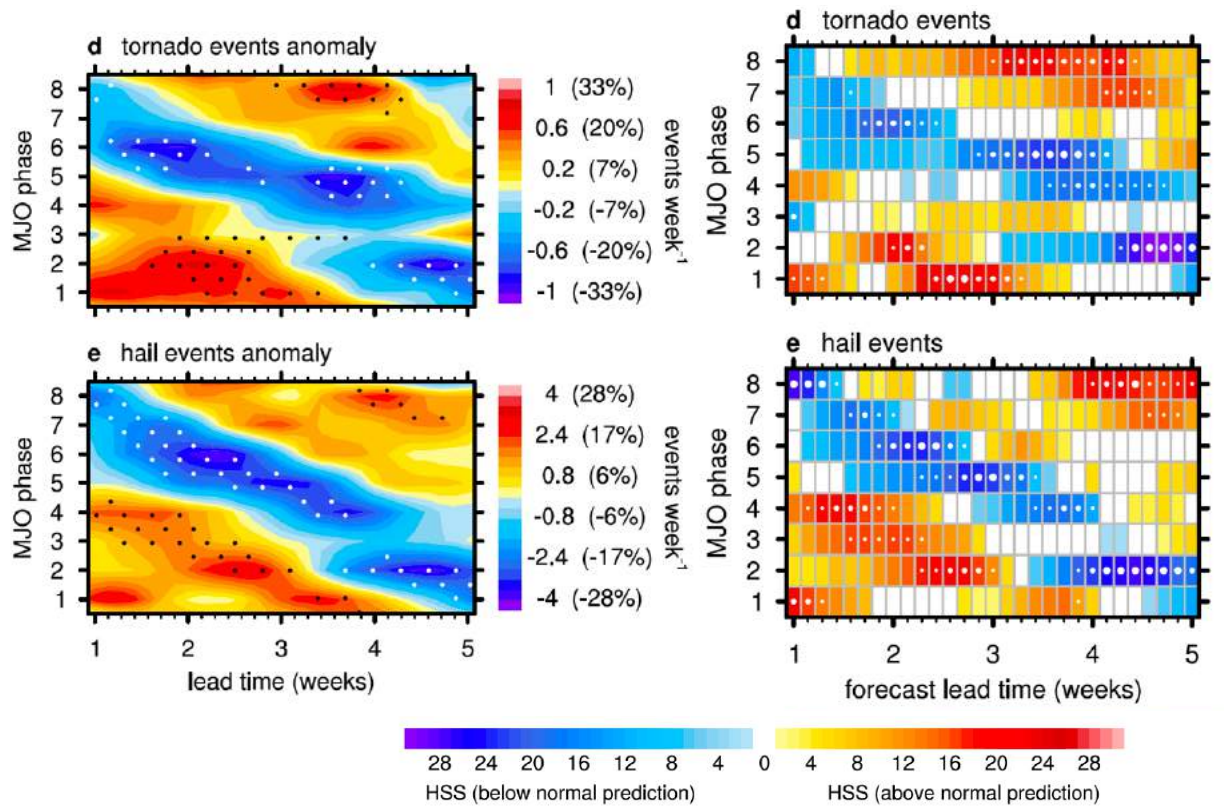
We also have primary goals related to leadership of the MAPP S2S Task Force:

E. provide scientific leadership to the Task Force (PI Barnes is the Lead of the Task Force) by leading scientific papers, reports and special collections, organizing meetings and meeting sessions, leading teleconferences, facilitating collaboration across the Task Force.
F. linking to international efforts on advancing S2S prediction

3. Results and accomplishments *(links to goals given in brackets)*

Science Accomplishments/Results

- [A,B,D,F] Publication of Mundhenk et al. (2018) in *npj Climate and Atmospheric Science* (a special issue with the international S2S Project): this paper introduces a statistical model based on the MJO and QBO that can skillfully predict atmospheric river activity up to 5 weeks in advance. A media piece at research.noaa.gov, as well as other sites, was written on this work: https://tinyurl.com/yahl8r8s
- [A,B] Publication of Baggett et al. (2017) in *Geophysical Research Letters* on the role of the QBO and MJO providing knowledge of atmospheric-river occurrence on S2S timescales. This work demonstrates that the QBO (quasi-biennial oscillation) modulates the impact of the MJO on landfalling atmospheric rivers over the western U.S. It also shows that the ECMWF forecast system is unable to take advantage of this information, although certain phases of the QBO/MJO provide additional skill in this forecast system.
- [A,B] Publication of Tseng et al. (2018) in *Geophysical Research Letters* on the consistency of MJO teleconnections as a function of lead time. This work shows that there is potential to forecast 500 hPa geopotential heights over the North Pacific on S2S time scales based on knowledge of certain phases of the MJO. That is, some phases of the MJO provide a more consistent midlatitude response than others, and the robust teleconnection signals for MJO phases 2 and 6 increase the prediction skill of 500 hPa geopotential heights at S2S lead times in the ECMWF forecast system.
- [B] A manuscript will be submitted in March to the *Journal of Climate* (Tseng et al. 2018b) exploring the underlying reasons for why particular phases of the MJO produce more consistent teleconnection responses than other phases. Using a linear baroclinic model (LBM), this work shows that certain phases of the MJO produce Rossby wave source patterns that reinforce the midlatitude teleconnection pattern while other MJO phases produce a Rossby wave source pattern that tends to cancel out the teleconnection pattern.
- [A] Research on the response to sea ice loss of moisture transport associated with atmospheric rivers was performed, with a manuscript to be submitted to the *Journal of Climate* in April 2017 (McGraw et al. 2018; in prep). A key result is that changes in the midlatitude circulation can explain increased equatorward moisture fluxes out of the Arctic--in particular, an increase in cyclonic Rossby wave breaking near 60N. Poleward moisture fluxes across 70N also increase as expected due to the Clausius-Clapeyron relationship linking increased atmospheric temperatures with increased atmospheric water vapor.



PRELIMINARY RESULT (submitted): (left panels) Anomalous weekly tornado and hail activity U.S. Plains in MAMJ. (right panels) Heidke skill scores of the empirical prediction model based solely on the phase of the MJO for tornado and hail events over the U.S. Plains. In both panels the MJO phase is shown on the y-axis and lead day on the x-axis. Both panels show the influence of the propagating MJO, but sub-setting by QBO shows that the easterly and westerly phases in general cancel each other. [results from submitted manuscript by Baggett et al. (2018)]

- [A,B,D] A manuscript (Baggett et al. 2018; submitted) has been submitted to *Nature* whereby knowledge of the MJO provides forecast skill of tornado and hail probabilities at S2S timescales. This work demonstrates the physical mechanisms by which this occurs, as well as presents an empirical model with skill for specific forecasts of opportunity out to 4 weeks. If the paper is not ultimately published in *Nature,* we will seek publication in *Nature Geoscience* or *Geophysical Research Letters.* A key result is shown in the Figure above.

[E,F] Task Force Leadership Accomplishments/Results

- the internal wiki has continued to be used by the TF, providing resources for obtaining processed data, raw model output, overview presentations, etc.
- PI Barnes and the other Task Force leads have organized and facilitated monthly telecons across the Task Force in all months (except December 2017 due to AGU). These telecons have focused on science results across the Task Force, and average 30 participants per call.
- PI Barnes flew to Washington D.C. to present about the MAPP S2S Task Force at a science and media event at NOAA Science days in June 2017.
- PI Barnes and TF Leads Andrea Lang and Kathy Pegion have successfully negotiated with AGU journals *Geophysical Reasearch Letters* and *Journal of Geophysical Research – Atmospheres* for a joint special collection titled “Bridging Weather and Climate: Subseasonal-to-Seasonal (S2S) Prediciton” running from May 2018-April 2019 for use by the entire international S2S community.
- PI Barnes presented on S2S Task Force activities at the MAPP S2S Webinar held Feb. 21, 2018 – 100+ in attendance

[E, F] Workshop Organization

- Successfully coordinated an AGU 2017 session on S2S Prediction with the broader S2S community: Duane Waliser, Fred Vitart and Arun Kumar
- PI Barnes is part of the International Conferences on Subseasonal to Decadal Predictions (held in Boulder, CO in Sept. 2018) Scientific Organizing Committee

[F] Linking to international efforts

- Many presentations on the results of this project at the following conferences/workshops: AMS 2018, AGU 2017, NOAA Science Days – June 2017, Climate Diagnostics and Prediction Workshop 2017, MAPP S2S Webinar 2018, AMS 30th Conference on Climate Variability and Change 2017

4. Highlights of Accomplishments

- Three high profile publications on using the MJO to predict atmospheric blocking and atmospheric river activity along the U.S. west coast.
- Support and publicity of the S2S Task Force – including presentations at NOAA Science Days, media articles on the work being done on this project,
- The development of a statistical forecast model, based on the MJO, of tornado and hail activity in the central United States showing skill out 4+ weeks.

5. Transitions to Applications

N/A

6. Publications from the Project *(not including submitted)*

Baggett, C. F., E. A. Barnes, E. D. Maloney, and B. D. Mundhenk, 2017: Advancing atmospheric river forecasts into subseasonal-to-seasonal time scales. *Geophys. Res. Lett.*, **44**, 2017GL074434.

Mundhenk, B. D., E. A. Barnes, E. D. Maloney, and C. F. Baggett, 2018: Skillful empirical subseasonal prediction of landfalling atmospheric river activity using the Madden–Julian oscillation and quasi-biennial oscillation. *npj Climate and Atmospheric Science*, **1**, 7.

Tseng, K.-C., E. A. Barnes, and E. D. Maloney, 2018: Prediction of the Midlatitude Response to Strong Madden-Julian Oscillation Events on S2S Time Scales. *Geophys. Res. Lett.*, **45**, 2017GL075734.

7. PI Contact Information

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8. Budget for Coming Year (annual progress reports only)

	Year 1 Jul 2016 – Jun 2017		Year 2 To Date Jul 2017 – Feb 2018		Year 2 Projected Mar 2018 – Jun 2018		Total – Years 1 and 2			Year 3 Projected Jul 2018-Jun 2019		Total – All Years		
	Spent Amount	MM	Spent Amount	MM	Planned Amount	MM	Budget	Total Spent & Planned	Variance	Planned Amount	MM	Budget	Total Spent & Planned	Variance
Barnes salary & fringe	20,941	1.6	11,313	0.7	2,297	0.15	41,814	34,551	7,263	11,862	0.75	63,983	46,413	17,570
Maloney salary & fringe	9,547	0.5			9,711	0.5	18,032	19,258	- 1,226	10,031	0.5	27,592	29,289	-1,697
Postdoc salary & fringe	47,525	10.8	43,942	8.0	22,354	4.0	127,704	113,821	13,883	69,101	12.0	195,411	182,922	12,489
Graduate Student salary & fringe	28,755	5.7	22,985	4.4	13,337	2.4	68,863	65,077	3,786	38,876	6.75	105,374	103,953	1,421
Travel	5,069		7,423				15,513	12,492	3,021			26,393	12,492	13,901
Supplies	4,899		5				5,200	4,904	296			5,200	4,904	296
Tuition	11,608		5,949		5,949		25,447	23,506	1,941	12,789		39,717	36,295	3,422
Publications			1,000				6,365	1,000	5,365			13,114	1,000	12,114
Other Direct-network & comp support	7,838		5,563		2,861		18,058	16,262	1,796	8,305		27,633	24,567	3,066
Indirect Costs	37,372		27,670		15,168		90,465	80,210	10,255	41,452		139,410	121,662	17,748
TOTAL	173,554		125,850		71,677		417,461	371,081	46,380	192,416		643,827	563,497	80,330

We plan to ask for a No Cost Extension (NCE) at the end of year 3 to continue work on the project using the leftover $80K. This additional $80K is present, in part, because PI Barnes will be taking parental leave in 2018.

9. Future Work

In the coming year…

- Submit Tseng et al. (2018b) on linear baroclinic model results
- Publish Baggett et al. (2018)
- Continue to organize and lead Task Force telecons; keep the wiki up-to-date; garner interest in the AGU Special Collection on S2S
- Investigate how the QBO modulates MJO teleconnections and associated predictability of extreme weather over the U.S.
- Continued investigation into the predictability of atmospheric rivers and their associated wind and precipitation extremes
- Organize AGU session in 2018
- Support the writing of an EOS Projects article on the Task Force activities (spring/early summer 2018)

Implementation and testing of lognormal humidity and cloud-related control variables for the NCEP GSI hybrid EnVar assimilation scheme. Last 6 month's report.

1. **Key scientific accomplishments**

   Dr. Fletcher at CSU has been making progress with introducing the changes to the GSI codes to enable a lognormal approach to be used for the moisture control variable. Dr. Fletcher, through code shared to him by Dr. Kleist now has adapted the NMC code to provide first order covariances for the lognormal approach for the static component of the GSI system.

   Dr. Fletcher attended the WMO's 7th International Symposium on Data Assimilation in Florianopolis, Brazil in September 2017 where he presented a poster on the new incremental formulation and presented properties of the mixed Gaussian-lognormal distribution, which was well received. Dr. Fletcher at this conference had interactions with many international scientists as well as with Federal data assimilation scientist from different Federal agencies.

   Dr. Fletcher also attended the Annual Fall Meeting of the AGU in New Orleans in December 2017 where he presented a poster on work associated with the project.

   At University of Maryland (UMD) through the interaction with Dr. Kleist of NOAA/EMC and Dr. Fletcher of CSU/CIRA, Dr. Ide formulated a Multi-scale (MS) algorithm for hybrid EnVar using the lognormal humidity and cloud-related variables that was developed by Dr. Fletcher. This MS algorithm is in alignment with EMC's MS approach.

2. **Progress on testing, summary of evaluation and/or verification of proposed improvements**

   As per Dr. Kleist's advice, Dr. Fletcher has applied for access to the STMP directory to be able to start the testing of single observation experiments, as well having memory available to complete the first order, coarse, NMC runs for the new lognormal component for specific humidity.

   We have hired a postdoctoral fellow at UMD, to conduct testing starting in May 2018. Verification and evaluation will follow shortly.

3. **Interactions with scientists at EMC, other NCEP centers, NOAA labs, and/or NOAA Testbeds**

   Dr. Fletcher has been working with Dr. Kleist of EMC to be able to utilize the NMC code to generate the lognormal based covariances, and variances. Dr. Kleist has also been helping Dr. Fletcher set up the GSI code on Theia, with guidance of what allocations and how much memory should be requested to run the NMC and the GSI codes.

   We have been in close contact with Dr. Daryl Kleist of EMC, who will participate in the testing/verification/validation/evaluation process.

4. **Progress against milestones/schedules in proposal**

Due to some administration problems with access to Theia, which has now been resolved, the implementation is slightly behind but with all the pieces in place and the code changes identified, then testing and validation should be able to still be completed in the remaining 6 months of the project.

We are behind the original schedule for the sub award to UMD. With the hiring of the new postdoctoral fellow, we expect to make a rapid progress in the coming 12-month period.

5. **Any previously unreported changes to the execution of the originally submitted proposal**

   We have incorporated the MS aspect in the algorithm, which is expected to provide improvement. This will be tested and validated in the coming 12-month period.

6. **Any outcomes that could be transitioned or offered to operations**

   Not at this point.

7. **Budget issues**

   With the hiring of the postdoctoral fellow, we will complete the tasks with the planned budget.

Semi-Annual progress report for **Implementation and testing of lognormal humidity and cloud-related control variables for the NCEP GSI hybrid EnVar assimilation scheme**.

1. **Key scientific accomplishments**

Dr. Fletcher has been working on the linearization that is needed to implement the lognormal component in the form of the uncorrelated variable with the Gaussian distributed random variables. When access was re-authorized for Theia, see explanation below, Dr. Fletcher was able to derive the linearization between the model increments and the logarithmic transformed increment as follows: The first increment is $\delta q \equiv q^t - q_b$ while the second increment is given by $\delta Q \equiv \ln q^t - \ln q_b$, where the superscript t represents the truth and the subscript b represents the background. Therefore

$$q^t \equiv q_b + (q^t - q_b) \equiv q_b + \delta q,$$

$$\frac{q^t}{q_b} = \frac{q_b}{q_b} + \frac{(q^t - q_b)}{q_b} \equiv 1 + \frac{\delta q}{q_b},$$

$$\Rightarrow \ln q^t - \ln q_b \equiv \ln\left(1 + \frac{\delta q}{q_b}\right),$$

$$\Rightarrow \delta Q \equiv \ln\left(1 + \frac{\delta q}{q_b}\right).$$

While the relationship between the two increments is nonlinear, if a Taylor series approximation is applied to the right hand side then the approximate linear relationship between the two increments is given by

$$\delta Q \approx \frac{\delta q}{q_b}.$$

This increment along with its adjoint equation have been implemented into the normal_rh_to_q routine and are now awaiting testing.

There is ongoing research into how to implement the equivalent increment into the ensemble component.

The next scientific achievement was the submission of two abstracts to present this work at conferences. The first abstract was to the WMO 7th International Symposium on Data Assimilation in Florianopolis, Brazil, with Prof. Ide and Dr. Kleist. The second abstract was submitted to the AGU annual Fall meeting in New Orleans.

Dr. Fletcher attended the unified data assimilation planning meeting at NCWCP center on April 4 and 5 where Dr. Fletcher was able to interact with the data assimilation scientists at NCEP and other operational and research centers.

Dr. Fletcher also presented the initial derivation of the incremental formulation at the NGGPS program review at the NCWCP center in August 2017.

2. **Progress on testing, summary of evaluation and/or verification of proposed improvements**

Dr. Fletcher's computer access was suspended when it became apparent that the wrong Steven Fletcher's background check had been used to issue the clearance. Upon this error being detected Dr. Fletcher worked with the security office in Boulder and Seattle to follow the procedure to have the access reinstated. However, this took over 2 months to correct as the original documents went missing but luckily there was a second set of fingerprints that were submitted to Boulder. Dr. Fletcher now has access back to Theia and Jet. Dr. Fletcher is in the process of applying for a CAC card.

3. **Interactions with scientists at EMC, other NCEP centers, NOAA labs, and/or NOAA Testbeds**

Dr. Fletcher attended the unified data assimilation planning meeting at the NCWCP center where he was able to interact with Dr. Kleist to discuss coding structures in the GSI code to identify where the modifications for the lognormal transform should be introduced.

In August Dr. Fletcher was able to meet with Dr. Kleist at the NGGPS program review and discussed how to generate the variances and covariances, along with the length scales for the logarithm of the moisture variable. Dr. Kleist has agreed to generate these variances and covariances through an NMC algorithm.

4. **Progress against milestones/schedules in proposal**

The project is on schedule for the implementation and testing of the lognormal independent and to start in September.

5. **Any previously unreported changes to the execution of the originally submitted proposal**

The University of Maryland will be hiring a post doc to fulfill the proposed research.

6. **Any outcomes that could be transitioned or offered to operations**

At this time there are no outcomes that could be transitions to operations.

7. **Budget issues**

NOAA FY 15 Joint Hurricane Testbed (JHT) program

Project Title: Improvement and Implementation of the Probability-based Microwave Ring Rapid Intensification Index for NHC/JTWC Forecast Basins

PI: Haiyan Jiang, Associate Professor, Ph: 305-348-2984, haiyan.jiang@fiu.edu
Co-PI: Kate Musgrave, Research Scientist, Ph: 970-491-8382, kate.musgrave@colostate.edu

Submission Date: Nov. 29, 2017

Recipient Organization: Cooperative Institute for Research in the Atmosphere,
Colorado State University,
1375 Campus Delivery, Fort Collins, CO 80523-1375

Project/Grant Period: 09/01/2015 – 08/31/2018 (on no-cost extension)

Reporting Period: 09/01/2015 - 08/31/2017

Report Term or Frequency: semi-annual

Final Annual Report? Yes

NOAA AWARD NUMBER: NA15OAR4590200

1. ACCOMPLISHMENTS

The CIRA portion of this project is complete with the delivery of developmental datasets for all global TC basins, so no no-cost extension was taken for the CIRA portion. As such this final report is due in advance of the FIU portion final report by a year. For the full project final report, please see the final report filed by PI Haiyan Jiang after the no-cost extension is complete.

This project is under a one-year no-cost extension. The major proposed goal was to improve the probability-based tropical cyclone (TC) rapid intensification (RI) forecast method under our JHT FY-13 project by adding two additional 37 GHz predictors on top of the original the 37 GHz ring and three 85 GHz predictors. The final product is called the **probability-based microwave ring RI index (hereafter PMWRing RII).** It was proposed to implement the PMWRing RII in the NHC and JTWC forecast basins, including Atlantic (ATL), Eastern & Central North Pacific (EPA), North Western Pacific (NWP), North Indian Ocean (NIO), and Southern Hemisphere (SH) basins. Under this major goal, there were five tasks proposed. Please see the table below for the planned vs. actuals for these tasks.

Tasks	Planned	Actuals
Task 1	*Collecting historical microwave data from AMSR-E, SSM/I, and SSMIS and calibrating their T_B's to be compatible with TMI T_B's*	Completed, although we made some changes from the original plan. We chose to we choose to treat each sensor differently to avoid the sensor inter-calibration and different sensor resolution issue. The sample size is large enough for each sensor.
Task 2	*(CIRA) Generating the SHIPS RI developmental dataset for JHT basins*	Completed for North Hemisphere basins (ATL, EPA, NWP & NIO) and Southern Hemisphere(SH) basin
Task 3	*Development of the PMWRing RII for each basin*	Completed for North Hemisphere basins (ATL, EPA, NWP & NIO) and Southern Hemisphere(SH) basin
Task 4	*Real-time testing at NHC and JTWC*	Real-time testing has been completed for the 2016 season and is ongoing for the 2017 season for ATL, EPA, NWP & NIO basins; The SH basin's real-time testing code has been implemented. But there is no storm yet. We are waiting for the SH TC season to be started around Nov. 2017.
Task 5	*Evaluate the real-time testing results and refine the index based on lessons learned*	We have finished evaluation of 2016's real-time results. Problems were identified and the algorithm was refined based on the solution of the problems, as we presented at the IHC.

There were 6 milestones proposed for year-1 and 7 milestones for year-2. All 6 milestones for year-1 have been completed as planned. Please see the table below.

Milestones for year-1	**Planned**	**Actuals**
Milestone 1 (Sep 2015)	FIU: Generate the developmental microwave data including TMI, AMSR-E, SSM/I, and SSMIS data for ATL, EPA, NWP and NIO basins; CIRA: Generate the developmental SHIPS RII dataset for NWP and NIO basins	Completed as planned
Milestone 2 (Nov 2015)	FIU: develop RI thresholds for SHIPS RII and microwave predictors for ATL, EPA, NWP and NIO basins	Completed as planned
Milestone 3 (Jan 2016)	Begin development of the PMWRing RII for ATL, EPA, and NWP/NIO basins	Completed as planned
Milestone 4 (Mar 2016)	Present preliminary results at the IHC; Mid-year report	Completed as planned
Milestone 5 (May 2016)	Complete the algorithm development and implement the real-time testing code for 2016 Hurricane/Typhoon season in ATL, EPA, NWP, and NIO basins	Completed as planned
Milestone 6 (June 2016-Nov 2016)	Real-time testing in ATL, EPA, NWP, and NIO basins	Completed as planned
Milestones for year-2	**Planned**	**Actuals**
Milestone 1 (Sep 2016)	FIU: Generate the developmental microwave data including TMI, AMSR-E, SSM/I, and SSMIS data for SH; CIRA: Generate the developmental SHIPS RII dataset for SH	Completed as planned
Milestone 2 (Nov 2016)	FIU: develop RI thresholds for SHIPS RII and microwave predictors for SH	Completed as planned
Milestone 3 (Dec 2016)	Complete development of the PMWRing RII and implement the real-time testing code for 2017 TC season for SH;	The SH basin's real-time testing code has been implemented. But there is no storm yet. We are waiting for the SH TC season to be started around Nov. 2017.
Milestone 4 (Jan 2017)	Evaluate the year-1 testing results for ATL, EPA, NWP, and NIO basins	Completed as planned

Milestone 5 (Mar 2017)	Adjust the index based on real-time testing results; Present preliminary results at the IHC	Completed as planned
Milestone 6 (Jun 2017)	Complete the algorithm refinement and implement the real-time testing code for 2017 Hurricane/Typhoon season in all northern hemisphere basins	Not started yet. Will do it after 2017 season's real-time testing in all basins.
Milestone 7 (Jul-Aug 2017)	Year 2 final report	Completed as plan

This project has provided training and professional development opportunities for two post-doctoral research scientists (Jon Zawislak and Cheng Tao) and two graduate students (Yongxian Pei and Margie Kieper). The results of the real-time RI index have been disseminated to NHC & JTWC points of contact through emails and a website at http://tcpf.fiu.edu/JHT/ during 2016 & 2017 hurricane/Typhoon season. Publications and conference presentations have also been made (please see the following section).

2. PRODUCTS

There were two products/deliverables proposed. See the table below for the planned vs. actuals:

products/deliverables	Planned	Actuals
Product 1	Code (in IDL) that will produce the PMWRing RI index	Not completely finished yet
Product 2	A detailed document of the guidance for running the code, and predicting RI using the 37 GHz index with the SHIPS RI index	The document for predicting RI using the PMWRing RI index with the SHIPS RI index has been completed. The document of the guidance for running the code will be done at the ending period of this project by closely collaborating with NHC/JTWC folks.
Product 3	Not planned	1)A product of the FIU PMWRing RI Index 2) A real-time RI forecast website: http://tcpf.fiu.edu/JHT/; 3) Publications (please see the list below)

Publications and presentations from this reporting period:

Jiang, H., J. P. Zagrodnik, C. Tao, and E. J. Zipser 2017: What type of precipitation is represented by different color regions in the NRL 37 GHz color tropical cyclone product? *J. Geophys. Res.*, in revision.

Tao, C., H. Jiang, and J. Zawislak 2016: The Relative Importance of Stratiform and Convective Rainfall in Rapidly Intensifying Tropical Cyclones, *Mon. Wea. Rev.*, **145**, 795-809.

Rogers, R. F., J. Zhang, Zawislak, J., H. Jiang, G. R. Alvey III, E. J. Zipser, and S. Stevenson, 2016: Observations of the structure and evolution of Hurricane Edouard (2014) during intensity change. Part II: Kinematic structure and the distribution of deep convection. *Mon. Wea. Rev*., **144**, 3355–3376.
Zawislak, J., H. Jiang, G. R. Alvey III, E. J. Zipser, R. F. Rogers, J. Zhang, and S. Stevenson, 2016: Observations of the structure and evolution of Hurricane Edouard (2014) during intensity change. Part I: Relationship between the thermodynamic structure and precipitation. *Mon. Wea. Rev*., **144**, 3333–3354.
Jiang, H., B. You, and C. Tao 2017: Estimation of Tropical Cyclone Intensity Using Satellite Passive Microwave Observations. 71st *Interdepartmental Hurricane Conference/2017 Tropical Cyclone Research Forum*, Mar 14-16, 2017.
Jiang, H., J. Zawislak, Y. Pei, C. Tao, K. Musgrave, and G. Chirokova 2017: JHT Project 3: "Improvement and Implementation of the Probability-based Microwave Ring Rapid Intensification Index for NHC/JTWC Forecast Basins" 71st *Interdepartmental Hurricane Conference/2017 Tropical Cyclone Research Forum,* Mar 14-16, 2017.
Jiang, H. and C. Tao, 2016: The TRMM Tropical Cyclone Precipitation Feature (TCPF) database and Its Usage in Rapid Intensification Studies. *AMS 32nd Conference on Hurricanes and Tropical Meteorology Session 15B.6*, San Juan, Puerto Rico, April 17-22, 2016.
Pei, Y. and H. Jiang, 2016: Quantification of Shear-relative Precipitation Asymmetries of Tropical Cyclones in Different Intensity Change Stages. *AMS 32nd Conference on Hurricanes and Tropical Meteorology Session 9D.2*, San Juan, Puerto Rico, April 17-22, 2016.
Tao, C. and H. Jiang, 2016: The Evolution of Rainfall and Convection in Rapidly Intensifying Tropical Cyclones based on 16 years of TRMM Data. *AMS 32nd Conference on Hurricanes and Tropical Meteorology Session 6D.1*, San Juan, Puerto Rico, April 17-22, 2016.
Rogers, R. F., J. Zhang, Zawislak, J., H. Jiang, G. R. Alvey III, E. J. Zipser, and S. Stevenson, 2016: Observations of the structure and evolution of Hurricane Edouard (2014) during intensity change. Part II: Kinematic structure and the distribution of deep convection. *AMS 32nd Conference on Hurricanes and Tropical Meteorology Session 1C.2*, San Juan, Puerto Rico, April 17-22, 2016.
Zawislak, J., H. Jiang, G. R. Alvey III, E. J. Zipser, R. F. Rogers, J. Zhang, and S. Stevenson, 2016: Observations of the structure and evolution of Hurricane Edouard (2014) during intensity change. Part I: Relationship between the thermodynamic structure and precipitation. *AMS 32nd Conference on Hurricanes and Tropical Meteorology Session 1C.1*, San Juan, Puerto Rico, April 17-22, 2016.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

Individuals have worked on this project include Haiyan Jiang (PI), Jon Zawislak (research scientist), Cheng Tao (Postdoc Research Associate), Yongxian Pei (PhD student), and Margie Kieper (PhD student). There have been no changes in the PI and senior/key personnel since the last reporting period. FIU is partnering with CSU CIRA (Kate Musgrave) on this project. NHC points of contact (Chris Landsea, John Cangialosi, and Stacy Stewart) and JTWC point of contact (Brian DeCicco) have been involved.

4. IMPACT

According to the evaluation results of 2016 real-time testing & post-season re-run, our algorithm was able to provide a higher probability of detection (POD) in AL, EP, and WP basins and a lower false alarm ratio (FAR) in the WP basin than the SHIPS RII. The impact of this project on the prediction of rapid intensification in SH will be assessed later in year 3 as part of the evaluation of real- time testing results. The education and professional training impact is addressed in Section 1. None of the FIU portion of the budget has been spent in foreign countries.

5. CHANGES/PROBLEMS

No significant changes have occurred in the planned/completed work of the project.

6. SPECIAL REPORTING REQUIREMENTS

a. The project's Readiness Level:

Current: RL 6-7
At the start of project: RL 3

b. Transition to operations activities and summary of testbed-related collaborations, activities, and outcomes:

The quasi-real-time testing of the PMWRing RI index (RII) for ATL and EPA basins for NHC and NWP & NIO basins for JTWC has started in June 2016 and is still ongoing. The real-time forecasts are provided to NHC/JTWC points of contact through emails (only when a positive RI forecast is made) and our JHT project webpage (http://tcpf.fiu.edu/JHT/).

c. Has the project been approved for testbed testing yet? What was transitioned to NOAA?

Yes, the project has been approved for testbed testing. But it wasn't transitioned to NOAA because NHC and/or JTWC haven't decided to either transition it or not. The final decision will be made after this project is completed.

d. Test plans for the 2017 Hurricane/Typhoon season:

I. What **concepts/techniques** will be tested? What is the scope of testing (what will be tested, what won't be tested)?

The PMWRing RII is being tested for RI forecasts in AL, EP/CP, WP/IO, & SH basins. We are testing the code for reading different microwave satellite data. We also test the strategy of using SHIPS RII as a criterion in generating our probability output.

II. **How** will they be tested? What **tasks** (processes and procedures) and activities will be performed, what preparatory work has to happen to make it ready for testing, and what will occur during the experimental testing?

We are running the real-time code separately for each basin and each satellite sensor. The real-time forecasts are provided to NHC/JTWC points of contact through emails (only when a positive RI forecast is made) and our JHT project webpage (http://tcpf.fiu.edu/JHT/).

III. **When** will it be tested? What are **schedules and milestones** for all tasks described in section II that need to occur leading up to testing, during testing, and after testing?

For AL, EP/CP, and WP/IO basins, the 2017 testing started on June 1, 2017. For the SH, the code has been implemented since June 1, 2017, but the formal testing will be starting on Nov. 1, 2017 when the TC season starts in SH. We are on a 1-yr no-cost extension of this funding. That way, we'll continue the real-time testing till the NH 2017 hurricane/Typhoon season ends at around Nov. 1, 2017 and till the SH TC season ends at around Apr. 30, 2017. For the schedules/milestones, please see the table in section 1.

IV. **Where** will it be tested? Will it be done at the PI location or a NOAA location?

The testing code runs at FIU, the PI's location.

V. Who are the key **stakeholders** involved in testing (PIs, testbed support staff, testbed manager, forecasters, etc.)? Briefly what are their **roles and responsibilities**?

The PI and her research team will be responsible for maintaining the testing code & running; NHC Points of Contact Stacy Stewart, John Cangialosi, and Chris Landsea and JTWC Point of Contact Brian deCicco will help evaluate the real-time results.

VI. What **testing resources** will be needed from each participant (hardware, software, data flow, internet connectivity, office space, video teleconferencing, etc.), and who will provide them?

FIU will provide all the hardware & software for testing.

VII. What are the **test goals, performance measures, and success criteria** that will need to be achieved at the end of testing to measure and demonstrate success and to advance Readiness Levels?

The **goal** is to test the code reliability and evaluate the performance of the algorithm.
The **performance measures** are the Brier skill scores (BSSs), which should show the algorithm is at least skillful (better than climatology), and ideally better than the SHIPS RII.
The **success criteria** are 1) the algorithm can run smoothly in a quasi-operational environment; 2) the performance measures are met.

VIII. How will testing **results** be documented? Describe what information will be included in the **test results final report**.

The test results will be presented in IHC 2018. They will also be written in our final report, including the statistics of the algorithm performance for 2017 hurricane/typhoon season, i.e., POD, FAR, and BSS.

7. BUDGETARY INFORMATION

There are some changes in the original budget for the FIU portion of this project. We originally planned for 1.5 months of summer salary for the PI Jiang and 6 months of salary for the research scientist Dr. Zawislak. However, during year-1, only one month of salary for Dr. Zawislak was charged to the project. During year-2, the project is paying 3 months of summer salary ($64515.13) for the PI Jiang during May 19, 2017-August 20, 2017. Therefore, the estimated remaining funds will be $73,244.76 at the end of Year 2 (August 30, 2017). Since we are on a one year no-cost extension, we plan to cover 3 months of summer salary (about $64515.13*1.03 = $66,450.58) for the PI Jiang and about $5K of travel expenses to IHC and/or AMS Hurricane conferences during the no-cost extension year (year 3). No changes in the original budget were required for the CIRA portion of this project, which completed on schedule in year 2.

8. PROJECT OUTCOMES

The milestones of this project and the progress towards them are discussed in Section 1, with the deliverables discussed in Section 2. The outcome of this award will be the implementation of the PMWRing RII if NHC and/or JTWC decide to transition the product, which will be decided after the project is completed (as discussed in Section 6). An additional outcome of this project is the list of products contained in Section 2.

Submitted to: OAR Office of Weather and Air Quality (OWAQ)

Federal Grant Number: NA15OAR4590201

Project Title: Improvement to the Tropical Cyclone Genesis Index (TCGI)

Principal Investigator: Jason P. Dunion, Meteorologist; University of Miami/CIMAS – NOAA/HRD; jason.dunion@noaa.gov; (c) 305-720-3060

Submission Date: September 30, 2017

Recipient Organization: University of Miami, 1320 S Dixie Hwy, Coral Gables, FL 33146

Project/Grant Period: 09/01/2015 - 08/31/2017
This project was granted a no-cost extension with an end date of 8/31/2018

Reporting Period Start/End Date: 03/01/2017 **-** 08/31/2017

Report Term or Frequency: Quarterly

Reporting Timeline: Year-2 final report

1. ACCOMPLISHMENTS

The main goal of this project is to implement improvements to the Tropical Cyclone (TC) Genesis Index (TCGI) that was transitioned to operations at the NOAA National Hurricane Center (NHC) in October 2014. TCGI is a disturbance-following scheme designed to provide forecasters with an objective tool for identifying the 0-48hr and 0-120hr probability of TC genesis in the North Atlantic basin. Progress made under this current funded project includes expanding the TCGI North Atlantic database to include the years 2001-2014, developing a new 2001-2014 Pacific (eastern north Pacific (EPAC) and central North Pacific (CPAC)) TCGI database, identifying new predictors to test in both the Atlantic and Pacific versions of TCGI, deriving an eastern/central Pacific basin TCGI utilizing predictors that were employed in the previously developed Atlantic basin version and developing an ECMWF-based Atlantic TCGI using predictors and predictor weights that were developed for the GFS version of TCGI. The following tasks were conducted and/or completed during this reporting period:

i. *Begin development of an ECMWF-based Atlantic TCGI using predictors and predictor weights that were developed for the GFS version of TCGI (April 2016)*
    - Development of the ECMWF TCGI is complete and real-time code has been implemented and tested on WCOSS (Sept 2017). We are still working with the Technology & Science Branch (TSB) at NHC to obtain real-time ECMWF tracks and forecast fields at CIRA so that parallel runs can be performed.

ii. *Begin sensitivity testing for optimal combinations of Atlantic and Pacific TCGI predictors- GFS version (June-November 2016)*

- New TCGI predictors using the 2001-2014 Atlantic and Pacific datasets were tested alongside ~60 other previously tested predictors. Sensitivity tests included WWLLN lightning data, Tropical Overshooting Tops (only available in the Atlantic), and several GFS-based predictors: (1) relative humidity (850-600 hPa and 1000-925 hPa), (2) moisture convergence at 850 hPa, (3) vertical wind shear magnitude and direction for the 850-500 hPa layer, (4) generalized vertical wind shear from 1000-100 hPa, and (5) vorticity x divergence at 850 hPa.
- All area-averaged predictors were calculated using the original TCGI 0-500 km predictor search radius, as well as several smaller search radii: 0-200, 0-300, and 0-400 km. Although dependent dataset tests indicated that smaller search radii were increasingly skillful, simulated real-time tests for 2011-2016 showed that smaller search radii, in fact, produce increasingly less skillful TCGI forecasts. This discrepancy likely relates to the fact that the dependent test benefitted "perfect prog" forecasts (i.e. tropical disturbance positions were known throughout the storm lifecycle), which is not representative of real-time operations. The 2011-2016 simulated real-time tests suggest that track forecast uncertainty inherent in weak tropical disturbances is significant and requires the use of 0-500 km search radii for both 0-48 and 0-120 hr TCGI forecasts.
- Sensitivity tests were conducted to identify the optimal combination of predictors for the expanded version of the Atlantic TCGI and new Pacific TCGI. These 6 optimal predictors calculated using the 0-500 km search radius are highlighted in Fig. 1 and will be used for both the Atlantic and Pacific versions of TCGI. Figure 2 shows the cross-validated Brier Skill Score for the new Atlantic and Pacific versions of TCGI derived from the 2001-2014 TCGI invest database.

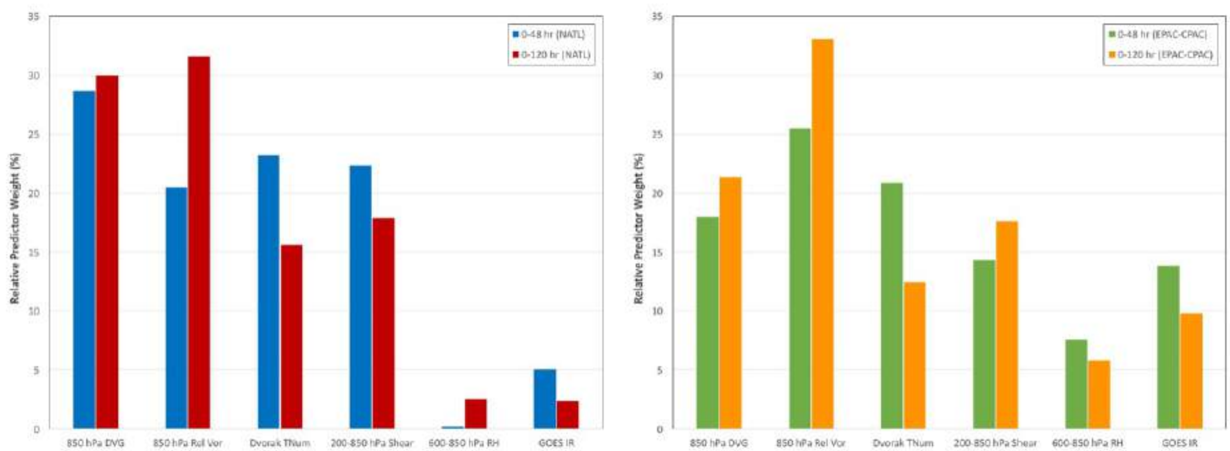

Fig. 1: Relative predictor weights for the new 2001-2014 Atlantic (left) and Pacific (right) versions of TCGI. The 0-48 hr predictor weights are shown in blue (Atlantic TCGI) and green (Pacific TCGI) and the 0-120 hr predictor weights are shown in red (Atlantic TCGI) and orange (Pacific TCGI). Predictors include: 850 hPa divergence (DVG), 850 hPa relative vorticity (Rel Vor), Dvorak T-number (TNum), 200-850 hPa vertical wind shear (Shear), 600-850 hPa relative humidity (RH), and GOES water vapor pixels <-40ºC (GOES IR). Predictor weights were derived using 0-500 km search radii.

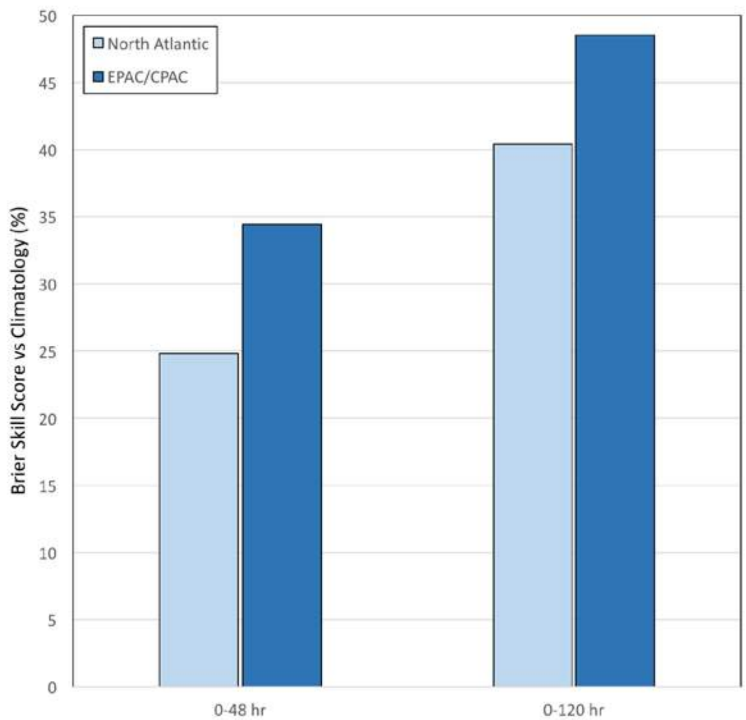

Fig. 2: Cross-validated Brier Skill Score (relatively to climatology) for the new Atlantic and Pacific versions of TCGI based on the 2001-2014 TCGI invest database.

iii. *Perform real-time tests of 0-48 and 0-120 h Atlantic and Pacific TCGI (GFS version) on NESDIS computers at CIRA with output being made available online at (May-August 2017): http://rammb.cira.colostate.edu/realtime_data/nhc/tcgi/*

- The new Atlantic and Pacific versions of TCGI have been running in real-time at CIRA through the 2017 season. Output has been available online at: http://rammb.cira.colostate.edu/projects/tc_genesis/

iv. *Perform real-time tests of 0-48 and 0-120 h Atlantic and Pacific TCGI (ECMWF version) at NHC (requires computing and IT support from NHC) (May-August 2017)*

- Real-time tests of the ECMWF TCGI were conducted during Co-PI Schumacher's visit to NHC from 8/28-9/1 2017. The ECMWF TCGI was set up to run right after the GFS version finishes, with output files named: YYMMDDHH{bas}YY_tcgie.txt. After this visit, a small script error was found by Co-PI Schumacher that is preventing the ECMWF files from being created since 9/1/17. Co-PI Schumacher will fix this bug during her next scheduled visit to NHC in November 2017.

v. *Finish development/evaluation of prototype ECMWF-based Atlantic TCGI (May-August 2017)*

- See item *iv* above.

vi. *Work with IT personnel at NOAA NHC to establish a means to more efficiently access real-time NOAA TAFB Dvorak fix information. This will help ensure increased reliability of real-time TCGI forecasts for use by NHC forecasters (May-August 2017).*

- The new Atlantic and Pacific versions of TCGI now use NOAA TAFB Dvorak fix files instead of fixes from the f-decks. Since this change was put into place, TCGI runs have been much more timely and consistent. This improvement was implemented for TCGI on WCOSS and the parallel TCGI being run at CIRA.

vii. *Final code for running both the Atlantic and Pacific versions of TCGI on operational NCEP computers will be provided to NHC/NCEP IT personnel if the project is accepted for operational transition (August 2017).*

- Atlantic and N.E. Pacific versions of the updated GFS-based TCGI and the new ECMWF-based TCGI are running in a quasi-production environment on WCOSS. A few minor bug fixes need to be implemented during A. Schumacher's next visit to NHC (November 2017) based on product feedback gathered since the last updates made in September 2017.

Deliverables *ii*, *iii*, and *vi* have been completed. Deliverables *i*, *iv*, *v*, and *vii* are nearing completion and will be carried out during the approved no-cost extension period of this project. We anticipate that all deliverables will be completed by the end of the calendar year 2017.

2. PRODUCTS

Efforts related to this project's current reporting period have produced the following:

a. Conference Papers & Presentations
   - Dunion, J.P., J. Kaplan, A.B. Schumacher, J. Cossuth, K.D. Musgrave, and P. Leighton, 2017: Improvements to the Tropical Cyclone Genesis Index (TCGI). *71st Tropical Cyclone Operations and Research Forum*, Miami, FL, Office of Fed. Coord. For Meteor. Services and Supporting Research, NOAA. http://www.ofcm.gov/meetings/TCORF/tcorf.htm
   - Dunion, J.P., J. Kaplan, A. B. Schumacher, J. Cossuth, K.D. Musgrave, and P. Leighton, 2016: The Tropical Cyclone Genesis Index (TCGI), *32nd Amer. Meteor. Soc. Conf. on Hurricanes and Tropical Meteor.*, San Juan, Puerto Rico. https://ams.confex.com/ams/32Hurr/webprogram/start.html

b. Real-Time TCGI Website (hosted by the Colorado State University-CIRA):
   - http://rammb.cira.colostate.edu/projects/tc_genesis/

c. 2001-2014 Tropical Disturbance Database for the Atlantic and Pacific
   - An updated tropical disturbance database for the North Atlantic spanning the years 2001-2014 has been developed under this project.
   - A new tropical disturbance database for the central and eastern North Pacific spanning the years 2001-2014 has been developed under this project.

d. Software for Analyzing Tropical Cyclone Genesis in Atlantic and Pacific

- New software has been developed to analyze important tropical cyclone inner core and environmental predictors for forecasting tropical cyclone genesis.
- Algorithms have been developed to analyze the 2001-2014 Atlantic and Pacific databases and have be incorporated into the upgraded (new) TCGI for the Atlantic (Pacific).

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

The following team members have contributed to this project (no changes to senior/key project personnel has occurred since the last reporting period and only the personnel and institutions listed below have been involved in the project during this reporting period):

PI:

Jason Dunion, University of Miami/CIMAS – NOAA/AOML/HRD, jason.dunion@noaa.gov

Co-PIs:

John Kaplan, NOAA/AOML/Hurricane Research Division, john.kaplan@noaa.gov
Andrea Schumacher, Colorado State University/CIRA, schumacher@cira.colostate.edu
Joshua Cossuth, Naval Research Laboratory-Monterey, Joshua.Cossuth.ctr@nrlmry.navy.mil

Co-Is:

Paul Leighton, NOAA/AOML/Hurricane Research Division, paul.leighton@noaa.gov
Kate Musgrave, Colorado State University/CIRA, Kate.Musgrave@colostate.edu

The following lists the tasks outlined in Sec. 1 and the project team members who contributed to those efforts:

- Task i: Co-PI Schumacher and Co-I Musgrave
- Task ii: PI Dunion and Co-PI Kaplan
- Task iii: Co-PI Schumacher and Co-I Musgrave
- Task iv: Co-PI Schumacher
- Task vi: Co-PI Schumacher and Co-I Musgrave
- Task vii: Co-PI Schumacher

4. IMPACT

This project is in the developmental year-2 phase the important NOAA-identified impacts for this reporting period do not apply. None of this project's awarded budget has been spent in a foreign country.

5. CHANGES/PROBLEMS

No changes to the methodology and approach for this project have been made for this reporting period. The project budget is on track and future changes are not anticipated. A few of the project timelines require assistance from TSB IT personnel at NHC and were delayed. A no-cost extension was requested and approved to allow extra time for these final deliverables to be completed.

6. SPECIAL REPORTING REQUIREMENTS

The readiness level for this reporting period is estimated to be RL5 to RL6. Upcoming efforts in fall 2017 will elevate the project to RL7 to RL8. The following outlines test plans for this USWRP-supported testbed project:

I. *What concepts/techniques will be tested? What is the scope of testing (what will be tested, what won't be tested)?*
   - TC genesis forecasts from the new GFS model-based Atlantic and Pacific versions of TCGI are being tested in real-time on the NOAA/NCEP WCOSS computer.
   - TC genesis forecasts from the new ECMWF model-based Atlantic and Pacific versions of TCGI will be tested in real-time on the NOAA/NCEP WCOSS computer.

II. *How will they be tested? What tasks (processes and procedures) and activities will be performed, what preparatory work has to happen to make it ready for testing, and what will occur during the experimental testing?*
   - The new Atlantic and Pacific versions of TCGI are being run in a parallel real-time mode to the current operational version of TCGI. The computer code for the new TCGI has also been installed on WCOSS and is running in real-time.

III. *When will it be tested? What are schedules and milestones for all tasks described in section II that need to occur leading up to testing, during testing, and after testing?*
   - Testing and evaluation of the new TCGI code has been conducted since the beginning of the 2017 Atlantic hurricane season.

IV. *Where will it be tested? Will it be done at the PI location or a NOAA location?*
   - The new TCGI is being run in parallel on both the NOAA/NCEP WCOSS computer and on servers at the Cooperative Institute for Research in the Atmosphere. Project personnel are testing and evaluating TCGI on both computing systems.

V. *Who are the key stakeholders involved in testing (PIs, testbed support staff, testbed manager, forecasters, etc.)? Briefly what are their roles and responsibilities?*
   - The entire project team is involved in testing and evaluating the new TCGI. Feedback from this project's NHC points of contact have also been vital and they have been included during the ongoing testing and evaluation process. Some support/input from IT personnel at NOAA NHC has been and still is required to ensure that the ECMWF model data is available in real-time for use in the ECMWF-based Atlantic TCGI.

VI. *What testing resources will be needed from each participant (hardware, software, data flow, internet connectivity, office space, video teleconferencing, etc.), and who will provide them?*
   - Continued access to the NOAA/NCEP WCOSS system will be required.

VII. *What are the test goals, performance measures, and success criteria that will need to be achieved at the end of testing to measure and demonstrate success and to advance Readiness Levels?*

- Real-time availability of TCGI, as well as statistical assessments of TCGI's performance during the 2017 Atlantic and eastern/central North Pacific hurricane seasons will be assessed to demonstrate success and advance the readiness levels.

VIII. *How will testing results be documented? Describe what information will be included in the test results final report.*

- Statistics of TCGI's performance during the 2017 Atlantic and eastern/central North Pacific hurricane seasons will be made and will include reliability diagrams and Brier Skill Scores. These results will be included in a final JHT report to NOAA.

7. BUDGETARY INFORMATION

This project's budget is on track and no budget changes are anticipated.

8. PROJECT OUTCOMES

The main deliverable of this project is to implement improvements to the Tropical Cyclone Genesis Index (TCGI) that was transitioned to operations at NOAA NHC in October 2014. The outcome of this effort will be to turn over the operational code for running the upgraded TCGI to NOAA by the end of the 2017 calendar year. Performance measures that are defined in this project are being achieved and although a few of the deliverables have been delayed, a recently approved no-cost extension will help ensure that these deliverables will be completed.

NOAA/JHT

Federal Grant Number Assigned by Agency: NA15OAR4590204

Title: Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models

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Award Period: 9/1/15-8/31/18

Reporting Period End Date: 2/28/18

Report Term or Frequency: semi-annual

Final Annual Report? No

1. ACCOMPLISHMENTS

Summary of the project accomplishments for the 3 main project tasks:

1) **Replace in SHIPS and LGEM weekly 1° resolution SSTs with daily 0.25° resolution SSTs.** These changes were designed to improve forecast performance and set the stage for including upper-ocean data to explicitly account for SST cooling. The software for pre-processing daily Reynolds SST (DSST) data was developed and modifications to the model to add the option to use either weekly SST (RSST) or DSST were completed. A new module was added to SHIPS/LGEM to handle the selection of SST and ocean heat content (OHC) data and that module was implemented in the 2016 version of SHIPS on WCOSS. Changes for this task were incorporated into the 2016 version of SHIPS and retrospective and parallel runs with daily SST and verification have been completed. The code to generate global and regional DSST, the modified SHIPS/LGEM, and verification results have been provided to NHC for evaluation. Statistical tests were performed and demonstrated that DSST is very noisy compared to RSST.

It was also found that using temporally or spatially averaged DSST produces better improvement to SHIPS and LGEM forecasts, as compared to DSST. The updated real-time processing for DSST data and the updated database of 1982 - 2017 DSST data were provided to NHC, and will be used for operational runs and to include DSST in the SHIPS predictors' database. The spatially-averaged DSST (DSTA) will be implemented in the operational versions of SHIPS and LGEM on WCOSS for 2018.

2) **Add to SHIPS/LGEM a physical mechanism to account for storm-induced SST cooling.** Lin et al. (2013) and Price (2009) have demonstrated that the use of tropical cyclone- (TC) cooled SST instead of SST to calculate the storm maximum potential intensity (MPI) produces a more realistic upper intensity bound estimate and that the ocean temperature vertically-averaged from the surface to the depth of TC-induced mixing is a more robust metric of the SST cooling effect than the OHC. The algorithm for estimating the depth-averaged temperature (DAVT) assuming constant and variable mixing depth from the OHC data available in real-time has been developed and incorporated into the SHIPS and LGEM processing scripts. The option to use either SST or DAVT has been added to both SHIPS and LGEM. It was found that the results of using DAVT in SHIPS and LGEM are not as good as expected to the large extend due to poor quality of input data. The available ocean data that include SST, mixed-layer depth (DML), and depths of 26° and 20° isotherms (D26 and D20), do not provide enough information to accurately estimate DAVT. The OHC, the subsurface ocean data, and the corresponding climatologies were completely re-derived from full ocean profiles to obtain an input dataset (the Extended OHC, EOHC) that allows for the accurate calculation of DAVT. The dependent tests demonstrated improved SHIPS and LGEM forecasts with using re-derived data. The OHC data from EOHC dataset were also found beneficial for SHIPS, LGEM, and RII, and will be used with the operational 2018 version of SHIPS on WCOSS. The final version of the algorithm to use DAVT with variable mixing depth and final regression coefficients will be derived using the 2018 version of SHIPS/LGEM to allow direct comparison of the experimental version with the operational version during 2018 Atlantic and East Pacific hurricane seasons. It is planned to run SHIPS with DAVT in quasi-production on WCOSS for 2018.

3) **Add forecasts of TC structure (wind radii and MSLP) to SHIPS/LGEM.** A statistical-dynamical method to predict TC wind structure (Decay SHIPS Wind Radii, DSWR) in terms of wind radii has been developed and has been running in real-time at CIRA since August 2016. The basis for TC size variations is developed from an infrared satellite-based record of TC size (Knaff et al. 2014), which is homogenously calculated from a 1996-2012 sample. The change in TC size is predicted using a statistical-dynamical approach where predictors are based on environmental diagnostics derived from global model forecasts and observed storm conditions. Once the TC size has been predicted, the forecast intensity and track are used along with a parametric wind model to estimate the resulting wind radii following Knaff et al. (2017). The DSWR code and verification for 2017 was completed and results were provided to NHC and JTWC. DSWR was transitioned to operations at the Joint Typhoon Warning Center (JTWC) in September, 2017. It is planned to run DSWR in quasi-production at WCOSS for the 2018 Atlantic Hurricane season.

What were the major proposed **goals, objectives, and tasks** of this project, and what was accomplished this period under each task? (a table of planned vs. actuals is recommended as a function of each task identified in the funded proposal)

Goals, Objectives, Tasks	Planned: Sep 2017 – Feb 2018	Actual: Sep 2017 – Feb 2018
Modify SHIPS and LGEM to use 0.25° daily Reynolds SST	Update DSST database and software and provide final software and data to NHC.	The DSST database was updated to account for the new data format and provided to NHC together with the updated SHIPS and software for processing DSST in real-time.

Modify SHIPS and LGEM models to use DAVT	Derive new ocean data including OHC and subsurface data to obtain a dataset that allows deriving accurate DAVT, and complete depended sample tests with the updated data.	A comprehensive dataset of OHC, DML, and subsurface ocean data was derived from the full ocean profiles. The dependent sample testing demonstrated that the new data provide better improvement to SHIPS and LGEM forecasts. In addition updated OHC proved to be beneficial for SHIPS, LGEM, and RII and will be used in the 2018 operational version of SHIPS.
Add forecasts of TC structure (wind radii and MSLP) to SHIPS/LGEM	Complete verification for 2017 and provided updated software to NHC and JTWC.	Verification for 2017 was completed and the results were provided to NHC and JTWC. DSWR was transitioned to operations at JTWC in September 2017. It is planned to run DSWR in quasi-production on WCOSS from 2018 Atlantic Hurricane season.

Are the proposed project tasks **on schedule**? What is the cumulative percent toward completion of each task and the due dates? (table recommended)

Task	Cumulative percent towards completion and due dates	Due Date	On schedule (yes/no)
Modify SHIPS and LGEM models to use 0.25° daily Reynolds SST	100%	Feb 2017	Yes
Modify SHIPS and LGEM models to use DAVT	90%	Aug 2018	Yes
Add forecasts of TC structure (wind radii and MSLP) to SHIPS/LGEM	100%	Feb 2017	Yes

What were the major completed **milestones** this period, and how do they compare to your proposed milestones? (planned vs. actuals table recommended)

Milestone	Completed vs proposed
Updated DSST database and software to account for the changed format of the input data	DSST software and database were updated as planned and provided to NHC
Re- derive ocean dataset required for producing accurate estimates of DAVT	That was additional task requested by NHC based on the results of previous testing. The task was completed as planned and the updated software and databases were provided to NHC
Complete SHIPS verification by comparing the intensity forecasts against the final NHC best track, and size parameters against the final wind radii in the best track	Verification of 2017 DSWR was completed as planned and the results were provided to NHC and JTWC. Verification of SHIPS with DAVT will be completed by August 2018, using 2018 version of SHIPS, as planned.

Detailed description of the work completed for each milestone since the last report is presented below. Some milestones were updated to include additional testing for DAVT and changed datasets. The original milestones are expected to be completed by the end of NCE as planned.

Milestone: updated DSST database and software to account for the changed format of the input data. The format of the DSST data was changed in April 2017 from NetCDF3 to compressed NetCDF4. The software for processing DSST was updated to account for that change. The full 1982 - 2017 database of DSST was updated to ensure that it contains exactly the same data that are available in the updated DSST archive on https://www.ncei.noaa.gov/data/sea-surface-temperature-optimum-interpolation/access/. The updated database and software were provided to NHC. The data will be included in SHIPS developmental database and the software will be used to generate at NHC DSST in SHIPS format that will be used for the 2018 operational versions of SHIPS and LGEM.

Milestone: Re-derive ocean dataset required for producing accurate estimates of DAVT. Testing of SHIPS and LGEM with DAVT completed at the earlier stages of this project demonstrated that DAVT does not provide the expected forecast improvement. It was found that the available ocean data that include SST, mixed-layer depth (DML), and depths of 26° and 20° isotherms (D26 and D20), do not provide enough information to accurately estimate DAVT. NHC requested that ocean data be completely re-derived from the full NCODA ocean profiles available at ftp://usgodae.org/pub/outgoing/fnmoc/models/glb_ocn/. The OHC, the subsurface ocean data, and the corresponding climatologies were completely re-derived from full ocean profiles to obtain an input dataset that allows for the accurate calculation of DAVT. The new dataset includes, DML, OHC, OHC relative to 20° isotherm, depth of all isotherms from 16° to 32°, as well as the maximum temperature (Tmax) at each point to capture temperature inversions, and the depth of the ocean and the temperature of the lowest available level in each profile. These additional points allow for a very accurate estimation of DAVT. Figure 1 shows the R^2 (upper) and Yerr (lower) percent improvement for the dependent tests for the Atlantic (left) and east Pacific (right), showing that use of DAVT results in SHIPS forecast improvement at all forecast times. The global re-derived ocean data together with the software for generating these data in real-time were provided to NHC. The dependent sample tests of SHIPS and LGEM with DAVT estimated from re-derived data demonstrated much better forecast improvement compared to earlier results which used DAVT estimated from just 4 points, SST, DML, D26, and D20. The best results are obtained when using DAVT assuming constant mixing depth of 80 m or variables DAVT, which is consistent with the previous results (i.e. Lin et al. (2013) and Price (2009))

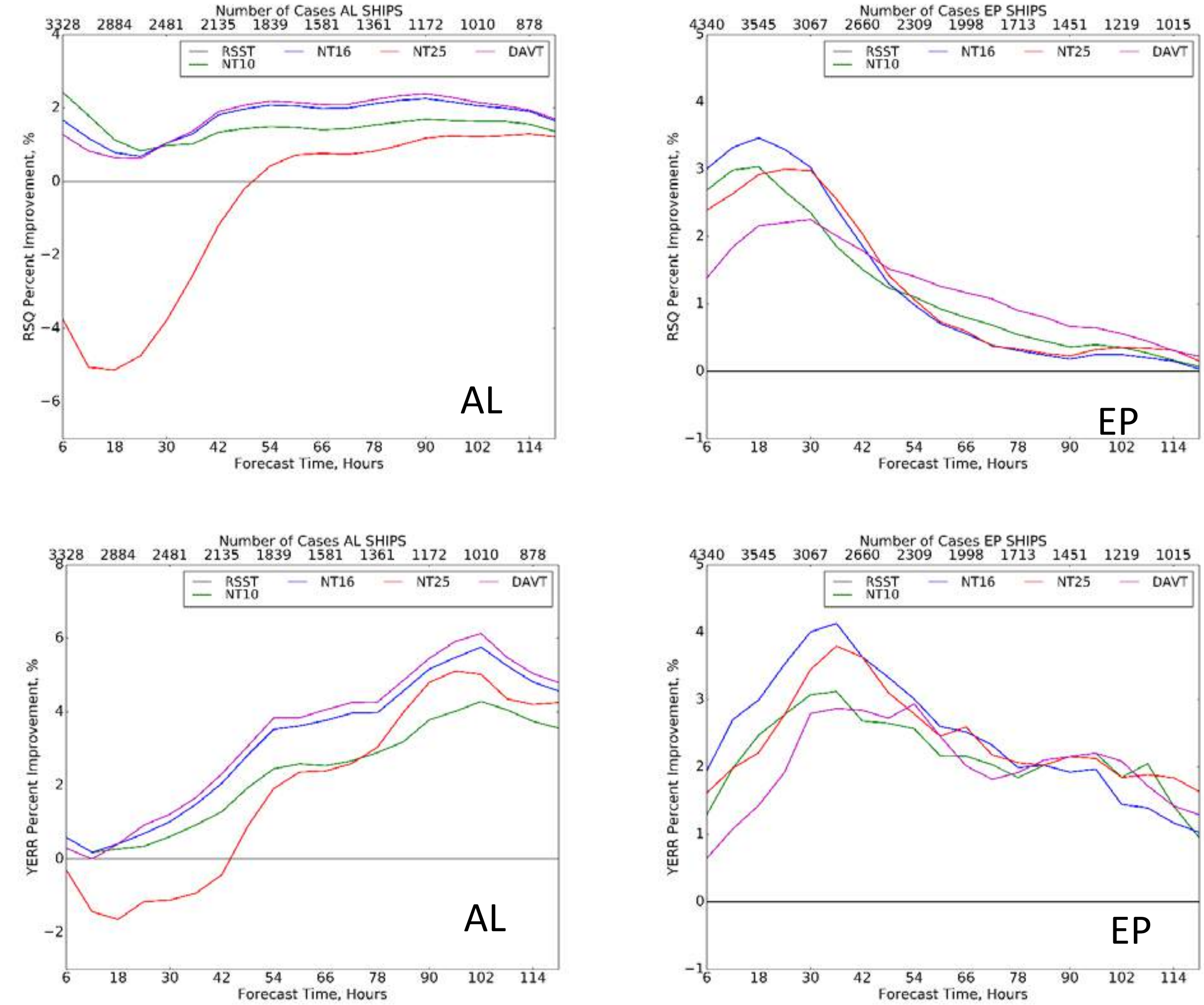

Figure 1. Upper left: R^2 percent improvement for SHIPS/LGEM dependent tests for the Atlantic with weekly SST replaced by DAVT. Black horizontal line is the baseline daily SST (RSST), green line - DAVT assuming constant mixing depth of 50 m (NT10), blue line - same for constant mixing depth of 80 m, red line - 125 m, and purple line - assuming variable mixing depth based on the "ocean age". Lower left: same for east Pacific. Upper right: same for Yerr for the Atlantic, and lower right: same for Yerr for the east Pacific.

Milestone: Complete SHIPS verification by comparing the intensity forecasts against the final NHC best track, and size parameters against the final wind radii in the best track. Verification of DSWR for 2017 was completed and provided to NHC and JTWC. It was found that in the Atlantic DSWP performs similar to other methods and is high-biased. In the east Pacific DSWR is skillful relative to DRCL for 2017. The biases in both east and west Pacific are very low. In addition, it was found that DSWR improves the multi-model wind radii consensus, RVCN that includes GFS (AHNI), HWRF (HHFI), and ECMWF (EMXI). DSWR provided either improvements or no degradation to RVCN when added as a member for all basins and all wind radii thresholds. Figure 2 shows MAE for 2017 RVCN consensus wind radii forecasts with and without using DSWR. The DSWR was transitioned to operations at JTWC in September 2017. It is planned to run DSWR in quasi-production at NHC on WCOSS for the 2018 Atlantic Hurricane season. SHIPS and LGEM verification with final modifications will be completed in the next reporting period using 2018 versions of SHIPS and LGEM to allow for direct comparison with the operational versions of the models.

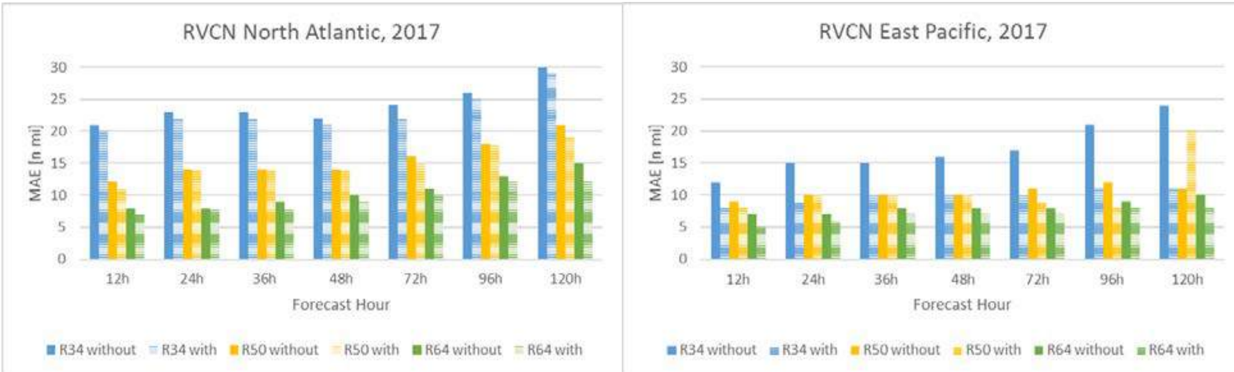

Figure 2: RVCN MAE (Left) for the Atlantic and (Right) East Pacific basin. RVCN included HWRF, GFS, and ECMWF. Solid bars show runs without DSWR and dashed bars show runs with DSWR.

What opportunities for training and professional development has the project provided?

People working on the project obtained increased knowledge and skills in the development of statistical models. Project PIs, Galina Chirokova (in 2016, 2017, and 2018), Andrea Schumacher (in 2017) and Collaborator, John Knaff (in 2016) participated in the TCORF/IHC conferences. There were no training activities during the reporting period.

How were the results disseminated to communities of interest?

1) The project results were presented at the IHC in 2016, 2017, and 2018) The IHC presentations and previous project reports are available online at http://www.nhc.noaa.gov/jht/15-17_proj.php?large. Additional details about the project were communicated to NHC points of contact, Dan Brown, Lixion Avila, and Chris Landsea.

2) Real-time DSWR (2016 and 2017) and SHIPS/LGEM with DSST (2016) forecasts were also provided to NHC POCs via an ftp server per NHC's request.

3) Verification of 2016 retrospective runs with DSST and dependent test with DAVT were provided to NHC.

3) The DSWR code has been provided to NHC and Naval Research Laboratory (NRL), Monterey for implementation at JTWC. The DSWR was transitioned to operations at JTWC in September, 2017.

4) The 2017 SHIPS/LGEM code updated to use RSST, DSST, or DAVT was provided to NHC. The changes will be implemented in the 2018 operational version of SHIPS.

5) The global and regional DSST and the new EOHC ocean data together with the software for creating and reading historical and real-time DSST and EOHC data were provided to NHC. The updated database of DSST, OHC, and ocean data will be included in the SHIPS developmental database, and should eventually replace the RSST and the old OHC data. The software for generating real-time DSST and OHC data will be used to generate data for the operational 2018 SHIPS and LGEM.

6) The updated climatology of DSST, OHC, D20, D26, DML, and all other variables included in the EOHC dataset, as well as the software for updating, reading, and including that climatology into SHIPS developmental database was provided to NHC.

What do you plan to do during the next reporting period to accomplish the goals and objectives?

During the next reporting period we plan to conduct retrospective runs and verification of the experimental version of the 2018 SHIPS/LGEM with DAVT assuming either constant or variable mixing depth. In addition, final adjustments and modifications to the code will be implemented based on the results of the retrospective runs. We will further work with JHT and NHC TSB staff to implement experimental versions of SHIPS/LGEM and DSWR on quasi-production on WCOSS for the 2018 season and/or will implement parallel runs at CIRA.

2. PRODUCTS

What were the major completed **products or deliverables** this period, and how do they compare to your proposed deliverables? (planned vs. actuals table recommended)

Product/Deliverable	Actual
2017 SHIPS/LGEM code modified to work with RSST, DSST, and DAVT	Provided to NHC as planned
Updated DSST database in SHIPS format for global and regional files for 1982 - 2017	Provided to NHC as planned
Verification of SHIPS/LGEM dependent tests with the re-derived DAVT	Provided to NHC as planned
New dataset of the OHC and subsurface ocean data for 2006 - 2017	Provided to NHC as planned
Updated climatology for DSST, OHC, MLD, and depths of 16° (D16) - d32° (D20) isotherms	Provided to NHC as planned
Updated software for processing DSST and EOHC climatology	Provided to NHC as planned
Software for real-time processing of DSST and EOHC data	Provided to NHC as planned
Verification of DSWR runs	Provided to NHC as planned

What has the project produced?
-publications, conference papers, and presentations*;

Presentations:

Chirokova G., J. Kaplan, and J. Knaff, 2018: Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models Using Wind Structure and Eye Predictors. *2018 Tropical Cyclone Operations and Research Forum (TCORF)/71th Interdepartmental Hurricane Conference (IHC), 13-15 March, 2018, Miami, Florida.* The presentation will be available online at http://www.nhc.noaa.gov/jht/15-17_proj.php?large.

Schumacher A., G. Chirokova, J. Knaff, and M. DeMaria, 2018: Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models. 98th AMS Annual Meeting / 22nd Conference on Satellite Meteorology and Oceanography, 7 - 11 January 2018, Austin Texas

Publication: A manuscript detailing the statistical-dynamical method to predict tropical cyclone wind structure in terms of wind radii method, its independent performance in 2014 and 2015, and how it may contribute to the wind radii consensus has been published in Weather and Forecasting.

Knaff, J., C. Sampson, and G. Chirokova, 2017: A global statistical–dynamical tropical cyclone wind radii forecast scheme. *Wea. Forecasting*, **32**, 629–644, doi: 10.1175/WAF-D-16-0168.1.

Highlights of that paper suggest:

1. This method (DSWR) is a competitive method for predicting the wind radii, even if the SHIPS forecasts of intensity and track are used for wind radii estimates.
2. That its inclusion in a simple wind radii consensus (RVCN), results in no degradation, and, in most cases, improves the consensus forecasts.
3. That the predictors related to mid-level moisture (+), initial size (-), storm latitude (+), 200 hPa divergence (+) are best related to changes in TC size, the sign of the relationships is shown in parentheses.

-website(s) or other Internet site(s);

- The real-time DSRW forecasts are available at ftp://rammftp.cira.colostate.edu/knaff/DSWR/

-technologies or techniques;

- Improved (lower biased) TC vortex model for wind radii.
- Method to estimate DAVT from limited, yet routinely measured ocean parameters.

-inventions, patent applications, and/or licenses; and

None

-other products, such as data or databases, physical collections, audio or video products, software, models, educational aids or curricula, instruments or equipment, research material, interventions (e.g., clinical or educational), or new business creation.

- New improved EOHC dataset that includes OHC and other subsurface ocean data. EOHC dataset includes both global and regional files.
- Database of DSST data converted to SHIPS input format. The database includes both global and regional files.
- Updated climatology of DSST, OHC, MDL, D16 - D32, based on the EOHC data for 2005 - 2017
- Database of NCODA OHC, D16 - D32, OHC20, and MLD converted to SHIPS input format. The database includes both global and regional files.

*For **publications**, please include a full reference and digital object identifier (DOI; http://www.apastyle.org/learn/faqs/what-is-doi.aspx) and attach all publications and presentations on this project from this reporting period to the progress report, or include web links to on-line versions. Within your publications and presentations, please include language crediting the appropriate NOAA/OAR organization and program (e.g., NOAA/OAR/OWAQ and the U.S. Weather Research Program; or NOAA/OAR/NSSL and the VORTEX-SE program) for financially supporting your project. Suggested language is as follows:
"This material is based upon work supported by the U.S. Weather Research Program within NOAA/OAR Office of Weather and Air Quality under Grant No. XXXXXXX."

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on this project?

Galina Chirokova, John Knaff, Andrea Schumacher, Robert DeMaria, Jack Dostalek

Has there been a change in the PD/PI(s) or senior/key personnel since the last reporting period?

No

What other organizations have been involved as partners? Have other collaborators or contacts been involved?

NHC points of contact have been involved. Also, work for this project has been coordinated with NHC TSB branch.

4. IMPACT

What was the impact on the development of the principal discipline(s) of the project?
The project addresses program priorities NHC-1/JTWC- 1, NHC-13/JTWC- 10, and NHC-17/JTWC-13. The results of this project will first provide improved statistical-dynamical guidance for TC intensity. These intensity guidance techniques are routinely used operationally at NHC and JTWC to forecast TC intensity. Secondly this project developed a new statistical-dynamical forecast guidance for TC structure (i.e., wind radii) that appears somewhat independent to NWP guidance, making it a nice addition to wind radii consensus methods.

What was the impact on other disciplines?
The results of this project should allow for improved operational TC intensity and structure forecasts that are important for other agencies and general public. Improvements in these capabilities may also lead to other high priority forecasts (e.g., storm surge watch/warnings, wave forecasts) and decisions (e.g., evacuations, ship routing).

What was the impact on the development of human resources?
Nothing to report

What was the impact on teaching and educational experiences?
Nothing to report

What was the impact on physical, institutional, and information resources that form infrastructure?
Nothing to report

What was the impact on technology transfer?
Methods developed at CIRA, if approved by the JHT, will transition to NHC operations. Examples include DAVT calculations assuming constant or variable storm-induced mixing depth and a simple vortex model.

What was the impact on society beyond science and technology?
The results of this project should allow for improved operational TC intensity forecasts that are important for other governmental agencies, industry, and general public. These efforts significantly contribute to NOAA's goal of a *Weather-Ready Nation*.

What percentage of the award's budget was spent in a foreign country(ies)?
None

5. CHANGES/PROBLEMS

Describe the following:

-Changes in approach and reasons for the change.

It was found that the available ocean data that include SST, mixed-layer depth (DML), and depths of 26° and 20° isotherms (D26 and D20), do not provide enough information to accurately estimate DAVT. NHC requested that ocean data be completely re-derived from the full NCODA ocean profiles available at ftp://usgodae.org/pub/outgoing/fnmoc/models/glb_ocn/. The ocean data were re-derived, and the new EOHC dataset was developed using subsurface ocean data from full ocean profiles. The DAVT estimated from re-derived data provides improvement to the SHIPS/LGEM forecasts. In addition, OHC data from the EOHC dataset will be implemented in the 2018 operational version of SHIPS, LGEM, and RII.

-Actual or anticipated problems or delays and actions or plans to resolve them.

A one-year NCE for the project was requested and approved by NOAA. The extension is used to complete additional testing and provide to NHC the final updated version of the developed software and databases, as well as final verification results. Additional milestones required to produce new datasets and conduct additional testing were completed in this reporting period. The remaining project milestones are expected to be completed by August 2018.

-Changes that had a significant impact on expenditures.
None
-Change of primary performance site location from that originally proposed.
None

6. SPECIAL REPORTING REQUIREMENTS

Report on any special reporting requirements here (see previous instruction #3). If there are none, state so.

- Your assessment of the project's Readiness Level (current and at the start of project; see definitions in Appendix B)

Start of the project: RL3
Current: RL6-7

-If not already reported on in Section 1, please discuss:
-- Transition to operations activities

The transition to operations for this project is scheduled after the end of NCE, in the spring of 2019, if accepted by NHC. The timing of the final transition will depend on the availability of NHC Technology and Science Branch (TSB) resources.

However, several items developed as part of this project were already transitioned to operations, including:

- Fixes to some minor computer bugs in the SHIPS/LGEM/RII processing that were identified in the course of this work were implemented in the 2016 operational version of the NHC guidance suite on WCOSS.
- The spatially-averaged DSST data and OHC data from the new EOHC dataset produced by this project will be implemented in the operational 2018 version of SHIPS and LGEM in the NHC guidance suite on WCOSS.
- The DSWR was transitioned to operations at JTWC in September, 2017.

-- Summary of testbed-related collaborations, activities, and outcomes (if it's a testbed project)

1) Real-time forecasts of the TC-size estimates were made available via the CIRA ftp server, server at ftp://rammftp.cira.colostate.edu/knaff/DSWR/ starting on the 18th of August. Past forecasts made in 2016 were also provided at this time.

2) Real-time SHIPS forecasts with DSST were made available via CIRA ftp server at ftp://rammftp.cira.colostate.edu/chirokova/JHT_2015_2017/rt_demo/ during 2016 Atlantic and East Pacific Hurricane seasons.

3) Verification of the retrospective SHIPS runs with DSST and parallel runs from 2016 season were provided to NHC

4) 2017 version of SHIPS modified to use DSST and DAVT was provided to NHC.

5) DSWR model was provided and tested on WCOSS for potential 2017 or 2018 quasi-prod production.

6) Updated database of DSST global and regional data from 1982 – 2017 in SHIPS format was provided to NHC

7) Re-derived EOHC global and regional datasets for 2005 - 2017 were provided to NHC

8) Updated NCODA-based climatology of DSST, OHC, MLD, D26, and D20 and all ocean variables included in the EOHC dataset was provided to NHC together with the software for creating and reading that climatology and adding climatological data to the SHIPS diagnostic files

9) Software for generating DSST and EOHC data in SHIPS format in real-time was provided to NHC and will be used to generate data for the operational 2018 versions of SHIPS and LGEM.

9) The possibility of including Decay SHIPS Wind Radii (DSWR) and MSLP estimates in operational Automated Tropical Cyclone Forecast System (ATCF) A-decks has been discussed with NHC points of contact (POCs). The implementation of DSWR in the operational A-decks for 2018 season will depend on the availability of NHC resources.

9) The possibility of implementing SHIPS with DAVT in the quasi-production version of SHIPS on WCOSS for 2018 seasons has been discussed with NHC POCs and NHC TSB staff. The implementation

of SHIPS with DAVT in the quasi-production for 2018 season will depend on the availability of NHC TSB resources.

-- Has the project been approved for testbed testing yet (if it's a testbed project)?

Testing of SHIPS with DAVT and DSWR for this project is planned for the experimental quasi-production version of the NHC Guidance Suite on WCOSS during 2018 season. The implementation of the new products in the quasi-production for 2018 season will depend on the availability of NHC TSB resources.

-- What was transitioned to NOAA?

The following software was transitioned to NOAA:

1) Some minor computer bugs in the SHIPS/LGEM/RII processing were identified in the course of this work, and were corrected in the 2016 operational version of the NHC guidance suite on WCOSS.

2) Software necessary for DSWR forecasts with updated coefficients were provided to NHC. The implementation of DSWR is planned (personal communication, Mark DeMaria) on quasi production for forecasting during the 2018 season, depending on the availability of NHC TSB resources

3) 2017 version of SHIPS model with the option to use both DSST and DAVT was provided to NHC. The new modifications will be implemented in the 2018 operational version of SHIPS and LGEM.

4) Updated database of DSST data (1982 - 2017) and newly derived EOHC data (2005 - 2017) were provided to NHC and will be included in the SHIPS developmental database

5) Updated climatology of DSST and ocean data, including IHC, D26, D20, and MLD climatology, as well as climatology of other variables included in the EOHC dataset and related software.

6) Software for generating real-time DSST and EOHC data that will be used to run 2018 operational versions of SHIPS, LGEM, and RII

7) DSWR model was transitioned to operations at JTWC in September, 2017

<u>Test Plans for USWRP-supported Testbed Projects</u>

I. *What **concepts/techniques** will be tested? What is the scope of testing (what will be tested, what won't be tested)?*

The following models will be tested:

- SHIPS/LGEM with DAVT assuming constant mixing depth
- SHIPS/LGEM with DAVT assuming variable mixing depth
- DSWR

II. ***How** will they be tested? What **tasks** (processes and procedures) and activities will be performed, what preparatory work has to happen to make it ready for testing, and what will occur during the experimental testing?*

1) Tasks that will be performed during testing at CIRA:

- run scripts to receive operational SHIPS diagnostic files in real-time

- run scripts to add DAVT to the operational diagnostic files
- run the models
- save the model output and make it available to NHC and JTWC via ftp

2) Preparatory work:
- complete retrospective runs using 2018 version of SHIPS/LGEM
- derive updated coefficients for different version of SHIPS

3) During the testing:
- monitor model performance
- conduct post-season verification

III. ***When** will it be tested? What are **schedules and milestones** for all tasks described in section II that need to occur leading up to testing, during testing, and after testing?*

1) When it will be tested:
- During the 2018 Atlantic and East Pacific Hurricane seasons

2) Schedules and Milestones:
- Complete retrospective runs of modified SHIPS/LGEM (Oct 2017 - June 2018)
- Coordinate with TSB staff to implement parallel runs on quasi-production on WCOSS or implement them at CIRA (Jun 2018 - Aug 2018)
- Complete post-season verification (Dec 2018 - Jan 2019)

IV. ***Where** will it be tested? Will it be done at the PI location or a NOAA location?*

1) If possible, the updated models will tested on quasi-production on WCOSS, depending on the availability of TSB resources.

2) If parallel runs of experimental SHIPS/LGEM and DSWR cannot be implemented on quasi-production, they will be implemented at CIRA.

V. *Who are the key **stakeholders** involved in testing (PIs, testbed support staff, testbed manager, forecasters, etc.)? Briefly what are their **roles and responsibilities**?*

Stakeholders and Roles:
- PIs: prepare model: provide code and data to NHC, conduct parallel runs at CIRA if needed
- TSB staff and JHT support staff: if possible, implement updated models on quasi-production on WCOSS. Evaluate the new products and provide feedback.
- JHT POCs: monitor the model performance and provide feedback to PIs

VI. *What **testing resources** will be needed from each participant (hardware, software, data flow, internet connectivity, office space, video teleconferencing, etc.), and who will provide them?*

- The updates models require resources similar to the operational versions. Existing hardware and software will be used for testing on quasi-production on WCOSS and/or at CIRA.

VII. *What are the **test goals, performance measures, and success criteria** that will need to be achieved at the end of testing to measure and demonstrate success and to advance Readiness Levels?*

1) Test goals:
- Evaluate the performance of the updated and new models
- Compare experimental parallel runs with operational runs
- Provide testing results to NHC and JTWC and respond to feedback

2) Performance measures:
- Model verification with the algorithms that are used to evaluate the performance of the operational models

3) Success criteria:
- Performance of the experimental models compared to the performance of the operational models

VIII. *How will testing* ***results*** *be documented? Describe what information will be included in the* ***test results final report****.*

Test results will be provided to NHC and JHT in the final project report and test results final report.
1) The documentation of the test results will include:
- the results of retrospective model verification
- the results of the post season verification of real-time runs.

2) The test results final report will include the result of the retrospective model verification. The post season verification cannot be completed until the end of the hurricane season, therefore these results might not be available in time to be included in the test results final report.

7. BUDGETARY INFORMATION

Is the project on budget? Much of the quantitative budget information is submitted separately in the Federal Financial Report. However, describe here any major budget anomalies or deviations from the original planned budget expenditure plan and why.

The project is on budget

8. PROJECT OUTCOMES

What are the outcomes of the award?

The improved version of the operational statistical-dynamical models for forecasting TC intensity is being developed. The new statistical dynamical model for forecasting TC wind radii has been developed.

Are performance measures defined in the proposal being achieved and to what extent?

The performance measures defined in the proposal (the milestones) are being achieved as planned.

9. REFERENCES

Knaff, J., C. Sampson, and G. Chirokova, 2017: A global statistical–dynamical tropical cyclone wind radii forecast scheme. *Wea. Forecasting*, **32**, 629–644, doi: 10.1175/WAF-D-16-0168.1.

Knaff, J. A., S. P. Longmore, and D. A. Molenar, 2014a: An Objective Satellite-Based Tropical Cyclone Size Climatology. *J. Climate*, **27**, 455–476. doi: http://dx.doi.org/10.1175/JCLI-D-13-00096.1

I.-I. Lin, P. Black, J. F. Price, C.-Y. Yang, S. S. Chen, C.-C. Lien, P. Harr, N.-H. Chi, C.-C. Wu and E. A. D'Asaro, 2013: An ocean coupling potential intensity index for tropical cyclones. *Geophysical Res. Letters*, **40**, 1878–1882. DOI: 10.1002/grl.50091

Price, J. F., 2009: Metrics of hurricane-ocean interaction: vertically-integrated or vertically-averaged ocean temperature. *Ocean Sci*., **5**, 351-368, doi:10.5194/os-5-351-2009.

Appendix B

NOAA READINESS LEVELS (RLs)

There are nine readiness levels defined in NOAA Administrative Order 216-105A as follows:

A. Research

RL 1: Basic research: experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. Basic research can be oriented or directed towards some broad fields of general interest, with the explicit goal of a range of future applications;

RL 2: Applied research: original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective. Applied research is undertaken either to determine possible uses for the findings of basic research or to determine new methods or ways of achieving specific and predetermined objectives.

B. Development

RL 3: Proof-of-concept for system, process, product, service or tool; this can be considered an early phase of experimental development; feasibility studies may be included;

RL 4: Successful evaluation of system, subsystem, process, product, service or tool in laboratory or other experimental environment; this can be considered an intermediate phase of development;

RL 5: Successful evaluation of system, subsystem process, product, service or tool in relevant environment through testing and prototyping; this can be considered the final stage of development before demonstration begins;

C. Demonstration

RL 6: Demonstration of prototype system, subsystem, process, product, service or tool in relevant or test environment (potential demonstrated);

RL 7: Prototype system, process, product, service or tool demonstrated in an operational or other relevant environment (functionality demonstrated in near-real world environment; subsystem components fully integrated into system);

RL 8: Finalized system, process, product, service or tool tested, and shown to operate or function as expected within user's environment; user training and documentation completed; operator or user approval given;

D. Deployment

RL 9: System, process, product, service or tool deployed and used routinely.

NOAA/JHT

Federal Grant Number Assigned by Agency: NA17OAR4590138

Title: Improvements to Operational Statistical Tropical Cyclone Intensity Forecast Models

Using Wind Structure and Eye Predictors

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Submission Date: 03/02/2018

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Award Period: 8/1/17-7/31/19

Reporting Period End Date: 1/31/18

Report Term or Frequency: semi-annual

Final Annual Report? No

1. ACCOMPLISHMENTS

Summary of the project accomplishments for the 4 main project tasks:

Tasks 1 and 2: Add a tropical cyclone (TC) wind structure based predictor or combination of predictors to Statistical Hurricane Intensity Prediction Scheme (SHIPS), the Logistic Growth Equation Model (LGEM), the multi-lead time probabilistic Rapid Intensification Index (MLTRII), and the global Rapid Intensification Index (GRII). These changes were designed to improve SHIPS, LGEM, and RIIs forecast performance based on the recent research that demonstrated that both TC intensification rate and the likelihood of undergoing Rapid Intensification (RI) are related to storm size, with smaller storms found to be more likely to intensify, and that the wind structure parameters, such as the radius of maximum winds (RMW), the average radius of gale-force winds (R34), and the objective size parameter (R5, Knaff et al, 2014) are strongly negatively correlated with the rate of change of intensity. The software for creating databases of RMW, R34, and corresponding climatological parameters was developed. The full developmental database of R34 and RMW was created for the years 1982-2017, which is the full length of the developmental database sample used for SHIPS, LGEM, and RIIs development. The software for performing dependent sample testing for SHIPS, LGEM, GRII, and MLTRII was modified to use new size-based predictors, including RMW, R34, R5, and storm latitude. Depended sample testing demonstrated that the use of a combination of data and climatology for size predictors produces results similar or better that use of data only for the cases when data are available. In addition, the option to use size-based predictors was added to the models, and retrospective model runs with the new predictors are in progress.

Tasks 3 and 4: Add a predictor or a group of predictors based on the probability of the eye existence and the code to calculate that probability to SHIPS/LGEM, MLTRII, and GRII. These changes were designed to use the automated objective eye-detection algorithm (EDA) recently developed at CIRA (Knaff and DeMaria, 2017) to improve SHIPS, LGEM, and RIIs forecast performance based on multiple studies that demonstrated that the appearance of the eye is strongly related to storm intensity and often indicates the beginning of RI (Weatherford and Gray 1988, Willoughby 1990, Vigh 2012). The current intensity combined with the intensification trend over the last 12 hours was shown to be one of the most important predictors for TC intensity (Fitzpatrick, 1997). In operations, eye-detection is currently performed manually by forecasters. The EDA allows to automate that procedure making it possible to use eye-existence based predictors for statistical intensity forecast models. Work on these tasks is scheduled to begin in May, 2018. However, some preliminary tests were run using 2017 EDA data and work has started on adapting EDA to work with GOES-16 data.

What were the major proposed **goals, objectives, and tasks** of this project, and what was accomplished this period under each task? (a table of planned vs. actuals is recommended as a function of each task identified in the funded proposal)

Note: Funding for this project arrived 1 month later than expected. All the millstones were shifted accordingly, which was approved by JHT. All milestone dates below are adjusted dates.

Goals, Objectives, Tasks	Planned: Aug 2016 – Aug 2017	Actual: Sep 2016 – Aug 2017
Create updated database of wind structure predictors	Create SHIPS developmental database of R34, RMW, and R5 predictors and corresponding climatology	The databases of R34, RMW, and R5 and corresponding climatologies were created for the years 1982 - 2017, and added to the SHIPS developmental database.
Complete SHIPS dependent sample testing and RII statistical testing to determine the best combination of wind structure parameters to use as new predictors	Perform dependent sample testing of SHIPS/LGEM, and RIIs to determine the best combination of wind structure predictors.	The preliminary dependent sample testing was completed. The testing included the use of both data and climatology (when data are not available). The improvement is similar or better compared to the preliminary testing that used a limited dataset.
Modify SHIPS and both RIIs to use wind structure predictors	Modify SHIPS and both RIIs to use wind structure predictors	SHIPS, LGEM, and RIIs were updated to use additional wind structure predictors.

Are the proposed project tasks **on schedule**? What is the cumulative percent toward completion of each task and the due dates? (table recommended)

Task	Cumulative percent towards completion and due dates	Due Date	On schedule (yes/no)
Create updated database of wind structure predictors	100%	Nov 2017	Yes
Complete SHIPS dependent sample testing and RII statistical testing to determine the best combination of wind structure parameters to use as new predictors	90%	Jan 2018	Yes. The final combination of predictors will be determined based on the results of retrospective runs.
Modify SHIPS and both RIIs to use wind structure predictors	90%	Feb 2017	Yes. Additional adjustment might be required based on the results of retrospective and real-time runs

What were the major completed **milestones** this period, and how do they compare to your proposed milestones? (planned vs. actuals table recommended)

Milestone	Completed vs proposed
Create updated database of wind structure predictors	Completed as proposed
Complete SHIPS dependent sample testing and RII statistical testing to determine the best combination of wind structure parameters to use as new predictors	Completed as proposed
Modify SHIPS and both RIIs to use wind structure predictors	Completed as proposed

Detailed description of the work completed for each milestone since the last report is presented below.

Milestone: Create updated database of wind structure predictors. The updated databases of RMW, R34A, and R5 were created and added to a full SHIPS developmental database for the years 1982 - 2017. The operational SHIPS developmental database is available at http://rammb.cira.colostate.edu/research/tropical_cyclones/ships/developmental_data.asp. The R34 and RMW wind data were obtained from the extended best track (http://rammb.cira.colostate.edu/research/tropical_cyclones/tc_extended_best_track_dataset/, Demuth et al, 2006) and from the ATCF a- and b-deck for data after 1990 for RMW (after 2002 for R34). Updated readers for the ATCF data were developed to complete these tasks. The statistical models require input at all synoptic times, however, data are not available at all times. For example, RMW is not available prior to 1987 for the Atlantic (prior to 2000 for east Pacific), and R34 data are not available prior to 1988 for the Atlantic (prior to 2001 for eat Pacific). Thus, a climatology is required for running the models. The climatology of RMW as a function of maximum wind speed and latitude was created following Willougby and Rahn (2004), who found that RMW can be approximated as

$$RMW = 51.6\ \exp(-0.0223Vmax + 0.0.281\ \varphi),$$

where Vmax is the maximum intensity and φ is the latitude. The climatology for the R34 was derived based on Knaff et all (2007) using the modified Rankine vortex, assuming there are no asymmetries:

$$V(r) = Vmax\left(\frac{r^m}{r}\right)^x,$$

where Vmax is the maximum wind speed and m and x can be determined as function of Vmax and latitude as described in Knaff et al (2007). The R5, the normalized R5, and the corresponding climatological values were determined as described in Knaff et al 2015.

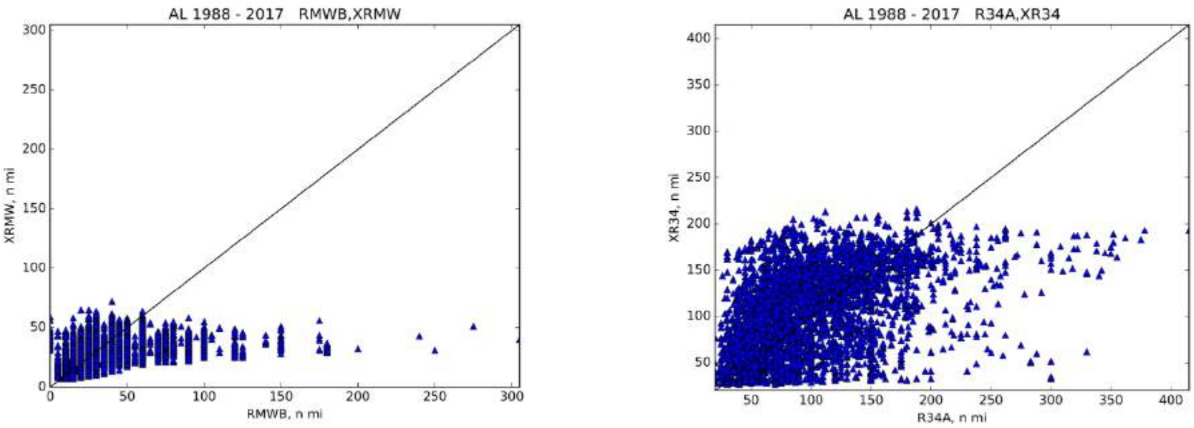

Figure 1. Left: scatter plot of climatological RMW (XRMW) vs RMW from ATCF and extended best track. Right: the same for R34.

Complete SHIPS dependent sample testing and RII statistical testing to determine the best combination of wind structure parameters to use as new predictors.

The software for performing dependent sample testing for SHIPS, LGEM, GRII, and MLTRII was modified to use new size-based predictors, including RMW, R34, R5, and storm latitude. Depended sample testing demonstrated that the use of a combination of data and climatology for size predictors produces results similar or better that use of data only for the cases when data are available. Figure 2 shows the dependent sample testing results for SHIPS for the Atlantic. For these test a full data sample for the years 1982 - 2017 was used, and climatological values were used for the cases when data are not available. The test results show almost one percent improvement in forecast for the forecast lead time of 18 hours. That is a significant improvement compared to preliminary tests that were performed using a limited subset of cases. The most improvement is observed when using a combination of R34, R5, and storm latitude as new predictors. The final combination of new predictors will be determined based on the results of retrospective runs.

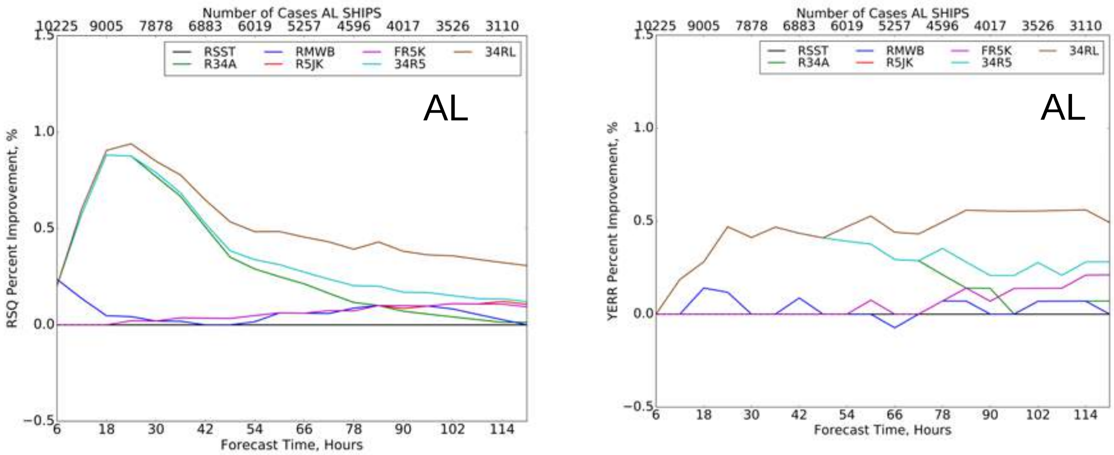

Figure 2. Results of SHIPS dependent sample testing with using size predictors. Left: percent improvement in R^2. Right: percent improvement in Yerr. Predictors shown: RSST - baseline using operation model; R34A - non-zero averaged R34; RMWB - RMW from ATCF best track; R5JK - objective TC size parameter R5l FR5K - normalized objective TC size parameter FR5; 34R5 - both R35 and R5 added; 35RL - 3 predcitors added, R34, R5, and storm latitude. All predictors use climatological values when data are not available.

Milestone: Modify SHIPS and both RIIs to use wind structure predictors. The option to use size-based predictors was added to the models. Additional adjustment to the code might be required based on the results of retrospective runs.

Milestone: Derive updated regression coefficients and complete retrospective SHIPS and RII runs with new structure predictors. Updated regression coefficients were derived for SHIPS and LGEM, and the retrospective model runs are currently in progress. This Milestone is scheduled to be completed in March, 2018.

Milestone: Develop operational version of the CIRA's EDA and incorporate it into SHIPS processing. In addition, the work to adapt the EDA to work with GOES-16 data has begun ahead of time.

What opportunities for training and professional development has the project provided?

People working on the project obtained increased knowledge and skills in the development of statistical models. Also, collaboration between CIRA and AOML on this project provides opportunities for professional development for people working on the project

How were the results disseminated to communities of interest?

1) The project results will be presented at the IHC in March 2018. Also, John Kaplan visited CIRA in September, 2017, and presented a talk "Statistical rapid intensity prediction: Implications of recent Model Results 2016 and 2017" at a CIRA seminar. The talk included some of preliminary results and future plans for this project. Additional details about the project were communicated to JHT points of contact, Dan Brown (NHC), Mark DeMaria (NHC), Robert Ballard (CPHC), Brian Strahl (JTWC) and Chris Landsea (NHC).

2) The project was discussed with JTWC POC, Brian Strahl by Kate Musgrave (CIRA) during her visit to JTWC in October, 2017

2) At later stages of the project updated software and databases will be provided to NHC, and test results will be provided to NHC, CPHC, and JTWC POCs.

What do you plan to do during the next reporting period to accomplish the goals and objectives?

During the next reporting period we plan to conduct retrospective runs of the experimental version of the SHIPS/LGEM and RIIs with size predictors. In addition, final adjustments and modifications to the code will be implemented based on the results of the retrospective runs. We will further work with JHT and NHC TSB staff to implement experimental versions of SHIPS/LGEM and RIIs on quasi-production on WCOSS for the 2018 season and/or will implement parallel runs at CIRA. In addition the EDA will be adapted to work with GOES-16 data and converted to Fortran.

2. PRODUCTS

What were the major completed **products or deliverables** this period, and how do they compare to your proposed deliverables? (planned vs. actuals table recommended)

Product/Deliverable	Actual
Updated database of size predictors and corresponding climatological values for the years 1982 - 2017.	Developed as planned. The updated 2018 version will be provided to NHC.

What has the project produced?
-publications, conference papers, and presentations*;

-technologies or techniques;

None

-inventions, patent applications, and/or licenses; and

None

-other products, such as data or databases, physical collections, audio or video products, software, models, educational aids or curricula, instruments or equipment, research material, interventions (e.g., clinical or educational), or new business creation.

- Database of TC-size predictors converted to SHIPS input format. The database includes both available data and climatology.
- Updated climatology of RMW, R34, and R5

*For **publications**, please include a full reference and digital object identifier (DOI; http://www.apastyle.org/learn/faqs/what-is-doi.aspx) and attach all publications and presentations on this project from this reporting period to the progress report, or include web links to on-line versions. Within your publications and presentations, please include language crediting the appropriate NOAA/OAR organization and program (e.g., NOAA/OAR/OWAQ and the U.S. Weather Research Program; or NOAA/OAR/NSSL and the VORTEX-SE program) for financially supporting your project. Suggested language is as follows:
"This material is based upon work supported by the U.S. Weather Research Program within NOAA/OAR Office of Weather and Air Quality under Grant No. XXXXXXX."

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on this project?

Galina Chirokova, John Knaff, John Kaplan

Has there been a change in the PD/PI(s) or senior/key personnel since the last reporting period?

No

What other organizations have been involved as partners? Have other collaborators or contacts been involved?

NHC points of contact have been involved. Also work for this project has been coordinated with NHC TSB branch.

4. IMPACT

What was the impact on the development of the principal discipline(s) of the project?

The project directly address the program priorities JHT-3 and JHT-1. Specifically, improved SHIPS and RIIs will provide a better guidance for TC intensity change including the onset, duration, and magnitude of RI events, and over-water weakening events (JHT-3). These intensity guidance techniques are routinely used operationally at NHC, CPHC, and JTWC to forecast TC intensity. In addition, the use of the EDA output as predictor in SHIPS and RIIs will provide improved capability to observe the TC and its environment to support forecaster analysis and model initialization (JHT-1). This work also addresses the NOAA goal for a Weather-Ready Nation. NOAA's Weather-Ready Nation is about *"building community resilience in the face of increasing vulnerability to extreme weather and water events. Record-breaking snowfall, cold temperatures, extended drought, high heat, severe flooding, violent tornadoes, and <u>massive hurricanes</u> have all combined to reach the greatest number of multi-billion-dollar weather disasters in the nation's history. The devastating impacts of extreme events can be reduced through improved readiness."*

What was the impact on other disciplines?
The results of this project should allow for improved operational TC intensity and structure forecasts that are important for other agencies and general public. Improvements in these capabilities may also lead to other high priority forecasts (e.g., storm surge watch/warnings, wave forecasts) and decisions (e.g., evacuations, ship routing).

What was the impact on the development of human resources?
Nothing to report

What was the impact on teaching and educational experiences?
Nothing to report

What was the impact on physical, institutional, and information resources that form infrastructure?
Nothing to report

What was the impact on technology transfer?
Methods developed at CIRA, if approved by the JHT, will transition to NHC, CPHC, and JTWC operations. Examples include the automated objective EDA.

What was the impact on society beyond science and technology?
The results of this project should allow for improved operational TC intensity forecasts that are important for other governmental agencies, industry, and general public. These efforts significantly contribute to NOAA's goal of a *Weather-Ready Nation*.

What percentage of the award's budget was spent in a foreign country(ies)?
None

5. CHANGES/PROBLEMS

Describe the following:

-Changes in approach and reasons for the change.
None
-Actual or anticipated problems or delays and actions or plans to resolve them.
None
-Changes that had a significant impact on expenditures.
None
-Change of primary performance site location from that originally proposed.
None

6. SPECIAL REPORTING REQUIREMENTS

Report on any special reporting requirements here (see previous instruction #3). If there are none, state so.

- Your assessment of the project's Readiness Level (current and at the start of project; see definitions in Appendix B)

Start of the project: RL3

Current: RL3-4

-If not already reported on in Section 1, please discuss:
-- Transition to operations activities

The transition to operations for this project is scheduled after the end of Year 2, in 2019, if accepted by NHC. The timing of the final transition will depend on the availability of NHC Technology and Science Branch (TSB) resources.

-- Summary of testbed-related collaborations, activities, and outcomes (if it's a testbed project)

1) Result and verification of the retrospective and real-time runs will be made available to JHT POCs when these are produced.

2) Updated software and databases will be provided to NHC toward the end of the Year 2 of the project.

3) The possibility of implementing real-time EDA processing in quasi-production on WCOSS for 2018 season has been discussed with NHC POCs and NHC TSB staff. The implementation of EDA in the quasi-production for 2018 season will depend on the availability of NHC TSB resources.

-- Has the project been approved for testbed testing yet (if it's a testbed project)?

Testing of the EDA in quasi-production at NHC might be implemented for 2018 season based on the availability of NHC TSB resources. Real-time runs of the updated models with size predictors will be tested at CIRA for the 2018 season. Additional details are provide in Testing Plan.

-- What was transitioned to NOAA?

The transition activities for this project are planned at the end of the Year 2 of the project, as described in Research to Operations Transition Plan.

Test Plans for USWRP-supported Testbed Projects. Test plan for this project is submitted as a separate document.

7. BUDGETARY INFORMATION

Is the project on budget? Much of the quantitative budget information is submitted separately in the Federal Financial Report. However, describe here any major budget anomalies or deviations from the original planned budget expenditure plan and why.

The project is on budget

8. PROJECT OUTCOMES

What are the outcomes of the award?

The improved versions of the operational statistical-dynamical models for forecasting TC intensity are being developed.

Are performance measures defined in the proposal being achieved and to what extent?

The performance measures defined in the proposal (the milestones) are being achieved as planned.

9. REFERENCES

Demuth, J., M. DeMaria, and J.A. Knaff, 2006: Improvement of advanced microwave sounder unit tropical cyclone intensity and size estimation algorithms. J. Appl. Meteor., 45, 1573-1581.)

Fitzpatrick, P. J., 1997: Understanding and forecasting tropical cyclone intensity change with the typhoon intensity prediction scheme (TIPS). *Wea. Forecasting*, **12**, 826-846.

Knaff, J.A. and R. DeMaria, 2017: Forecasting tropical cyclone eye formation and dissipation in infrared imagery. *Accepted by Wea. Forecasting*. The paper is available via Early Online Release at http://journals.ametsoc.org/doi/pdf/10.1175/WAF-D-17-0037.1.

Knaff, J. A., S. P. Longmore, D. A. Molenar, 2014: An objective satellite-based tropical cyclone size climatology. *J. Climate*, **27**, 455–476. doi: http://dx.doi.org/10.1175/JCLI-D-13-00096.1

Knaff, J. A., C. R. Sampson, M. DeMaria, T. P. Marchok, J. M. Gross, and C. J. McAdie, 2007: Statistical Tropical Cyclone Wind Radii Prediction Using Climatology and Persistence, Wea. Forecasting, 22(4), 781–791.

Vigh, J. L.**,** J. A. Knaff, and W. H. Schubert, 2012: A climatology of hurricane eye formation. *Mon. Wea. Rev.*, **140**, 1405-1426, doi:10.1175/MWR-D-11-00108.1.

Weatherford, C. L., and W. M. Gray, 1988: Typhoon structure as revealed by aircraft reconnaissance. Part II: Structural variability. *Mon. Wea. Rev.*, **116**, 1044–1056.

Willoughby, H. E., and M. E. Rahn, 2004: Parametric Representation of the Primary Hurricane Vortex. Part I: Observations and Evaluation of the Holland (1980) model. *MWR*, **132**, 3033–3048.

Willoughby, H. E., 1990: Temporal changes of the primary circulation in tropical cyclones. *J. Atmos. Sci.*, **47**, 242–264.

Appendix B

NOAA READINESS LEVELS (RLs)

There are nine readiness levels defined in NOAA Administrative Order 216-105A as follows:

A. Research

RL 1: Basic research: experimental or theoretical work undertaken primarily to acquire new knowledge of the underlying foundations of phenomena and observable facts, without any particular application or use in view. Basic research can be oriented or directed towards some broad fields of general interest, with the explicit goal of a range of future applications;

RL 2: Applied research: original investigation undertaken in order to acquire new knowledge. It is, however, directed primarily towards a specific, practical aim or objective. Applied research is undertaken either to determine possible uses for the findings of basic research or to determine new methods or ways of achieving specific and predetermined objectives.

B. Development

RL 3: Proof-of-concept for system, process, product, service or tool; this can be considered an early phase of experimental development; feasibility studies may be included;

RL 4: Successful evaluation of system, subsystem, process, product, service or tool in laboratory or other experimental environment; this can be considered an intermediate phase of development;

RL 5: Successful evaluation of system, subsystem process, product, service or tool in relevant environment through testing and prototyping; this can be considered the final stage of development before demonstration begins;

C. Demonstration

RL 6: Demonstration of prototype system, subsystem, process, product, service or tool in relevant or test environment (potential demonstrated);

RL 7: Prototype system, process, product, service or tool demonstrated in an operational or other relevant environment (functionality demonstrated in near-real world environment; subsystem components fully integrated into system);

RL 8: Finalized system, process, product, service or tool tested, and shown to operate or function as expected within user’s environment; user training and documentation completed; operator or user approval given;

D. Deployment

RL 9: System, process, product, service or tool deployed and used routinely.

PROJECT TITLE: Improving CarbonTracker Flux Estimates for North America using Carbonyl Sulfide (OCS)

PRINCIPAL INVESTIGATOR: Ian Baker

RESEARCH TEAM: Ian Baker

NOAA TECHNICAL CONTACT: Huilin Chen (project PI)

NOAA RESEARCH TEAM: Andrew Jacobson

PROJECT OBJECTIVES:
1--Develop and test mechanistic representations of carbonyl sulfide (OCS) within landsurface models.
2--Evaluate and quantify relationships between OCS flux and CO2 biophysics.
3--Exploit results from 1 and 2 to constrain continental-scale CO2 flux in a data-assimilation framework.

PROJECT ACCOMPLISHMENTS:

In 2016, the project received a no-cost extension to continue previous research. Our contribution to the project was to provide surface fluxes from the SiB4 model to project PI Chen, as well as provide support for their inversion analyses. We have done this. We have successfully completed our project goals. We continue to support PI Chen during analysis and publication of results.

In 2016, we continued support to PI Chen for inversions, and continued investigating issues pertaining to the flux of carbonyl sulfide (OCS) into and out of the soil.

As of October 2017 The main CSU contribution to this project has been completed. We have fulfilled our contracted objectives, which as stated in the original proposal are:

"Dr. Ian Baker will assist Dr. Huilin Chen with the development of the soil uptake map of OCS, and the set-up of the STILT-SiB inversion system. He will also support analyzing the CarbonTracker simulation results."

We delivered model code, in the form of the SiB4 model, to PI Huilin Chen. This model simulates the exchange of energy, water, momentum and traces gases (CO2 and OCS in this case) between the atmosphere and terrestrial biosphere. This model generates maps of ecosystem exchange of CO2 and OCS (vegetation and soil), which PI Chen has used in his inversion system. We assisted PI Chen with the STILT-SiB inversion system, particularly with code that allowed inline modification of SiB model parameters during the inversion process. We have participated in analysis of results. To date, we credit this project for support in one paper (Wang et al., 2016). PI Chen has obtained a one-year no-cost extension, and we are working with Dr. Chen in the preparation of additional manuscripts.

We are continuing our investigation into the processes that control OCS exchange between the atmosphere and terrestrial biosphere, and are searching for funding opportunities that can exploit what we have learned during this project.

In short, we delivered what we committed to do with respect to code and research. We spent the money allocated to us. We have published our results at conferences, workshops, and in the refereed literature. We're checking the box marked 'success' for this contract.

Below we summarize some research from the final year of the project.

[The 'Initial Inversion' section below is reproduced from the 2016 annual report. This section is a jumping-off point for research conducted in 2016-2017.]

Initial inversion

Huilin Chen has completed an initial inversion, the details of which I assume he described in his progress report. I will provide some interpretation of these initial inversion results. Figure 1 shows the observed, prior, and optimized OCS and CO2 concentrations. The prior CO2 value (Figure 1, bottom) is extremely close to the observation. This is not unexpected: The SiB crop treatment (Lokupitya et al., 2009) has demonstrated fidelity when compared to observations, as well as when compared to other models (Lokupitya et al., 2016). West Branch Iowa is in the center of the North American crop region.

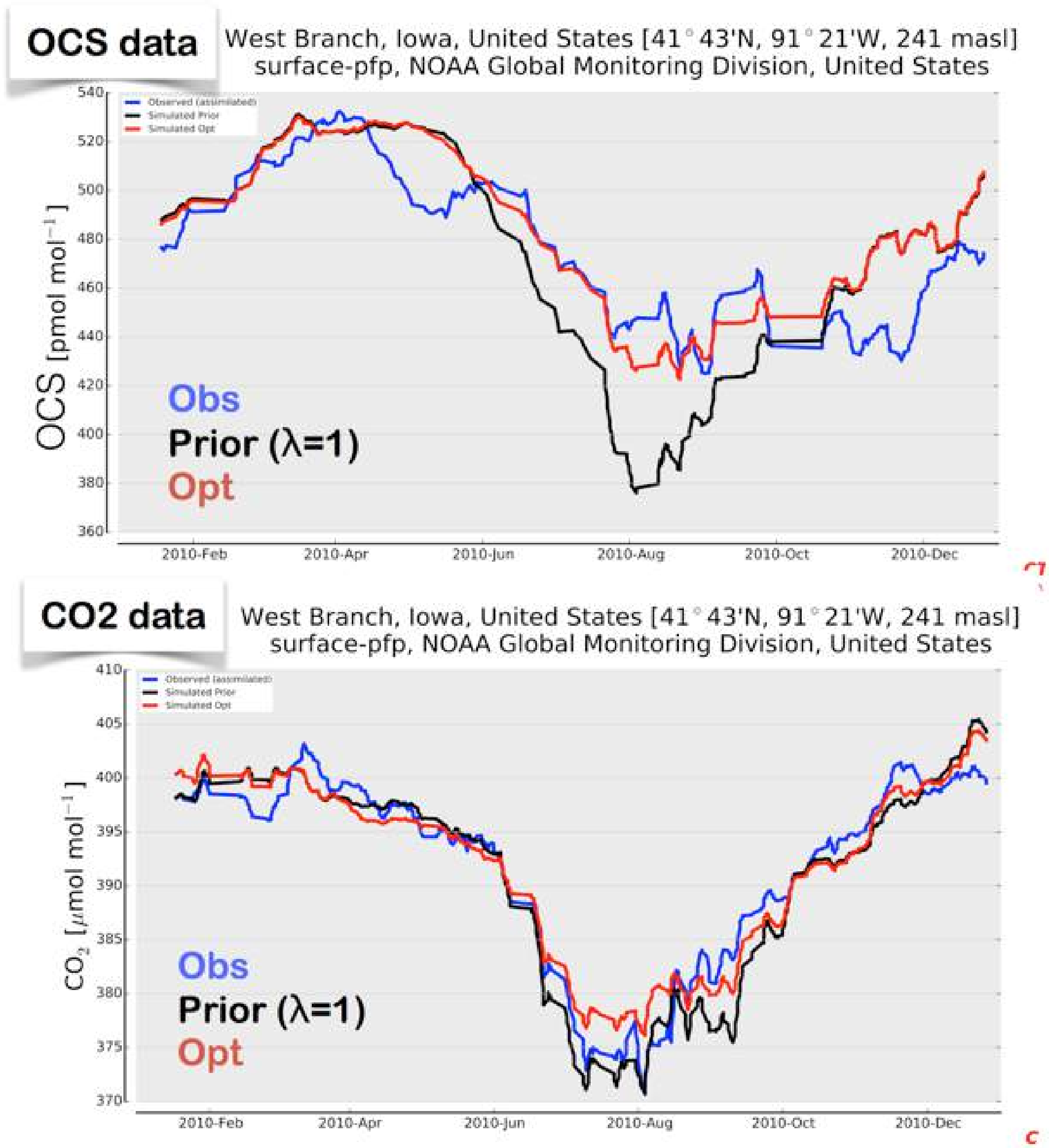

Figure 1. Annual cycle of observed (blue), prior (black) and optimized OCS concentration (top) and CO2 concentation (bottom), for West Branch, Iowa in 2010.

The OCS comparison in Figure 1 is troublesome. The SiB4 OCS prior shows much stronger uptake than observed; therefore, OCS uptake must be reduced to bring the simulation in to agreement with observations during optimization. Basically, the inversion wants to close plant stomates to reduce OCS uptake, and this has the effect of reducing GPP from a value that matches observed CO2 concentration very well to a value that does not uptake as much CO2. Previous studies that include the Lokupitya crop treatment have never demonstrated crop region uptake in excess of that observed (Corbin et al., 2010; Schuh et al., 2013). It is our experience that almost all crop models underestimate uptake in the North American corn/soy belt. But this inversion suggests a large overestimation of GPP in the region (Figure 2), in disagreement with all of our prior experience. We have advised PI Chen to compare SiB4 crop yield values from the SiB4 prior (and optimization) with observations as an evaluation.

One reason that we suspect for this discrepancy is the OCS soil term (research goal 3). In the initial model treatment, as we've mentioned before, OCS soil flux is always an uptake. A sensitivity test that Huilin Chen ran, where he decreased the soil uptake by 25%, made a difference but not a large one. However, a decrease in soil sink by 25% is not the same as changing the sign of the soil OCS flux term, as would happen if the soil was a source of OCS. Agricultural soils have been observed to be a source of OCS (Maseyk et al., 2013; Whelan and Rhew, 2014; Whelan et al., 2016) and this can happen in more 'natural' environments as well (Commane et al., 2015), and sometimes this source can be of a large magnitude. Our current thinking is that in the North American Midwest crop region there may be an efflux of OCS from the soil that is not represented in our model. This may explain some of the behavior that we are seeing in these inversion results. We are currently exploring alternative treatments soil OCS flux simulation, both in reviewing available literature and in discussions with collaborators.

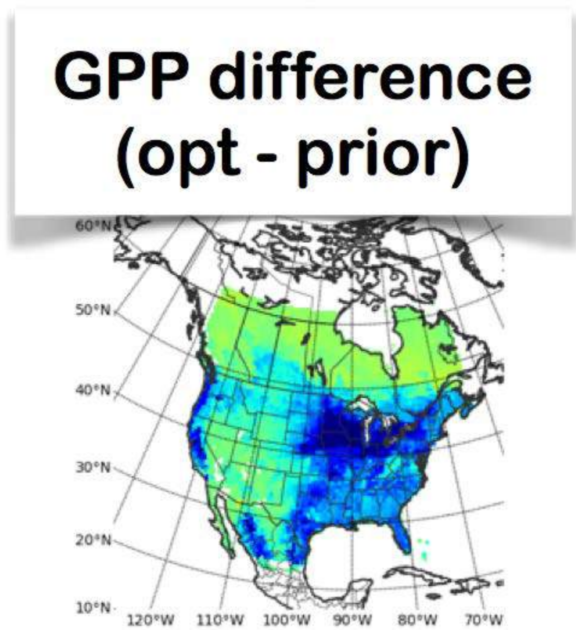

Figure 2. GPP difference betwen the prior value and optimized in the initial inversion. Dark blue shows region of decreased GPP.

[End of material reproduced from April 2016 Annual Report]

Soil OCS Flux

It is well-known that carbonyl sulfide (OCS) is a CO2 analog with value for constraining estimates of photosynthesis in terrestrial biosphere models (Campbell et al., 2008; Seibt et al., 2010; Berry et al., 2013). OCS is taken up during photosynthesis, but, unlike CO2, has not been thought to have concomitant efflux. The global OCS budget largely balances a large terrestrial sink term with large tropical oceanic sources (Montzka et al., 2007;Berry et al., 2013; Kuai et al., 2015). Whereas determining net CO2 flux requires finding the small difference between large gross uptake (photosynthesis) and efflux (respiration) terms, the idea has been that with OCS we are only looking at uptake in the terrestrial biosphere.

But as the initial inversion results shown above suggest, a simplified conceptual model of the global OCS budget may not hold up to more detailed regional investigation. Soil surface OCS flux is generally an uptake term, and an order of magnitude less than uptake of OCS through stomates. And yet, site-level observations have demonstrated that under specific circumstances the soil flux can not only be a source to the atmosphere rather than a sink, but it may even overwhelm the plant uptake, resulting in the terrestrial biosphere being a source of OCS to the atmosphere.

In the initial simulations of global OCS flux made by Berry et al. [2013], the soil flux was always into the soil, and amplitude was a function of moisture, temperature, and ecosystem productivity, on the premise that soil uptake of OCS was related to CO2 production. Previously, however, Melillo and Steudler [1989] had reported that nitrogen fertilization in hardwood forest resulted in efflux of OCS from soil, by a factor of 3 over the control, yet in a pine stand OCS ground flux was unaffected by fertilization. Billesbach et al. [2014] reported that eddy covariance OCS fluxes measured over a senescent (late summer) wheat field in Oklahoma were into the atmosphere and equal in amplitude to maximum growing season uptake, albeit with less diurnal variation. Commane et al. [2015] reported on a strong OCS environmental efflux during an extremely warm period of the growing season at a mixed forest in Massachussetts, in a interruption of growing season uptake. Recent studies have taken data from the Oklahoma site as well as several other agricultural sites in an attempt to relate soil OCS flux amplitude, as well as the sign of the flux signal (uptake/efflux) to moisture, temperature, and biotic and abiotic components (Maseyk et al., 2014; Whelan and Rhew, 2015; Whelan et al., 2016). However, at the time of this writing (October 2017), a consensus on the soil type or conditions that results in efflux of OCS has not been reached, nor has the community identified all factors that determine the amplitude of this efflux when it occurs.

At this point a couple of things are evident. 1) The initial inversions yield results that are completely inconsistent with a body of work, going back 10 years or more, associated with simulated CO2 flux in the North American crop belt. These initial results point to the simulation of soil OCS flux amplitude and sign, as being a possible reason for this mismatch. 2) Site-level studies of soil OCS flux are not mature enough to provide a strong constraint on the uncertainty evident from 1).

We have advised PI Chen at his team to run the inversion with soil OCS flux set to zero. This will not 'solve' the issue, but may provide insight. We expect that PI Chen and his team will report on the results.

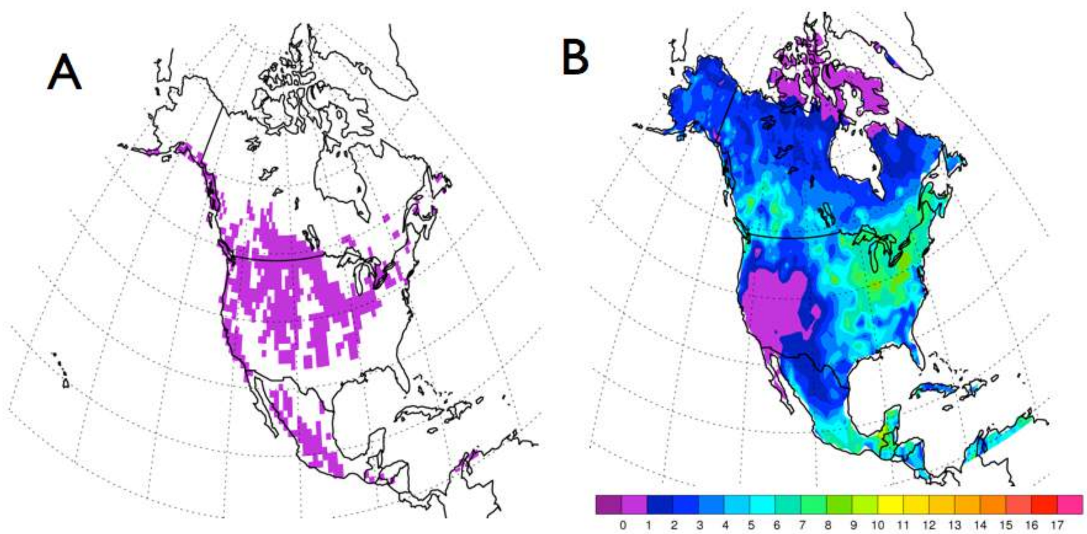

Figure 3. Pixels marked as 'crop' on a one-degree grid (A), and monthly-mean photosynthesis for July (B, in μmol m^{-2} sec^{-1}). Photosynthesis is identical between the 3 models.

We have begun some preliminary investigation of soil OCS flux behavior. Given the results of Melillo and Steudler (1989), which discussed heavily fertilized conditions, and Maseyk et al. (2014), Whelan and Rhew (2015) and Whelan et al. (2016), we will limit our experiment to gridcells identified as crop on the 1x1 degree grid (Figure 3, panel A). Using the results of Maseyk et al. (2014) and Whelan and Rhew (2015) and Whelan et al. (2016), we will employ two simple empirical relationships that depend either on near-surface soil temperature alone (Maseyk) or near-surface soil temperature and moisture (Whelan). These new treatments are different from the default SiB soil OCS flux parameterization in that OCS soil flux can be into or out of the soil depending on environmental conditions. [NOTE: For simplicity, we are running these soil OCS soil flux estimates in the 3rd version of SiB, SiB3, rather than the version used in the inversions, SiB4. These results are preliminary, and we do not expect them to be appreciably different between the two model versions.]

Figure 3 shows the pixels identified as crop (panel A), and North American GPP for July on the right. The GPP 'bullseye' in Figure 2 is actually to the east of the crop pixels in the Dakotas and north of the Iowa-Illinois corn/soy region, but it bears mentioning that the inversion incorporates transport and our surface flux simulations do not. Any patterns found in the simulations will need to be interpreted through a lens of surface-to-atmosphere exchange and transport prior to inverting fluxes.

The three simulations compared below are identical in every way EXCEPT their treatment of OCS soil flux. SiB3 has soil OCS uptake only, following Berry et al. (2013), and uptake is based on near-surface soil temperature and moisture, as well as CO2 respiration amplitude. The runs labeled 'Maseyk' employ an empirical treatment of OCS soil flux based on near-surface soil temperature, and the runs labeled 'Whelan' employ an empirical calculation of soil OCS flux based on near-surface soil temperature and moisture, as well as a partition of soil OCS flux into biotic and abiotic components. For simplicity, we will investigate one month, July 2013.

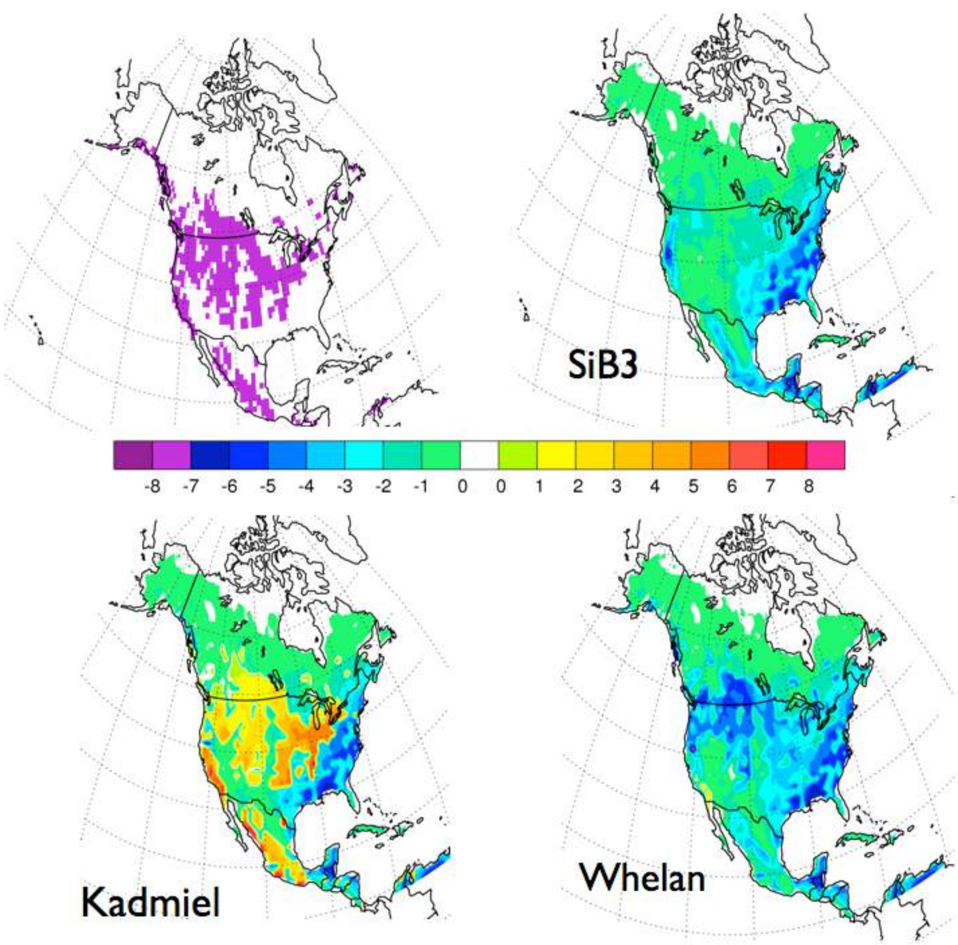

Figure 4. Monthly-averaged soil OCS flux for the 3 models, in pmol m^{-2} sec^{-1}, for July 2013. Negative values represent OCS being taken up by the soil, positive values represent efflux.

Soil uptake for July 2013 is shown in Figure 4. The SiB3 flux, as specified by following Berry et al. (2013), is negative or close to zero in all gridcells. The 'Whelan' model has OCS uptake by the soil for almost all gridcells in North America, except for a smattering of pixels in the Imperial Valley of California. Interestingly, the 'Whelan' soil OCS uptake exceeds the default (SiB3) for a large fraction of the crop pixels. Almost all crop regions north of 40° and west of the Mississippi River have stronger uptake than SiB3 in the Whelan treatment. The 'Kadmiel' treatment is a different story. Here, we see efflux in almost all crop pixels.

Soil OCS flux will be coupled with plant uptake to influence OCS concentration in the Canopy Air Space (CAS) in the model. Since we are running SiB3 here in 'offline' mode, the model is not interactive with the atmosphere. Therefore, OCS exchange between the boundary layer and the CAS will be controlled by turbulent exchange and an atmospheric OCS concentration, which is fixed globally during these 'decoupled' experiments. During transport modeling this flux is scaled by the ratio of atmospheric OCS concentration in each pixel of the transport model to the global value used in the offline simulations.

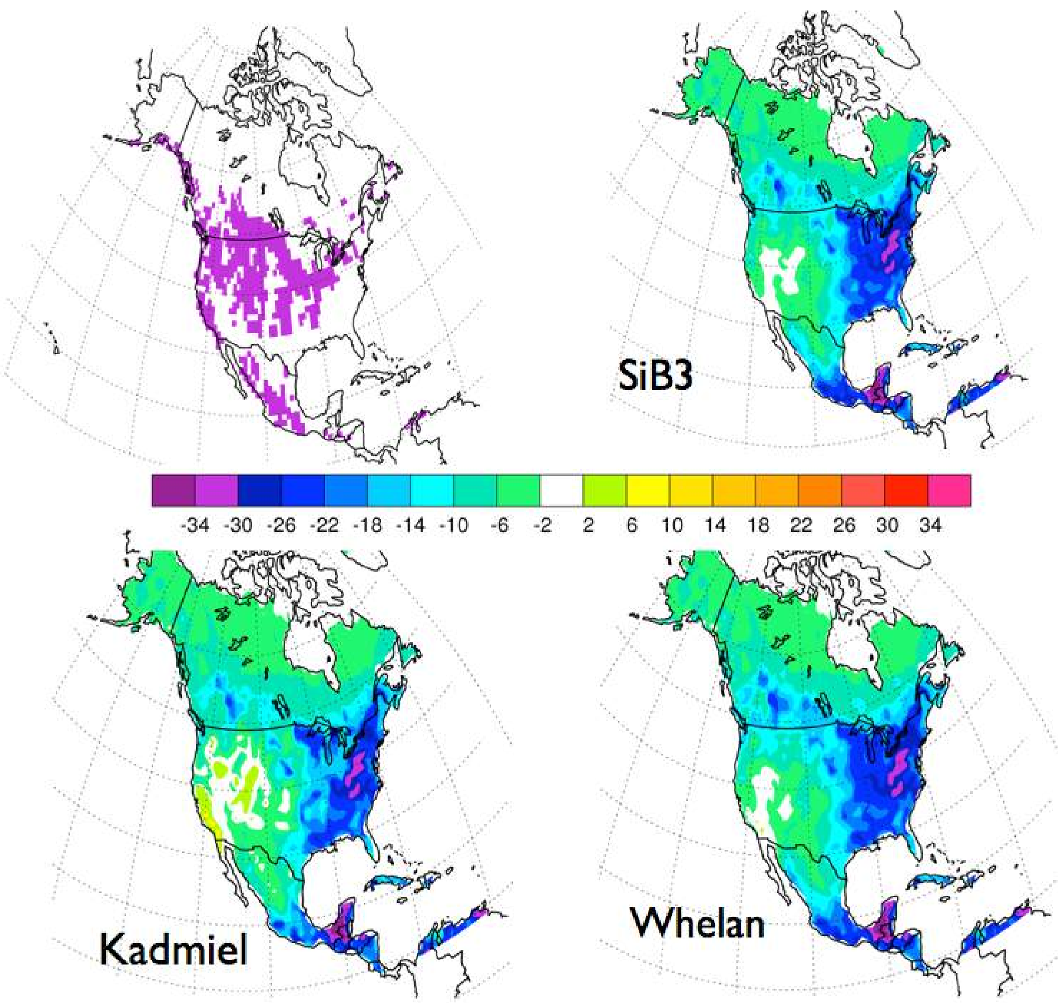

Figure 5. Monthly-averaged OCS exchange between atmosphere and canopy air for July 2013. Negative values represent OCS flux into the CAS, positive values are efflux to the atmosphere. Units are pmol m^{-2} sec^{-1}.

The OCS exchange between atmosphere-Canopy Air Space (CAS) is shown in Figure 5. This flux will be identical in all non-crop gridcells between the 3 models, which is easily seen in the Southeastern USA.

Positive values represent efflux to the atmosphere, negative represent uptake. There is not a significant difference between the models in the ‘bullseye’ region of the upper Midwest highlighted in Figure 2. The largest differences are in the desert Southwest and intermountain region, west of 100° west longitude, where both SiB3 and Whelan show very small uptake, and Kadmiel shows efflux of up to 6 pmol m^{-2} sec^{-1} in the monthly average.

It would be conjecture to try to describe the convolvement of these surface fluxes with atmospheric concentrations (which would influence the OCS gradient across the top of the canopy, and therefore the strength of the exchange) and circulation. However, it would seem unlikely that the changes from SiB3 to Whelan would make much difference; in fact, the Whelan simulation shows even higher OCS uptake than SiB3 in the Canadian prairie provinces, which might seem to be in the wrong direction with regard to the upper Midwest bullseye (Figure 2) which is downstream from this region. The effluxes in Kadmiel are quite remote from the region where the largest modification to model GPP was suggested.

Taken together, these simulations do not suggest that the OCS soil flux question has been ‘solved’. We find that the results of the initial inversion are inconsistent with our understanding of model and ecosystem behavior, and would likely remain inconsistent if either of the alternative treatments for soil OCS flux described above were used. However, we believe that these results may provide helpful information. Bottom-up site-level observations of OCS soil flux will likely never provide a conclusive picture of the mechanisms and processes that control amplitude, flux direction, and variability of this component. Top-down (inversion) studies, when coupled with available observations and bottom-up simulations, may be a means to shed light on this important element of the global OCS budget.

Comprehensive coupled studies that focus on OCS soil flux are beyond the scope of our commitment to this project, but do provide suggestions for future research proposals. We are working with PI Huilin Chen to prepare a manuscript that will describe what we have learned from the initial inversions.

Summary: The CSU contribution to this project was a commitment to provide model code that simulated surface CO2 and OCS fluxes on an hourly (or less) timestep. We provided SiB4 model code that simulates surface-atmosphere fluxes of energy, water, momentum and trace gases (CO2 and OCS). In addition to providing this code, we assisted PI Chen and his team in learning how to run the code, as well as setting up the means to modify model parameters interactively during the inversion process. Furthermore, we have been involved with interpretation of results and suggestions for further research directions during every step of the project lifetime. During the project, we have collaborated with researchers globally, as a means to improve our OCS (and CO2) ‘priors’ that are ingested into the inversion process. More realistic prior fluxes means that the inversion can expend its energy and resources on the fine-scale adjustments that will yield the most valuable results. CSU research associated with this project has contributed to paper published in the refereed literature, with more in preparation. During the project lifetime we have contributed or been lead presenter in over 10 presentations associated with this contract at conferences and professional workshops.

Publications:

Wang, Y., N.M. Deutscher, M. Palm, T. Warneke, J. Nothold, I. Baker, J. Berry, P. Suntharalingam, N. Jones, E. Mahieu, B. Lejeune, J.E. Campbell, A. Wolf, S. Kremser, 2016: Towards understanding the variability in biospheric CO2 fluxes: using FTIR spectrometry and a chemical transport model to investigate the sources and sinks of carbonyl sulfide and its link to CO2. Atmos. Chem. Phys. Discuss., 16, 2123-2138, doi:10.5194/acp-16-2123-2016.

Presentations:

Baker, I.T. and many coauthors, 2017: Incorporating OCS and SIF Observations into Carbon Cycle Models. Invited oral presentation, Keck Institute for Space Studies, Next-Generation Approach for Detecting Carbon-Climate Feedbacks Workshop, 18-22 September 2017.

Hilton, T.W., M.E. Whelan, A. Zumkehr, S. Kulkarni, J.A. Berry, I.T. Baker, S.A. Montzka, C. Sweeney, B.R. Miller, U. Seibt, S.J. Smith, T. Launois, S. Belviso, L. Bopp, M. Laine, J.E. Campbell, 2017: Carbonyl sulfide constrains regional GPP spatial placement and industrial era global GPP historical trends. Oral Presentation, 10th International Carbon Dioxide Conference, Interlaken, Switzerland, 21-25 August 2017.

Whelan, M., B.W. LaFranchi, R. Bambha, H.A. Michelsen, M.L. Fischer, H.D. Graven, I.T. Baker, T. Guilderson, J.E. Campbell, 2016: Improved Carbon Flux Observations over Urban Areas Using Carbonyl Sulfide (COS) to Differentiate Contributions from Biosphere. Oral Presentation, American Geophysical Union Fall Meeting, San Francisco CA, 12-16 December 2016.

Glatthor, Norbert, Michael Hpfner, Ian T. Baker, Joe Berry, Elliott Campbell, Stephan R. Kawa, Gisele Krysztofiak, Bjorn-Martin Sinnhuber, Gabriele Stiller, Jim Stinecipher, and Thomas von Clarmann, 2016: Poster presentation, European Geosciences Union General Assembly, Vienna Austria, 17-22 April 2016.

He, Wei, Huilin Chen, Ivar van der Velde, Arlyn Andrews, Colm Sweeney, Ian Baker, Weimin Ju, Ingrid van der Laan-Luijkx, Pieter Tans, and Wouter Peters, 2016: CarbonTracker-Lagrange: A model-data assimilation system for North American carbon flux estimates. Oral Presentation, European Geosciences Union General Assembly, Vienna Austria, 17-22 April 2016.

Kooijmans, Linda M.J. , Kadmiel Maseyk, Ulli Seibt, Timo Vesala, Ivan Mammarella, Ian T. Baker, Alessandro Franchin, Pasi Kolari, Wu Sun, Helmi Keskinen, Janne Levula, and Huilin Chen, 2016: Stomata-controlled nighttime COS fluxes in a boreal forest: implications for the use of COS as a GPP tracer. Oral Presentation, European Geosciences Union General Assembly, Vienna Austria, 17-22 April 2016.

Wang, Yuting, Julia Marshall, Mathias Palm, Nicholas Deutscher, Christian Roedenbeck, Thorsten Warneke, Justus Notholt, Ian Baker, Joe Berry, Parvadha Suntharalingam, Nicholas Jones, Emmanuel Mahieu, Bernard Lejeune, James Hannigan, Stephanie Conway, Kimberly Strong, Elliott Campbell, Adam Wolf, and Stefanie Kremser, 2016: Using NDACC column measurements of carbonyl sulfide to estimate its sources and sinks. Oral Presentation, European Geosciences Union General Assembly, Vienna Austria, 17-22 April 2016.

Papers cited in this document

Berry, J.A., A. Wolf, J.E. Campbell, I. Baker, N. Blake, D.Blake, A.S. Denning, S.R. Kawa, S.A. Montzka, U. Seibt, K. Stimler, D. Yakir, Z. Zhu, 2013: A coupled model of the global cycles of carbonyl sulfide and CO_2: A possible new window on the carbon cycle. J. Geophys. Res., doi:10.1002/jgrg.20068.

Campbell, J.E., G.R. Carmichael, T. Chai, M. Mena-Carrasco, Y. Tang, D.R. Blake, N.J. Blake, S.A. Vay, G.J. Collatz, I. Baker, J.A. Berry, S.A. Montzka, C. Sweeney, J.L. Schnoor, C.O. Stanier, 2008; Photosynthetic control of atmospheric carbonyl sulfide during the growing season. Science, 322, 1085-1088.

Corbin, K.D., A.S. Denning, E.Y. Lokupitya, A.E. Schuh, N.L. Miles, K.J. Davis, S. Richardson, I.T. Baker, 2010: Assessing the Impact of Crops on Regional CO2 Fluxes and Atmospheric Concentrations. Tellus, 62B, 521-532.j

Costa, M.H., M.C. Biajoli, L. Sanches, A.C.M. Malhado, L.R. Hutyra, H.R. da Rocha, R.G. Aguiar, A.C. de Araujo, 2010: Atmospheric versus vegetation controls of Amazonian tropical rain forest evapotranspiration: Are the wet and seasonally dry rain forests any different? J. Geophys. Res., 115, G04021, doi:10.1029/2009JG001179.

Kuai, L., J.R. Worden, J.E. Campbell, S.S. Kulawik, M. Lee, K.-F. Li, S.A. Montzka, J.A. Berry, I. Baker, S. Denning. R. Kawa, H. Bian, K. Bowman, J. Liu, Y.L. Yung, 2015: Estimate of Carbonyl Sulfide Tropical Oceanic Surface Fluxes using Aura Tropospheric Emission Spectrometer Observations. J. Geophys.

Res., 120(20), 11012-11023, doi:10.1002/2015JD023493.

Lokupitya E., Denning, S., Paustian, K., Baker, I., Schaefer, K., Verma, S., Meyers, T., Bernacchi, C. J., Suyker, A., and Fischer, M.: Incorporation of crop phenology in Simple Biosphere Model (SiBcrop) to improve land-atmosphere carbon exchanges from croplands, Biogeosciences, 6, 969-986, 2009.

Maseyk, K., J.A. Berry, D. Billesbach, J.E. Campbell, M.S. Torn, M. Zahniser, U. Seibt, 2013: Sources and sinks of carbonyl sulfide in an agricultural field in the southern great plains. Proc. Nat. Acad. Sci., www.pnas.org/cgi/doi/10.1073/pnas.1319132111.

Melillo, J.M. and Steudler, P.A., 1989; The effect of nitrogen fertilization on the COS and CS2 emissions from temperature forest soils. Journal of Atmospheric Chemistry, 9:411-417.

Montzka, S.A., P. Calvert, B.D. Hall, J.W. Elkins, T.J. Conway, P.P. Tans, C. Sweeney, 2007: On the global distribution, seasonality, and budget of atmospheric carbonyl sulfide (COS) and some similarities to CO_2, J. Geophys. Res., 112, D09302, doi:10.1029/2006JD007665.

Schuh, A.E., T. Lauvaux, T.O. West, A.S. Denning, K.J. Davis, N. Miles, S. Richardson, M. Uliasz, E. Lokupitya, D. Cooley, A. Andrews, S. Ogle, 2013: Evaluating atmospheric CO2 inversions at multiple scales over a highly inventoried agricultural landscape. Glob. Change Biol., 19, 1424-1439, doi:10.1111/gcb.12141.

Seibt, U., J. Kesselmeier, L. Sandoval-Soto, U. Kuhn, J.A. Berry, 2010: A kinetic analysis of leaf u ptake of COS and its relation to transpiration, photosynthesis, and carbon isotope fraction. Biogeosciences, 7, 333–341, 2010 www.biogeosciences.net/7/333/2010/.

Whelan, M.E. and Rhew, R.C., 2014: Carbonyl sulfide produced by abiotic thermal and hotodegratation of soil organic matter from wheat field substrate. J. Geophys. Res. Biogeosci., 120, 54–62, doi:10.1002/2014JG002661.

Whelan, M.E., T.W. Hilton, J.A. Berry, M. Berkelhammer, A.R. Desai, J.E. Campbell, 2016: Carbonyl sulfide exchange in soils for better estimates of ecosystem carbon uptake. Atmos. Chem. Phys., 16, 3711–3726, 2016 www.atmos-chem-phys.net/16/3711/2016/ doi:10.5194/acp-16-3711-2016.

COVER PAGE

Federal Agency and Organization Element to Which the Report is Submitted: NOAA/OAR/OWAQ

Federal Grant Number Assigned by Agency: NA16OAR4590238

Project Title: Improving probabilistic forecasts of extreme rainfall through intelligent processing of high-resolution ensemble predictions

Project Director/Principal Investigator (PD/PI): Russ Schumacher, Associate Professor, Department of Atmospheric Science, Colorado State University. Email: russ.schumacher@colostate.edu; phone: 970.491.8084

Submission Date: 30 October 2017

Recipient Organization: Colorado State University/Cooperative Institute for Research in the Atmosphere, Fort Collins, Colorado

Project/Grant Period (Start Date, End Date): 10/01/2016 - 09/30/2018

Reporting Period End Date: 9/30/2017

Report Term or Frequency (annual, semi-annual, quarterly, other): semi-annual

Final Annual Report? No

1. ACCOMPLISHMENTS

What were the major proposed goals, objectives, and tasks of this project, and what was accomplished this period under each task?

Are the proposed project tasks on schedule? What is the cumulative percent toward completion of each task and the due dates? (table recommended)

What were the major completed milestones this period, and how do they compare to your proposed milestones? (planned vs. actuals table recommended)

As outlined in the original proposal, the specific objectives of this project are as follows:

- **Using this forecast system, identify the ensemble membership that optimizes the skill and reliability of probabilistic forecasts of extreme local rainfall.** Some of this research has already been conducted and is outlined in greater detail below. This support will allow for continued fine-tuning of this analysis for different models and regions of the US.
- **Evaluate a prototype of this forecast system in the Flash Flood and Intense Rainfall (FFaIR) experiment and in an operational environment at the Weather Prediction Center (WPC).** FFaIR allows for robust evaluation of a forecast system by forecasters and researchers in a realistic real-time environment. Based on this evaluation, the system will be improved and prepared for evaluation in WPC operations.
- **Implement an operational version of this forecast system at WPC.** Assuming the evaluations are successful, we will work with WPC to implement an operational version of the forecast system after incorporating relevant feedback and suggestions.

The proposed work plan for tasks through the end of the reporting period is reproduced from the original proposal in the table below, and the current status of these tasks is given in the right-hand column.

Time	**Tasks and milestones**	**Accomplishments/completion**
Months 1-8 (Oct 2016-May 2017)	Prepare the forecast system for formal evaluation in the FFaIR experiment in the summer of 2017; fine-tune the code; work with HMT/WPC staff to provide real-time forecast files	**complete**
Months 9-10 (June-July 2017)	Participate in FFaIR, including evaluation of the forecast data	**complete**

Months 11-18 (August 2017-Jan 2018)	Make use of the feedback from FFaIR to make necessary improvements to the forecast system	**Ongoing (~50% complete)**

The first half of this reporting period primarily involved preparing our forecast products for the FFaIR experiment. This involved establishing a configuration of the models that would be used during FFaIR (including choices of smoothing, etc.), producing output files in a suitable format for computers at WPC/HMT to process, and routinely making those files available to FFaIR staff. These tasks were completed well ahead of the beginning of FFaIR.

Then, the primary work during this reporting period was our participation in FFaIR and the evaluation of our forecast products. The primary forecast tool that was evaluated during FFaIR was a machine-learning based system for highlighting areas of potential extreme precipitation on days 2 and 3 (i.e., 36-60 and 60-84 hour forecasts). This method requires a historical record of at least a few years, and as such the inputs to this forecast system at present are the global Reforecast-2 dataset (GEFS-R; Hamill et al. 2013), which has forecasts from a fixed version of the GFS model going back to 1985. This product was evaluated as a potential 'first-guess' product for WPC forecasters when preparing their excessive rainfall outlooks (EROs) for days 2 and 3.

Each day during FFaIR, day 2 and 3 experimental EROs were produced by the participants (including forecasters and researchers), and one of the primary tools that was used as guidance for these outlooks was our machine-learning 'first guess' product (Fig. 1). For its first quasi-operational test, the forecast product performed very well – it generally provided useful guidance on days 2 and 3, and also highlighted regions with potential for excessive rainfall that may have otherwise gone unnoticed. Feedback from FFaIR participants suggested that the forecasters really like the product, as it fills an existing gap (plenty of individual model QPFs, but not much post-processed output, nor products focused specifically on excessive rainfall. There were issues with 'overforecasting' in a couple specific regions, particularly New Mexico; possible methods for addressing these issues are being tested now and will be in place prior to next year's FFaIR.

In the 2017 FFaIR final report (http://www.wpc.ncep.noaa.gov/hmt/2017_FFaIR_final_report.pdf), the feedback regarding the product was very favorable, with a summary statement of ""The **CSU Machine-Learning First Guess field** for the ERO showed great potential and was scored well by participants. It is recommended that the CSU developers work to reduce recurring biases and continue to refine the tool and reintroduce it into the testbed next year for further evaluation."

Based on this feedback, we have developed a strategy to address the concerns leading up to FFaIR in 2018. We are currently testing some methods to alleviate the frequent over-forecasting in specific areas (e.g., New Mexico). Greg Herman will also visit WPC in January or February 2018 to begin the process of transitioning code to the WPC “quasi-operational” computers, as a first step to potential future transition of the code to operations.

What opportunities for training and professional development has the project provided?

The project has provided invaluable training and professional development experience for graduate student Greg Herman. He has been the primary developer of these forecast systems, and has worked to prepare them in a manner that they can be tested for operational use. At the end of this project, he will be very well-prepared to apply his training and expertise to operational forecast problems.

How were the results disseminated to communities of interest?

Greg Herman presented his results at the AMS 30th Conference on Climate Variability and Change, 24th Conference on Probability and Statistics, and 16th Conference on Artificial Intelligence in Baltimore, July 2017.

During the two separate weeks that they attended the FFaIR experiment, Russ Schumacher and Greg Herman gave presentations at NCEP on various aspects of this research.

A manuscript describing the forecast system and its performance was submitted to *Monthly Weather Review* in August 2017. It was returned for major revisions, which we are currently working to address.

Herman, G.R., and R.S. Schumacher, 2017: Money Doesn't Grow on Trees, But Forecasts Do: Forecasting Extreme Precipitation with Random Forests. Submitted to *Mon. Wea. Rev.*, August 2017.

We have multiple presentations on this work scheduled at the AMS annual meeting in January 2018.

Our work on this project was featured in a story on Denver’s 9News (NBC affiliate): http://www.9news.com/weather/weather-colorado/new-flash-flood-model-built-out-at-csu/460300898

What do you plan to do during the next reporting period to accomplish the goals and objectives?

The primary task for the next reporting period will be addressing the feedback on our forecast products that came from the 2017 FFaIR, to make improvements to the product for 2018. We will also begin taking steps toward transitioning the code to quasi-operational systems.

2. PRODUCTS

What were the major completed products or deliverables this period, and how do they compare to your proposed deliverables? (planned vs. actuals table recommended)

Proposed deliverable	**Status**
Gridded output of the probabilistic forecasts for WPC/HMT staff to obtain and test in FFaIR computing environment	Complete
Journal article describing forecast system	Submitted; a second will be submitted in October 2017
Operational version of forecast system	Will not be complete until after FFaIR testing and evaluation
Final report	To be submitted at end of project

What has the project produced?

Real-time web graphics of the two forecast systems:
http://schumacher.atmos.colostate.edu/gherman/expcp.php
http://schumacher.atmos.colostate.edu/gherman/expcp_ml.php

Gridded forecast files that are being disseminated to HMT/WPC.

See also the conference presentations and manuscript listed above.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on this project?

PI Russ Schumacher, graduate research assistant Greg Herman, and CSU computer systems support staff.

Has there been a change in the PD/PI(s) or senior/key personnel since the last reporting period?

No changes.

What other organizations have been involved as partners? Have other collaborators or contacts been involved?

HMT/WPC partners, including Sarah Perfater, Jim Nelson, Diana Stovern, and Ben Albright.

4. IMPACT

What was the impact on the development of the principal discipline(s) of the project?

This project applies new methods for probabilistic prediction of extreme rainfall into an operational forecast setting. It has the potential to improve operational forecasts of heavy precipitation and flash flooding.

What was the impact on other disciplines?

Possible impacts on other disciplines are not yet clear.

What was the impact on the development of human resources?

The project is providing substantial training to a graduate student who is pioneering forecasting methods. This training will be very valuable as he completes his PhD and enters the workforce.

What was the impact on teaching and educational experiences?

The project is providing valuable education and training to a graduate student in atmospheric science.

What was the impact on physical, institutional, and information resources that form infrastructure?

The project has the potential to transition a new forecasting method into WPC operations.

What was the impact on technology transfer?

The project has the potential to transfer new methods and software into WPC operations.

What was the impact on society beyond science and technology?

This project may ultimately yield improved forecasts of extreme precipitation and flash flooding, which could have many benefits to society in terms of mitigating flood impacts.

What percentage of the award's budget was spent in a foreign country(ies)?

0%

5. CHANGES/PROBLEMS

Describe the following:

-Changes in approach and reasons for the change.
-Actual or anticipated problems or delays and actions or plans to resolve them.
-Changes that had a significant impact on expenditures.
-Change of primary performance site location from that originally proposed.

There have been no substantial changes or problems during this reporting period.

6. SPECIAL REPORTING REQUIREMENTS

- Your assessment of the project's Readiness Level (current and at the start of project; see definitions in Appendix B)
- Transition to operations activities
- Summary of testbed-related collaborations, activities, and outcomes (if it's a testbed project)
- Has the project been approved for testbed testing yet (if it's a testbed project)?
- What was transitioned to NOAA?

At the start of the project, we estimated this forecast system to be at Readiness Level 5, as it was nearly ready for demonstration. It is now at RL6 after the demonstration at FFaIR in June-July 2017. We expect the project to be at either RL7 or 8 by the end of the project. We expect to demonstrate the improved product at FFaIR in 2018.

The primary potential roadblock to operational transition is the fact that the GEFS/R forecasts used to drive our model are not themselves truly operational. But we are currently testing how model performance would be affected if the operational GEFS were used instead.

7. BUDGETARY INFORMATION

Is the project on budget? Much of the quantitative budget information is submitted separately in the Federal Financial Report. However, describe here any major budget anomalies or deviations from the original planned budget expenditure plan and why.

The project is just slightly under budget for the first year. No substantial anomalies or deviations are expected at this time.

8. PROJECT OUTCOMES

What are the outcomes of the award?

The outcomes of this award will include the development of new methods for probabilistic forecasts of extreme precipitation, and ultimately improved forecasts of this important weather hazard.

Are performance measures defined in the proposal being achieved and to what extent?

We believe that we are on track to achieve all of the goals outlined in the original proposal.

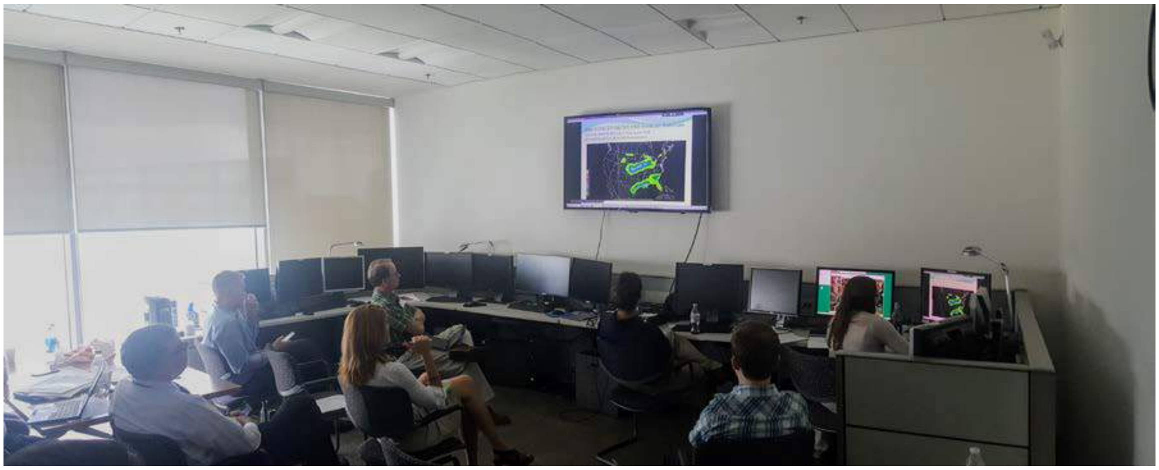

Fig. 1: Forecast briefing during FFaIR in June 2017, with the CSU machine learning product being featured in the discussion of the day-2 and 3 forecasts.

COVER PAGE

Federal Agency and Organization Element to Which the Report is Submitted:
NOAA/OAR/OWAQ

Federal Grant Number Assigned by Agency: NA16OAR4590215

Project Title: Improving understanding and prediction of concurrent tornadoes and flash floods with numerical models and VORTEX-SE observations

Project Director/Principal Investigator (PD/PI): Russ Schumacher, Associate Professor, Department of Atmospheric Science, Colorado State University. Email: russ.schumacher@colostate.edu; phone: 970.491.8084

Submission Date: 26 October 2017

Recipient Organization: Colorado State University/Cooperative Institute for Research in the Atmosphere, Fort Collins, Colorado

Project/Grant Period (Start Date, End Date): 10/01/2016 - 09/30/2018

Reporting Period End Date: 9/30/2017

Report Term or Frequency (annual, semi-annual, quarterly, other): semi-annual

Final Annual Report? No

1. ACCOMPLISHMENTS

What were the major proposed goals, objectives, and tasks of this project, and what was accomplished this period under each task?

Are the proposed project tasks on schedule? What is the cumulative percent toward completion of each task and the due dates? (table recommended)

What were the major completed milestones this period, and how do they compare to your proposed milestones? (planned vs. actuals table recommended)

As outlined in the original proposal, the specific objectives of this project are as follows:

- **Collect and analyze field observations of boundary-layer winds, thermodynamics, and precipitation structures in both tornado-only and TORFF situations to reveal important physical processes and environmental sensitivities.** We propose to collect radiosonde observations in coordination with other VORTEX-SE groups, and to assist in the collection and analysis of data from the Colorado State University Dual-Pol C-band Doppler Radar (referred to as CSU-POL). Furthermore, we will analyze other available VORTEX-SE observations from radars, profiling instruments, rain gauges, and disdrometers, to better understand these processes, particularly in TORFF situations in the southeast.
- **Use case-study and idealized numerical modeling experiments to quantify the influence of boundary-layer wind shear and thermodynamics on rainfall production in supercell storms and vortices embedded in convective lines.** We hypothesize that very strong low-level wind shear in moist, but relatively stable, low-level conditions are optimal for producing extreme rainfall rates in addition to being favorable for tornadoes. We will continue to use operational observations and analyses, along with high-resolution numerical model experiments, to test this hypothesis and to reveal important sensitivities.
- **Continue analysis of the NWS warning process during multi-hazard events by documenting the unique challenges in these events.** Our current VORTEX-SE project has enabled the collection of a thorough and unique dataset on the warning process in multi-hazard situations, and further support will allow for the possibility of collecting additional observations and more detailed analysis of the existing dataset.

The proposed work plan for tasks through the end of the reporting period is reproduced from the original proposal in the table below, and the current status of these tasks is given in the right-hand column.

<u>**Time**</u>	<u>**Tasks and milestones**</u>	<u>**Accomplishments/completion**</u>
Months 1-3 (Oct-Dec 2016)	Begin numerical simulations of cases observed in 2016 VORTEX-SE campaign (as well as historical cases), continue analysis of idealized	**~90% complete**

	simulations in high-shear, high-moisture environments	
Months 4-5 (Jan-Feb 2017)	Prepare for 2017 field phase; assist in deployment of CSU-POL radar and CSU radiosonde system. Continue analysis of numerical simulations.	**Complete**
Months 6-8 (March-May 2017)	Collect data in 2017 field phase IOPs	**Complete**
Months 9-12 (June-Sept 2017)	Analyze observations collected in field phase; participate in processing and analysis of radar data	**Ongoing (~70% complete)**

There have been four primary efforts during the second six months of the project, falling under the categories of (1) analysis of TORFF events in the southeast; (2) idealized numerical simulations; (3) VORTEX-SE field research; and (4) investigation of cold-season tornadoes in the southeast. These aspects have primarily been led by PI Schumacher and graduate students Erik Nielsen and Sam Childs.

For (1), we have extended the analysis conducted under our 2015 VORTEX-SE grant to further understand the threat from TORFF events in the southeast. First, we expanded the very strict definition of "TORFF" that was used in the Nielsen et al. (2015) article (in which the tornado and flash flood report needed to be at the same location) to allow for spatial buffers of 10 and 50 km. This, of course, increases the number of events to analyze. If we define a geographical boundary for the southeast that extends from the Texas/Louisiana border eastward, and south of the Tennessee/Kentucky border, we find that 34% of tornado/flash flood warning intersections, and approximately 25% of 'verified' TORFF events (using either spatial buffer), occur in the southeast US. However, there is also a sharp gradient from west-to-east in the number of TORFF events, with high frequency in the Mississippi River valley and lower frequency over eastern Alabama and Georgia. These results are summarized in Fig. 1.

During the field phases of VORTEX-SE in 2016 and 2017, several TORFF events occurred in the broader southeast region (e.g., in Tennessee, Arkansas, and Mississippi), but none occurred within the limited operating domain over northern Alabama during intensive observing periods. As a result, no field data were collected during 'true' TORFF events, but other useful data were collected that will be addressed below.

For (2), we have designed and run a series of numerical model experiments that are representative of situations that often produce both strong low-level rotation and very heavy precipitation. The primary hypothesis being tested is that stronger low-level vertical wind shear promotes both near-surface rotation and the production of high rain rates, both through the enhancement of dynamically forced (as opposed to buoyant) updrafts. In the experiments, only the low-level shear is altered, with the storm motion and mesoscale ascent kept the same across the simulations. The high-shear simulation is representative of several observed TORFF cases. These simulations do indeed show a substantial increase in both low-level rotation and rainfall production in the high-shear simulations. General summaries of these results are shown in Figs. 2 and 3 below. Furthermore, we have conducted dynamical analysis to quantify and generalize these effects. A manuscript (led by Erik Nielsen) describing these results will be submitted for publication in November.

For (3), we participated in the 2017 field phase of VORTEX-SE. Our group launched mobile radiosondes in coordination with the other research groups involved in the project. In total, we collected 32 soundings during VORTEX-SE. The final data have been submitted to NCAR-EOL, and are available to authorized users at https://data.eol.ucar.edu/dataset/541.020. Some changes to our participation in the field phase from what was described in the original proposal were required, which were approved in a budget revision in January 2017; these changes are summarized later in the report.

Although, as noted above, we were unable to observe any TORFF events during the field phase, there were several interesting events that were observed. In particular, we collected 8 soundings from the same location in Gadsden, AL on 5 April 2017 (IOP3). This day had an SPC “high risk” outlook in Georgia and South Carolina, surrounded by a moderate risk covering most of Alabama. There was also a slight risk for excessive rainfall from WPC. However, relatively few tornadoes ended up occurring in the VORTEX-SE domain. Our soundings showed progressive drying, along with strengthening winds aloft over the course of the day (Fig. 4-5), which may have been important in limiting the development of deep convection that day. Going forward, we will work with other VORTEX-SE research groups to continue analyzing the field data.

Lastly, for (4), the project has supported graduate student Sam Childs’ research into the climatology of cold-season tornadoes in the southeast, and to examine how broadcasters and NWS forecasters perceive cold-season tornado threats. He deployed a detailed survey that received 16 responses over four different tornado events in the 2016-17 cold season. His findings highlighted that major barriers to tornado risk communication included a public “me-centeredness”, inconsistency of messages, uncertainties related to timing and meteorology, and case-specific circumstances. A conceptual model of these barriers that was developed from these results is shown in Fig. 6. Two manuscripts from Sam’s research were submitted, one on the meteorology and climatology of cold-season tornadoes to *Weather and Forecasting*, and one on the survey results to *Weather, Climate, and Society.* Both received initial editorial decisions of major revisions, and we are now revising the manuscripts to respond to the reviewer comments.

What opportunities for training and professional development has the project provided?

The project has partially or fully supported two graduate students (Erik Nielsen and Sam Childs) at Colorado State University as they conduct research toward their graduate degrees. During the field phase, several other graduate students have participated in data collection, giving them valuable training in collecting field data and insights into the process of conducting field campaigns.

How were the results disseminated to communities of interest?

As outlined above, two manuscripts were submitted based on Sam Childs's research, and a third based on Erik Nielsen's research will be submitted soon.

Several conference presentations were also made during the reporting period:

- "Dynamical Insights into Extreme Short-Term Precipitation Associated with Supercells and Mesovortices", 17th Conference on Mesoscale Processes, AMS, San Diego, CA, July 2017 (Erik Nielsen)
- "A Closer Look at Upper-Air Data and 'TORFF' Events Observed During the Second Year of VORTEX-SE", 17th Conference on Mesoscale Processes, AMS, San Diego, CA, July 2017 (Erik Nielsen)
- "Communication of Cold-season Tornado Risk: Case Studies from November 2016 – February 2017", Fourth Conference on Weather Warnings and Communication, AMS, Kansas City, MO, June 2017 (Sam Childs)
- "Communication of Cold-season Tornado Risk: Case Studies from November 2016 – February 2017", 2017 Hazards Workshop, Broomfield, CO, July 2017 (Sam Childs)

What do you plan to do during the next reporting period to accomplish the goals and objectives?

We intend to continue to analyze the data collected during the 2017 field campaign, the output of our numerical experiments, and the results of the cold-season tornado study. Erik Nielsen and Sam Childs will be presenting their research at the AMS annual meeting in January 2017.

2. PRODUCTS

What were the major completed products or deliverables this period, and how do they compare to your proposed deliverables? (planned vs. actuals table recommended)

Proposed deliverable	**Status**
Sounding data from VORTEX-SE field phase	**Complete**
Numerical model output	Underway
Conference presentations	Complete for some results; further presentations will be made as appropriate
Journal article	Two have been submitted, a third to be submitted soon
Final report	To be submitted at end of project

What has the project produced?

Sounding data collected in the field, available at: https://data.eol.ucar.edu/dataset/541.020 for authorized users.

See also the list of conference presentations given above. Two manuscripts have been submitted for publication, with a third nearly ready for submission.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on this project?

PI Russ Schumacher, graduate research assistants Erik Nielsen, Sam Childs, Greg Herman, Chris Slocum, Stacey Hitchcock, Ben Toms (several of these students were only involved in field data collection), researcher Jen Henderson, and CSU computer systems support staff.

Has there been a change in the PD/PI(s) or senior/key personnel since the last reporting period?

No changes.

What other organizations have been involved as partners? Have other collaborators or contacts been involved?

We have collaborated with Jen Henderson (CIRES/University of Colorado) and the group funded under VORTEX-SE led by Julie Demuth at NCAR. We have also been coordinating closely with many other groups during the field phase of VORTEX-SE (including the University of Alabama at Huntsville).

4. IMPACT

What was the impact on the development of the principal discipline(s) of the project?

The outcomes of this work will improve understanding, and potentially prediction, of weather events with multiple hazards.

What was the impact on other disciplines?

By integrating meteorological information with social-science methods, this project will inform future improvements in how operational forecasters approach the challenge of cold-season tornadoes and multi-hazard weather events.

What was the impact on the development of human resources?

None yet.

What was the impact on teaching and educational experiences?

Several graduate students have been supported as they conduct research toward their degrees. These students will have obtained skills in field data collection, data analysis and modeling from multiple disciplinary perspectives.

What was the impact on physical, institutional, and information resources that form infrastructure?

N/A

What was the impact on technology transfer?

N/A

What was the impact on society beyond science and technology?

By examining the processes by which NWS forecasters issue warnings in multi-hazard events and address cold-season tornadoes, it may ultimately lead to improvements in how those forecasts and warnings are disseminated and communicated.

What percentage of the award's budget was spent in a foreign country(ies)?

0%

5. CHANGES/PROBLEMS

Describe the following:

-Changes in approach and reasons for the change.
-Actual or anticipated problems or delays and actions or plans to resolve them.
-Changes that had a significant impact on expenditures.
-Change of primary performance site location from that originally proposed.

No new changes have arisen during this reporting period. Some substantive changes were made during the first reporting period, which were outlined in the report submitted in April 2017, and those changes still apply to this project.

6. SPECIAL REPORTING REQUIREMENTS

N/A

7. BUDGETARY INFORMATION

Is the project on budget? Much of the quantitative budget information is submitted separately in the Federal Financial Report. However, describe here any major budget anomalies or deviations from the original planned budget expenditure plan and why.

No substantial anomalies or deviations are expected; we are on budget for the revised budget approved in January 2017.

8. PROJECT OUTCOMES

What are the outcomes of the award?

The outcomes will include information about TORFF events in the southeast US from both a meteorological and warning/communication perspective.

Are performance measures defined in the proposal being achieved and to what extent?

We believe that we are on track to achieve all of the goals outlined in the original proposal.

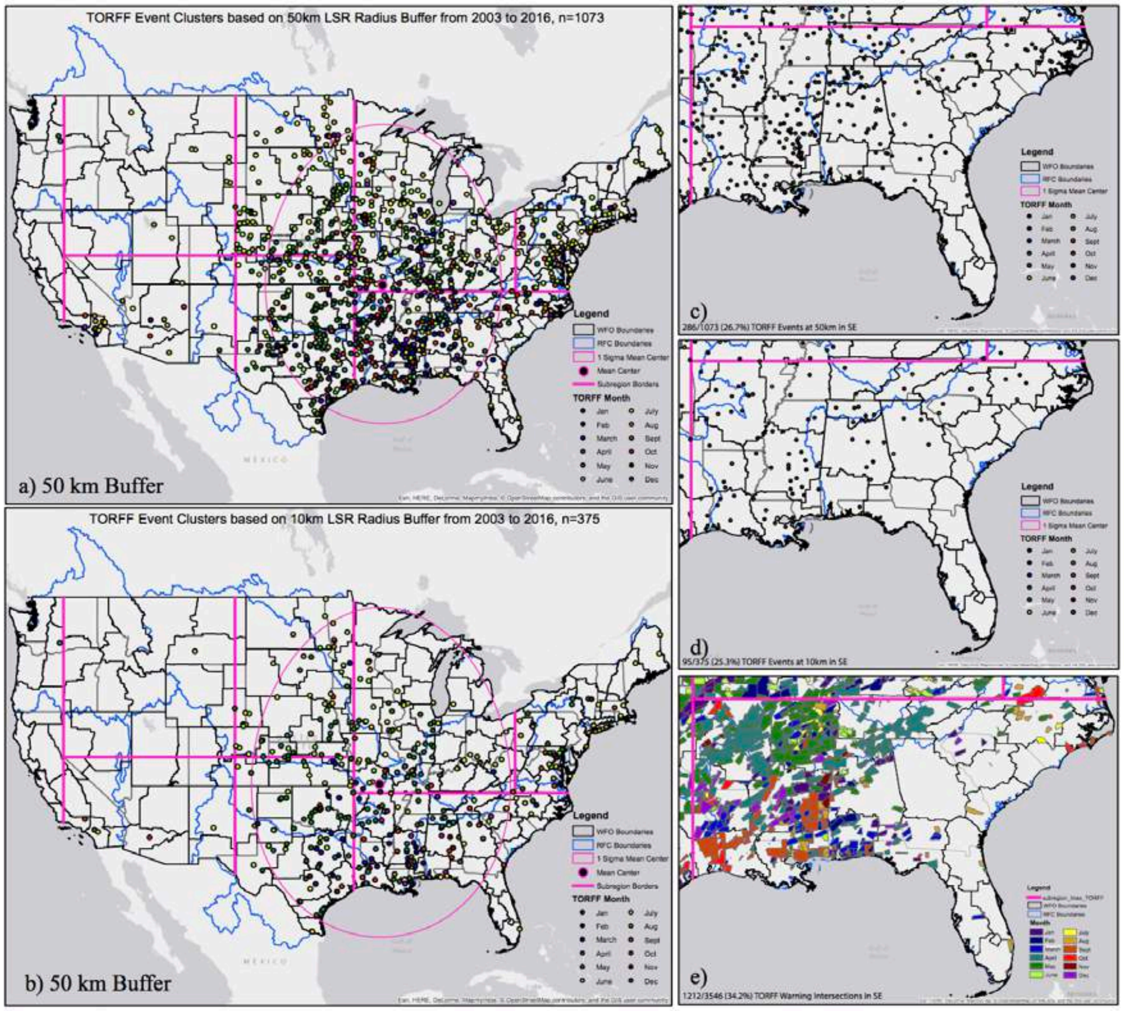

Figure 1: (a-b) *Geographic distribution of concurrent, collocated tornado and flash flood events from 2003 to 2016 (colored by month) based upon intersections between tornado tracks and 50 or10 km, respectively, buffers placed around flash flood local storm reports. Pink dot (a-b) represents the geographic mean center, pink ellipse (a-b) represents one spatial standard deviation away from mean center, and the black and blue lines (a-e) represent NWS WFO and RFC boundaries, respectively. (c-d) same as (a-b) except zoomed in over the Southeastern United States. (e) flash flood and tornado warning intersections (WI) within 30-min over the Southeastern U.S. from 2008 to July 2017.*

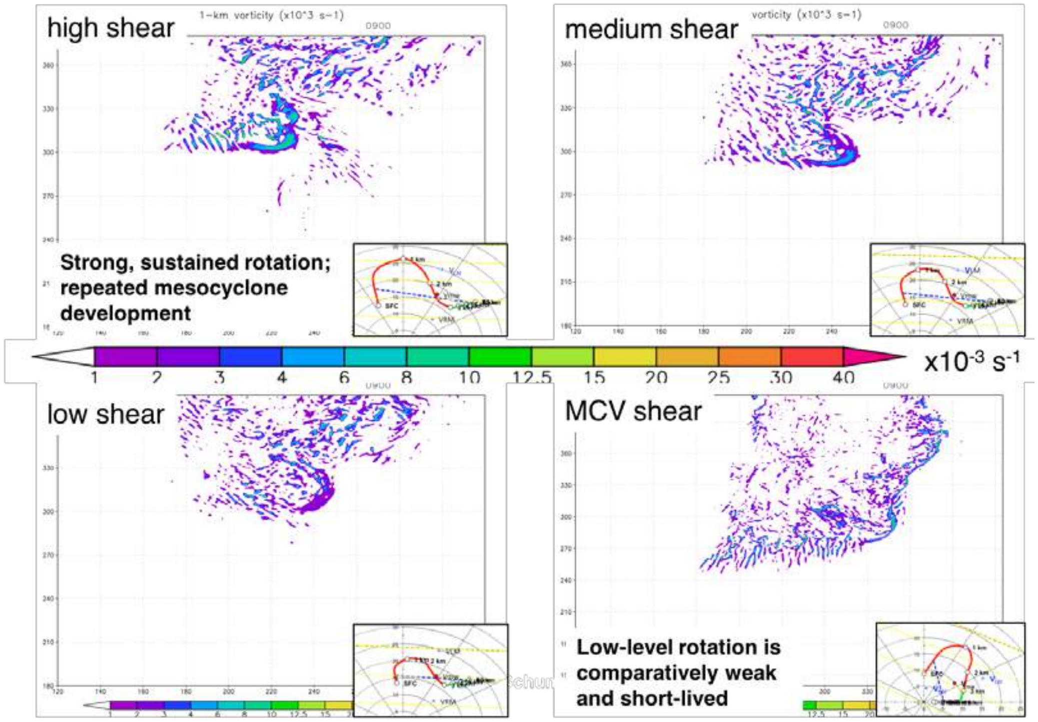

Figure 2: Vertical vorticity at 1-km AGL at t=9 h, for the (a) high shear, (b) medium shear, (c) low shear, and (d) MCV shear experiments. Hodographs for the different experiments are shown in the insets. The high-shear simulation shows long-lived mesocyclones and repeated mesocyclone development, in comparison with the other simulations that have shorter-lived and weaker rotation.

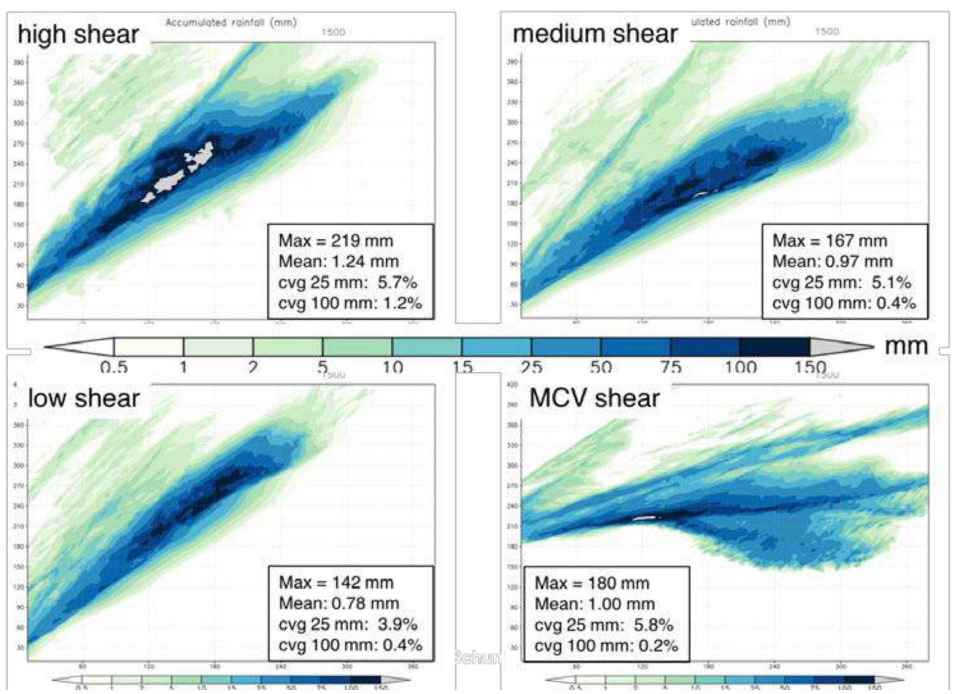

Figure 3: As in Fig. 1, except for total precipitation through t=15 h. The high-shear case has more precipitation than the other simulations by a variety of measures.

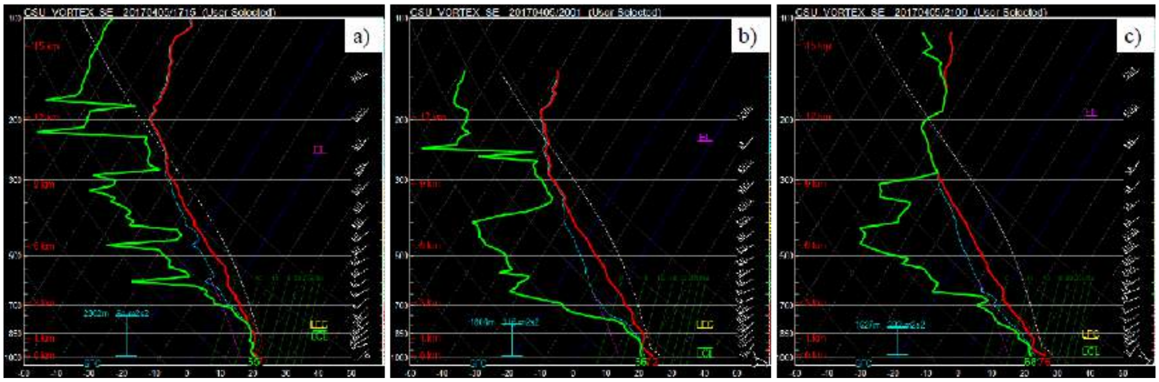

Figure 4: Soundings taken by the CSU team in Gadsden, AL at (a) 1715, (b) 2001, and (c) 2100 UTC 5 April 2017.

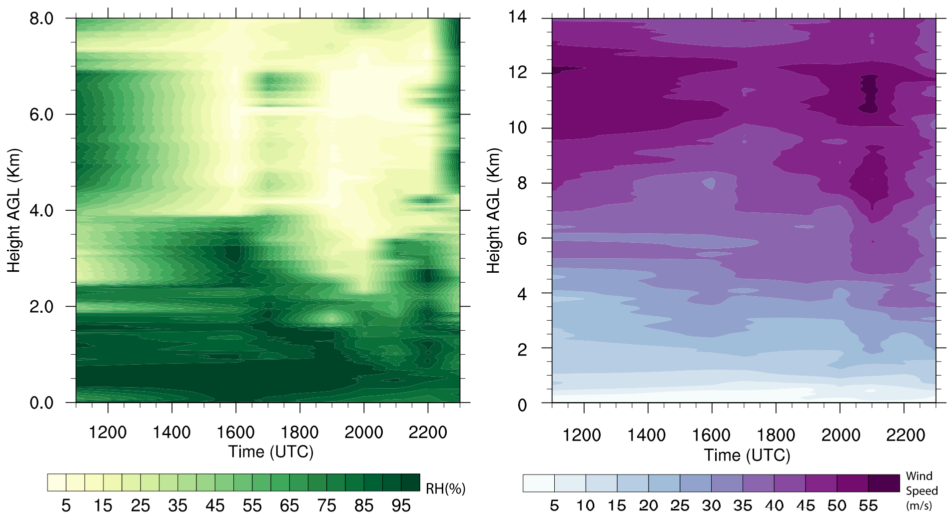

Figure 5: Time-height diagrams of (a) relative humidity and (b) wind speed created from the 8 soundings taken by the CSU team in Gadsden, AL. Data included from 1055, 1400, 1600, 1715, 1900, 2001, 2200, and 2302 UTC 5 April 2017.

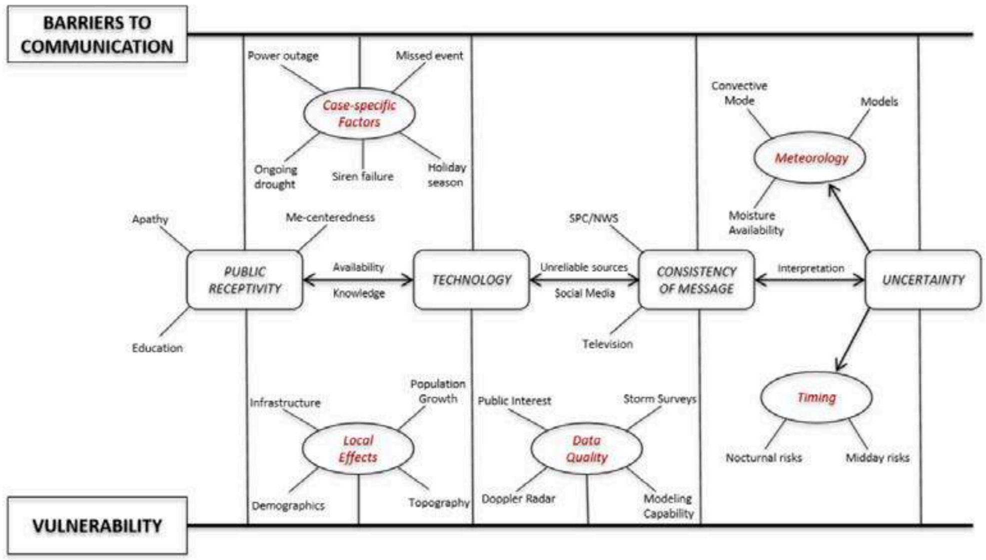

Figure 6: Conceptual model of cold-season tornado risk communication. The two large rectangles on the left represent two main categories of analysis ('Barriers to Communication' and 'Vulnerability'); the four rounded rectangles represent factors related to both of the categories (which are also interrelated via the double arrows), with straight-line appendages pointing to specific components within that factor; the ovals represent factors that play a role in only one of the categories, with their specific components marked by straight-line appendages; the ovals connected to the 'Uncertainty' factor represent the two main sources of uncertainty which play roles in both categories, with straight-line appendages similarly pointing to specific components of those factors. From Childs and Schumacher (2017, submitted to Weather, Climate, and Society*).*

Progress Report
Investigating the Underlying Mechanisms and Predictability of the MJO - NAM Linkage in the NMME Phase-2 Models

1. General Information

Project Title: Investigating the Underlying Mechanisms and Predictability of the MJO - NAM Linkage in the NMME Phase-2 Models

PI/co-PI names and institutions

- **Lead PI:** Jason C. Furtado, School of Meteorology, University of Oklahoma
- **Co-PI:** Elizabeth A. Barnes, Department of Atmospheric Sciences, Colorado State University
- **Co-PI:** Michelle L'Heureux, NOAA Climate Prediction Center
- **Co-PI:** Adam Allgood, NOAA Climate Prediction Center

Report Year : FY18 (1 January 2017 – 31 December 2017)

Grant #: NA16OAR4310090

2. Main goals of the project, as outlined in the funded proposal

- Enhance our knowledge about the dynamical links between the MJO and the NAM by considering the modulating influence of the extratropical stratosphere / stratospheric polar vortex (SPV).
- Evaluate these mechanisms of MJO-NH extratropical atmospheric teleconnections in the North American Multi-Model Ensemble Phase-2 (NMME-2) system.
- Connect and apply our findings and evaluations to predictions of atmospheric blocking and extreme weather events.

3. Results and accomplishments

Team Organization and Meetings

Over the past year, the team has worked both independently and cohesively toward accomplishing **Tasks #1 and #2** from the proposal. In the last year, **Co-PIs L'Heureux** and **Allgood** hired Dr. Laura Ciasto and Dr. Kirstin Harnos as contractors to work on the project. Drs. Ciasto and Harnos familiarized themselves with the project and elements of the MJO / stratosphere dynamics. They have also moved forward with several activities associated with working with the S2S database (see below) and complemented well the analyses that **PI Furtado** and his graduate student Green have accomplished over the last year.

Meetings between the PIs occurred on a few occasions throughout the year. **Co-PI Barnes** visited OU in late March 2017 and met with **PI Furtado** and his graduate student to go over the results shown in this report. They also outlined steps forward for blocking analysis and further steps forward on data analysis of MJO-stratospheric polar vortex (SPV)-midlatitude weather linkages. In October 2017, **PI Furtado** hosted the 42nd Annual NOAA Climate Prediction and Diagnostics Workshop, attended by **co-PI L'Heureux**, Ciasto, and Harnos. During that meeting, formal oral presentations were given on the work presented on the project (given by Green and Ciasto), and the group also met in-person to discuss individual results from the project. Additionally, the team held a telecom on 31 October 2017 in which results from Ciasto and Green were presented to **co-PI Barnes.** At this meeting, **co-PI Barnes** announced that she would be pursuing a new angle in the project – applying Granger causality to the MJO-SPV project. To that end, Dr. Imme Ebert-Uphoff of CSU's Department of Electrical and Computer Engineering has been added to the CSU team. Ebert-Uphoff is an international leader on causal discovery in geosciences and thus, will perform the causality analysis to establish causal, mechanistic links between the MJO, the SPV, and European weather at S2S timescales. She will help **co-PI Barnes** in interpreting the results and will communicate results with the rest of the project team. She will also assist in the writing-up of the results in the peer-reviewed literature anticipated to start this year.

Results from Reanalysis (**Task #1**) (**Lead: Furtado**)

Most of the results from **Task #1** of the proposal involved generating composites of several atmospheric variables associated with specific MJO phases, the strength of the SPV, and their joint composites. Analyses are restricted to the extended boreal cold season (October – April). To categorize the MJO, we first used the *Wheeler and Hendon* [2004] (WH) Real-Time Multivariate MJO (RMM) Index. While this index is widely used in the operational community, its applicability to dynamical connections may not be ideal. For example, *Kiladis et al.* [2014] showed that using the WH RMM index for MJO teleconnections focuses more on the wind than convective elements associated with the MJO. Since MJO-related convection is a source of Rossby wave initiation that can subsequently propagate from the tropics into the mid-latitudes, an index representative of MJO convection may be more appropriate for mid-latitude teleconnections. After some testing with this index and others (e.g., a pure OLR-based index), we decided to switch the basis index from the WH RMM index to the OLR MJO Index [OMI; *Kiladis et al.*, 2014], which allows us to categorize all eight phases of the MJO, for all analyses with reanalysis data.

For SPV "events", we use the phase and magnitude of the Northern Annular Mode (NAM) index at 100 hPa (NAM_{100}). A positive (negative) value of the NAM_{100} index indicates a strong (weak) SPV. Composites were constructed for several atmospheric fields, but for brevity, we will show results from geopotential heights and surface temperature only.

For our composites, we made the following definitions:

- The start date for a MJO event in phase *p* is when $|\,OMI\,| \geq 1$.
- The start date for a NAM event is when $|\,NAM_{100}\,| \geq 1$ *and* is the same sign for five (5) consecutive days after that day.
- A MJO-NAM event is defined when the start date of the MJO event either coincides with the start date of the NAM event or within a week thereafter (we have varied this between 2-7 days and have found minimal differences in composite results). These latter criteria are added because of the nature of the propagation of the induced Rossby wave from the MJO event and to increase sample size for compositing.

Figure 1 shows five composite cases for 500 hPa geopotential height anomalies for MJO Phase 3. Note that we added the criterion for a neutral vortex (MJO state) to the MJO (NAM)-only composites to minimize the influence of the stratosphere on the circulation of the troposphere. The main findings are more readily apparent when examining differences between multiple composites and also by sector (**Figs. 1f – 1i**). The way to interpret the difference plots are as follows. The "*MJO/Vortex – MJO*" composite differences (**Figs. 1f** and **1h**) represent those regions where the state of the SPV plays a significant role in modulating the collective teleconnected response of the two climate modes. Likewise, the "*MJO / Vortex – Vortex*" composite differences (**Figs. 1g**

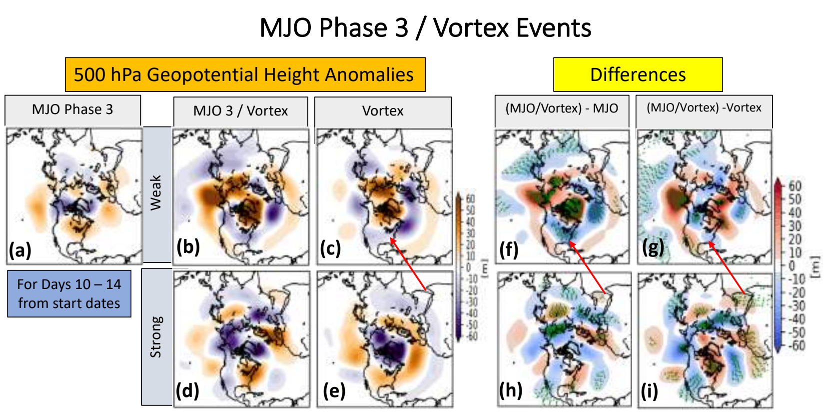

FIG. 1. (left panels) Day +10 to +14 composite of October – April 500 hPa geopotential height anomalies (m) for (a) MJO Phase 3 events coinciding with a neutral polar vortex ($|NAM_{100}| < 1$), (b) MJO events coinciding with a weak polar vortex (i.e., $NAM_{100} < -1$), (c) weak polar vortex events coinciding with neutral MJO ($|MJO| < 1$), (d) MJO events coinciding with a strong polar vortex (i.e., $NAM_{100} > 1$), and (e) strong polar vortex events coinciding with neutral MJO conditions. (right panels) (shading) Composite difference of 500 hPa geopotential heights (m) between: (f) panel (b) – panel (a); (g) panel (b) – panel (c); (h) panel (d) – panel (a); and (i) panel (d) – panel (e). Green dots indicate where composite differences are significant at the $p < 0.1$ level from Monte Carlo testing.

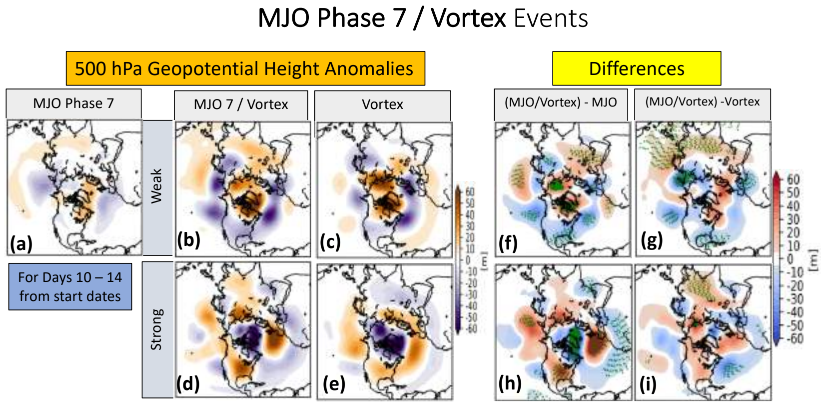

FIG. 2. As in **Fig. 1** but for MJO Phase 7.

and **1i**) represent those regions where the MJO plays a more significant role in modulating the collective response of the two climate modes. **The general conclusion is that the weather regimes in the North Pacific region are more strongly controlled by the phase of the MJO while those in the Atlantic sector and Europe resemble more like the corresponding NAM-only composites (though subtle differences emerge, as noted below)**. This finding is particularly important when considering subseasonal forecasting and which mode to consider. This result holds for other MJO phases, including Phase 7 (**Fig. 2**), and other variables (e.g., zonal-mean zonal wind, not shown). The region "in between", namely North America, however, is more complicated and variable. That is, the resulting circulation and temperature anomalies are more of a function of the joint influence, again supporting our motivating hypothesis.

This research is not only interested in the wave patterns that are a result of the joint influence of the MJO and the SPV, but also sensible weather impacts like temperature anomalies. **Figure 3** shows the surface air temperature composite anomalies 10-14 days (i.e., 2 pentads) after MJO phase 7 and SPV events. MJO phase 7 events generally result in a warm Arctic while much of North America experiences weak cold anomalies (**Fig. 3a**), a pattern reminiscent of weak SPV event composites (**Fig. 3c**). Strong SPV events (**Fig. 3e**) feature mild conditions over the southern half of North America, while northern North America and the Arctic remain anomalously cold. The conditional composites present some significant differences from either of the single event composites. Note that significant differences emerge for North America when considering the influences of the weak vortex and MJO Phase 7, particularly over Alaska and the Northern Plains (**Figs. 3f** and **3g**). Interestingly, the main differences for Europe emerge only for the strong vortex cases (**Figs. 3h** and **3i**), an indication again that the European sector is more strongly controlled by the SPV than the MJO.

PI Furtado and M. Green also worked with **co-PI Barnes** and her Ph.D. student to implement a blocking regime alogorithm for reanalysis. The algorithm, which is similar to *Henderson et al.* [2016], was applied in three specific sectors: the North Pacific, the Atlantic, and Europe. **Figure 4** shows the results for the Atlantic sector when considering MJO Phase 7 events. The figure is aligned similar to **Figs. 1a-1e** and **2a-2e** in terms of the single and conditional composites. Through examining the conditional composites, the blocking locations are different than the MJO or SPV events alone. For example, **Fig. 4b** (i.e., MJO Phase 7 and a weak SPV) displays an anomalously large blocking frequency located to the east of Hudson Bay. Note that when considering *only* the weak SPV cases (and MJO neutral conditions; **Fig. 4c**), however, anomalously *less* blocking frequency exists in the North Atlantic, a result counterintuitive from the classical -NAO regime expected with weak SPV events. *This may suggest that the manifestation of the -NAO*

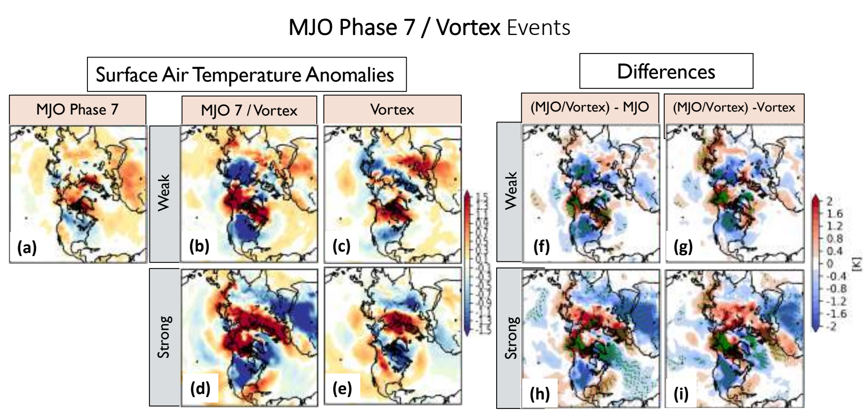

FIG. 3. As in **Fig. 2** but for surface air temperature anomalies (K).

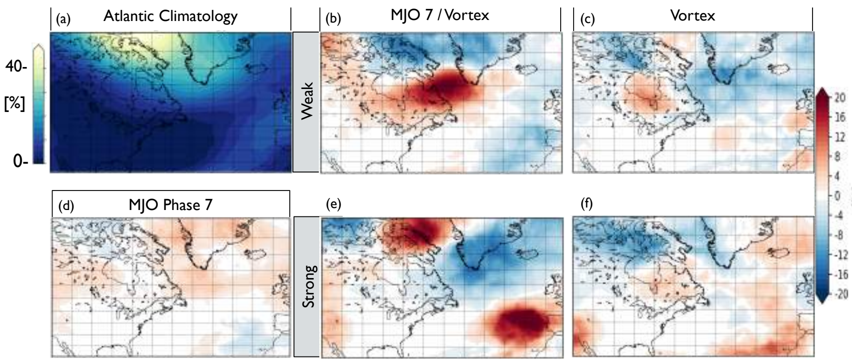

FIG. 4. (a) Climatological wintertime blocking frequency (presented as percent of days when blocking exists), as measured from the 500 hPa geopotential height field, across the North Atlantic. (b) – (f) Days 0-9 anomalous blocking frequency observed following (b) MJO phase 7 / weak SPV events, (c) neutral MJO / weak SPV events, (d) MJO phase 7 / neutral SPV events, (e) MJO phase 7 / strong SPV events, and (f) MJO neutral / strong SPV events.

blocking regime could be dependent on the phase of the MJO. This would be one example where our "general" conclusion of the SPV dominating control over Atlantic and European weather breaks down. Conversely, when considering the MJO Phase 7 and strong SPV conditional composites (**Fig. 4e**), a tripole pattern in blocking frequency anomalies (anomalously higher frequency over the Labrador Sea and near Iberia and anomalously lower frequency over Greenland / Iceland) exists. This pattern again is distinctly different when considering either the MJO or the SPV separately. More work on aspects like blocking and extreme temperatures are currently underway. We have also started preparing a publication on the composite results (e.g., *Green et al.* [2018], **in prep**.).

Finally, upon discussing these results among the co-PIs and other colleagues, one question / comment consistently came up – Aren't these composites really just linear combinations of the two influences, with special areas of constructive and destructive interference? This comment is valid and would imply that (a) the two modes are independent (or independent enough to consider separately) and (b) compositing would yield similar results to linear regression relationships. The fact that there are statistically significant differences between the conditional and single composites (e.g., **Figs. 1f-1i, 2f-2i,** and **3f-3i**) at least implies that the relationship is not purely linear, at least in some places. However, to explicitly test this linear independence assumption, we constructed a simple linear regression model for the two predictors: $y = a \times NAM_{100}' + b \times RMM_1' + c \times RMM_2' + d$, where the OMI index has been deconstructed into each of its components. *y* for these purposes will be 500 hPa geopotential height anomalies, and the "prime" notation denotes that the cross-correlation between terms has been explicitly removed (i.e., "residual"). **Figure 5** presents the comparison between the conditional composites and the corresponding linear regression coefficients for each conditional case for MJO Phases 3 and 7. When considering the conditional composites for MJO Phase 3 (**Figs. 5a-5b**, **5e-f**), geopotential height anomalies in the Arctic and North Atlantic are very similar between the two methods. Differences (i.e., a sign of non-linearity) emerge in the North Pacific and North America, particularly for weak SPV events (**Figs. 5b** and **5f**). For conditional composites during MJO Phase 7, high linearity is seen in the Pacific basin and Europe, and especially for MJO Phase 7 / weak vortex episodes (**Figs. 5d** and **5h**). Meanwhile, eastern North America displays significant differences during strong SPV events (**Figs. 5c** and **5g**). Therefore, we conclude that the degree of linearity (and independence) of these two modes is indeed important to consider, but the non-linear interactions over particularly North America make this research valuable and worthy of digging further into the dynamics.

MJO-NAM Relationships in S2S Models (**Task #2**) (**Lead: L'Heureux, Ciasto, and Harnos**)

Team members at NOAA CPC have been actively working on parallel analyses to the analyses conducted at OU but using hindcasts from operational S2S models (i.e., **Task #2**). Originally, our plan was to use the

NMME Phase-2 database for this area of the research. However, due to the lack of sufficient stratospheric data from the NMME Phase-2 models, the team decided to use the hindcasts in the International Subseasonal to Seasonal (S2S) Database to evaluate the MJO-stratospheric connections. A major benefit of this model database is that it includes models with a range of vertical levels and low-top as well as high-top models. This range of model configurations affords us the opportunity to examine how vertical model resolution and model top influences the ability of the models to capture the stratospheric role in MJO teleconnections to the extratropical Northern Hemisphere. **This characterization is a central tenet to the NOAA MAPP call under which this proposal was funded.** Thus far, output from 8 of the 11 models in the database have been downloaded for examination (ECMWF, CNRM, NCEP, UKMO, JMA, ECCC, HMCR, and BOM). The other three models have incomplete data and are thus not used.

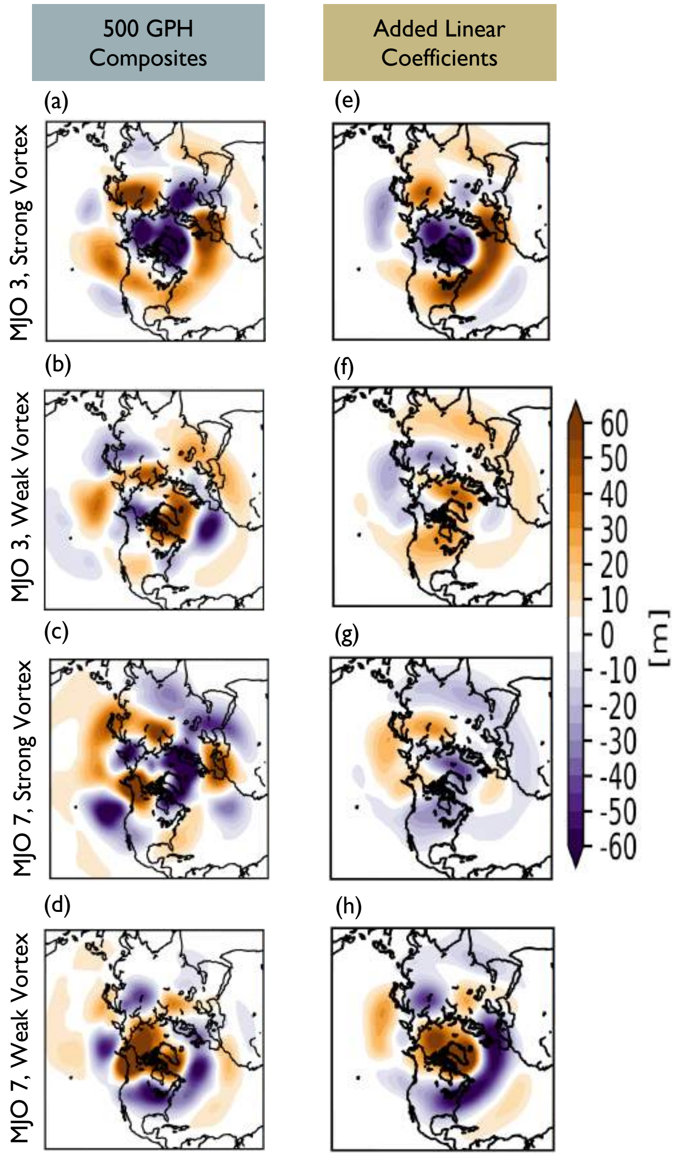

FIG. 5. A comparison of the 500 hPa geopotential height composites and the linear regression model (see text). The composite of (a) MJO Phase 3 / strong SPV events is compared to (e) the regression model with (+RMM1,-RMM2,+NAM_{100}), The composite of (b) MJO Phase 3 / weak SPV events is compared to (f) the regression model with (+RMM1, -RMM2, -NAM_{100}), The composite of (c) MJO Phase 7/ strong SPV events is compared to (g) the regression model with (-RMM1, +RMM2, +NAM_{100}), The composite of (d) MJO Phase 7 / weak SPV events is compared to (h) the regression model with (-RMM1, +RMM2, -NAM).

The first steps for the S2S model analysis involved examining how well the models are able to capture the three main modes of interest: (a) the (tropospheric) NAM, (b) the SPV, and (c) the MJO. **Figure 6** summarizes these findings in the form of December – February (DJF) anomaly correlation coefficients (ACC) for the three indices as a function for forecast lead time. For the tropospheric NAM/AO (**Fig. 6a**), all models perform reasonably similar: high correlations (i.e. higher skill at forecasting the target date) extend out to ~1 week before decaying quickly. Comparing intermodal performance, the ECMWF hindcasts perform slightly better than the other models, while BOM and HMCR (i.e., the more coarse-resolved models) decay noticeably faster in forecast skill than the other models. By comparison, higher correlation coefficients remain for longer forecasts lead times for the stratospheric NAM (i.e., strength of the SPV; **Fig. 6b**) versus the same lead for the surface NAM (**Fig. 6a**). This result is expected as the stratosphere exhibits less high frequency variability and more persistence, thus making it “easier” to predict. For intermodal comparison, the BOM, JMA, and HMCR exhibit the fastest decay in anomaly correlation skill. Finally, when examining for predictions of the MJO (**Fig. 6c**), we see that the models have substantially less and much more intermodal variance in skill.

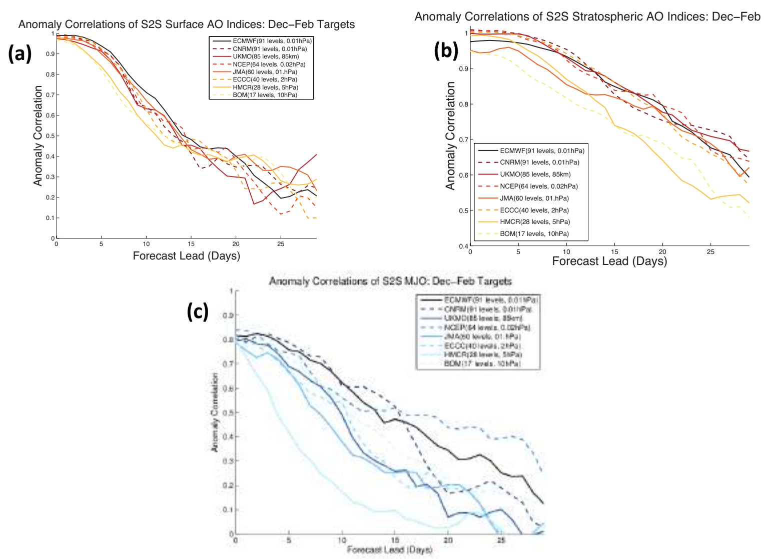

FIG. 6. (a) Anomaly correlation coefficient of the DJF near-surface NAM / AO index as a function of lead time from hindcasts of several S2S models (see legend). (b) As in (a) but for the stratospheric NAM index (i.e., NAM at 50 hPa). (c) As in (a) but for the MJO index.

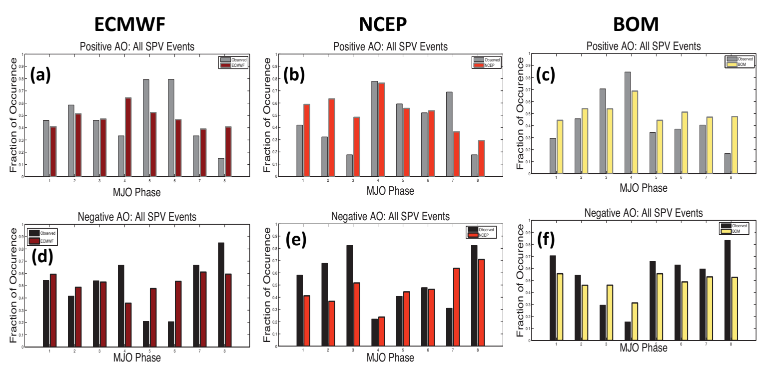

FIG. 7. (a) The fraction of occurrence of positive near-surface NAM / AO regimes during November – March as a function of the phase of the MJO in reanalysis (gray bars) and the ECMWF model hindcasts (dark red bars). (b) As in (a) but for the NCEP model hindcasts (red bars). (c) As in (a) but for the BOM model hindcasts (yellow bars). (d) As in (a) but for negative near-surface NAM / AO regimes. Results from reanalysis shown in black bars. (e) As in (d) but for NCEP model hindcasts (red bars). (f) As in (d) but for the BOM model hindcasts (yellow bars).

The next step in the model evaluation was to see if the models replicate the known links between the near-surface NAM and the MJO, as documented in *L'Heureux and Higgins* [2008]. That is, the positive (negative) phase of the near-surface NAM is linked to the phase 3-4 (7-8) of the MJO. **Figure 7** shows the results of this analysis in the form of histograms of the frequency of positive AO (**Fig. 7, top row**) and negative near-surface NAM / AO (**Fig. 7, bottom row**) as a function of the phase of the MJO for observations (gray and black bars) and three select models: the ECMWF, NCEP, and BOM. Performance within the models varies for both the phase of the AO and the MJO state. For example, the ECMWF model hindcasts replicate well the negative near-surface NAM / MJO Phase-7 relationship (**Fig. 7d**) with less coherence for the positive near-surface NAM / MJO Phase 3-4 relationship (**Fig. 7a**). By contrast, the NCEP model hindcasts recover the positive near-surface NAM / MJO Phase 4 relationship but not the negative near-surface NAM states (**Figs. 7b** and **7e**). The BOM hindcasts are the best performing of the sub-selection of S2S models chosen – it recovers the documented relationships between the MJO and the near-surface NAM for both positive and negative AO regimes. The CPC team is currently expanding on these results and working on understanding how these relationships may or may not change given the added condition of the state of the SPV.

References

Kiladis G.N., J. Dias, K.H. Straub, M.C Wheeler, S.N. Tulich, K. Kikuchi, K.M. Weickmann, M.J. Ventrice, 2014: A comparison of OLR and circulation based indices for tracking the MJO. *Mon. Wea. Rev.*, **142**, 1697-1715.

Henderson, S.A., E.D. Maloney, and E.A. Barnes, 2016: The influence of the Madden–Julian Oscillation on Northern Hemisphere winter blocking. *J. Climate,* **29**, 4597–4616.

L'Heureux, M. L., and R. W. Higgins, 2008: Boreal winter links between the Madden–Julian Oscillation and the Arctic Oscillation. *J. Climate*, **21**, 3040–3050.

Wheeler, M.C. and H.H. Hendon, 2004: An all-season real-time multivariate MJO index: Development of an index for monitoring and prediction. *Mon. Wea. Rev.,* **132**,1917–1932.

4. Highlights of Accomplishments

- The team held several telecons and face-to-face meetings to advance the project. In addition, the team has recruited two new collaborators for the project: Dr. Harnos at CPC and Dr. Ebert-Uphoff. Dr. Harnos will work with **co-PI L'Heureux** at CPC, and Dr. Ebert-Uphoff will be working with **co-Pi Barnes** at CSU on causality theory involving the MJO/SPV.

- Initial compositing results (**Task #1**) support the proposal's central hypothesis – i.e., there are demonstrable spatial and amplitude differences in the Northern Hemispheric teleconnected responses when considering the conditional composites of strong MJO events and the state of the SPV versus the composites of each mode separately.

- Our composites allow us to make the following general conclusions: (1) The SPV regime has a more dominant control of the Atlantic / European sector longwave and sensible weather patterns irrespective of the phase of the MJO; (2) For the Pacific sector and western North America, the phase of the MJO dominates subseasonal weather influences more so than the SPV. This leaves much of North America "in the middle" and variable (**Figs. 1-3**).

- The combined influence of the MJO and the SPV is *not* wholly linear, meaning that composite analysis is an appropriate method to answer this research questions (**Fig. 5**).

- Work at CPC has focused on accomplishing **Task #2**. Instead of using the NMME Phase-2 models as planned, we are using the International S2S Database because of availability of models with stratospheric output and a selection of models with differing resolutions (vertical and horizontal), satisfying a key component of our research (i.e., explaining model performance of the MJO/SPV linkages as a function of model resolution).

- The S2S models investigated perform decently well with forecasting the NAM in the stratosphere and troposphere but struggle more with MJO long-lead forecasts (**Fig. 6**). The models also have mixed performance in recovering documented contemporaneous links between the MJO the near-surface NAM (**Fig. 7**).

- The team has presented results shown above (and more) at several conferences and workshops including the 18th Cyclone Workshop (October 2017), 42nd Annual NOAA Climate Diagnostics and Prediction Workshop (October 2017), a seminar at the University of Virginia (December 2017), and the 98th Annual Meeting of the American Meteorological Society (January 2018).

- Two publications are currently underway: *Green et al.* [2018] for **Task #1** results and *Ciasto et al.* [2018] for initial **Task #2** results.

5. Transitions to Applications
None

6. Publications from the Project
None

7. PI Contact Information
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8. Budget for Coming Year

Year 3 Budget

Furtado (OU)	L'Heureux / Allgood NOAA CPC)	Barnes (CSU)	TOTAL
$63.494	**$77.610**	**$22,901**	**$164,005**

9. Future Work

- Finish **Task #1**, including dynamical considerations associated with the MJO/SPV linkages and extreme weather analysis (e.g., blocking). **PI Furtado** will work with his graduate student (M. Green), **co-PI Barnes** and Dr. Ebert-Uphoff for this task. A paper is anticipated to be submitted in late Spring or early Summer 2018.
- The CPC team will continue working on **Task #2**, including further quantifications of the SPV/MJO ties to sensible weather regimes. The results presented above will be expanded to include stratosphere-troposphere coupling metrics as well. **PI Furtado** will work with the CPC team on those metrics. The goal will be to benchmark the performance of the models in the International S2S Database for both of these important S2S teleconnection patterns, including potential biases in winter weather patterns associated with the MJO and SPV regimes. A paper (perhaps two) are anticipated for submission during Summer or Fall 2018.
- With results from **Task #1** and **Task #2** synthesized, the group will move toward tackling **Task #3** – i.e., examining the joint influence of the MJO and SPV as simulated by the International S2S database models. We will use case studies and events identified in **Task #1** from reanalysis to guide this analysis. We anticipate starting this work in Fall 2018.
- Dr. Ebert-Uphoff will work with **co-PI Barnes** on exploring how is the phase and magnitude of the North Atlantic Oscillation (NAO) is actually affected by MJO and NAM_{100}, collectively and separately. Using Granger causality theory, the group will also investigate the strongest potential cause-effect relationships between the variables (and associated lags) and the NAO.
- The group will also maintain frequent communication and hold team telecons to document and ensure steady progress for the completion of the remainder of the project.

PROJECT TITLE: Modeling the Complex and Dynamic Physicochemical Evolution of Primary and Secondary Organic Aerosol from Wildfire Smoke

PRINCIPAL INVESTIGATORS: Shantanu Jathar, Jeffrey Pierce

RESEARCH TEAM: Shantanu Jathar, Jeffrey Pierce, Ali Akherati, Shiva Tarun, Liam Lewane, and Abril Galang

NOAA TECHNICAL CONTACT: Monika Kopacz and Kenneth Mooney

NOAA RESEARCH TEAM: Carsten Warneke, Jim Roberts, and Joshua Schwarz

PROJECT OBJECTIVES:

Objective 1 (revised scope): We will perform environmental chamber experiments at the Fire Sciences Laboratory in Missoula, MT to characterize the chemical evolution of organic aerosol from wildfire smoke samples representative of the Western United States. We will examine the organic aerosol evolution and determine its relationship to fuel type, burn conditions, oxidant exposure, and experimental artifacts.

Objective 2: We will develop a state-of-the-science OA model that combines the two-dimensional statistical oxidation model (SOM) with a detailed microphysics model (TOMAS) to simulate the physics, chemistry and thermodynamics of BBOA. The model will include recent findings about OA (effects of dilution, photochemistry, aqueous processing and experimental artifacts) and will be constrained using new laboratory data from the FIREX campaign.

PROJECT ACCOMPLISHMENTS:

Objective 1: Environmental Chamber Experiments and Data Analysis

	day			night		
Fuels	*UV*	*OH (low NO_x)*	*OH (high NO_x)*	*O_3*	*NO_3*	***Total***
Ponderosa Pine	1	1	3	×	1	6
Lodgepole Pine	×	×	4	×	1	5
Douglas Fir	1	×	1	×	1	3
Chapparal Manzanita	×	1	1	×	1	3
Engelmann Spruce	×	1	×	×	×	1
Subalpine Fir	×	×	1	1	1	3
Total	2	3	10	1	5	***21***

Table 1. Chamber experimental matrix undertaken at the Fire Sciences Laboratory as part of FIREX-2016. Table shows the fuels, oxidants, conditions and number of experiments performed.

Chamber Experiments. Our team at Colorado State University (CSU) developed a portable environmental chamber to perform photochemistry experiments at the Fire Sciences Laboratory (FSL) in Missoula, MT in October-November of 2016. The chamber consists of a 0.051 mm thick 10 m^3 Teflon™ FEP bag suspended inside a steel-plywood structure. The chamber is equipped with eighty 32W UVA lights (peak intensity 350 nm; NO_2 photolysis rate of 0.25 min^{-1}, approximately equivalent to half of the midday photolysis measured in summer at mid-latitudes in clear sky conditions). A one-ton air conditioning system manages temperature inside the enclosure and Teflon™ bag.

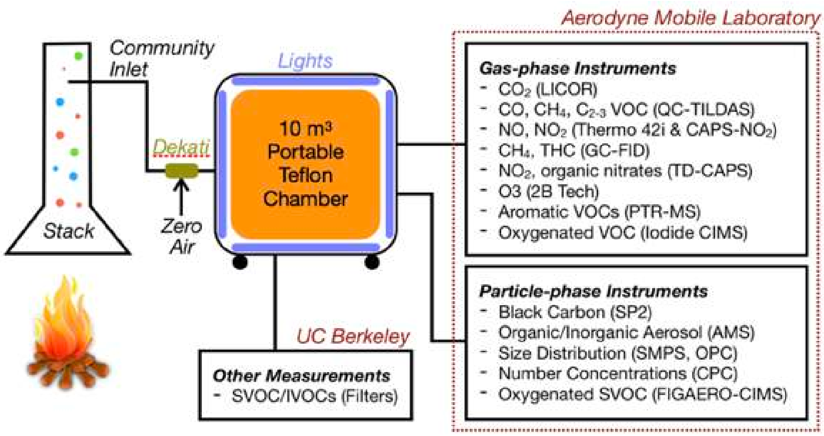


Figure 1. Cartoon of the chamber experimental setup and details about the gas- and particle-phase instrumentation provided by Aerodyne Research Inc.

The chamber was shipped to the FSL to perform day- and night-time aging experiments on wildfire smoke, as part of the laboratory portion of the FIREX campaign. The chamber experiments were performed in collaboration with Aerodyne Research Inc (ARI) where CSU performed the chamber experiment and ARI provided the instrumentation support. A total of sixteen chamber experiments were performed on wildfire smoke emissions from six different fuels and three different atmospheric oxidants (see Table 1 for experimental matrix and Figure 1 for an overview of the physical setup and instrumentation). For each experiment, emissions from the stack were drawn through a community inlet line (~100 feet) and pushed into a clean chamber using three ejector diluters. The flow rates through the community inlet were kept high to keep the residence times low (less than a few seconds) and the losses of gases and particles to the walls to a minimum. Emissions were sampled over the entire course of the fire and hence we sampled emissions during both the flaming and smoldering phases. Depending on the experiment to be performed, the chamber was primed with the oxidant (e.g., O_3, NO_3) or the precursor for the oxidant (e.g., HONO) before the smoke was fed to the chamber. In case of the O_3 and NO_3 radical experiments, chemistry was initiated immediately after the smoke entered the chamber. For the OH radical experiments, chemistry was initiated after the lights were turned on. The chamber was synthetically diluted with clean air to compensate for the volume lost to the sampling instruments. Gas- and particle-phase emissions were sampled through Teflon/copper lines to a suite of instrumentation to measure both the dark and light portions of the chamber experiment. We also performed two blank experiments to account for the influence of the room air.

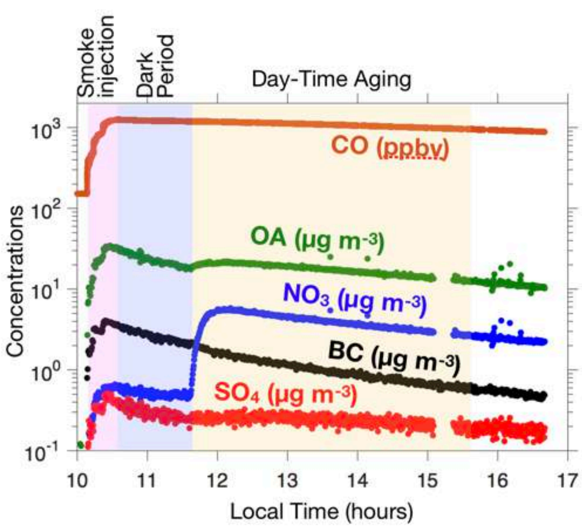


Figure 2. Temporal evolution of CO (gas), organic aerosol (OA), nitrate aerosol (NO_3), sulfate aerosol (SO_4), and black carbon (BC) for the photooxidation experiment performed on October 8th, 2016 with emissions from burning lodgepole pine.

Sample Experiment. A sample of the gas- and particle-phase measurements from an OH radical experiment performed on lodgepole pine on October 8th, 2016 are show in Figure 2. In this experiment, smoke was added to the chamber slightly after 10 am local time for about 20 minutes. The smoke was allowed to homogeneously mix inside the chamber for approximately an hour. The lights were turned on slightly before noon and turned off around 3:30 pm local time. The chamber contents were left unperturbed for an additional hour before turning the instrumentation off and preparing the chamber for the next experiment. All gas- and particle-phase data were corrected for the synthetic dilution using the CO data and assuming that CO was a non-reactive tracer that was not lost to the walls. All particle-phase data were additionally corrected for particle losses to the walls using the black carbon (BC) data and assuming that BC was non-reactive but was lost to the walls. Although the data in Figure 2 are not corrected for dilution or particle wall losses, differences in the trends in the measurements between the dark and light periods suggest that aging resulted in an increase in organic, nitrate, and sulfate aerosol.

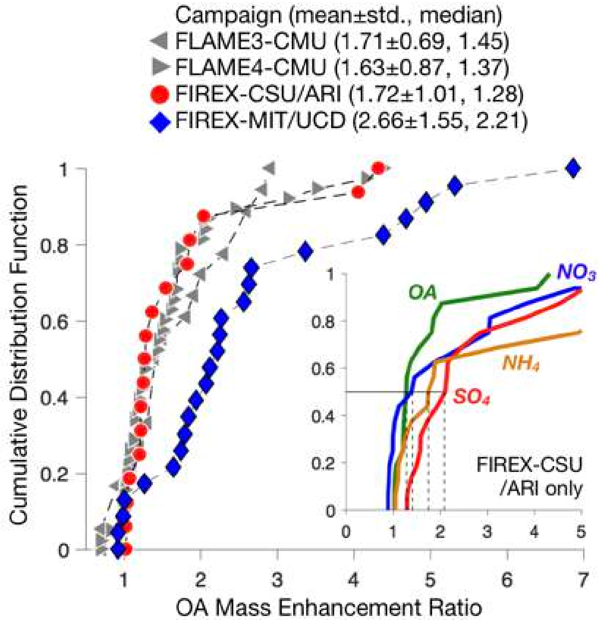


Figure 3. Cumulative distribution function for the organic aerosol (OA) mass enhancement ratios from the day-time experiments (labelled as FIREX-CSU/ARI) compared against those from the mini-chamber operated by Jesse Kroll and Christopher Cappa (labelled as FIREX-MIT/UCD). Also shown are data from previous chamber experiments performed by Hennigan et al. (2011) and Tkacik et al. (2017) at the FSL. The inset shows the cumulative distribution function for the OA, NO_3, SO_4, and NH_4 mass enhancement ratios.

Data Analysis and Preliminary Findings. We computed an aerosol mass enhancement ratio for four aerosol components (OA, NO_3, SO_4, NH_4) by assuming that the particle wall loss rate was well characterized by the reduction in the BC mass concentration. The distribution of aerosol mass enhancement ratios is plotted in Figure 3 and compared against other data from FIREX and earlier chamber studies done at the FSL. The comparison shows that the OA mass enhancement ratios obtained in this work were consistent with those from earlier chamber studies (FLAME3 and FLAME 4) suggesting that there were few differences in the fuels, burn conditions, oxidants, chambers, and sampling techniques across the three different studies. The OA mass enhancement ratios from the MIT/UCD group were higher than our work most likely because we simulated much lower photochemical exposures (2-8 equivalent hours of aging at an OH concentration of 1.5×10^6 molecules cm^{-3}) than the MIT/UCD group (>1 equivalent week of aging at an OH concentration of 1.5×10^6 molecules cm^{-3}). The inorganic aerosol mass enhancement ratios in our work were higher than those for OA but despite the enhancements the inorganic aerosol mass concentrations were only a few percent of the fine aerosol mass. Regardless, the enhancement in inorganic aerosol with aging has implications for water uptake and subsequent uptake and processing of water soluble organic gases in wildfire plumes.

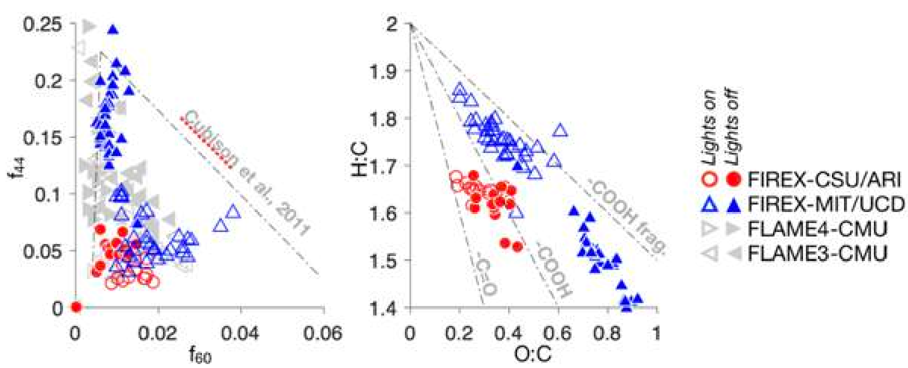


Figure 4. Fresh and aged f_{44} versus f_{60} and H:C versus O:C ratios of the OA for all experiments performed in this work.

Along with the enhancement in OA mass, we observed changes in the OA chemical composition (see Figure 4). We saw an average decrease of 30% in the f_{60} (fraction of OA mass at an m/z ratio of 60) and slightly more than a 50% increase in the f_{44}. On average, we saw a negligible change in the H:C ratio but saw a 30% increase in the O:C ratio These changes were dwarfed by the changes witnessed by the MIT/UCD group presumably from the aforementioned differences in photochemical exposure.

Future Work. We will continue to analyze the chamber data with an immediate focus on understanding the formation of organic nitrates during the night-time and high NO_X experiments. We are also working towards developing an integrated dataset that combines chamber- and flow tube-based measurements from wildfire smoke (~130 experiments) and perform an intercomparison study to understand the variability in OA mass enhancmeent ratios as a function of fuel, burn conditions, oxidant exposure, and experimental artifacts.

Objective 2: Next-generation Organic Aerosol Size and Composition Model

SOM-TOMAS. Over the past month, we have begun the process to integrate the Statistical Oxidation Model (SOM; simulates the chemical evolution of the gas and aerosol species) with the TwO Moment Aerosol Sectional model (TOMAS; simulates the aerosol microphysics) into a Fortran code. The code, once developed and debugged, will be applied first to the FIREX chamber data and then to the other wildfire smoke aging experiments performed during FLAME3 and FLAME4.

Publications:

McDonald, B. C., de Gouw, J. A., Gilman, J. B., Jathar, S. H., Akherati, A., Cappa, C. D., Jimenez, J. L., Lee-Taylor, J., Hayes, P. L., and McKeen, S. A.: Volatile chemical products emerging as largest petrochemical source of urban organic emissions, Science, 359, 760-764, 2018.

Presentations:

Investigating the Role of Aromatic Compounds on Anthropogenic Secondary Organic Aerosol in Urban Environments, 36th American Association for Aerosol Research Conference, October 16-20, 2017, Raleigh, NC. Presented by Ali Akherati.

Atmospheric Formation of Secondary Organic Fine Particles from Combustion Sources: Tractors, Trees, and Traffic, University of Wyoming, November 28, 2017, Laramie, WY. Presented by Shantanu Jathar.

Physicochemical Evolution of Organic Aerosol from Wildfire Emissions, American Geophysical Union, December 11-15, 2017, New Orleans, LA. Presented by Phil Croteau.

Posters:

The Role of Day- and Night-time Aging on the Evolution and Composition of Aerosols from Wildfire Emissions, 36th American Association for Aerosol Research Conference, October 16-20, 2017, Raleigh, NC. Presented by Shantanu Jathar.

The Role of Day- and Night-time Aging on the Evolution and Composition of Aerosols from Wildfire Emissions, International Aerosol Modeling Algorithms, December 6-8, 2017, Davis, CA. Presented by Shantanu Jathar.

COVER PAGE

Federal Agency and Organization Element to Which the Report is Submitted:
NOAA/OAR/OWAQ

Federal Grant Number Assigned by Agency: NA15OAR4590233

Project Title: Multi-disciplinary investigation of concurrent tornadoes and flash floods in the Southeastern US

Project Director/Principal Investigator (PD/PI): Russ Schumacher, Associate Professor, Department of Atmospheric Science, Colorado State University. Email: russ.schumacher@colostate.edu; phone: 970.491.8084

Submission Date: 29 December 2017

Recipient Organization: Colorado State University/Cooperative Institute for Research in the Atmosphere, Fort Collins, Colorado

Project/Grant Period (Start Date, End Date): 10/01/2015 - 09/30/2017

Reporting Period End Date: 9/30/2017

Report Term or Frequency (annual, semi-annual, quarterly, other): semi-annual

Final Annual Report? Yes

1. ACCOMPLISHMENTS

What were the major proposed goals, objectives, and tasks of this project, and what was accomplished this period under each task?

Are the proposed project tasks on schedule? What is the cumulative percent toward completion of each task and the due dates? (table recommended)

What were the major completed milestones this period, and how do they compare to your proposed milestones? (planned vs. actuals table recommended)

As outlined in the original proposal, the specific objectives of this project are as follows:

- **Investigate the detailed meteorological conditions in concurrent, co-located tornado and flash flood (TORFF) events in the southeastern US, including how they evolve in time, and how they differ from cases where only the individual hazards occur.** Using readily available radar, precipitation, and reanalysis datasets, we will quantitatively identify the meteorological factors that commonly lead to TORFF events in the southeast, along with one or two detailed case studies of particularly destructive events.
- **Investigate the NWS warning process during multi-hazard events, and document the unique challenges in these events.** By conducting observational analysis and interviews with NWS forecasters in the southeast, we will examine the challenges they encounter in preparing for, identifying, and issuing warnings with enough lead time for appropriate societal response.

The proposed work plan from the original proposal is reproduced in the table below, and the current status of these tasks is given in the right-hand column.

Time	Meteorological research	Social science research	Accomplishments/ completion
Months 1-2 (Oct-Nov 2015)	Compile database of TORFF events in southeast US, begin analysis of these cases; coordinate integration of meteorological and social-science research plan	Review past TORFF warning issuances for SE US; create interview protocols and apply for institutional review board (IRB) approval; coordinate integration of meteorological and social science research plan	**Complete**
Months 3-5 (Dec 2015-Feb 2016)	Continue analysis of aggregated SE TORFF events; begin case study analysis	Coordinate interviews and observations at participating National Weather Service (NWS) office	**Complete**

Months 6-9 (Mar 2016- June 2016)	Complete analysis of aggregated SE TORFF events; continue case study analysis; participate in field-phase intensive observing periods (IOPs) as appropriate	Travel to NWS office for interviews and observations during identified 3-week severe weather window; send out audio files for interview transcription; begin coding interviews and observations	**Complete**
Months 10-12 (July- Sept 2016)	Complete and synthesize meteorological studies, prepare report and paper for publication, present research at AMS severe local storms (SLS) and/or NWA conference	Complete coding and analyzing interviews and observations; synthesize results; prepare report and paper for publication; present research at AMS SLS and/or NWA conference	**Complete (manuscripts have been submitted for publication but are still under review)**

The meteorological research for this project covered numerous topics, which are summarized as (1a) analyzing the meteorology of TORFFs in the southeast US in an aggregate sense; (1b) analyzing the observed TORFF that occurred during the VORTEX-SE field phase; (1c) conducting numerical simulations to understand the processes supporting concurrent heavy precipitation and strong low-level rotation; and (1d) analyzing the climatology of cold-season tornadoes in the southeast US. This work was conducted by PI Russ Schumacher and graduate students Erik Nielsen, Greg Herman, and Sam Childs.

For (1a), we compiled a database of observed TORFF events in the southeast and an aggregate analysis, including standardized anomalies and composite analysis of meteorological fields. Furthermore, we established a website for near-real-time monitoring of overlapping tornado and flash-flood warnings nationwide, with graphics available at: http://schumacher.atmos.colostate.edu/weather/TORFF_rt/ . There were 211 overlapping warning polygons in 2016, which is among the fewest in the record. There have been 254 overlapping warnings in 2017 as of this writing. The results of this research were presented at the AMS Severe Local Storms conference in November 2016 and the AMS Annual Meeting in January 2017, and at the VORTEX-SE workshop in November 2017.

For (1b), we analyzed the one confirmed TORFF event that occurred during the first VORTEX-SE observing period in 2016. This event occurred when both physical and social scientists were conducting observations. An EF-1 tornado and flash flooding from a quasi-linear convective system (QLCS) struck a small town and surrounding rural areas (Fig. 1). Both the tornado track and flash flood local storm reports (LSRs) fell within an overlapping tornado and flash flood warnings (Fig. 1). We conducted a case-study simulation of this event using the Weather Research and Forecasting (WRF) model with initial conditions coming from a member of the NCAR ensemble (courtesy of Glen Romine). This simulation produced a reasonably accurate representation of the observed precipitation, and also showed strong updraft helicity and moderately heavy hourly rainfall near the time and place when it was observed. The atmospheric profile from the simulation showed a stable boundary layer in the inflow region, but extremely strong low-level vertical wind shear. These results were presented at the AMS Severe Local Storms conference in November 2016, and the AMS annual meeting in January 2017. Erik Nielsen's poster at the annual meeting received the 2nd place student poster award for the special symposium on severe storms.

For (1c), we have used observations of TORFF environments, including those in the southeast, to inform a series of numerical experiments that test the influence of low-level vertical wind shear on rainfall production. It is well known that strong low-level shear is one of the factors that promotes tornadogenesis, and our work has shown that many cases of extreme rainfall rates also occur with strong low-level shear. The numerical simulations bear this out, with the runs having strong low-level shear having strong low-level rotation, and also the heaviest rainfall. Furthermore, the dynamically forced ascent owing to the rotation is directly connected to the rainfall accumulations. These results help to explain the abundance of TORFFs that have been observed, and also the dynamics of the storms that produce them. This work has been presented at several conferences, and a manuscript (led by Erik Nielsen) has been submitted for publication in *Journal of the Atmospheric Sciences*.

For (1d), we have analyzed long-term trends in cold-season tornadoes and the characteristics of their environments in the southeast. After accounting (to the extent possible) for reporting biases, etc., we found a long-term increase in cold-season tornadoes in the southeast, with much of that increase coming in November. The environmental conditions associated with active vs. less-active cold seasons in terms of tornadoes were compared, and we also compared the environmental conditions of cold-season tornadoes to those occurring at other times of the year. Sam Childs has led this research, which he presented at the AMS Severe Local Storms conference in November 2016 and received the 3rd place student award for oral presentations. This work has also been submitted for publication in *Weather and Forecasting*, and has been returned for minor revisions.

The social science research for this project was led by Jen Henderson, who conducted observations and interviews at a NWS office for 2.5 weeks during January-April 2016. In total, this work involved 88 hours of ethnographic observations, 11 interviews with NWS staff, interviews with two emergency managers, and analysis of NWS and broadcast media products and policies. Results suggest that TORFFs are created through an amplification of tornado threats over flash flood threats at multiple scales. Specifically, this work points to five specific ways that TORFFS are co-produced: definitions, terminology, office organization, national office influence, and technologies.

First, NWS forecaster definitions and perceptions of threats: In this office, tornadoes were defined by staff as significantly more unpredictable, dangerous and deadly; whereas flash flooding is dangerous only if people are driving through flooded roads that may be compromised. In effect, tornadoes are always a threat; flash flooding is, as one forecaster said, “just water.” Similarly, forecasters perceive the public and their partners as more aware of and concerned about tornadoes and less so about flash floods.

Second, terminology used in website and social media products highlights the threat and danger of tornadoes over flash flooding, as well. In the headlines for graphics and uncertainty products, the descriptive phrase, “Heavy Rain,” is used to describe significant flash flood threats whereas the more risk-oriented language, “Severe Weather,” is used to describe tornadoes, hail, and wind threats. This language was then echoed by broadcast media. In interviews, forecasters acknowledged that they used “heavy rain” to express uncertainty about flash flooding whereas, with tornadoes, modifiers such as “possible” and “likely” were used to express uncertainty.

Third, the organization of warning operations also encourages forecasters to attend to tornadoes more so than flash floods in two ways: 1) the warning desks include several staff assigned to sectorize radar for tornado detection and warning issuance; flash flooding is often a “secondary concern” and so has fewer staff assigned during warning operations. 2) those in the office with the most hydrologic expertise, in this case the hydrologist, are usually not on radar during warnings; instead this person is mainly responsible for river flooding in separate software with a different network of expertise from the RFC.

Fourth, while forecasters consult both Storm Prediction Center (SPC) and Weather Prediction Center (WPC) products and consult through 12 Planet (a secure chat interface between NWS offices), SPC Outlooks can factor more heavily in forecaster decisions than WPC products. Mention of possible tornadoes in products from the SPC on day 7 overdetermined increased messaging through local WFO AFDs, website graphics, and webinars for tornadoes in this office; this influence created difficult choices later on for how to downgrade the tornado threat when flash flooding became more of a concern.

Finally, Dual Polarization radar was heavily used and emphasized by the forecaster in charge in the office as a tool to help adjudicate warnings. The Science and Operations Officer (SOO) had conducted research about the value of Dual Pol radar in the Southeast and as an instrument for detecting tornadoes, and this radar was highly trusted by forecasters. As guidance for flash floods, the Flash Flood Monitoring and Prediction (FFMP) tool was not as trusted by the office during this event. It was underestimating the rainfall given the antecedent conditions of flooding in the area; the forecaster assigned to flash flood detection called its estimates “garbage” and issued flash flood warnings based on his internal beliefs about the threat and reports of flooding.

Such differences between flash flooding and tornado practices, policies, and beliefs, may propagate throughout the warning system, in news media and in partner conversations, shaping how different publics react to these threats. Other findings worth mentioning include the need to look at other overlapping hazards that can co-occur in a county warning area, including flash flood and severe thunderstorm warnings with “tornado possible” tags. In several instances in this office, a “tor possible” tag triggers similar language to a tornado warning and can conflict with messages in flash flood warnings; and there are many of these variations of TORFFs. For example, recent hurricanes also suggest the need to better understand public experiences with overlapping storm surge and tornado warnings, or general flooding and tornadoes.

Importantly, while this study revealed several ways that tornado threats can be collectively amplified within a forecast office and partner communities, we still understand little about how people experience, perceive, and act on co-occurring warnings. During a damage survey after the TORFF, one woman whose home was impacted by flash flooding and the tornado noted she and her daughter were sheltering in the hall. “Then the tornado blew the door open and all this water rushed in” the house. Other examples suggest that those in mobile homes who must evacuate because of the tornado will encounter flooded and potentially damaged roads. Antecedent flooding conditions likewise can affect people’s ability to evacuate in towns where there are few basements and people must leave their homes to find shelter.

Results of this research were presented at several NWA and AMS meetings over the course of the project, along with the VORTEX-SE workshop in November 2017. Furthermore, Jen Henderson led a webinar on social science findings for the partnering NWS office in November 2017. We are currently in the process of writing a manuscript that focuses on the integration of meteorological and social-science results from this project; we expect to submit that manuscript early in 2018. We have included as an attachment the poster from the 2017 VORTEX-SE workshop that provides an overview and outline of some of the work that will be included in the manuscript.

What opportunities for training and professional development has the project provided?

The project has partially or fully supported three graduate students (Erik Nielsen, Greg Herman, Sam Childs) at Colorado State University as they conduct research toward their graduate degrees. Furthermore, the project supported Jen Henderson as she completed her PhD research in science and technology in society, and her ongoing research after finishing the degree. All participants in the project have been exposed to research that integrates meteorological and social science methods.

How were the results disseminated to communities of interest?

Much of the effort in this reporting period involved disseminating results at conferences, and also transitioning our results into the associated VORTEX-SE project in 2016-2017. In total, nine conference presentations were made on this work, summarized below:

A list of conference presentations made during the reporting period is given below:

- TORFF: Operational Challenges While Warning for Multiple Hazards, 42nd National Weather Association Annual Meeting, September 2016 (Jen Henderson)

- Tornado and Flash Flood (TORFF) Warnings: Operational Challenges during Multiple Hazards (Invited Presentation), 97th American Meteorological Society Annual Meeting, January 2017 (Jen Henderson)
- An Updated U.S. Geographic Distribution of Concurrent, Collocated Tornado and Flash Flood Events and Look at those Observed during the First Year of VORTEX-SE, 97th American Meteorological Society Annual Meeting, January 2017 (Erik Nielsen)
- "Cold-season Tornadoes: Climatological, Meteorological, and Social Perspectives", 28th Conference on Severe Local Storms, American Meteorological Society, Portland, OR, November 2016 (Sam Childs)
- "Predicting 'Double Impact' Concurrent and Collocated Tornadoes and Flash Floods", 28th Conference on Severe Local Storms, American Meteorological Society, Portland, OR, November 2016 (Greg Herman)
- **"**A Closer Look at Concurrent, Collocated Tornado and Flash Flood Events Observed during the First Year of VORTEX-SE", 28th Conference on Severe Local Storms, American Meteorological Society, Portland, OR, November 2016 (Erik Nielsen)
- "Extreme short-term precipitation from supercells and mesovortices: Insights from numerical simulations," 28th Conference on Severe Local Storms, American Meteorological Society, Portland, OR, November 2016 (Russ Schumacher)
- "Observations of Extreme Short-term Precipitation Associated with Supercells and Mesovortices", 28th Conference on Severe Local Storms, American Meteorological Society, Portland, OR, November 2016 (Erik Nielsen)
- "Multi-disciplinary investigation of concurrent tornadoes and flash floods in the Southeastern US", VORTEX-SE workshop, Huntsville, AL, November 2017 (Russ Schumacher and Jen Henderson)

Additionally, Jen Henderson gave a webinar discussing her results to relevant NWS offices in November 2017, and Sam Childs presented (remotely) to the Huntsville AMS chapter on his research in November 2017.

What do you plan to do during the next reporting period to accomplish the goals and objectives?

n/a (the project is now complete)

2. PRODUCTS

What were the major completed products or deliverables this period, and how do they compare to your proposed deliverables? (planned vs. actuals table recommended)

Proposed deliverable	**Status**
Dissemination of aggregate TORFF data for southeast	Complete

Dissemination of analysis of forecaster challenges	Complete
Webinar with partnering NWS office	Complete
Journal article	Multiple manuscripts have been submitted and are under review
Final report	(This report).

What has the project produced?

Near-real-time TORFF monitoring website:
http://schumacher.atmos.colostate.edu/weather/TORFF_rt/

See also the list of conference presentations given above.

Several manuscripts have been submitted and are in the peer review process.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

What individuals have worked on this project?

PI Russ Schumacher, graduate research assistants Erik Nielsen, Greg Herman, and Sam Childs, student researcher Jen Henderson, and research associates Matthew Bishop and Ammon Redman.

Has there been a change in the PD/PI(s) or senior/key personnel since the last reporting period?

No changes.

What other organizations have been involved as partners? Have other collaborators or contacts been involved?

We collaborated with Glen Romine of NCAR in the design of the numerical model simulations.

4. IMPACT

What was the impact on the development of the principal discipline(s) of the project?

The outcomes of this work will improve understanding, and potentially prediction, of weather events with multiple hazards.

What was the impact on other disciplines?

By integrating meteorological information with social science methods, this project will inform future improvements in how operational forecasters approach the challenge of multi-hazard weather events.

What was the impact on the development of human resources?

None yet.

What was the impact on teaching and educational experiences?

Several graduate students have been supported as they conduct research toward their degrees. These students will have obtained skills in data analysis and modeling from multiple disciplinary perspectives.

What was the impact on physical, institutional, and information resources that form infrastructure?

N/A

What was the impact on technology transfer?

N/A

What was the impact on society beyond science and technology?

By examining the processes by which NWS forecasters issue warnings in multi-hazard events, it may ultimately lead to improvements in how those forecasts and warnings are disseminated and communicated.

What percentage of the award's budget was spent in a foreign country(ies)?

0%

5. CHANGES/PROBLEMS

Describe the following:

-Changes in approach and reasons for the change.
-Actual or anticipated problems or delays and actions or plans to resolve them.
-Changes that had a significant impact on expenditures.
-Change of primary performance site location from that originally proposed.

N/A

6. SPECIAL REPORTING REQUIREMENTS

N/A

7. BUDGETARY INFORMATION

Is the project on budget? Much of the quantitative budget information is submitted separately in the Federal Financial Report. However, describe here any major budget anomalies or deviations from the original planned budget expenditure plan and why.

N/A

8. PROJECT OUTCOMES

What are the outcomes of the award?

The outcomes include information about TORFF events in the southeast US from both a meteorological and warning/communication perspective.

Are performance measures defined in the proposal being achieved and to what extent?

We believe that we successfully achieved the goals that were outlined in the original proposal.

Annual Progress Report

Near-field Characterization of Biomass Burning Plumes

Award Number: NA17OAR4310010
Principal Investigator: Dr. Delphine K. Farmer
Institution: Colorado State University, Fort Collins, CO 80521
Co-investigators: Dr. Sonia Kreidenweis, Dr. Chris Kummerow
Start Date: July 1, 2017
Period Covered: July 1, 2017 – March 15, 2018

I Project Statement

This project is focused on investigating the near-field chemistry of biomass burning plumes as part of a larger aircraft-based measurement campaign, including sampling the source for extended periods and characterizing the evolution of emissions within the first few hours of aging. The proposed work includes these four specific objectives:
(1) To characterize the composition of biomass burning aerosol sources, and, in particular, emission ratios and their variability,
(2) To investigate the physical evolution of emissions in the near field, with emphasis on dilution effects,
(3) To characterize the emission ratios of black carbon, and
(4) To determine the contributions and variability in organic nitrate components of biomass burning aerosol in the near-field.

II Accomplishments

Summary: We have made clear progress in preparing the high resolution time-of-flight aerosol mass spectrometer for aircraft measurements on the NSF C-130 aircraft this summer, and are confident our instrument is adequately robust, calibrated and prepared for the measurements. In particular, we have:

- Successfully conducted three test flights, collecting and analyzing aerosol composition data in the Front Range.
- Quantified the size-dependence of the aerosol transmission efficiency in the laboratory for both ammonium nitrate and ammonium sulfate, in order to maximize the quality of data collected. We found a substantial size-dependence, and as a result have: tightened and cleaned the aerosol focusing lens, changed the aerosol vaporizer from the novel 'capture vaporizer' to a more traditional vaporizer, and calibrated all instrument flows. Further quality testing of the instrument will take place over the next two months to characterize the improved setup.
- Modified the internal vaporizer and electron source of the instrument to be more vibration resistant by adding ceramic spacers to internal wiring
- Tested the pressure controlled inlet and calibrated the instrument for inorganic particles as a function of particle size and composition. The next step is to repeat the characterization for organic particles, including organic nitrates.

IV Presentations and Publications for this Period

None yet.

Annual Progress Report

Observational constraints on the mechanisms that control size- and chemistry-resolved aerosol fluxes over a Colorado forest

Award Number:	NA14OAR4310141
Principal Investigator:	Dr. Delphine K. Farmer
Institution:	Colorado State University, Fort Collins, CO 80523
Co-investigators:	Dr. Chris Kummerow
Start Date:	August 1, 2014
Period Covered:	March 14, 2017 – March 15, 2018

I Project Statement

This project is focused on providing observational constraints on dry deposition of organic compounds in the gas and particle phase, and the extent to which forest-atmosphere exchange controls the fate of organic carbon in the atmosphere. The proposed work tackles the following questions:

1. Which chemical and physical components dominate the aerosol flux budget, and how do they vary seasonally?
2. How does dry deposition of accumulation mode aerosol over a temperate forest vary seasonally, and what is the impact of this sink on aerosol lifetime?
3. How important are the fluxes of semi-volatile organic compounds in controlling organic aerosol deposition?

II Accomplishments

Summary: Progress during the third year of research includes substantial advances in the analysis of flux measurements from five seasons at Manitou Experimental Forest. In particular, five papers are in progress and will be submitted shortly. These include: (A) a paper describing seasonal variability in organic acid fluxes at Manitou Experimental Forest (Fulgham et al.; to be submitted to Atmospheric Chemistry and Physics), (B) a paper describing total particle number fluxes at Manitou Experimental Forest (DeBolt et al.; to be submitted to Aerosol Science and Techology), (C) a paper describing wet deposition of carbon and nitrogen at the site (Riches et al.; to be submitted to Atmospheric Environment), and (D) soils as source of formic acid. In addition, papers describing (F) the overall carbon balance of the Manitou Experimental Forest site are in progress, and will be submitted over the next few months.

(A) *Seasonal cycles in organic acid fluxes over a ponderosa pine forest*
[Fulgham et al. To be submitted to Atmospheric Chemistry and Physics in April 2018]

This manuscript describes our measurements of eddy covariance flues of formic acid, butyric acid, methacrylic acid, and propanoic acid over Manitou Experimental Forest in summer 2015 and the four seasons of 2016. The manuscript includes descriptions of the measurement approach, analysis techniques, and method validation, including extensive spectral analysis of the time-of-flight chemical ionization mass spectrometry data. We find upward fluxes of formic and butyric acid in all seasons – though the magnitude of the fluxes are substantially greater in summer than in winter, consistent with a temperature dependence. These fluxes suggest ecosystem sources of these compounds to the atmosphere; wintertime fluxes are consistent with snow sources, potentially from methanogenic bacteria. Butryic acid may be indicative of fungal activity. Methacrylic and propanoic acid emissions are limited to summer months. We use these observations to integrate soil chamber measurements and branch enclosure measurements to identify the ecosystem flux budgets of these organic acids through the seasons.

(B) Total particle number fluxes over Manitou Experimental Forest
[DeBolt et al. To be submitted to Aerosol Science and Technology. May 2018]

This manuscript describes deposition of aerosol particles at Manitou Experimental Forest from measurements throughout 2016. Deposition fluxes, as determined by eddy covariance using an ultrahigh sensitivity aerosol spectrometry, follow aerosol number concentration. Aerosol concentrations and deposition fluxes are higher in the summer than spring and fall; winter time concentrations tend to be much smaller. We observe an increase in fluxes with friction velocity, a measure for turbulence; this relationship allows us to compare fluxes to studies in other locations, and contrast environments.

(C) Seasonal variability in wet deposition of organic carbon and nitrogen in the Rocky Mountains
[Riches et al. To be submitted to Atmospheric Environment. May 2018]

We use precipitation measurements collected from Manitou Experimental Forest to contribute to the limited literature on wet deposition as a loss process for organic carbon. We find that the concentration of organic carbon correlates to biogenic emissions and plant activity, indicating that wet deposition can be a substantial sink for biogenic carbon.

(D) Soils as a source of formic acid
[Mielnik et al. To be submitted to Environmental Science: Processes and Impacts as Invited Manuscript June 2018]

This manuscript describes laboratory and field chamber experiments of formic acid emissions from soils. We find soil sources of these acids increase with soil moisture and temperature, but remain a minor ecosystem source of these organic acids to the global atmosphere.

IV Presentations and Publications during the report period

D.K. Farmer. From ozone postcards to glacier grime: New frontiers in measuring sources and sinks of air pollution. Pacific Conference on Spectroscopy and Dynamics, San Diego, CA, January 2018. Invited Talk.

D.K. Farmer. Developing CIMS for atmospheric chemistry field measurements: Targeted quantitative and non-targeted qualitative analysis of reactive trace gases. Colorado Biological Mass Spectrometry Society, Broomfield CO, November 2017. Invited Talk.

D. K. Farmer. A new chemical ionization mass spectrometer: Applications to atmospheric chemistry. Arnold and Mabel Beckman Foundation Annual Symposium. August 2017. Invited Talk

D.K. Farmer, S. R. Fulgham, H.DeBolt, J. Ortega, E.Emerson, G. McMeeking, J. Schwarz. Investigating biosphere-atmosphere exchange of oxidized organic carbon, particles and black carbon. AGU Fall Meeting, New Orleans LA. Fall 2017. Oral presentation

H. DeBolt, J. Ortega, S.R. Fulgham, D.K. Farmer. Seasonal cycles of particle number fluxes over a forest. American Association for Aerosol Research. Raleigh, NC. Fall 2017. Oral presentation.

D. K. Farmer. Investigating biosphere-atmosphere exchange: Evidence and implications. Ozone deposition workshop. NY. 2017. Oral presentation.

National Oceanic and Atmospheric Administration

Grant # NA16OAR4590230

Quantifying Stochastic Forcing at Convective Scales

Principal Investigator: David Randall, Professor, randall@atmos.colostate.edu, (970) 491-8474

November 12, 2017

Colorado State University, Fort Collins, Colorado 80523

Project/Grant Period: October 1, 2016 to September 30, 2018

Reporting Period End Date: September 30, 2017

Semi-Annual Report

Final Annual Report? No

1. ACCOMPLISHMENTS

We proposed to provide the Environmental Modeling Center (EMC), which is one of NOAA's National Centers for Environmental Prediction (NCEP), with a modeling tool, called MP-NGGPS, that can be used to generate initial conditions for ensemble members that differ partially or even exclusively through stochastic perturbations of the parameterized cloud systems. This is beneficial because of the potential importance of convectively excited perturbations generating spread among the ensemble members.

In our proposal, the two tasks listed for Year 1 were:

1. Create and debug the MP-NGGPS.
2. Begin testing the use of MP-NGGPS to generate initial perturbations for SP-NGGPS and GFS ensembles, as discussed above and summarized in Fig. 7.

Task 1 is now 85% complete. We have coded a version of NEMS/GSM where multiple instances of the SAM cloud-resolving model with two moment microphysics replace the conventional convection, precipitation and turbulence parameterizations (multiparameterization). Some portions of this code have been tested with offline drivers. Debugging and testing of the full model awaits access to NOAA HPC resource theia, which depends on a background investigation that is underway. Debugging of the interface of the physics to the dynamical core remains but we anticipate will be quickly done once we have HPC access.

Task 2 has not started yet because it depends on the completion of Task 1.

In the process of our work on Task 1, two important milestones were installing the cloud-resolving model as a super-parameterization in the NGGPS.

Our project has not yet resulted in any training or professional development.

We will be presenting a paper on our work at the January 2018 meeting of the American Meteorological Society.

Year 2, we will complete creating and debugging the the MP-NGGPS, and carry out Task 2 as described above. Because of a delay in obtaining supercomputer access, discussed in Section 5 below, our work has been delayed by several months.

This may delay the completion of our project for several months beyond September 30, 2018. We anticipate that we can stretch our budget out to cover the additional calendar months, provided that NOAA gives us permission to do. In other words, we expect to be able to complete the project within the original budget amount, despite the delay.

2. PRODUCTS

No products or deliverables were planned for this period, and none were created.

As discussed above, our project has created a super-parameterized version of the NGGPS, that runs on the THEIA supercomputer.

3. PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

The work has been carried out by Donald Dazlich and David Randall.

There has been no change in the senior personnel on the project.

We have not partnered with any other organizations.

4. IMPACT

Our project has not yet had any impact on weather forecasting, although we anticipate that it will as it nears completion.

Our project has not had any impact on other disciplines.

Our project has not had any impact on the development of human resources.

Our project has not had nay impact on teaching and educational experiences.

Our project has not had any impact on physical, institutional, and information resources that form infrastructure.

Our creation of the super-parameterized NGGPS represents a technology transfer from our university to NOAA.

Our project has not yet had any impact on society beyond science and technology.

None of the award's budget was spent in any foreign country.

5. CHANGES/PROBLEMS

Since August 2017, a major problem has been that we have been unable to gain access to Theia, the NOAA supercomputer that we need to use for this work. We have communicated with many NAOO personnel in an attempt to resolve this problem. Although we do not understand exactly what the issues have been, it appears that there was some confusion about the nature of our NOAA support. We were funded under MAPP project that ended in August 2017, just as our request for Theia access was being processed. Apparently someone in the chain of command thought that we were requesting Theia access in connection with the ending MAPP project (rather than the current JTTI project), and for that reason our request was not granted. As of today (November 12, 2017) we still do not have access to Theia, although we think (we are not certain) that approval of our request is getting close.

This delay in access to Theia has impacted our progress and will cause our schedule to slip by several months.

6. SPECIAL REPORTING REQUIREMENTS

We are currently at Readiness Level 6. This is unchanged from the start of our project.

Our plan for Transition to Operations was approved in July, 2017.

7. BUDGETARY INFORMATION

Our project is currently on budget.

8. PROJECT OUTCOMES

Our award does not yet have any outcomes.

We have made good progress towards completion of the two Tasks planned for Year 1.

Final Report to the National Oceanographic and Atmospheric Administration

Office of Oceanic and Atmospheric Research (OAR)

for

A CPT for Improving Turbulence and Cloud Processes in the NCEP Global Models

Award Number: NA13OAR4310103

PIs/PDs: Christian Kummerow, David Randall

Award Period: 09/01/2013 - 08/31/2017

1. Introduction

David Randall of Colorado State University (CSU) participated as a Principal Investigator on a Climate Process Team (CPT) led by Steven Krueger of the University of Utah. CSU's participation was organized through CSU's Cooperative Institute for Research in the Atmosphere (CIRA), directed by Christian Kummerow. The other Investigators on the project were Peter Bogenschutz, now at the Lawrence Livermore National Laboratory, Shrinivas Moorthi of the National Centers for Environmental Prediction (NCEP), Andrew Gettelman of the National Center for Atmospheric Research and Robert Pincus of the University of Colorado Cooperative Institute for Research in Environmental Sciences (CIRES).

The main objectives of the CPT were as follows:

1. Improve the NCEP global models by installing an integrated, self-consistent descrip- tion of turbulence, clouds, deep convection, and the interactions between clouds and radiative and microphysical processes.
2. Unify the representation of turbulence and SGS cloud processes and the representation of subgrid-scale (SGS) deep convective precipitation and grid-scale precipitation as the horizontal resolution decreases.
3. Improve the representation of small-scale phenomena by implementing a PDF-based SGS turbulence and cloudiness scheme that will replace the boundary layer turbulence scheme, the shallow convection scheme, and the cloud fraction schemes in the GFS and CFS.
4. Improve the treatment of deep convection by introducing a unified parameterization that scales continuously between the simulation of individual clouds when and where the grid spacing is sufficiently fine and the behavior of a conventional parameterization of deep convection when and where the grid spacing is coarse.

5. Improve the representation of the interactions of clouds, radiation, and microphysics in the GFS/CFS by using the additional information provided by the PDF-based SGS cloud scheme.
6. Evaluate the impacts of the model upgrades with metrics used by the NCEP short- range and seasonal forecast operations.

The CSU part of the project related to Objective 4 above, which is focused on the problem of cumulus parameterization.

2. Scientific background

One of the primary goals of our CPT has been to develop and implement a version of the Unified Parameterization (described below) with multiple updraft types. As discussed by Jung and Arakawa (2004), the nature of the subgrid-scale (SGS) physical processes in a numerical model is strongly dependent on the horizontal grid spacing. In particular, cumulus updrafts and downdrafts, which produce strong vertical fluxes of energy and other quantities, are SGS for the horizontal grid spacings commonly used by current climate models, in the range 250 km to 25 km, but are at least partially resolved in models with grid spacings of a few kilometers or less. In the near future, such "cloud-resolving" (or "cloud-permitting") grid spacings will be used in some operational global forecast models. Microphysical processes are of course SGS for all climate and forecast models, regardless of horizontal grid spacing, and this will be true for the indefinite future. The same is true for turbulent processes and radiative transfer.

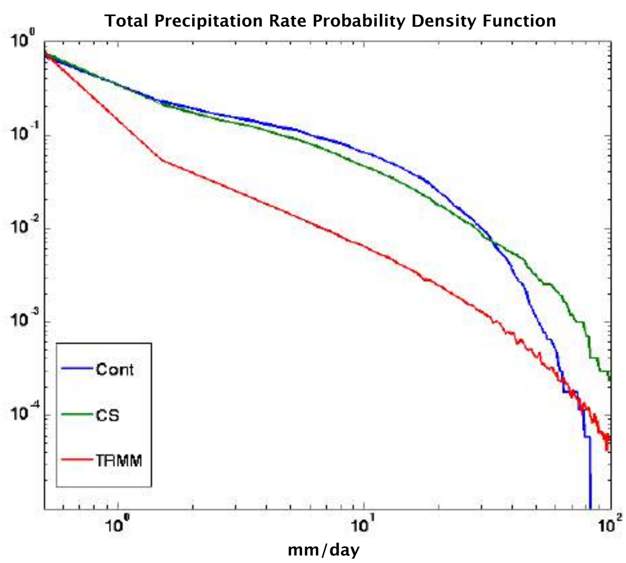


Figure 1: Total precipitation probability dis- tribution function for June 2011, 50 S to 50 N. Model outputs (30-day integrations at T62: Control, default GFS, and CS, GFS with Chikira-Sugiyama convection) are 6-hour av- erages on a 2.5-degree grid. TRMM data has been time-averaged to 6 hours and spatially averaged to a 2.5-degree grid.

Arakawa et al. (2011), Arakawa and Wu (2013; hereafter AW) and Wu and Arakawa (2014) presented the conceptual basis for a "Unified Parameterization" (hereafter UP) of cumulus convection that is resolution-independent and therefore suitable for use in models with a wide range of horizontal grid spacings, including cloud-resolving models. The UP can be regarded as a *framework* that makes use of a user-supplied conventional cumulus parameterization. AW described the UP in terms of a simplified conventional parameterization that includes a single cumulus updraft "type," and no convective downdrafts. A regional cloud-resolving model (CRM) was used to guide the design of the UP.

The main idea of the Unified Parameterization is that in a model with horizontal grid spacings comparable to or slightly larger than the scale of individual convective clouds, it is possible for a convective updraft to fill a significant fraction or even all of a grid cell. The Unified Parameterization therefore uses a closure assumption for σ , the fractional of the grid cell's area that is occupied by the updraft. Earlier in this project, we generalized the closure assumption to allow a spectrum of updrafts and also downdrafts. This generalized version of the Unified Parameterization is currently being tested in the GFS.

3. Initial testing

In our work, we implemented the Unified Parameterization using the conventional cumulus parameterization of Chikira and Sugiyama (2010; see also Chikira, 2010), which we refer to below as the CS parameterization. With assistance from S. Moorthi of NCEP, we installed the CS parameterization into the NCEP's Global Forecast System (GFS). Moorthi tuned the CS scheme for the GFS by allowing the cloud base maximum vertical velocity to vary with resolution.

The scheme was initially tested with 30-day integrations of the control model and the new scheme. These were initialized to 0Z 1 June 2011 and run at both T62 and T126 resolutions. Comparison of several output fields between the default and CS runs showed CS to perform satisfactorily. A comparison of the probability distribution functions of the total precipitation rates between the two models and TRMM satellite data (see Figure 1) show the CS can better represent the frequency of heavy rain events compared to the control. In these initial tests, the two models were integrated for one simulated year, with climatological SSTs, using very low T62 resolution. Monthly mean maps of CS fields compared well with the control model. Tropical intraseasonal variability was also compared and CS represented this well in the 850mb and 200mb zonal wind fields. CS reduced the top of atmosphere radiative imbalance in the annually- averaged global mean compared to the control (see Figure 2). These integrations are now being repeated at T126 resolution.

	Control	C-S
OLR	239.66	238.61
TOA net down SW	254.40	248.90
TOA net down rad	14.75	10.29
SFC latent heat flux	88.52	88.10
SFC sensible heat flux	15.65	14.60
SFC net up LW	63.06	61.73
SFC net down SW	178.40	172.85
SFC net down energy flux	11.17	8.41

Figure 2: Annually-averaged, global mean en- ergy fluxes at top of atmosphere and surface. All units W/m2. From one year T62 integrations with climatological SST with Chikira- Sugiyama convection (C-S) and without (Control).

Following these initial, low-resolution tests, the CS scheme was implemented as an option in the NOAA Environmental Modeling System (NEMS) and tested using T2046L64 resolution. As shown in Fig. 3,a forecast made from October 24, 00Z, 2012 produced a fairly good forecast for Hurricane Sandy.

4. Modifications

Next, we modified the CS parameterization to include the Arakawa-Wu diagnosis of σ , which was discussed in section 2 above. The Unified Parameterization is derived by removing the assumption of small σ (convec- tive updraft area fraction). When the grid spacing is coarse, small values of σ are expected, but when the grid spacing is fine it is possible for σ to approach

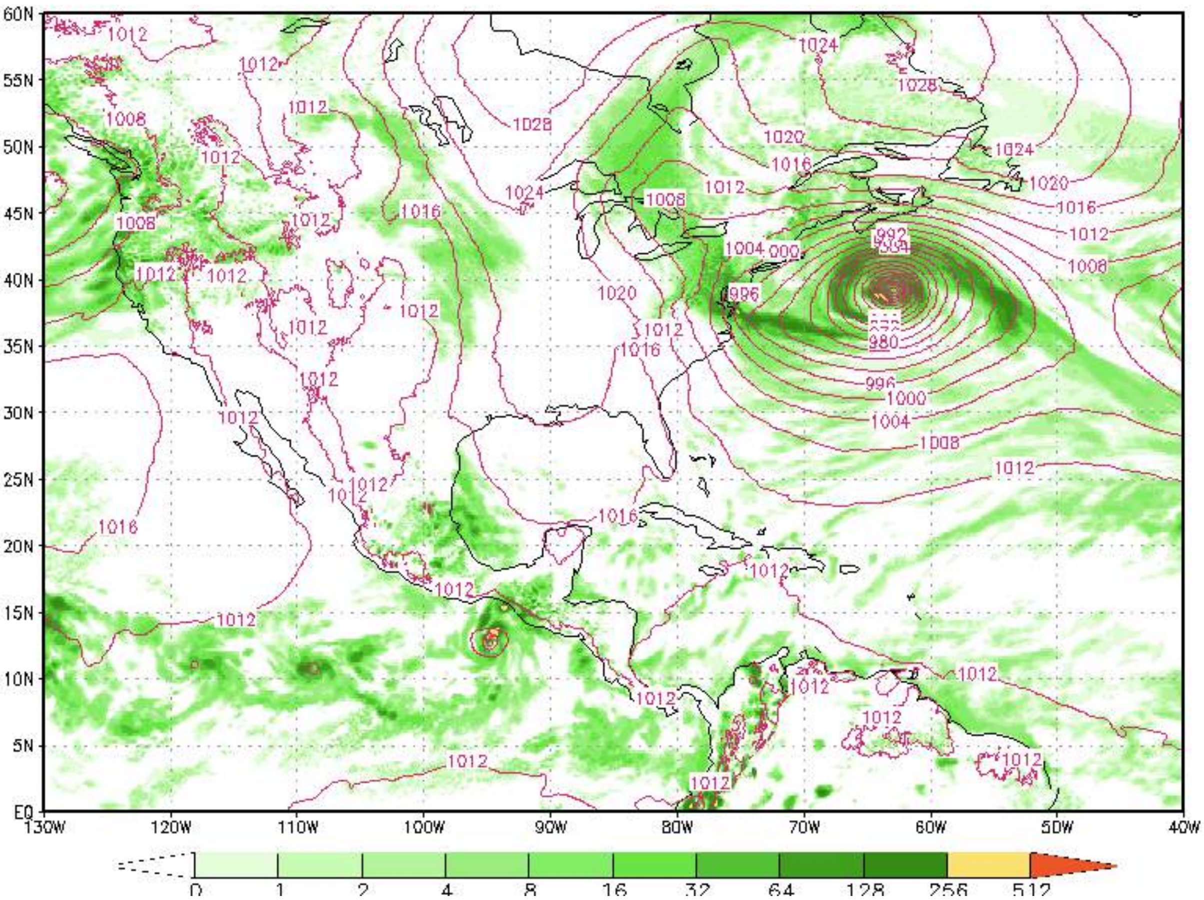


Figure 3: Sea level pressure and precipitation fields at 00Z of October 24, 2012 (forecast hour 177) from a T2046L64 NEMS run that also used the CS parameterization. This forecast correctly predicts the westward track of Hurricane Sandy.

1. The closure for σ is thus a crucial aspect of the Unified Parameterization. However, the closure was originally developed for a convection parameterization with a single updraft type.

We developed a generalized closure for σ that allows multiple updraft types. We then tested it in the GFS in a diagnostic mode, without allowing the values of σ to affect the forecast. We also identified the microphysical tendencies from both the convective updrafts and the environment, and the relevant area-weightings were computed.

The CS parameterization was converted from the original "compensating subsidence and detrainment" form, which is only valid for small σ, to the "flux divergence and source/sink form," which is valid even for large σ. The new code was tested in a two-month GFS run.

5. Ongoing work

During the final year of the project, the work at CSU focused on two activities. First, we worked to *test* the generalized closure mentioned above by using a large-eddy simulation of deep convection in a large domain. The simulation uses "large-scale forcing" data from the TWP-ICE field experiment; in the future, other sets of field data will also be used. A simulation of this type is described by Moeng et al. (2010). We want to test the closure (35) using one or more large-domain large-eddy simulations of deep convection, based on field data. Our approach is to use both the LES and the generalized closure to compute σ and various other parameters for an ensemble of updrafts and downdrafts, and for a wide range of "grid spacings." We then compare the results from the closure with the results from the LES. The steps involved are as follows:

1. We define subdomains of various sizes, by subdividing the large LES domain. The smallest subdomains considered are on the order of 1 to 2 km wide, and the analysis described below is based on averages over those smallest subdomains, rather than full-resolution LES data.
2. For each subdomain, and for each available simulation time, we use the LES results to diagnose the subdomain-averaged tendencies of temperature and water vapor due to the "resolved-scale flow," treating the subdomain as a "grid column." These advective tendencies are analogous to the advective tendencies computed from field data.
3. For each subdomain, we use the diagnosed advective tendencies, together with a conventional parameterization, to determine σ and the other parameters.
4. For each subdomain, diagnose σ and the other parameters directly from the LES results. A method to do this is discussed below.
5. Repeat the steps above for each vertical level within the convective system, and for each available time level in the LES results.
6. Compare the LES-based results for σ and the other parameters with the corresponding values obtained from the closure. The results of this comparison show the degree to which the LES results can be reproduced with a particular conventional parameterization.

The results of the test described above will depend on the particular conventional parameterization used, so to test the sensitivity we will use at least two.

Our second activity was to work towards "further unification" of the Unified Parameterization. This work is at an early, conceptual stage. The starting point is the recognition that determining the updraft fractional area is not sufficient for unification of a high-resolution numerical model with a cumulus parameterization. Here we mention three issues that motivate our thinking:

1. The conventional cumulus parameterization used with the Unified Parameterization must determine the vertical velocities of the parameterized convective updrafts, but at present the parameterized vertical velocities are not constrained to agree with the explicitly simulated vertical velocities in the limit of high resolution.
2. The high-resolution model simulates the growth and decay of individual clouds, while the cumulus parameterization is based on an entraining-plume model (Arakawa and Schubert, 1974) with no explicit representation of cloud life cycles.
3. The parameterized convective downdrafts must be formulated in a more realistic way. In nature, there is of course some tendency for a convective updraft to be followed by a convective downdraft that is driven by the rain falling out of the updraft. This is one aspect of the life-cycle effects mentioned above. At the same time, however, we recognize that particular downdrafts are not always closely tied to particular updrafts; real cloud systems are messier than that. We also recognize that it is possible for a convective downdraft to fill much or all of a grid cell in a high-resolution model. A future version of the Unified Parameterization should allow this.

These three issues present us with three challenges. Our admittedly somewhat distant goal is to create a conventional parameterization which uses cloud model that automatically “shadows” the explicitly resolved convection in the limit of high resolution, including updrafts, downdrafts, and life-cycle effects. By working towards this goal, we will learn something, and that is of course the point.

References

Arakawa, A and W. H. Schubert, 1974: Interaction of a cumulus cloud ensemble with the large-scale environment, Part I. *J. Atmos. Sci.,* **31**, 674-701.

Arakawa, A., J.-H. Jung, and C. M. Wu, 2011: *Atmos. Chem. Phys.*, **11**, 3731-3742, doi:10.5194/acp-11-3731-2011.

Arakawa, A. and C.-M. Wu, 2013: A Unified Representation of Deep Moist Convection in Numerical Modeling of the Atmosphere. Part I. *J. Atmos. Sci.*, **70**, 1977–1992.

Chikira, M., and M. Sugiyama, 2010: A Cumulus Parameterization with State-Dependent Entrainment Rate. Part I: Description and Sensitivity to Temperature and Humidity Profiles. *J. Atmos. Sci.*, **67**, 2171–2193.

Chikira, M., 2010: A Cumulus Parameterization with State-Dependent Entrainment Rate. Part II: Impact on Climatology in a General Circulation Model. *J. Atmos. Sci.*, **67**, 2194–2211.

Jung, J.-H. and A. Arakawa, 2004: The resolution dependency of model physics: Illustrations from nonhydrostatic model experiments. *J. Atmos. Sci.*, **61**, 88-102.

Moeng, C.-H., M. A. LeMone, M. Khairoutdinov, S. Krueger, P. Bogenschutzc and D. A. Randall, 2010: The tropical marine boundary layer under a deep convection system: a large-eddy simulation study. *J. Adv. Modeling Earth Syst*., Vol. 1, doi:10.3894/JAMES.2009.1.16.

Randall, D. A., C. DeMott, C. Stan, M. Khairoutdinov, J. Benedict, R. McCrary, and K. Thayer-Calder, 2016: Simulations of the tropical general circulation with a multiscale global model. Chapter 15 of *Multiscale Convection-Coupled Systems in the Tropics: A tribute to Dr. Michio Yanai*, R. G. Fovell and W.-W. Tung, Eds. *Meteorological Monographs*, **56**, published by the American Meteorological Society. DOI: http://dx.doi.org/10.1175/AMSMONOGRAPHS-D-15-0016.1.

Wu, C.-M., and A. Arakawa, 2014: A Unified Representation of Deep Moist Convection in Numerical Modeling of the Atmosphere. Part II. *J. Atmos. Sci*., **71**, 2089–2103.

Publications

Dazlich, D., S. Moorthi, and D. A. Randall, 2015: Impact of the Chikira-Sugiyama Convection Scheme on the GFS. Paper presented at the *Fall Meeting of the American Geophysical Union*.

Krueger, S. K., S. Moorthi, D. A. Randall, R. Pincus, P. Bogenschutz, and A. Belochitski, 2016: A CPT for Improving Turbulence and Cloud Processes in the NCEP Global Models. Paper presented at the *Fall Meeting of the American Geophysical Union*, San Francisco, California, December 12-16 2016. (Invited)

Chikira, M., and D. A. Randall, 2018: A generalization of the Unified Parameterization. In preparation for the *Journal of Advances in Modeling the Earth System*.

Year 4 Annual Report
June 1, 2016 – May 30, 2017

PROJECT TITLE: Towards Assimilation of Satellite, Aircraft, and Other Upper-Air CO_2 Data into CarbonTracker

PRINCIPAL INVESTIGATOR: David F. Baker
CIRA RESEARCH TEAM: Andrew Schuh, David F. Baker
NOAA RESEARCH TEAM: Andrew Jacobson, CIRES/University of Colorado
NOAA TECHNICAL CONTACT: Pieter Tans, ESRL/Global Modeling Division
NOAA AWARD NUMBER: NA13OAR4310077

PROJECT OBJECTIVES: CarbonTracker-CO_2 (CT) is a flux inversion system that estimates sources and sinks of CO_2 from atmospheric measurements, using an atmospheric transport model to link CO_2 concentrations to surface fluxes. It solves for fluxes across continental biome-sized regions over land, and basin-sized regions over the ocean, using data from NOAA/GMD's global network of *in situ* CO_2 measurement sites (flasks, tall towers, and continuous sensors), as well as similar measurements from other groups around the world. It is one of the most-used CO_2 flux products in the world. As currently configured, however, the link between surface fluxes and the down-stream effect on CO_2 concentrations is truncated after only five weeks: this is too short a time for these fluxes to mix well into the middle to upper part of the atmospheric column. As a result, CT does not properly use data taken far away from the surface, such as aircraft profiles and column-averaged CO_2 measurements from satellite and ground-based spectrometers, when constraining surface fluxes: signals in the upper part of the atmospheric column are mis-attributed to near-field fluxes (those emitted within 5 weeks) rather than to any far-field fluxes that might have caused them. Given the current explosion of such data from satellites (GOSAT, OCO-2, *etc*.) and from the Total Column Carbon Observing Network (TCCON), we would like to modify CT to be able to use these data. In this project, we will experiment with lengthening the 5-week assimilation window currently used in the CT ensemble Kalman smoother (EnKS), and add an "outer-loop" inversion if necessary to optimize the prior used in the enKS at coarser scales, to minimize truncation errors from shorter window lengths in the EnKS. We will also enhance CT to solve for the surface CO_2 fluxes at higher spatial resolution when using the new high-density data. Simulation experiments will be used to accurately assess the impact of the modifications.

A secondary goal is to diversify CarbonTracker by allowing the use of a second transport model as the basis of the inversion scheme. It was discovered in the past couple years that the TM5 model around which CarbonTracker was based did not have enough vertical mixing over the continents, causing the fluxes retrieved by the inversion to be skewed, particularly in terms of the partition of flux between the northern and tropical continents. Having a second model "opinion" will help diagnose such errors in the future.

CURRENT SPENDING ON THE PROJECT

A no-cost extension was filed last year for the CSU-based portion of this project; the current end date is July 31, 2017. Due to an administrative mishap, the portion of this project that funds Andy Jacobson, based out of the University of Colorado (as a separate award), did not get extended with a no-cost extension at the same time, and that portion of the grant money was forfeited. Since Andy is the one on this project most adept at pushing through full

CarbonTracker runs on the NOAA computer, it was deemed that the most efficient way to make progress on the remaining project goals was to give the remainder of the CSU money to Andy: this was done with a sub-contract from Colorado State to the University for $62,831 starting on 1 Feb 2017.

PROJECT ACCOMPLISHMENTS:

Integrating GEOS-Chem into the NOAA code base and testing it

Progress in the past year has been made in the area of assessing the broad-scale transport of the GEOS-Chem model and getting an up-to-date version of it integrated into the standard CarbonTracker code base on the NOAA computer.

Andy Jacobson has integrated GEOS-Chem version 11, running with 2.0°x2.5° (lat/lon) meteorological drivers, into his standard CarbonTracker code base, as a second transport option (in addition to the original TM5 option). This version of GEOS-Chem uses the HEMCO module to input constituent sources and sinks, including those for CO_2 and SF_6. Andy has also

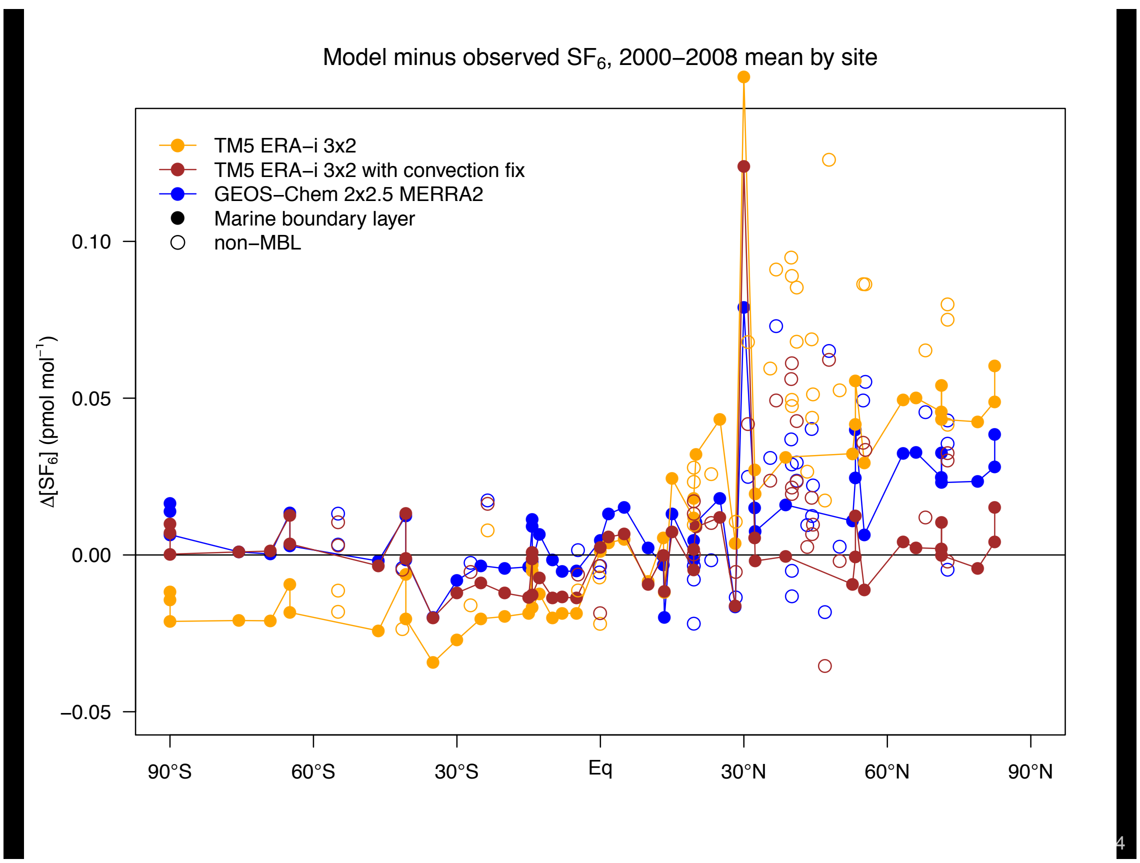


Figure 1: The difference in simulated and measured SF_6 mixing ratio vs. latitude for three different transport models available in CarbonTracker: TM5 before a recent fix to convection was made (tan), TM5 after that fix (red), and GEOS-Chem v11 (blue).

implemented the same ObsPack output capabilities for GEOS-Chem as for TM5, for use as diagnostics.

Andy Jacobson and Andrew Schuh have been working together to compare the transport properties of GEOS-Chem and TM5. Andy has run the same SF_6 emissions through TM5 and GEOS-Chem at similar spatial resolutions (TM5 at 2°x3° (lat/lon) and GEOS-Chem v11 at 2.0°x2.5° (lat/lon)). These SF_6 emissions have a spatial pattern similar to the CO_2 put into the atmosphere from fossil fuel burning, and thus are useful for assessing that portion of CO_2 associated with the fossil fuel input (mainly the north-south gradient caused by it). A plot of the annual-mean SF_6 values from by these runs as a function of latitude is given in Figure 1. GEOS-Chem and TM5 were previously assessed using SF6 as part of the TransCom project (Patra et al., 2011): in that study, the N/S gradient for GEOS-Chem was found to agree well with the measured N/S gradient of SF_6 computed using four background sites (BRW, MLO, CGO, and SPO), which that of the pre-convection-fix TM5 was found to be about 0.08 ppt too high. In Andy's new study, the results for the old version of TM5 are found to give a similar error in the SF_6 N/S gradient, but the new, convection-fixed version of TM5 is found to have good agreement with the observations across all latitudes. GEOS-Chem, with the MERRA2 drivers, on the other hand, is found to have a more positive N/S gradient than the observations: either the four sites used in the Patra et al study did not fully capture this gradient, or changes due to switching to the new MERRA2 drivers are to blame. The errors are less than half that of the pre-fix TM5 model, but they are still significant. Now that we know how large they are, we can assess their impact in terms of the N/S gradient of CO_2 when the GEOS-Chem option is used in CarbonTracker. Alternatively, if we do not fully trust the SF_6 measurements or the ability of these SF_6 simulations to replicate the fossil fuel portion of the CO_2 fields, we may take the difference between these TM5 and GEOS-Chem runs as a measure of transport error in the CarbonTracker CO_2 assimilations.

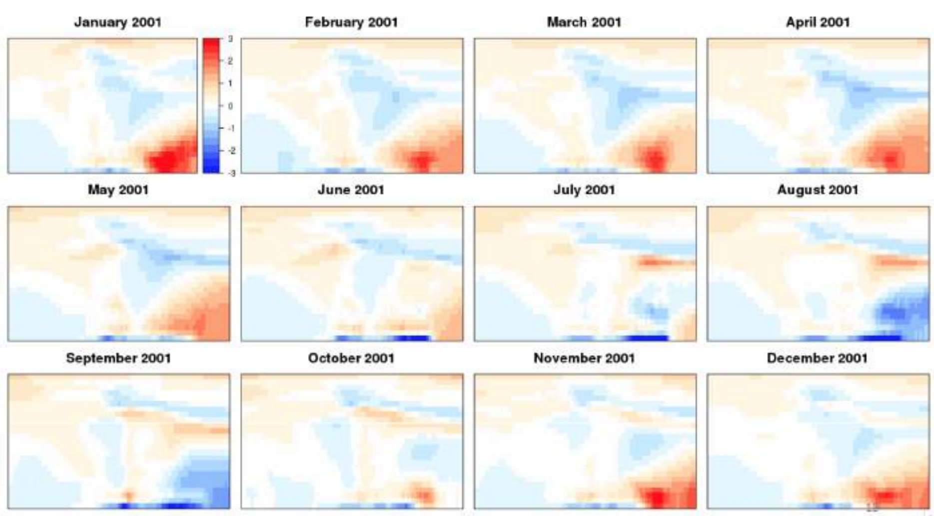


Figure 2: Difference between CO_2 concentrations [ppm] simulated by forward runs of the GEOS-Chem and TM5 transport models, as a function of season, altitude, and latitude. Latitudes run from 90°S to 90°N along the x axis.

Andrew Schuh has been running realistic CO_2 emissions through GEOS-Chem and comparing them to runs that Andy has done with TM5 using the same emissions. These runs include not only the fossil fuel input, but also the seasonally-varying land biospheric fluxes: they are better for revealing differences in mixing out of the planetary boundary layer over the continents, for example. Figure 2 shows the difference in simulated CO_2 mixing ratio between GEOS-Chem and TM5 for different months: GEOS-Chem traps the impact of the fluxes closer to the surface across the northern hemisphere in both winter and summer, indicating that the mixing out of the continental PBL is weaker in GEOS-Chem. This must play a role in the stronger N/S gradient seen in Andy's SF6 runs, as well. When integrated over the full atmospheric column, the difference in simulated CO_2 shows opposite seasonality for the low- to mid- northern latitudes than for the high northern latitudes (Figure 3). Thus, the impact of these transport differences might be expected to be different for when the models are used to invert satellite-based CO_2 data from when they are used to invert only surface-based CO_2.

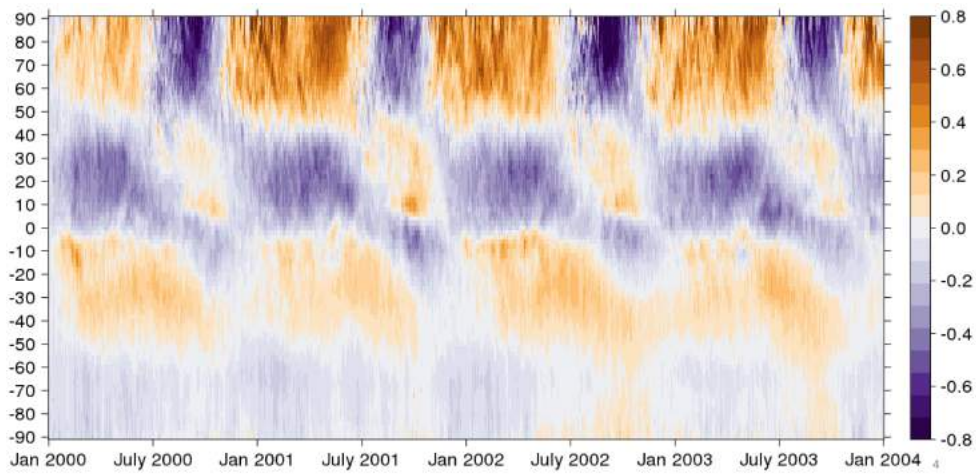


Figure 3: Difference between column-integrated CO_2 concentrations [ppm] simulated by forward runs of the GEOS-Chem and TM5 transport models, as a function of latitude and time.

WORK STILL TO BE ACCOMPLISHED

In the final couple months of the project, Andy Jacobson will work on further development of his EOF-based flux parameterization. David Baker will attempt to run CarbonTracker in observing system simulation experiments (OSSEs), with known truth fields, to assess the full magnitude of the estimation error for different EnKF window lengths.

References

Patra, P.K., S. Houweling, M. Krol, P. Bousquet, D. Belikov, D. Bergmann, H. Bian, P. Cameron-Smith, M. P. Chipperfield, K. Corbin, A. Fortems-Cheiney, A. Fraser, E. Gloor, P. Hess, A. Ito, S. R. Kawa, R. M. Law, Z. Loh, S. Maksyutov, L. Meng, P. I. Palmer, R. G. Prinn, M. Rigby, R. Saito, and C.Wilson, 2011: TransCom model simulations of CH_4 and related species: linking transport, surface flux and chemical loss with CH_4 variability in the troposphere and lower stratosphere, *Atmos. Chem. Phys.*, **11**, 12813–12837

Project Title: Use of the Ocean-Land-Atmosphere Model (OLAM) with Cloud System-Resolving Refined Local Mesh to Study MJO Initiation
Project Number: NA13OAR4310163
PIs: Eric D. Maloney and William Cotton (Colorado State University) and Robert Walko (University of Miami)
Report Type: Final Report

Results and Accomplishments

The following sections discuss publications and results from all years of the project. All publications resulting from this project are listed at the end of this report.

Consequences of systematic model drift in DYNAMO MJO hindcasts with SP-CAM and CAM5 (Hannah et al. 2015).

Hindcast simulations of MJO events during the Dynamics of the MJO (DYNAMO) field campaign are conducted with two models, one with conventional parameterization (CAM5) and a comparable model that utilizes super-parameterization (SP-CAM). SP-CAM is shown to produce a qualitatively better reproduction of the fluctuations of precipitation and low-level zonal wind associated with the first two DYNAMO MJO events compared to CAM5 (**Figure 1**). Interestingly, skill metrics using the real-time multivariate MJO index (RMM) suggest the opposite conclusion, that CAM5 has more skill than SP-CAM. This inconsistency can be

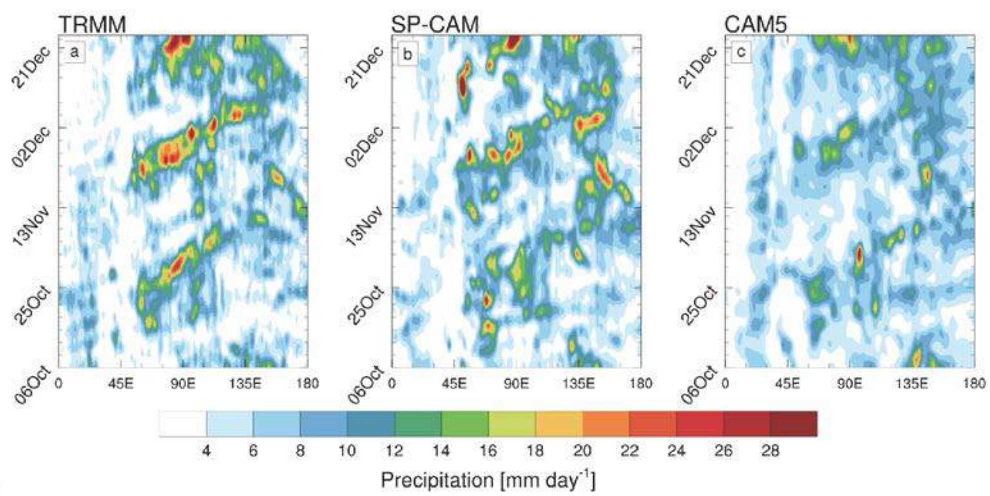


Figure 1. Hovmöller diagram of equatorial precipitation averaged from 5°S-5°N for 05-09 day lead times.

explained by a systematic increase of RMM amplitude with lead-time, which results from a drift of the large-scale wind field in SP-CAM that projects strongly onto the RMM index (**Figure 2**).

CAM5 hindcasts exhibit a contraction of the moisture distribution, in which extreme wet and dry conditions become less frequent with lead-time. SP-CAM hindcasts better reproduce the observed moisture distribution, but also have stronger drift patterns of moisture budget terms, such as an increase in drying by meridional advection in SP-CAM. This advection tendency in SP-CAM appears to be associated with enhanced off-equatorial synoptic eddy activity with lead-time. Systematic drift moisture tendencies in SP-CAM are of similar magnitude to intraseasonal moisture tendencies, and therefore are important for understanding MJO predictability.

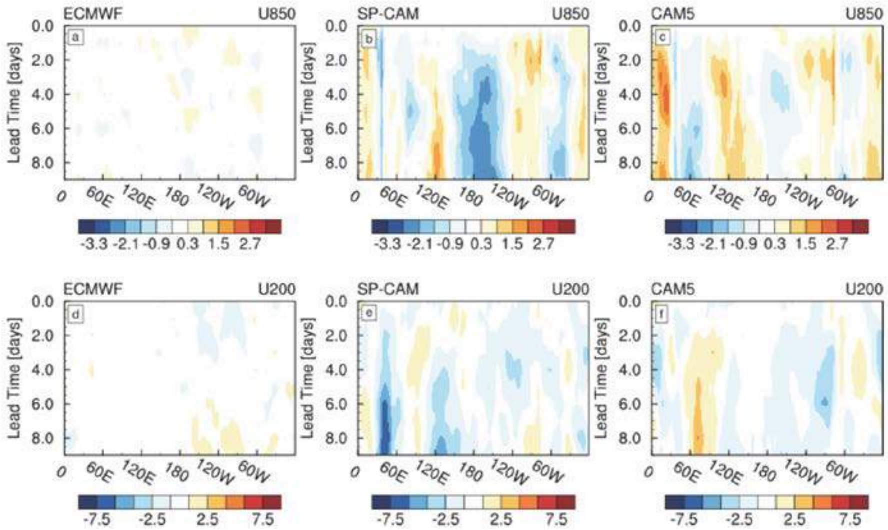


Figure 2. Hovmöller diagrams of the systematic drift over the DYNAMO period as a function of time since hindcast initialization (see text) in the wind fields used in the RMM index in ERAi, SP-CAM, and CAM5. Data was equatorial averaged from 15°S-15°N, consistent with the RMM index.

Development of advanced diagnostics that improve interpretation of MJO events during DYNAMO and over the broader record (Wolding and Maloney 2015a)

Graduate student Brandon Wolding, funded under this project, developed advanced MJO diagnostics that provided substantial insight into the nature of MJO events during DYNAMO and the ability of conventional MJO indices such as those of Wheeler and Hendon to successfully characterize the nature of the MJO. Diagnostics obtained as an extension of empirical orthogonal function (EOF) analysis are shown to address many disadvantages of using EOF-based indices to assess the state of the Madden-Julian Oscillation (MJO). The Realtime Multivariate MJO (RMM) index and the Filtered MJO OLR (FMO) index are used to demonstrate these diagnostics. General characteristics of the indices, such as the geographical regions that most heavily in each index, are assessed using the diagnostics. The diagnostics also identify how a given field at various geographical locations, influences the index value at a given time. Termination (as defined by the RMM index) of the October 2011 MJO event that occurred during the Cooperative Indian Ocean Experiment on Intraseasonal Variability in the Year 2011(CINDY) Dynamics of the MJO (DYNAMO) field campaign is shown to have resulted from changes in zonal wind anomalies at 200 hPa over the eastern Pacific Ocean, despite the onset of enhanced convection in the Indian Ocean and the persistence of favorable lower and upper level zonal wind anomalies near this region (**Figure 3**). The diagnostics objectively identify, for each specific geographical location, the index phase where the largest MJO-related anomalies in a given field are likely to be observed. This allows for the geographical variability of anomalous conditions associated with the MJO to be easily assessed throughout its lifecycle. This paper is published in *Journal of Climate*. In Part II of this study (see below), unique physical insight into the moist static energy and moisture budgets of the MJO is obtained from the application of diagnostics introduced here.

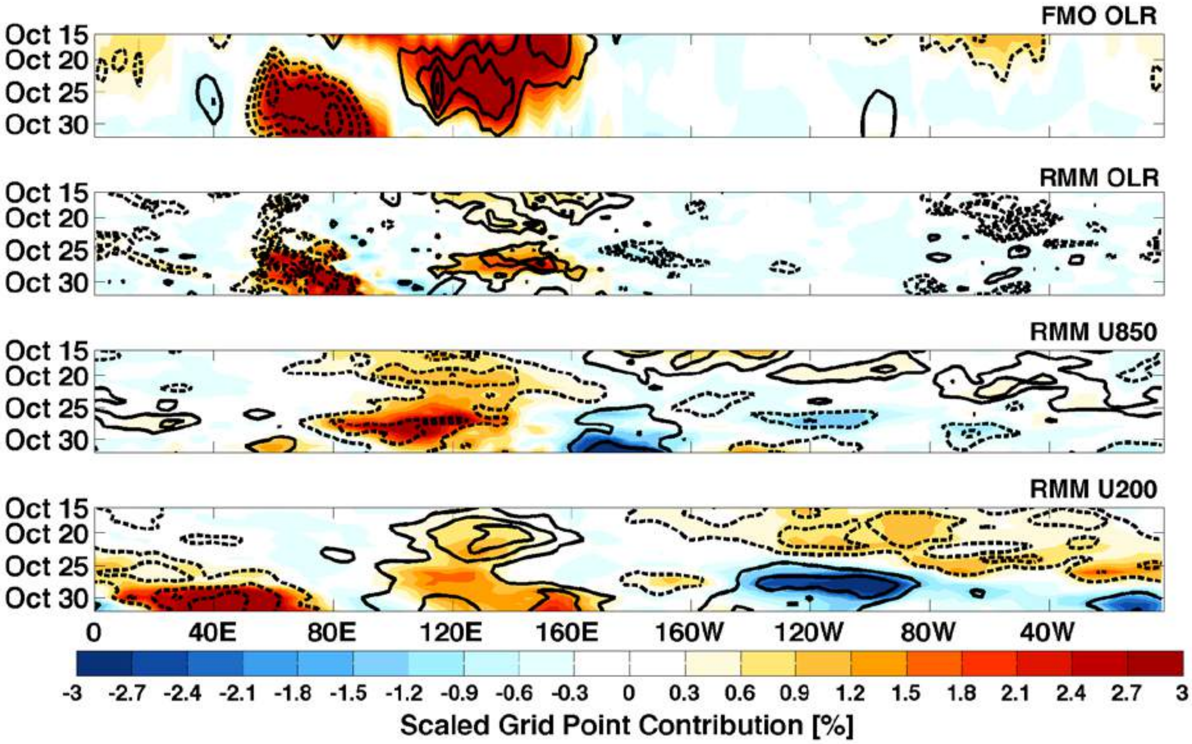


Figure 3. OLR, U850, and U200 anomalies (contours) averaged from 15N-15S and corresponding scaled grid point contribution (shading) for the RMM and FMO index from October 15-31. Positive (negative) anomalies are given by solid (dashed) contours. In the top panel, OLR has been bandpass filtered to 20-96 days. Contours for the filtered OLR, unfiltered OLR, U850, and U200 anomalies are, respectively, as follows: every 5 W/m^2 beginning at 10 W/m^2 , every 10 W/m^2 beginning at 20 W/m^2, every 2 m/s beginning at 2 m/s , every 5 m/s beginning at 5 m/s.

Development of advanced MJO diagnostics for the moisture and moist static energy budgets based on weak temperature gradient theory (Wolding and Maloney 2015b)

Processes controlling moisture variations associated with the MJO are investigated using budgets of moist static energy (MSE) and moisture. To first order, precipitation anomalies are maintained by anomalous large-scale vertical moisture advection, which can be understood through application of a weak temperature gradient balance framework to the MSE budget. Intraseasonal variations in longwave radiative cooling play a crucial role in destabilizing the MJO, allowing anomalous large-scale vertical advective moistening to meet or exceed the increase in moisture loss by net condensation during the enhanced phase, and anomalous large-scale vertical advective drying to meet or exceed the decrease in moisture loss by net condensation during the suppressed phase. The result is a positive feedback between the net effect of these processes and moisture anomalies. Intraseasonal variations in surface latent heat flux (SLHF) enhance this positive feedback, but appear to be insuffcient to destabilize the MJO in the absence of radiative feedbacks.

Insight into the response of an ensemble cloud population to an anomalous moisture source (e.g. enhanced SLHF) is gained by examining fields where only high frequency variability (< 20 days) has been removed. During the enhanced phase, approximately 85% of the moisture removed by net condensation is re-supplied by the large-scale vertical moisture advection associated with apparent heating by microphysical processes and sub-grid scale vertical fluxes of dry static energy. This suggests that a relatively large increase in net condensation could be supported by a relatively small anomalous moisture source, even in the absence of radiative feedbacks. These results highlight the importance of process-oriented assessment of MJO-like variability within models, and suggest a WTG balance framework may be used to identify destabilization mechanisms, thereby distinguishing between MJO-like variability of fundamentally different character. We are currently exploring ways to incorporate these model diagnostics into the standard evaluation packages of climate modeling centers (including GFDL and NCAR) to improve evaluation of global climate models, and ensure they are getting realistic simulations of tropical variability for the correct reasons. This paper is published in *Journal of Climate*.

Understanding MJO initiation and the role of moisture advection in an aquaplanet general circulation model (Maloney and Wolding 2015)

MJO initiation was studied in an aquaplanet general circulation model that has strong and highly regular MJO-like variability. About 80% of MJO events in the model are found to be successive events, immediately preceded by another strong MJO event. Rossby gyres associated with the previous cycle of suppressed MJO convection to the east are shown to help initiate the next cycle of MJO convection in the western warm pool, consistent with the recent study of Zhao et al. Meridional and vertical moisture advection associated with the anomalous Rossby gyres help to moisten the MJO initiation region in advance of convective onset.

An experiment is conducted in which circumnavigating Kelvin waves and their influence on the MJO initiation region are suppressed. While MJO activity in the model is just as regular with suppression of circumnavigation, MJO amplitude is reduced relative to the control simulation, especially in the western part of the warm pool. Possible physical mechanisms responsible for this change in MJO amplitude are discussed. This paper is published in *Journal of Advances in Modeling Earth Systems*.

Applying weak temperature gradient moistening diagnostics to understand MJO dynamics in a superparameterized climate model (Wolding et al. 2016)

Decade-long runs of the NCAR CESM are conducted to examine the initiation and maintenance mechanisms associated with the MJO. In particular, the moisture budget diagnostics of Wolding and Maloney (2015b) that take advantage of the weak temperature gradient nature of the tropical atmosphere are used to understand moistening processes. The collective effects of convection can influence large-scale circulations that, in turn, act to organize convective activity. Such scale interactions may play an important role in moisture-convection feedbacks thought to be important to both convective aggregation and the MJO, yet such interactions are not fully understood. New diagnostics based on tropical weak temperature gradient (WTG) theory have begun to make this problem more tractable, and are leveraged in this study to analyze the relationship between various apparent heating processes and large-scale vertical moisture advection in SP-CESM.

WTG theory provides a framework for accurately diagnosing intraseasonal variations in large-scale vertical motion from apparent heating, allowing large-scale vertical moisture advection to be decomposed into contributions from microphysical processes, sub-grid scale eddy fluxes, and radiative heating. This decomposition is used to show that the MJO is a radiative-driven instability damped by horizontal advection, consistent with the findings of previous studies. **Figure 4** shows the a) MJO growth rate explained by various processes and b) the contribution of various processes to MJO propagation. **Figure 4a** (columns C and E) verifies the importance of radiation for destabilization and horizontal advection as the damping mechanism. Periods of low and high intraseasonal moisture variance (i.e. low and high aggregation) are compared, and it is found that the evolution of the vertical structure of apparent heating does not cause the radiative driven instability to become "self limiting" in the absence of horizontal advective damping. Finally, a diagnostic approach to scale analysis of tropical dynamics is used to investigate how the governing dynamics of various phenomena differ throughout wavenumber-frequency space. Findings support previous studies that suggest the governing dynamics of the MJO differ from those of strongly divergent convectively coupled equatorial waves. A paper describing these results is published in *the Journal of Advances in Modeling Earth Sciences*

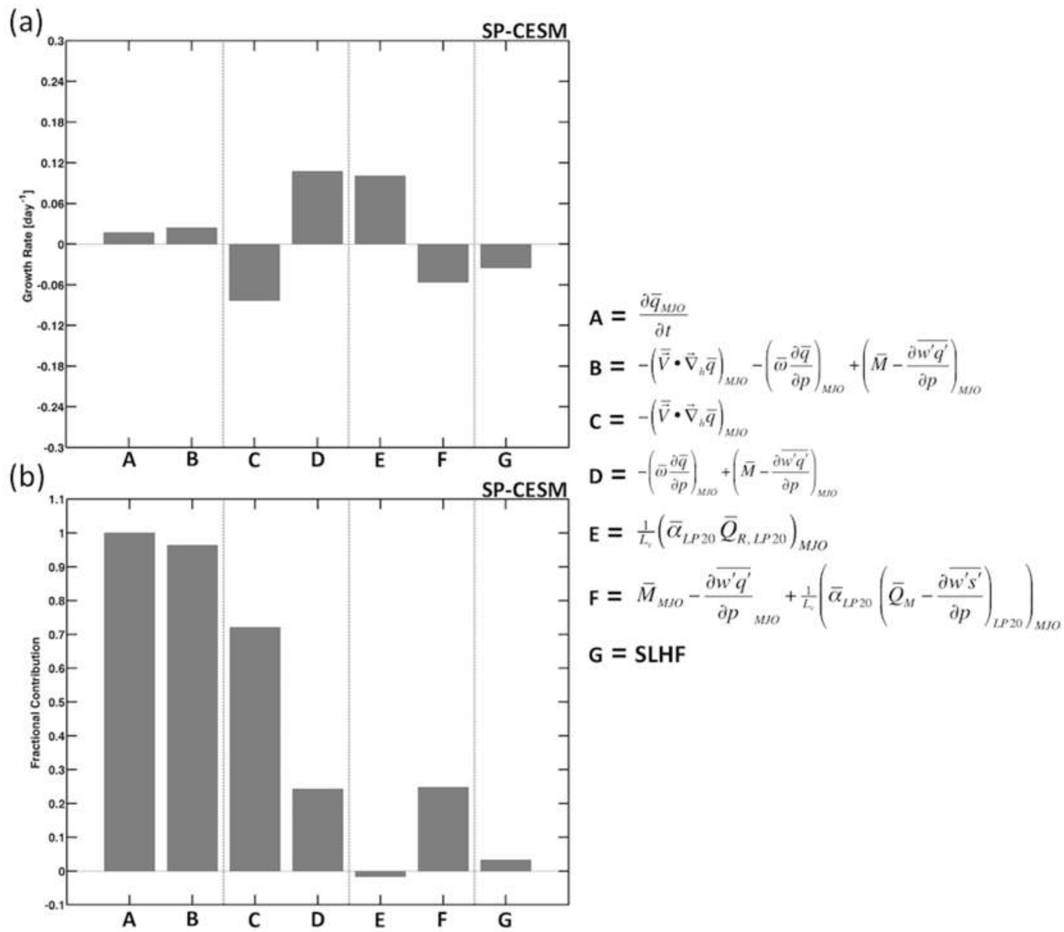


Figure 4. Vertically integrated contributions various budget terms make to the (a) column moisture variance growth rate and (b) column moisture tendency in SP-CESM. The area-weighted integral has been taken from 10.5N-14.5S; 60E-180E, and averaged from day -30 to day +30 for each of the 19 independent winter MJO events composited.

Climate change and the Madden-Julian Oscillation: A vertically resolved weak temperature gradient analysis (Wolding et al. 2017)

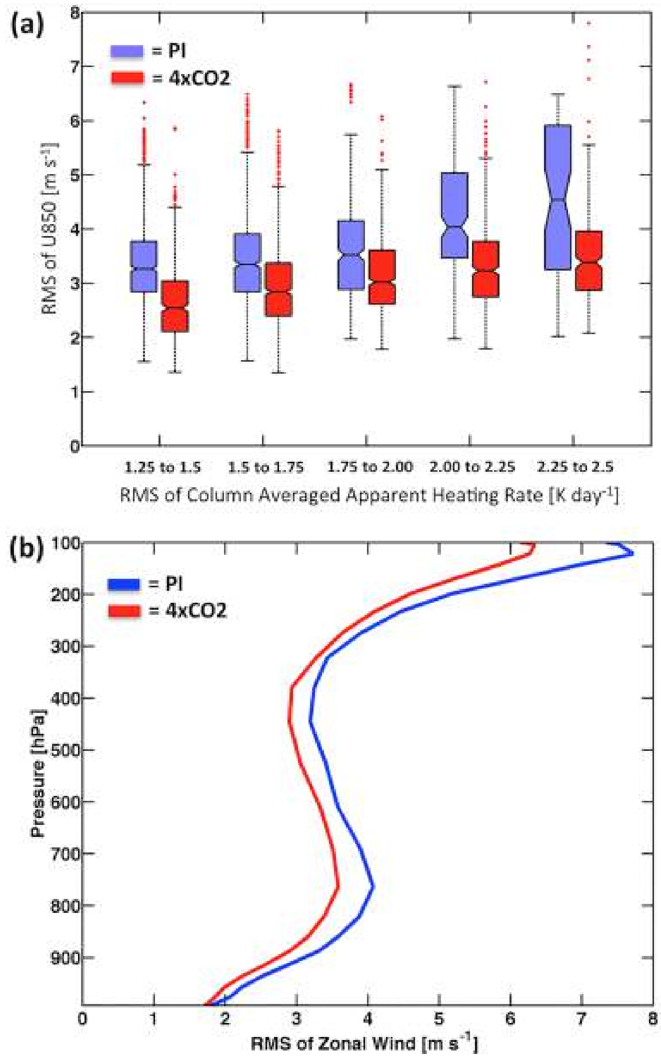


Figure 5. (a) Box and whisker plots of the root mean square (RMS) of 20–100 day band-pass filtered 850 hPa zonal wind for the domain 10N-10S, 60E-180E binned by the RMS of 20–100 day band-pass filtered column-averaged apparent heating rate over the same domain, for the PI (blue) and 4×CO_2 (red) simulations. Medians differ with 95% statistical significance if their notched intervals do not overlap. (b) Vertical profile of the RMS 20–100 day band-pass filtered zonal wind for the 1.75–2.00 K/day bin in Figure 2a.

WTG balance is used to examine how changes in the moist thermodynamic structure of the tropics affect the MJO in two simulations of the Superparameterized Community Earth System Model (SP-CESM), one at preindustrial (PI) levels of math formula and one where math formula levels have been quadrupled (4×CO2). While MJO convective variability increases considerably in the 4×CO2 simulation, the dynamical response to this convective variability decreases (**Figure 5**). Increased MJO convective variability is shown to be a robust response to the steepening vertical moisture gradient, consistent with the findings of previous studies. The steepened vertical moisture gradient allows MJO convective heating to drive stronger variations in large-scale vertical moisture advection, supporting destabilization of the MJO. The decreased dynamical response to MJO convective variability is shown to be a consequence of increased static stability, which allows weaker variations in large-scale vertical velocity to produce sufficient adiabatic cooling to balance variations in MJO convective heating. This weakened dynamical response results in a considerable reduction of the MJO's ability to influence the extratropics, which is closely tied to the strength of its associated divergence. A composite lifecycle of the MJO was used to show that northern hemisphere extratropical 525 hPa geopotential height anomalies decreased by 27% in the 4×CO2 simulation, despite a 22% increase in tropical convective heating associated with the MJO. Results of this study suggest that while MJO convective variability may increase in a warming climate, the MJO's role in "bridging weather and climate" in the extratropics may not. A paper describing these results is published in *the Journal of Advances in Modeling Earth Sciences*

Understanding MJO initiation and model bias for hindcast DYNAMO events in OLAM (Maloney et al. 2017)

We have continued to examine MJO behavior in hindcast experiments with OLAM during the DYNAMO period. We settled on a configuration that telescopes to 2.4 km inner mesh over the DYNAMO array region. This domain is shown in **Figure 6**. The WTG diagnostics of Wolding and Maloney (2015b) have been employed to diagnose MJO behavior in the model. **Figure 7** shows the propagation of precipitation anomalies during the November 2011 MJO event in TRMM (left), a free version of OLAM initialized in early November (center), and a second run in which 2-hour relaxation timescale nudging is only applied to the moisture field (right). Clearly the free run of OLAM in this configuration has trouble with the amplitude and propagation direction of intraseasonal precipitation anomalies. By only nudging moisture, the observed propagation pattern of MJO precipitation is recovered, supporting the hypothesis that realistic simulation of the processes controlling the moisture field is key for producing a realistic MJO in models. Nudging tendencies suggest that MJO convection is too strong of a drying mechanism in OLAM that weakens significant moisture anomalies once they are formed. The diagnostic method of Wolding and Maloney (2015b) is used to verify this hypothesis.

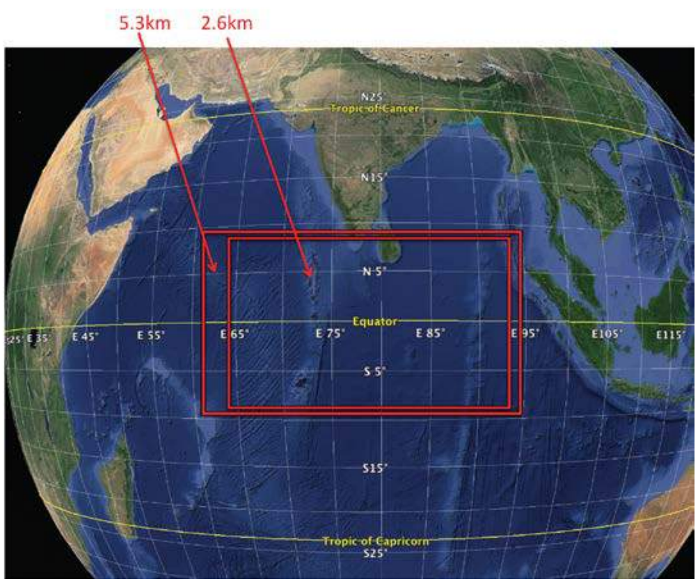


Figure 6. Map of the inner domain used in the OLAM simulation of the November 2011 MJO event.

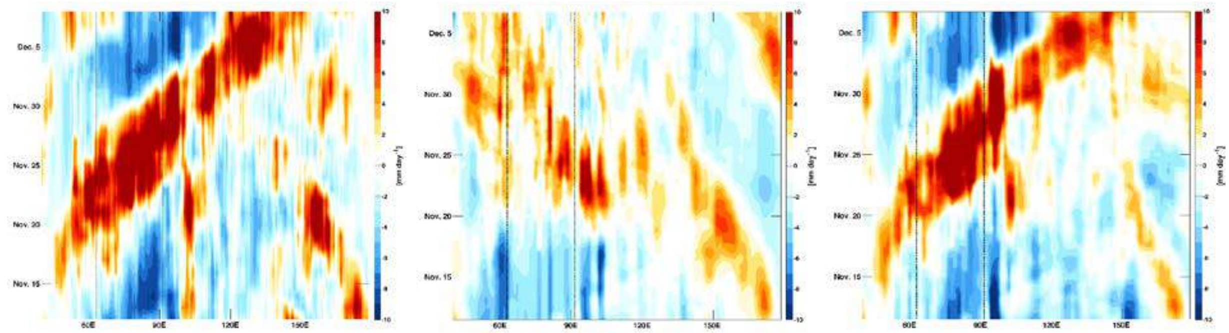


Figure 7. Precipitation anomalies for the November 2011 DYNAMO MJO event in a) TRMM, b) an un-nudged OLAM simulation, and c) the moisture-nudged OLAM simulation.

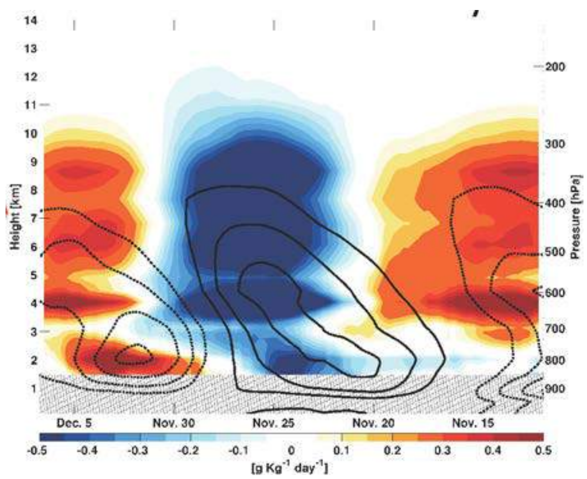


Figure 8. Net effect of convection on the anomalous moisture budget in OLAM in the moisture-nudged run (colors), and OLAM moisture anomalies (contours) during the November 2011 MJO event.

Figure 8 shows the net effect of convection on the MJO moisture budget in the OLAM nudged run (induced vertical advection plus condensational drying), indicating that the actions of convection create an extremely strong drying during the phase of the MJO when moisture and convection is enhanced. This strong drying by convection is overcome by the moisture-nudging tendency in the model to produce a realistic moisture evolution and resulting realistic MJO. We interpret this result as being associated with convection in the OLAM model that is too top-heavy when the MJO is active in the model. We are currently exploring whether higher model grid spacing (e.g. 1 km) in the refined mesh region may allow a more realistic simulation of convective entrainment that leads to more realistic vertical structure of convection. Modifications to the boundary layer treatment and configuration of the inner fine mesh and proximity to the parameterized convection region are also being examined. A manuscript is being generated detailing the OLAM runs and the application of moisture budget diagnostics to these runs (Maloney et al. 2017). We will publish these findings in an upcoming manuscript.

Atmospheric contributions to MJO decay over the Maritime Continent (DeMott et al. 2017a)

Eastward propagating Madden-Julian oscillation (MJO) events that develop in the Indian Ocean from November-April are separated into events whose convective anomalies do and do not propagate across the Maritime Continent (MC). Propagating (P) events are divided into strong (sP) and weak (wP) subsets based on the initial amplitudes of their Indian Ocean convective anomalies. Eastward-decaying (ED) MJO events have initial amplitudes similar to those of wP events. Roughly half of all MJO events encounter westward-propagating transient dry precursor (TDP) signals over the MC. These TDPs, which are external to the MJO circulation system, are driest in ED MJO events, and overwhelm the eastward-propagating moist anomaly, leading to MJO termination. In wP events, the TDP dry anomaly is weaker, the MJO positive moisture anomaly is sustained, and the MJO propagates beyond the MC. ED MJO events that do not encounter TDPs decay because of weak drying, rather than moistening over the MC. While MC moistening is dominated by meridional moisture advection, wP vs ED propagation differences, including TDP drying tendencies, are roote in zonal moisture advection differences which are the result of different mean state zonal moisture gradients. In ED events, large off-Equatorial surface Fluxes and vertical moisture advection in the Indian Ocean amplify the Rossby gyre part of the MJO. The resulting enhancement of low-level Equatorial westerly winds and dry advection further contribute to MC drying. A paper describing these results is accepted pending revision in *J. Geophys. Res.*

The importance of air-sea interaction for MJO Initiation in a coupled GCM (DeMott et al. 2017b).

We have investigated the impact of SST-driven boundary layer convergence to MJO initiation in a coupled GCM. The impact of ocean coupling on MJO dynamics is investigated in the superparameterized NCAR Community Earth System System Model (SPCESM), a model that produces realistic eastward propagating MJO variability in the tropics. The bulk boundary layer model of Back and Bretherton (2009) is first used to diagnose SST-driven convergence anomalies associated with composite SPCCSM MJO SST anomalies. **Figure 9** shows SST anomalies and associated surface convergence anomalies from two different phases of the SPCCSM MJO (these phases can be considered about 15 days apart in time). The SST anomalies drive surface convergence anomalies through a similar hydrostatic surface pressure adjustment mechanism to that proposed by Lindzen and Nigam (1987). Then, the moisture convergence anomalies associated with the anomalous mass convergence field are determined by assuming a characteristic boundary layer specific humidity content. **Figure 10** shows that SST-driven anomalies may be just as important as horizontal moisture advection for driving a positive moisture tendency in advance of enhanced MJO precipitation in the Indian Ocean MJO initiation region for plausible boundary layer model parameter settings. Horizontal advection was previously hypothesized to be the leading terms in the intraseasonal moisture budget in the context of MJO propagation. These results suggest that SST-induced boundary layer moisture convergence may play an important role in MJO propagation and initiation, and may help explain why coupled models produce better simulations of the MJO than uncoupled atmospheric models, and highlights the salient upper ocean and boundary layer processes that models need to get right to produce realistic MJO variability. A manuscript describing these results is being prepared for *J. Climate*.

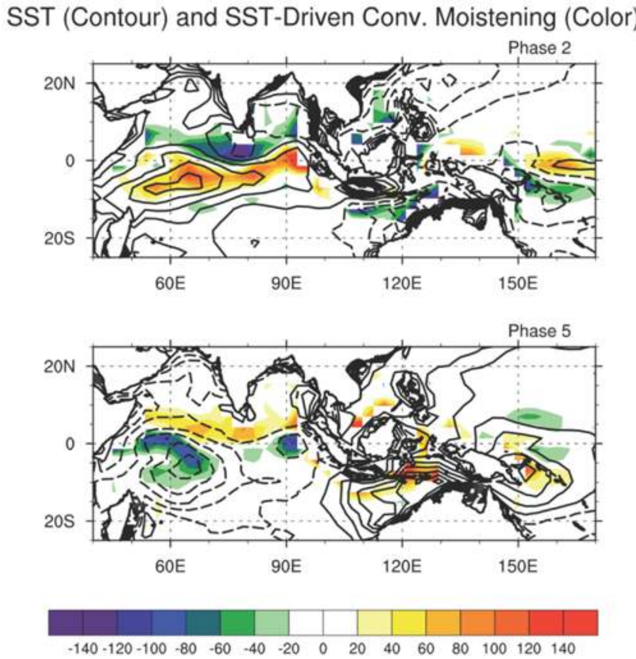


Figure 9. SST anomalies (contours) and SST-driven moisture convergence anomalies (colors) for Phases 2 and 5 of the MJO in the SPCCSM. The SST contour interval is 0.05ºC, and the units of convergence anomalies are W m^{-2}. Note that the convergence anomalies have been converted to energy units to reflect latent heat convergence.

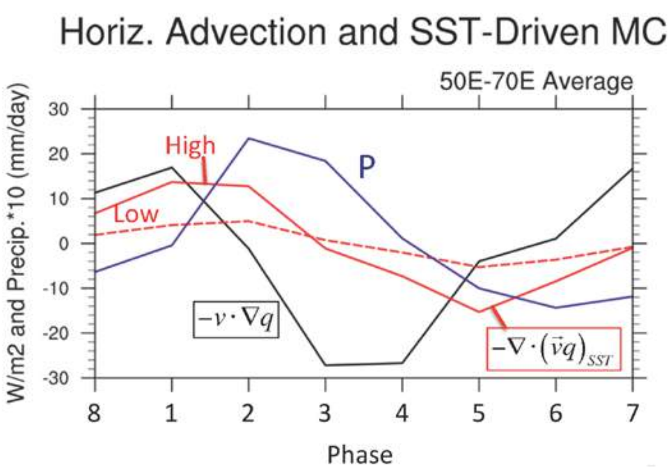
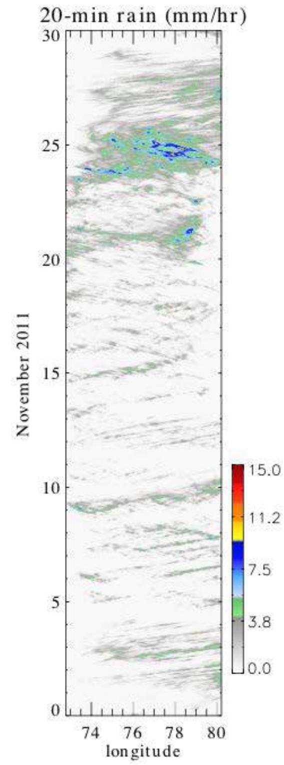


Figure 10. Composite 10ºN-10ºS averaged Indian Ocean precipitation, column-integrated horizontal moisture advection, and SST-driven moisture convergence anomalies in the SPCCSM as a function of MJO phase. High and low estimates for the SST-driven convergence anomalies are provided based on plausible parameter settings of the Back and Bretherton (2009) boundary layer model.

Understanding DYNAMO MJO Initiation in a high resolution regional model (Riley Dellaripa et al. 2017).

Figure 11. Model 20 minute rain rate in the DYNAMO Northern Sounding array as a function of time for the November 2011 DYNAMO event. Units of rainrate are mm day^{-1}.



A cloud system resolving version of the RAMS model (the predecessor regional version of OLAM) forced with DYNAMO datasets demonstrates realistic representation of MJO convective variability during the DYNAMO field program when integrated over the Northern Sounding Array (**Figure 11**). Horizontal model grid spacing in 1.5 km. The model demonstrates a realistic simulation of air-sea coupling via wind-induced surface flux variability, assessed versus buoy sites in the Indian Ocean initiation region, and also produces a comparable representation of convective organization to that of DYNAMO observations. Latent heat flux variability is very strongly correlated with precipitation variability, both locally and in the domain average. The realistic convective partitioning from the model is represented in a plot of stratiform-convective fraction as a function of time (**Figure 12**).

Detailed analysis of this run provides a mixed picture as to the support of convective organization in the model by surface fluxes. During the MJO suppressed phase, individual convective systems are supported by wind-driven flux feedbacks both before and during the mature phase of mesoscale convective systems. However, during the MJO onset and mature phases, while surface fluxes support individual mesoscale convective systems during their growth stage, mature MCSs are provided no support by wind-induced flux anomalies, similar to recent work in RCE frameworks used to examine self-aggregation. Model sensitivity tests that constrain fluxes to be homogeneous spatially or time invariant does not suggest that a robust wind-induced flux feedback is produced in this model, although a different form of simulations based on WTG theory may be needed to verify this. The WTG moistening diagnostics of Wolding and Maloney (2015b) are also applied in this run indicating substantial support for MJO convective variability by radiative feedbacks and their impact on the mid- and lower-tropospheric moisture budget. A paper describing these results is in press in *J. Atmos. Sci.*

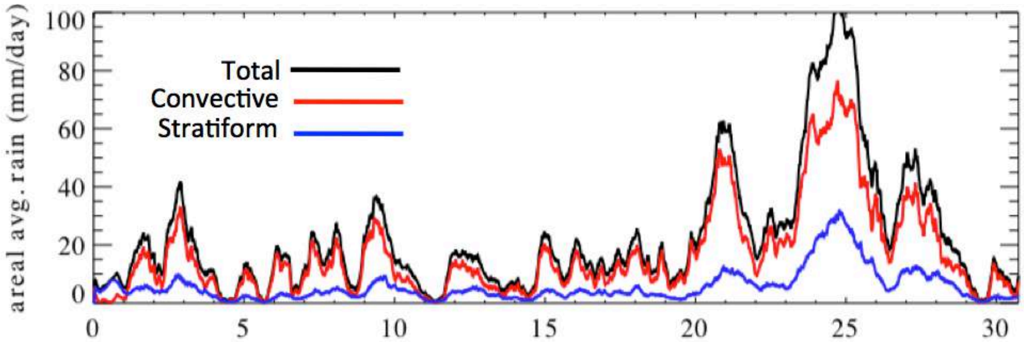


Figure 12. Northern Sounding Array stratiform-convective partitioning as simulated by the RAMS model. The x-axis represents day of the month November 2011.

Vertically-Resolved Weak Temperature Gradient Analysis of the Madden-Julian Oscillation (Wolding 2016).

Brandon Wolding completed his Ph.D research under this project. It contains much of the work described above. A further abstract is listed here:

Interactions between moisture, convection, and large-scale circulations are thought to play an important role in destabilizing the Madden-Julian Oscillation (MJO). A simpli- fied framework for understanding such interactions is developed, building upon the work of Chikira (2014). Tropical weak temperature gradient (WTG) balance is used to diagnose intraseasonal variations in large-scale vertical velocity from variations in apparent heating, allowing intraseasonal variations in large-scale vertical moisture advection to be decomposed into contributions from various apparent heating processes (e.g. radiative heating, micro- physical processes). The WTG diagnosis captures the vertical structure and magnitude of large-scale vertical velocity and vertical moisture advection with exceptional accuracy throughout the free troposphere.

Moisture and moisture variance budgets are used to investigate the MJO in ERA-interim (ERAi) reanalysis and the Superparameterized Community Earth System Model (SP-CESM). Moisture budgets indicate that during the enhanced phase of the MJO, anoma- lous moistening by large-scale vertical moisture advection exceeds anomalous drying by mi-crophysical processes and sub-grid scale (SGS) eddy fluxes, such that the net effect of these large and opposing processes (hereafter the column process) is to further moisten regions that are anomalously moist. Moisture variance budgets indicate that the column process helps grow moisture variance, acting to destabilize the MJO. Horizontal advective damping of moisture variance, associated with the modulation of higher frequency convective variability on intraseasonal timescales, acts to stabilize the MJO.

The vertically resolved WTG balance framework is used to assess the contribution various apparent heating processes make to the column process, and its ability to destabilize the MJO. Intraseasonal variations in longwave radiative heating enhance variations in large-scale vertical moisture advection at low and mid levels, strongly supporting destabilization of the MJO in both ERAi and SP-CESM. The effect of convection alone (i.e. without radiative and surface flux feedbacks) is to weakly grow moisture variance in SP-CESM, and weakly damp moisture variance in ERAi, suggesting that the MJO is unrealistically unstable in the former. Surface flux feedbacks appear to play a more important role in destabilizing the real world MJO. Moisture variance budget analysis of periods of weak, moderate, and strong MJO activity suggests that changes in the vertical structure of apparent heating do not play a dominant role in limiting the amplitude of the MJO in SP-CESM in the current climate.

WTG balance provides a useful framework for investigating how the MJO, and its impacts, may change as the climate system warms. Two simulations of SP-CESM, one at pre-industrial levels of CO_2 (280 ppm, hereafter PI) and one where CO_2 levels have been quadrupled (1120 ppm, hereafter $4xCO_2$), were analyzed. MJO convective variability increases considerably in the $4xCO_2$ simulation, a consequence of more favorable mean state moist thermodynamic conditions. A steepened mean state vertical moisture gradient allows MJO convective heating to drive stronger variations in large-scale vertical moisture advection, helping to support enhanced MJO convective variability in the $4xCO_2$ simulation. The dynamical response to MJO convective heating weakens in the warmer climate, a result of increased tropical static stability. One consequence of this weakened dynamical response is that the MJO's ability to influence the extratopics, which is closely tied to the strength of its associated divergence, is reduced considerably in the $4xCO_2$ simulation.

Highlights of Accomplishments

- Analysis of OLAM indicates the importance of simulating a realistic Indian Ocean moisture budget for producing a realistic MJO simulation, particularly an appropriate effect of deep convection and its associated large-scale circulations on the moisture budget
- Objective weak temperature gradient MJO diagnostics of the DYNAMO region and broader domain applied to observations and global and regional models indicate that the MJO is destabilized by radiative feedbacks, and propagated eastward by horizontal moisture advection.
- Aquaplanet model experiments indicate that Rossby gyres associated with the previous cycle of MJO convection help to initiate the MJO, and that Kelvin wave circumnavigation plays a secondary role.
- We showed that MJO hindcasts during the DYNAMO period could be improved through increasing convective entrainment.
- We showed that with increased entrainment, the NCAR CAM5 appears to produce a good MJO for the wrong reasons, with a bottom-heavy heating profile compensating for too weak of cloud-radiative feedbacks. This highlights areas of improvement for climate models.
- The SP-CAM produces an improved representation of the MJO relative to the NCAR CAM during the DYNAMO period, although the SP-CAM exhibits a poorer MJO skill score based on RMSE since SP-CAM mean state drift projects strongly onto the MJO indices used to assess skill.
- Advanced MJO diagnostics were developed that showed the RMM index to be dominated by east Pacific 200 hPa zonal wind variability during the October DYNAMO event that erroneously suggested a weakening of the event at the end of October.
- We showed that ocean coupling may help produce MJO initiation through SST-driven convergence that aids column moistening in advance of MJO convection, highlighting

why uncoupled models have difficulty simulating the MJO

Publications From the Project

Hannah, W. M., and E. D. Maloney, 2014: The Moist Static Energy Budget in NCAR CAM5 Hindcasts during DYNAMO. *J. Adv. Modeling Earth Sys*., **6**, doi:10.1002/2013MS000272.

Hannah, W. M., E. D. Maloney, and M. Pritchard, 2015: Consequences of Systematic Model Drift in DYNAMO MJO Hindcasts with SP-CAM and CAM5. *J. Adv. Modeling. Earth Sys*., **7**, 1051–1074.

Wolding, B. O., and E. D. Maloney, 2015: Objective Diagnostics and the Madden-Julian Oscillation. Part I: Methodology. *J. Climate*, **28**, 4127-4140.

Wolding, B. O., and E. D. Maloney, 2015: Objective Diagnostics and the Madden-Julian Oscillation. Part II: Application to Moist Static Energy and Moisture Budgets. *J. Climate,* **28**, 7786–7808.

Maloney, E. D., and B. O. Wolding, 2015: Initiation of an Intraseasonal Oscillation in an Aquaplanet General Circulation Model. *J. Adv. Model. Earth. Sys*., **7**, 1956–1976.

Wolding, B. O, E. D. Maloney, and M. Branson, 2016: Vertically Resolved Weak Temperature Gradient Analysis of the Madden-Julian Oscillation in SP-CESM. *J. Adv. Modeling. Earth. Sys.*, 8, doi:10.1002/2016MS000724.

Wolding, B. O., E. D. Maloney. S. A. Henderson, and M. Branson, 2017: Climate Change and the Madden-Julian Oscillation: A Vertically Resolved Weak Temperature Gradient Analysis. *J. Adv. Modeling Earth Sys*., **9**, doi:10.1002/2016MS000843.

DeMott, C., B. Wolding, E. Maloney, and D. Randall, 2017a: The shape of MJO heating in the Indian Ocean: relationship to background moisture and MJO propagation or decay. *J. Geophys. Res.*, accepted pending revision.

Riley Dellaripa, E, E. Maloney, and S. van den Heever, 2017: Wind-flux feedbacks and convective organization during the November 2011 MJO event in a high resolution model. *J. Atmos. Sci*, in press.

Maloney, E. D., B. O. Wolding, R. Walko, W. Cotton, and G. Carrio, 2017: MJO Initiation during DYNAMO events in the Ocean Atmosphere Land Model. *J. Adv. Model. Earth. Sys*., to be submitted.

DeMott, C., S. deSzoeke, B. O. Wolding, and E. D. Maloney, 2017b: SST-driven boundary layer convergence moistening and the MJO in the SPCESM. *J. Climate*, to be submitted.

Wolding, B., Ph.D, 12/5/16, Colorado State University, Title: Vertically-Resolved Weak Temperature Gradient Analysis of the Madden-Julian Oscillation, 190 pp.

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PROJECT TITLE: Use of the Stochastic-dynamic Approach in a Single Dynamic-Core Storm-Scale Ensemble for Improved Spread and Reliability of QPF and Surface Variables - Joint Technology Transfer Initiative funded (GSD-Task)

PRINCIPAL INVESTIGATOR: Isidora Jankov

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NOAA RESEARCH TEAM: Joseph Olson, Evan Kalina (CIRES)

FISCAL YEAR FUNDING: $199,582

PROJECT OBJECTIVE:

Recently the National Center for Environmental Prediction (NCEP)/Environmental Modeling Center (EMC) made a commitment to move towards a more unified and sustainable operational forecasting system, primarily by focusing on a single dynamic core, FV3, for global scales in the near future, and soon after for regional scales. For the purpose of designing a unified storm-scale ensemble forecasting system, the utilization of a single dynamic core with a single physics suite with stochastic approaches would be beneficial. The motivation for this work is to facilitate EMC's transition towards a sustainable and unified operational forecasting system by testing an *alternative* to multi-model, multi-physics approach employed in current High Resolution Ensemble Forecast (HREF) system v2 operational realization of the Storm Scale Ensemble of Opportunity; SSEO. The alternative is a single-model, single-physics, HRRR-based ensemble with stochastic parameterizations, and in the future single-physics, FV3-based ensemble, as the model around which we seek to unify.

The aim of the work is to design storm-scale ensemble configurations, based on Stochastic Parameter Perturbations (SPP), which will result in desirable spread and reliability for variables of interest. The focus is on the development of the best configuration for the SPP scheme to perturb parameters in the PBL, LSM, microphysics and radiation schemes.

PROJECT ACCOMPLISHMENTS:

During the past six months, since the beginning of the project, perturbations to additional parameters in the LSM scheme (vegetation fraction, emissivity and albedo) were added. As a part of the PBL parameter perturbation, code for perturbation of gravity wave drag (vertical component of stress) was implemented. Through collaboration with PIs Jason Otkins and Greg Thompson based on their funded work for "Assessing the impact of stochastic cloud microphysics in convection-resolving models using GOES-T Satellite observations", a capability of SPP within the Thompson microphysics was made available to our team. We made changes to the microphysics SPP to allow for perturbations in the microphysics to be combined with SPP perturbations in the other physics schemes. In terms of parameters that are going to be perturbed in microphysics, the team is considering collection coefficients and accretion coefficients. The impact of applying SPP on the graupel intercept parameter is currently being tested by the DTC Ensemble team. If the tests show potential, the graupel intercept parameter will be included in our overall tests. All parameter perturbations were implemented in close collaboration with the physical parameterization scheme experts, directly reflecting their knowledge of the *uncertainty* and *sensitivity* of these parameters.

The first part of testing was focused on a case study. For this purpose, the July 5-6 2015 case was selected. The case was chosen based on the presence of a low-level jet, convection initiation and development over the Kansas area during the Plains Elevated Convection At Night (PECAN) field experiment. Abundance of experimental observations will facilitate the detailed analysis of changes in model performance due to variety of SPP perturbations. For the purpose of testing recent code changes and their impact on the high-resolution ensemble an end-to-end Rocoto workflow was developed. So far, performance of the workflow has been tested with July 5, 2015 initial and boundary conditions.

In parallel, work was conducted to increase the computational performance of the SPP scheme. A prototype code was developed which allocates an array for the stochastic perturbation, which is optimally dimensioned with regard to Fast-Fourier-Transform requirements, independent of the WRF domain. After generation and update of the pattern, it is interpolated onto the WRF-grid and used for the parameter perturbations. The independence of this array from the WRF parent domain allows to over-resolve or under-resolve the pattern which can accommodate future requirements with regard to computational resources. In addition, the proto-type code allows for the pattern to be updated at every n-th timestep, further reducing the computational cost of the scheme, while allowing bit-reproducibility if updated at every timestep. The code has been tested and timed on a small domain, but not yet on the HRRR domain.