CIRA 2000

VOLUME 13

Colorado State University

CIRA

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The Cooperative Institute for Research in the Atmosphere at Colorado State University (CIRA) offers a limited number of one-year Associate Fellowships to research scientists. Awards may be made to senior scientists including those on sabbatical leave or recent Ph.D. recipients. Those receiving the awards will pursue their own research programs, collaborate with existing programs, and participate in Institute seminars and functions. Selection is based on the likelihood of an active exchange of ideas between the Fellows, the National Oceanic and Atmospheric Administration, Colorado State University and CIRA scientists. Salary is negotiable based on experience, qualifications, and funding support. The program is open to scientists of all countries. Submitted applications should include a curriculum vitae, publications list, brief outline of the intended research, a statement of estimated research support needs, and names and addresses of three professional references.

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Cover: Sponsored by the DoD Center for Geosciences Atmospheric/Research, the 5th Cloud Layer Experiment (CLEX-5), which was conducted in late 1999, featured a new, advanced airborne instrument (Cloud Particle Imager) for providing detailed images of cloud particles (mounted underneath aircraft as pictured). Also shown is the ground-based millimeter-wave radar used for observing clouds.

Greetings from the Editor,

We have an exciting new look for this issue. I hope you like it. Through the combined creative efforts of our new designers, my father Joe Greenwald and my sister Patty Jaworski, I think this issue has turned out to be our finest.

The CIRA web homepage also has a fresh look (pictured below). It was recently redesigned and developed by the CIRA GLOBE team at the Forecast Systems Lab in Boulder. Thanks to the team for a job well done! Visit CIRA on the web at http://www.cira.colostate.edu and access the links to various new sites. Also, check out the online version of the newsletter.

Finally, I would like to remind everyone that CIRA is celebrating its 20th anniversary later this year. To commemorate this occasion we are assembling a special fall newsletter issue. We invite anyone formerly or presently connected with CIRA to submit a brief article (1000 words or less) on your experiences working for CIRA, your achievements, or anything else you would like to say. Please send your articles directly to me, Tom Greenwald, no later than July 15 via email at greenwald@cira.colostate.edu.

Contents

THE MYSTERIOUS MID-LEVEL CLOUD

By J. Adam Kankiewicz

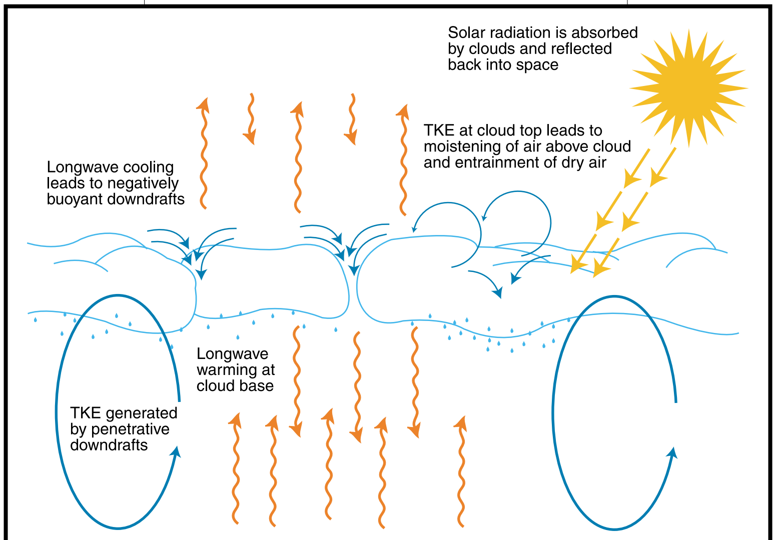


Fig. 1: *Conceptual diagram of mid-level cloud dynamics*

The Center for Geosciences recently completed the fifth in an ongoing series of field programs connected with the Complex Layered Cloud Experiment (CLEX). The motivation for CLEX-5 is to further our understanding of the processes inherent to the formation, maintenance and dissipation of mid-level, non-precipitating, mixed-phase clouds. A better understanding of mid-level clouds has many applications for both military and civilian purposes. For example, during DESERT SHIELD/STORM, mid-level cloud systems often masked target areas and hampered use of electro-optic sensors and weapons systems. For civilian pilots, poorly forecast mid-level clouds often restrict flight visibility and can create icing hazards. Figure 1 shows a conceptual diagram of the physics that govern the structure of mid-level clouds. Radiation and microphysical processes play a substantial role in the mid-level cloud life cycle.

Fundamental questions being addressed during the current investigation include the role of radiative energy transfer in the overall energy budget of mid-level clouds, and the potential for increasing forecasting skill of medium-range models by including satellite inferred parameters of mid-level clouds in the initial data field. Another major goal of the CLEX field campaigns is developing and testing methods for inferring not only cloud tops but also cloud bases from satellite observations.

"Radiation and microphysical processes play a substantial role in the mid-level cloud life cycle"

CLEX-5 Field Experiment

The CLEX-5 field observation phase of the research consisted of intensified satellite data collection, airborne in situ microphysics observations, and surface observations during the period November 4 - December 7, 1999. Satellite data were collected from GOES, NOAA, and DMSP platforms by CIRA's satellite downlink facility at Colorado State University. The primary area of operations was over the Atmospheric Radiation Measurement Cloud And Radiation Test Bed (ARM CART) site in northern Oklahoma, with a secondary set of ground instruments deployed from CSU to an area near Platteville, CO. Due to the sparse occurrence of mid-level clouds during the CLEX-5 period, no "candidate" clouds were sampled over the Platteville site.

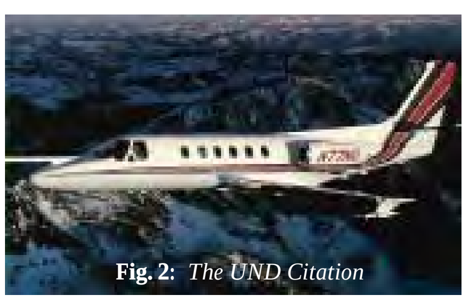


Fig. 2: *The UND Citation*

The University of North Dakota Citation aircraft (shown in Figure 2) was equipped with a suite of cloud microphysical and radiation sampling instruments and flown for multiple missions during CLEX-5. To further our understanding of the ice crystal habits located in mixed phase environments, a state-of-the-art Cloud Particle Imager (CPI) was also flown aboard the UND Citation. Airborne in-situ cloud observations made during CLEX-5 include:

- *Cloud Liquid Water/Ice Fractions*
- *Cloud Particle Imager (CPI) Observations*
- *Cloud Base/Top Radiometric Measurement*
- *Cloud Video*

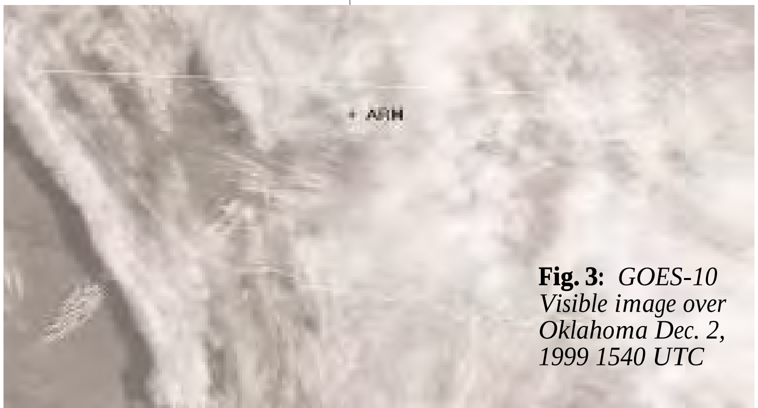


Fig. 3: *GOES-10 Visible image over Oklahoma Dec. 2, 1999 1540 UTC*

The basic purpose of the surface component is to provide ground truth of the cloud base (and to the extent possible cloud top), cloud base radiative fluxes, and remotely sensed cloud liquid water. Ground-based instruments used to collect data at the ARM CART site included:

- *Millimeter Cloud Radar (MMCR)*
- *Micropulse LIDAR (MPL)*
- *Microwave Radiometer (MWR)*
- *Video Time Lapse Camera (VTLC)*
- *Atmospheric Emitted Radiance Interferometer (AERI)*
- *Wind Profiler*
- *Pyranometer*
- *Surface State Parameters (Pressure, Temperature, Humidity, Winds, etc)*
- *Balloon-borne Sounding System(BBSS)*

A Case Study from CLEX-5

Figure 3 shows the GOES-10 visible image from Dec. 2, 1999 over the ARM CART site. This day was dominated by mid- and upper-level clouds advecting in from the southwest. Figure 4 shows the reflectivity (dBZ) return from the ARM CART Millimeter Cloud Radar (MMCR). The MMCR gives a visual look at the vertical extent of the clouds over the ARM CART site on this day. The UND Citation sampled mixed-phase clouds over the ARM CART site from 1500 to 1600 UTC. Cloud microphysical data from these sampled clouds can be seen in the CPI liquid water and ice crystal images (Figure 5). Both rimed ice and pristine ice particles are evident within the clouds sampled on Dec. 2, 1999. Data from the CPI will allow us to better understand the intricate relationship that the ice and liquid water cloud constituents have on each other and their immediate environment.

"The . . . data collected . . . will allow us to better understand mid-level cloud structures and the physical processes that cause their formation, evolution, and dissipation"

The unique set of data collected during the CLEX-5 field project will allow us to better understand mid-level cloud structures and the physical processes that cause their formation, evolution, and dissipation. By integrating the data set collected during CLEX-5 – including satellite, airborne and ground-based data – with a cloud modeling effort, we hope to better understand mid-level, mixed-phase cloud morphology. Gaining that, we might one day be able to better forecast these complex cloud systems.

Footnote: Mr. Kankiewicz is a member of the CLEX research team

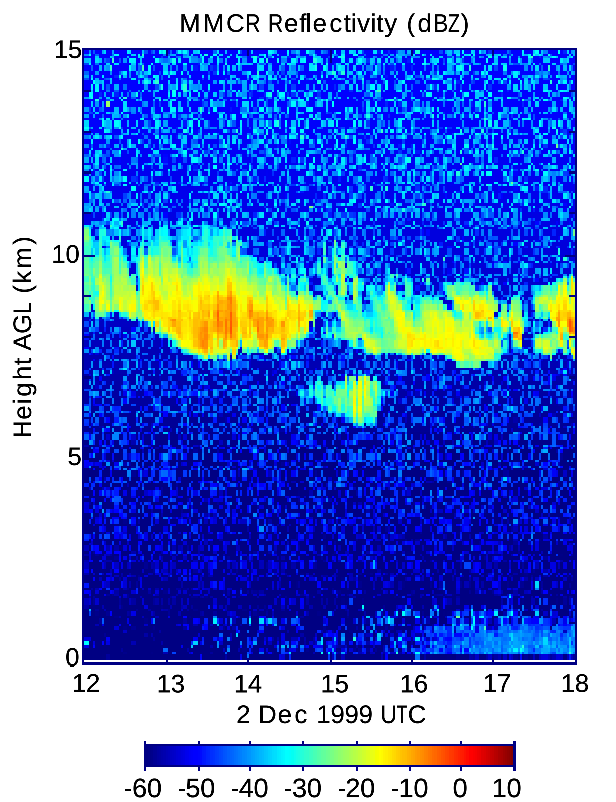


Fig. 4: *Millimeter Cloud Radar (MMCR) observations*

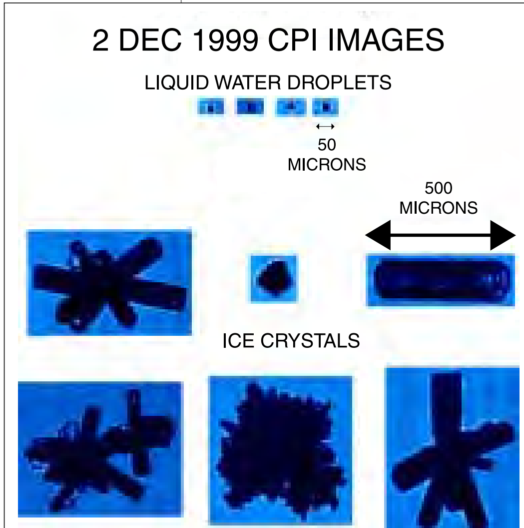


Fig. 5: *Cloud Particle Imager(CPI) images*

A GOES-EYE VIEW OF LOW-LEVEL CLOUDS

By Tom Greenwald

Satellite observations have helped us understand low-level stratiform clouds – those cloud systems that cover large portions of the Earth and produce a net cooling effect on the planet's climate. What has been lacking from these observations, however, has been the ability to track the evolution of the microphysics of these cloud systems. Now, with the advanced imagers on the latest series of Geostationary Operational Environmental Satellites (GOES I-M), this is possible. For the past 4 years, Dr. Tom Greenwald and his colleague, Assistant Professor Sundar Christopher from the University of Alabama, have been leading the effort in studying stratocumulus clouds using the latest GOES imagers. Their research has looked into new ways of using the imagers to study the microphysical properties of these cloud systems.

> **"A wealth of quantitative information concerning cloud microphysical properties is obtainable from the GOES imagers"**

The newest GOES imagers have been providing high quality visible and infrared imagery for nearly six years. GOES-8 (I) was launched in April 1994; its successors include GOES-9 (J), GOES-10 (K) and the recently launched GOES-11 (L). For operational applications, data collected by these instruments have improved estimates of cloud drift winds and sea surface temperatures and the detection of fires, to name a few.

The imager has five channels that measure scattered/reflected and emitted radiation in selected narrow spectral regions (see Figure 1). Cloud microphysical information can be obtained from scattered solar radiation measured by the visible and near-infrared channels. The theory behind this is that the radiation scattered by clouds in the visible spectrum, where the absorption by cloud liquid water droplets is negligible, is related to the opacity or optical thickness of the cloud. In contrast, at longer, near-infrared wavelengths, the scattered radiation is related to the effective size of the droplets due to droplet absorption concentrated near the cloud top. Given the cloud's optical thickness and mean radius of the droplets, a measure of the amount of liquid water mass in the clouds (the cloud liquid water path or LWP) can be estimated. The reliability of the cloud LWP estimates derived from the GOES imagers have been compared in detail against precise ground-based instrumentation (see Figure 2). The estimates of droplet size, however, have yet to be verified. This is expected to occur in the near future.

Being in geostationary orbit, the imager can provide frequent imagery (operationally, every 15 min in some regions) making it ideally suited for investigating the daily cycle of cloud microphysical properties. In their 1999 study (Greenwald and Christopher 1999a), half-hourly GOES-9 data were used to examine the timing and strength of the daytime cycle of cloud microphysics for a stratocumulus system off the coast of Baja California. This study was the first of its kind. They found that a maximum in cloud LWP appeared almost exclusively in the early to mid-morning hours (see Figure 3) consistent with other observational studies. This is attributed to the absorption of solar radiation dur-

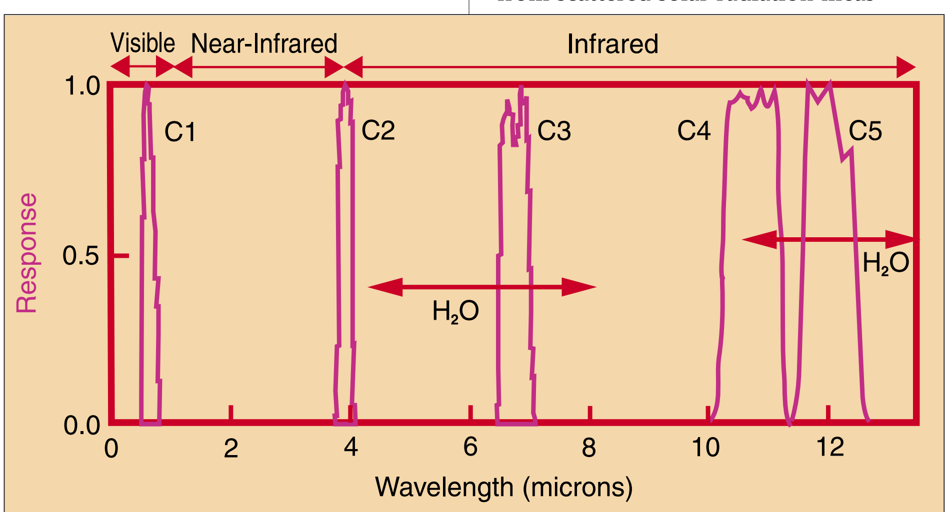
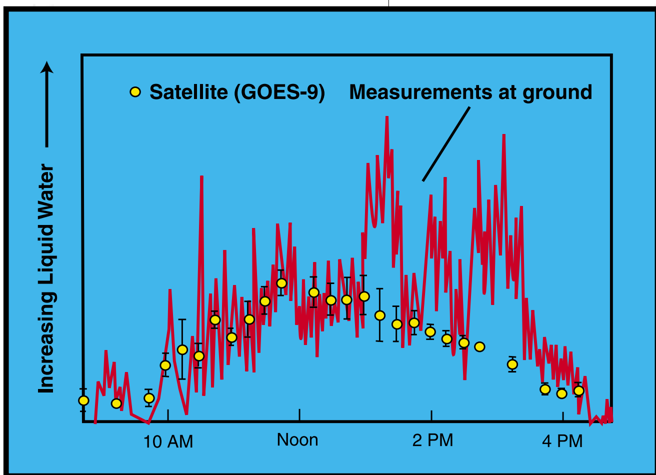


Fig.1: *Spectral regions sensed by the five GOES-9 imager channels (C1-C5)*

“the GOES imagers may also prove useful as additional tools in studying the effects of aerosols on cloud and precipitation formation”



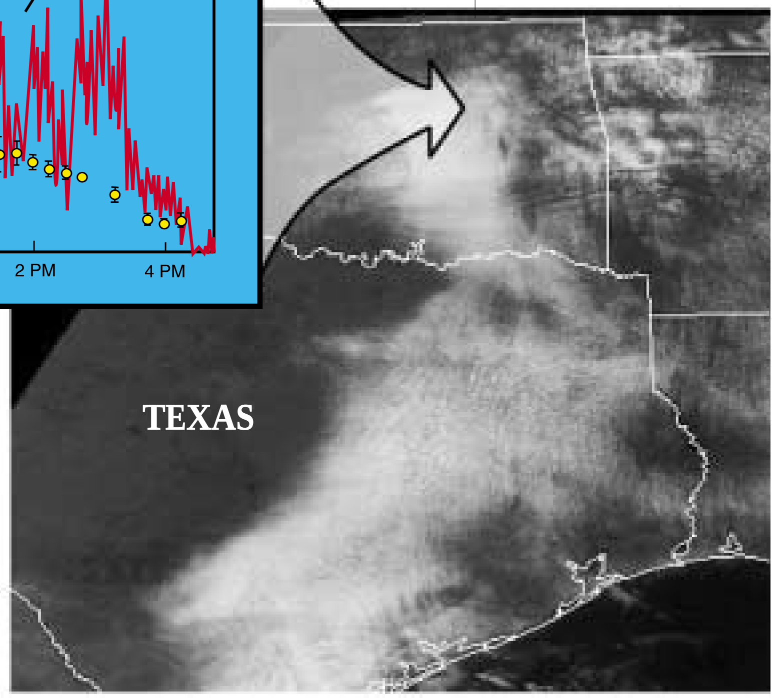


Fig. 2: *Verification of GOES-9 imager estimates of cloud liquid water path by comparison to surface microwave radiometer observations over Oklahoma. Differences occurring after 12:30 PM were likely caused by drizzle formation (from Greenwald et al. 1999)*

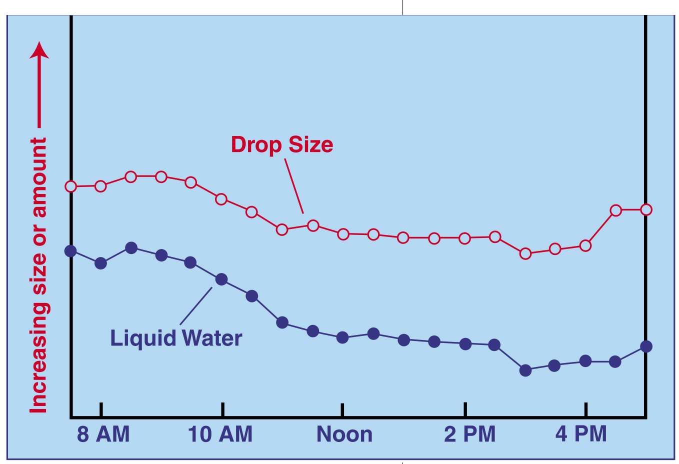


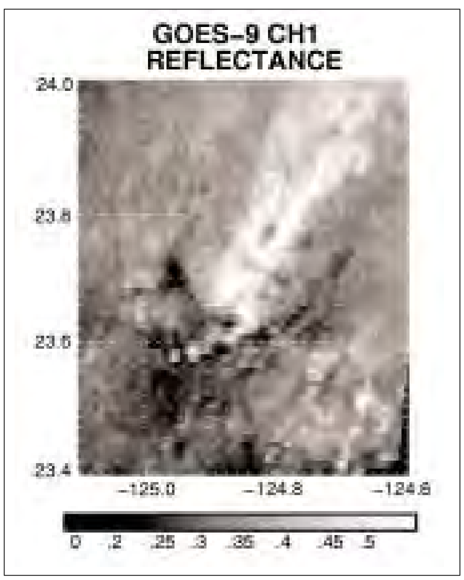
Fig. 3: *Daytime cycle of stratocumulus microphysical properties off the coast of Baja California as observed by the GOES-9 imager (from Greenwald and Christopher 1999a)*

ing the day that causes the clouds to become thinner. What was unexpected, however, was that a maximum in cloud droplet size was more significant and common in the morning. This is contrary to model predictions that indicate larger droplet sizes occur in the afternoon and early evening – a result of the clouds decoupling from the layer below them during the day.

The same study also produced another intriguing result. A distinct region of small droplet sizes was seen to extend away from the southern coast of California. Airborne particulates (or aerosols) are often transported from land to ocean, which can modify the formation of marine clouds. Although additional information is needed to corroborate their findings, the effects of continental aerosols were the likely cause of the reduction in the size of the cloud droplets in this case.

The indirect effect of aerosols on climate has recently become a hot topic. Rosenfeld (1999) provided evidence from satellites that smoke produced from human-induced forest fires effectively shuts down precipitation formation in nearby convective tropical clouds. The preliminary findings of Drs. Greenwald and Christopher indicate that the GOES imagers may also prove useful as additional tools in studying the effects of aerosols on cloud and precipitation formation.

Another capability of the GOES imager is its ability to observe the microphysics of drizzling stratocumulus systems. The formation of drizzle in stratocumuli is known to alter their cloud microphysical properties, hence changing how much solar radiation is scattered by the clouds. The magnitude of this effect, however, has been the subject of debate. In a 1999 study (Greenwald and Christopher 1999b), the GOES-9 imager and a ship-based radar in the West Pacific were used to observe precipitating stratocumuli (Figure 4). Surprisingly, it was found that drizzle cells as seen by the radar corresponded very well with larger effective droplet sizes (often exceeding 20 microns in size) inferred from the imager. This latest capability of the GOES imagers is anticipated to provide additional valuable information about these precipitating cloud systems



A wealth of quantitative information concerning cloud microphysical properties is obtainable from the GOES imagers. We have only begun to tap into the full potential of these instruments for these kinds of studies. The eventual goal of Dr. Greenwald's research is to determine whether the imager measurements, when incorporated into forecast models, can supply enough unique information about cloud microphysical properties to improve the forecasting of certain weather phenomena. This work is currently in progress as part of the DoD Center for Geosciences Atmospheric Research.

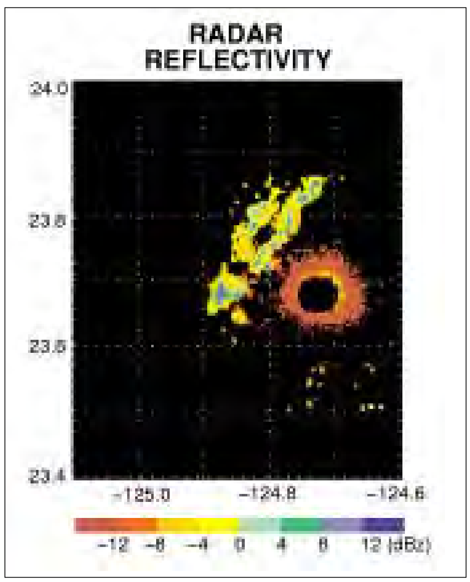


Fig. 4: *GOES-9 observed signatures of drizzling marine stratocumulus clouds in the West Pacific for imager channels 1 (left) and 2 (right). Coincident ship-based radar observations are also shown (center). Radar return strength given in units of dBZ (from Greenwald and Christopher 1999b)*

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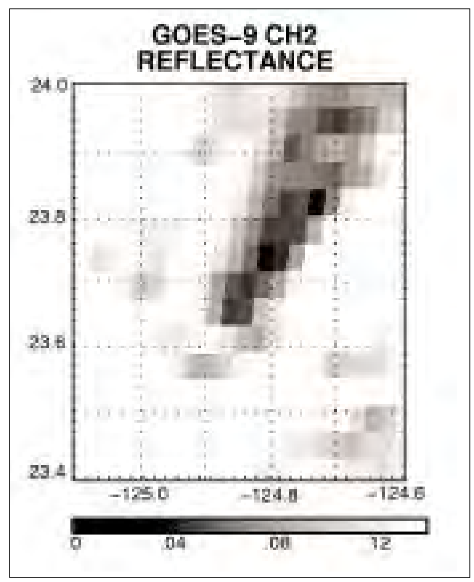


Note: Darker areas represent larger cloud droplets.

ATMOSPHERIC AEROSOLS AND VISIBILITY RESEARCH

By Sonia Kreidenweis

Since the early 1990's, the Atmospheric Science Department at Colorado State University has been conducting collaborative research with CIRA and the National Park Service on the relationships between atmospheric aerosol properties and visibility reduction. The CSU studies, led by Profs. Sonia Kreidenweis and Jeffrey Collett, Jr., have been aimed at collecting data needed for input to models of light extinction. Model predictions are based on measurements of fundamental properties, such as atmospheric aerosol mass and composition, aerosol water content, and particle size distributions. These predictions are compared with direct measurements of extinction, and analyses of discrepancies between the measured and modeled visibility are used to help improve the predictive capability of the models. Linking the "end effect" – visibility reduction – to variations in fundamental aerosol properties is an essential step in assessing the contributions of various sources of particulate matter – transportation, fossil fuel combustion, and biogenic emissions, for example – to impaired air quality. Assessments of how each source contributes to visibility impairment are used in the scientific and regulatory communities to guide recommendations for emission controls for improving future regional air quality.

" Linking . . . visibility reduction to variations in fundamental aerosol properties is an essential step in assessing the contributions of various sources of particulate matter . . . to impaired air quality. "

The Southeastern Aerosol and Visibility Study (SEAVS) was conducted in Great Smoky Mountains National Park in the summer of 1995. Measured aerosol size distributions, chemical composition, and optical properties reflected variations in the dominant particle types and in meteorology throughout the study period. Figure 1 shows examples from two extreme events. In the first, the remnants of Hurricane Erin swept through the southeastern U.S.; the wind direction at the study site was constant from the Gulf of Mexico, with relatively high wind speeds, and the aerosol mass concentration was low, with correspondingly low aerosol extinction coefficients. During this time the particles were composed primarily of sulfate compounds (~50% by mass), organic carbon (~30% by mass), and soil, with some sea salt also detected in the samples. In the second time period, occurring several weeks later, a high-pressure system over the region caused stagnation conditions. The wind directions show diurnal upslope / downslope variations caused by heating of the nearby mountain range. The lack of venting caused concentrations of particulate matter to build over several days, with corresponding increases in the extinction coefficient; the visual ranges during this time were some of the lowest

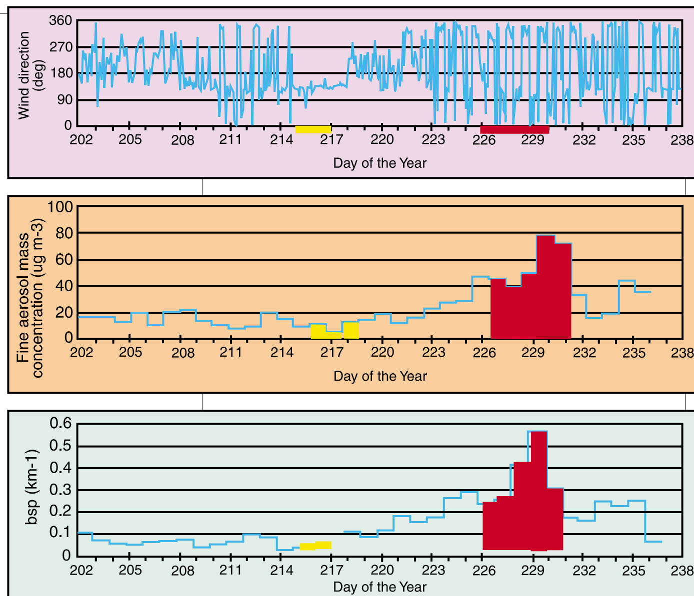


Fig. 1: *Timelines of three parameters measured during the 1995 SEAVS study.* ***(Top)*** *Wind direction at the Look Rock Tower site 739 m ASL on the western edge of Great Smoky Mountains National Park. The mountain ridge is oriented SW to NE. The yellow bar marks dates with constant SE flow associated with the passage of the remnants of Hurricane Erin. The red bar marks the calm stagnation (hazy) period, having diurnal wind shifts associated with upslope and downslope flows created by surface heating and cooling.* ***(Middle)****Fine aerosol mass concentrations in $\mu g\ m^{-3}$, from filters exposed for 24 hours. Yellow shading marks samples from the hurricane-influenced period; samples shaded red indicate the large increases observed in mass concentrations during the hazy period.* ***(Bottom)****Light scattering coefficient, bsp, in km^{-1}. Bsp is inversely related to the visual range. Note the large increase in bsp, and hence decrease in visual range, associated with the stagnation period (red), relative to the values in the marine air associated with the hurricane-influenced period (yellow).*

ever recorded at the site. The aerosol composition was dominated by sulfate compounds (~80% by mass), derived from the oxidation of sulfur gases released in coal combustion; the valleys in the region were fog-filled most of the mornings during this hazy period, providing sites for aqueous-phase chemical reactions that efficiently convert gaseous sulfur dioxide into particulate sulfate.

" improved understanding of the impacts of various sources is essential input to bi-national policy decisions regarding transboundary air pollution."

The field operations for the Big Bend Regional Aerosol and Visibility Observational Study (BRAVO) took place from July through October, 1999, in Big Bend National Park, on the Texas / Mexico border (Figure 2). The objectives of the study and a brief description of the measurements were reported in the Fall 1999 CIRA Newsletter, and preliminary data analyses are now underway (initial CSU data are reported at http://aerosol.atmos.colostate.edu/BRAVO). The haze in Big Bend National Park is derived from a variety of sources that include, among others, natural emissions (e.g., windblown dust and biogenic carbon); industrial source areas, power plants and refinery operations in Texas and along the Gulf of Mexico; and power plants and industrial sources in Mexico. An improved understanding of the impacts of various sources is essential input to bi-national policy decisions regarding transboundary air pollution. Figure 3 demonstrates the variations in particulate matter concentration that occurred over short time periods, as air masses with different origins and histories were transported to and sampled at the site. The study team is using the observed aerosol properties, along with meteorological information, to assess the relative contributions of various source types and regions during the four months of the study, and to further test models of aerosol extinction. Initial findings will be reported to the EPA later this year.

Fig. 2: *Location of Big Bend National Park, bordered by the Rio Grande River on the Texas / Mexico border.*

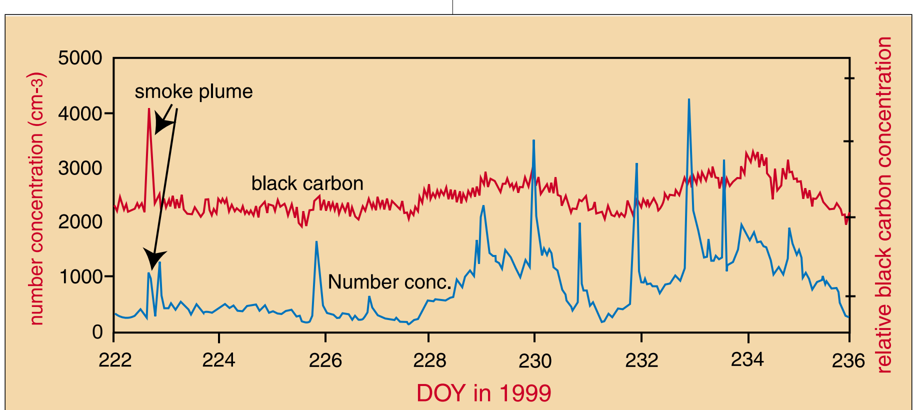


Fig. 3: *Timelines of accumulation mode aerosol number concentration and variations in measured black carbon concentrations for two weeks in August 1999 during the BRAVO field project. The spike in black carbon and in number concentration on DOY 222 was associated with transport of smoke from a nearby fire in the Rio Grande river basin. Explanations for other excursions in the two variables have not yet been identified.*

Regional And Mesoscale Meteorology Team Scientists Assess Impact and Service for Significant Weather Events

"Since 1970, more than half of the loss of life in the US due to tropical cyclones was caused by inland (fresh water) flooding"

By Brian Motta with contributions from Mark DeMaria and Ray Zehr

Over the past few years, the National Oceanic and Atmospheric Administration's (NOAA) National Environmental Satellite Data and Information Service (NESDIS) Regional and Mesoscale Meteorology Team has contributed to formal reviews of significant weather events. Events such as large tornado outbreaks and major flooding disasters have been examined from the perspective of satellite meteorology and the integrated use of modernized National Weather Service (NWS) data sets. The most recent event studied was Hurricane Floyd, which caused flooding over an extensive area of North Carolina during September of 1999.

A church in Princeville, NC showing the water marks from the height of the flood (about two-thirds of the way up the windows).

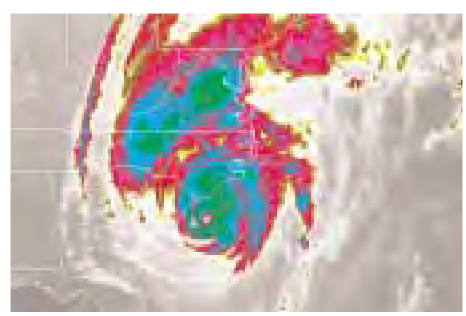
Dr. Mark DeMaria, Team Leader of the NOAA/NESDIS Regional and Mesoscale Meteorology Team, was asked to participate as part of the NWS Service Assessment Team. These assessments examine disasters from the pre-disaster environment to the post-disaster management and recovery. Often, site visits to NWS Warning and Forecast Offices, government emergency managers, Federal Emergency Management Agency, United States Geological Survey, NESDIS, and other actively involved entities reveal the most complete picture of how the crisis evolved.

The issue of hurricane forecasting has reached a high level of public awareness in the last few years as more intense and more frequent storms have affected the United States. In the case of Floyd, excessive rainfall was widespread and was exacerbated by previous recent rainfall from Hurricane Dennis. Although Floyd was moving relatively fast for a land-falling hurricane, its large circulation interacted with a frontal zone and generated up to a foot of rainfall in many Mid-Atlantic States. The maximum rainfall occurred in eastern North Carolina and nearby Virginia where up to 20 inches of rain fell.

A house surrounded by receding water in Boonville, NC. Notice the red X on the house to indicate that it has been checked for survivors. Also note the leaning tree and bridge swept "downstream" by the flood.

Since 1970, more than half of the loss of life in the US due to tropical cyclones was caused by inland (fresh water) flooding. This statistic is in contrast to the period from 1900-1970 when 90% of the loss of life was due to the storm surge along the coast. Floods are some of the most dangerous aspects of tropical systems impacting the United States because of the extent and depth of the flooding. Most of the deaths in Floyd were due to the record flooding. Based on current estimates, Floyd was the deadliest hurricane in the United States since Hurricane Agnes in 1972.

Approximately 3 million people attempted evacuation of coastal areas to avoid Floyd. Indications are that this was the largest evacuation in US history and provided many "lessons learned" to the communities and agencies directly involved. The effects of Floyd extended all along the eastern seaboard.



GOES-8 image of Hurricane Floyd as it approaches the North Carolina coast on the evening of September 15, 1999. The colors indicate infrared cloud-top temperatures. The coldest temperatures are near -80 degrees Celsius.

CloudSat: A New View of Clouds From Space

By Richard Austin

CloudSat is a satellite experiment designed to measure the vertical structure of clouds from space. The CloudSat mission, led by Dr. Graeme Stephens, CSU professor and CIRA fellow, was selected in late 1998 for launch in 2003 under the NASA Earth System Science Pathfinder (ESSP) program. CloudSat will use a profiling radar and an A-band spectrometer to provide vertical profiles of cloud physical and optical properties and images of the regional cloud field.

> **"CloudSat aims to . . . increase understanding of the cloud-climate feedback as part of a combined strategy of observations, cloud process modeling, and global model evaluations."**

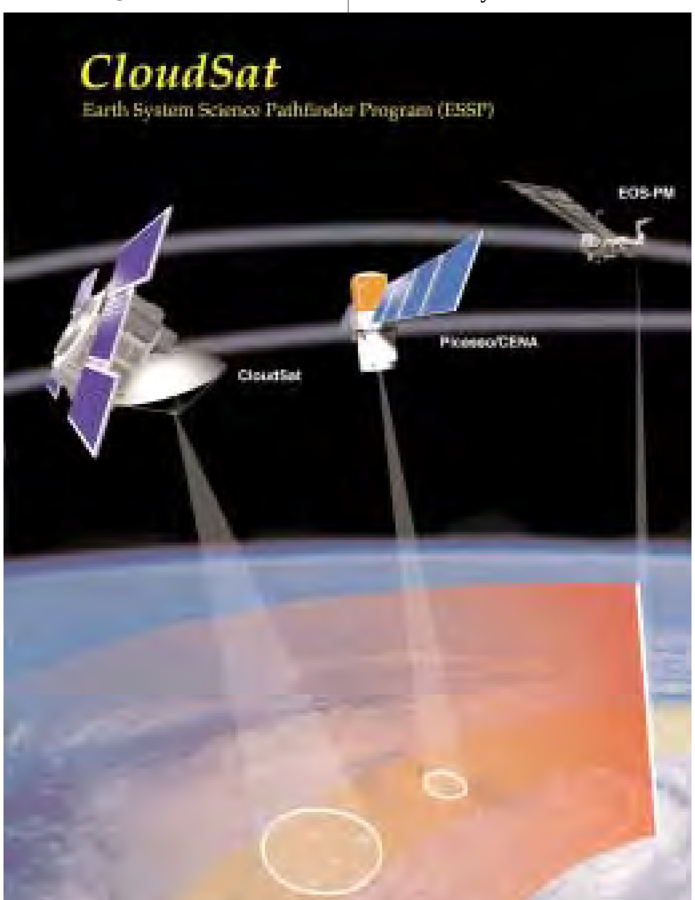


Fig. 1: *CloudSat will fly in formation with PICASSO-CENA*

Science Questions and Research Strategy

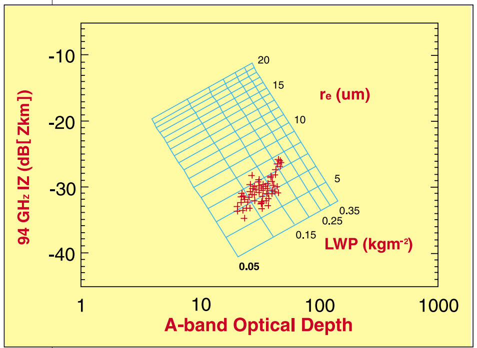
Clouds exert an enormous influence on our weather and climate. They dominate the energy budget of the planet, cooling the Earth by reflecting sunlight back to space and warming the Earth by trapping thermal radiation emitted by the surface and lower atmosphere. Because of their dominant role in the Earth's radiation budget, even small changes in the amount or characteristics of clouds could alter the climate as much or more than global change factors such as greenhouse gases. A detailed understanding of the role of clouds in the climate system is therefore essential for reliable climate simulation.

While existing measurements constrain the total incoming and outgoing radiation at the top of the atmosphere, they provide little information about how this energy is distributed in the atmosphere or how it is partitioned between the atmosphere and the surface. Clouds play a major role in this heat-partitioning process. By providing vertically resolved measurements of cloud physical and optical properties, CloudSat aims to reduce this source of uncertainty and increase understanding of the cloud-climate feedback as part of a combined strategy of observations, cloud process modeling, and global model evaluations.

The CloudSat Satellite and Mission

The CloudSat satellite has two instruments: the Cloud Profiling Radar (CPR) and the Profiling Oxygen A-Band Spectrometer and Visible Imager (PABSI). The CPR will provide calibrated 94-GHz radar reflectivity as a function of distance with a vertical res-

Fig. 2: *The relationship between integrated radar reflectivity and cloud optical depth provides independent information about liquid water path and particle size, as indicated by the nearly orthogonal grid.*



olution of 500 meters between the surface and 20 km altitude with an effective radar footprint of 1.4 km (cross-track) x 4 km (along-track). An alternate, pulse-compressed mode allows a vertical resolution of 250 m between 5 and 20 km altitude. The nominal detectable reflectivity factor is approximately -29 dBZ.

The PABSI instrument measures the atmospheric radiance of the O_2 A-band rotational spectrum between 761.61 nanometers (nm) and 772.20 nm and records narrow-band images at 747.5 and 761.5 nm. With a planned signal-to-noise of 100:1, the PABSI spectrometer will be able to determine the optical depth and altitude of thin clouds and aerosols, but will also be sensitive to small changes in the optical depth of very deep clouds – a capability not presently possible with current systems. The PABSI imager will allow researchers to identify mesoscale weather systems corresponding to the cloud and aerosol profiles. Both the imager and spectrometer measure reflected sunlight and thus can only operate during daylight. The imager has an instantaneous field-of-view of 0.5 km and an across-track swath of 15 km, while the spectrometer has multiple fields of view across the radar track with the nadir footprint matched to the 1.4 km footprint of the CPR.

Fig. 3: *The CIRPAS (left) and ARM/UAV (right) Twin Otter aircraft after a CAVEX flight at Marina Airport near Monterey, CA.*

CloudSat will fly in tight formation with the PICASSO-CENA satellite; these two satellites will follow behind the EOS-PM satellite in a somewhat looser formation (Figure 1). PICASSO-CENA, another ESSP platform, carries four nadir-viewing instruments: a two-wavelength (532 and 1064 nm) polarization-sensitive lidar, a high spectral resolution A-band spectrometer, an imaging infrared radiometer (10.5 and 12 microns), and a high-resolution wide-field camera. CloudSat and PICASSO-CENA will be controlled such that both sets of sensors view the same ground track most of the time, with a delay of approximately 60 seconds between lidar and radar measurements. EOS-PM will carry a variety of complementary instruments, including CERES, AIRS, AMSR, and MODIS.

Measurement Objectives and Approach

The measurement objectives of CloudSat are to (1) profile the vertical structure of clouds, (2) measure the profiles of cloud liquid water and ice water content, and (3) measure the profiles of cloud optical properties. The measurement approach and algorithms developed for CloudSat exploit the complementary properties of active and passive observing systems. Some data products can be derived from the CPR alone (e.g. cloud geometrical profile), but others will be obtained from a combination of CPR and PABSI data. For example, under certain conditions, radar reflectivity scales as the sixth power of cloud particle radius, while the optical depth scales as the square, and both are proportional to the particle number density. A model may be derived using this combination of measurements to retrieve cloud particle effective radius and liquid water path, as shown in Figure 2.

Formation flying with the PICASSO-CENA and EOS-PM platforms introduces many more possibilities for multi-instrument algorithms and cross-platform validations. PICASSO-CENA lidar and CloudSat radar data could be used to produce profiles of ice cloud particle size, for example.

Preparatory Studies

Field experiments in preparation for CloudSat have already begun. The CloudSat Antecedent Validation Experiment (CAVEX99) was one component of the Monterey Coastal Stratus Experiment (MCSE) – a multi-experiment campaign conducted off the Pacific coast near Monterey, CA in June and July 1999 (Figure 3). CAVEX99 used the UMass/JPL Airborne Cloud Radar (ACR), measuring cloud reflectivity at 95 GHz, and the CSU Scanning Spectral Polarimeter (SSP), measuring upwelling radiance and flux in the visible and near-infrared, to remotely sense maritime stratus clouds beneath the ARM/UAV Twin Otter aircraft. These instruments

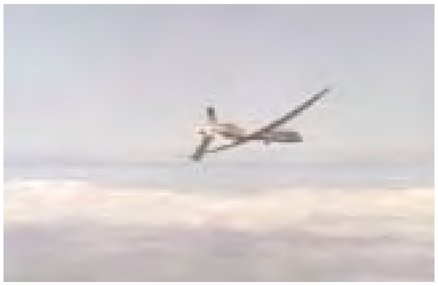


Fig. 4: *The ARM/UAV program's Altus II UAV is shown above a cloud deck in Hawaii.*

were chosen to simulate CloudSat sensors. A second Twin Otter aircraft, operated by the Center for Remote-Piloted Aircraft Studies (CIRPAS), flew inside the stratus deck in a stacked formation with the ARM aircraft above. The CIRPAS aircraft used various probes to make in situ measurements of the stratus cloud properties. Data from these measurements provide an opportunity to test retrieval algorithms developed for CloudSat.

A second field experiment was conducted in Hawaii near the island of Kauai in May 1999. This experiment involved the ARM/UAV Twin Otter aircraft and the Altus II Unmanned Aerospace Vehicle (UAV) (Figure 4), flying below and above cirrus clouds with the same sensors used in CAVEX. Work is progressing towards the goal of having a complete set of CloudSat-type sensors deployed on the UAV itself. This will allow simulations of CloudSat measurements from a platform that can overfly both low stratus and high cirrus.

Participants and Launch

CloudSat is a collaboration among a number of partners. Colorado State University is providing mission leadership through Prof. Stephens. The Jet Propulsion Laboratory will be responsible for mission operations and payload development. Ball Aerospace in Boulder is providing the spacecraft bus and will be responsible for spacecraft integration. The U. S. Air Force Space Test Program will provide ground operations and data communications. The Canadian Space Agency is contributing components to the CPR, and substantial validation support is being provided by the Dept. of Energy's Atmospheric Radiation Measurement (ARM) program, as well as by research agencies in Germany and Japan.

CIRA will play a major role in the CloudSat project, providing data processing and data archiving for all CloudSat data. CIRA will also collect and archive supportive data such as geostationary satellite imagery and upper air and surface observations.

CloudSat is scheduled to launch with PICASSO-CENA in 2003 on a Delta launch vehicle (Figure 5). The mission was designed with a two-year lifetime, but the radar is expected to operate for three years. More information on the CloudSat mission may be obtained at the CloudSat web page at http://cloudsat.atmos.colostate.edu.

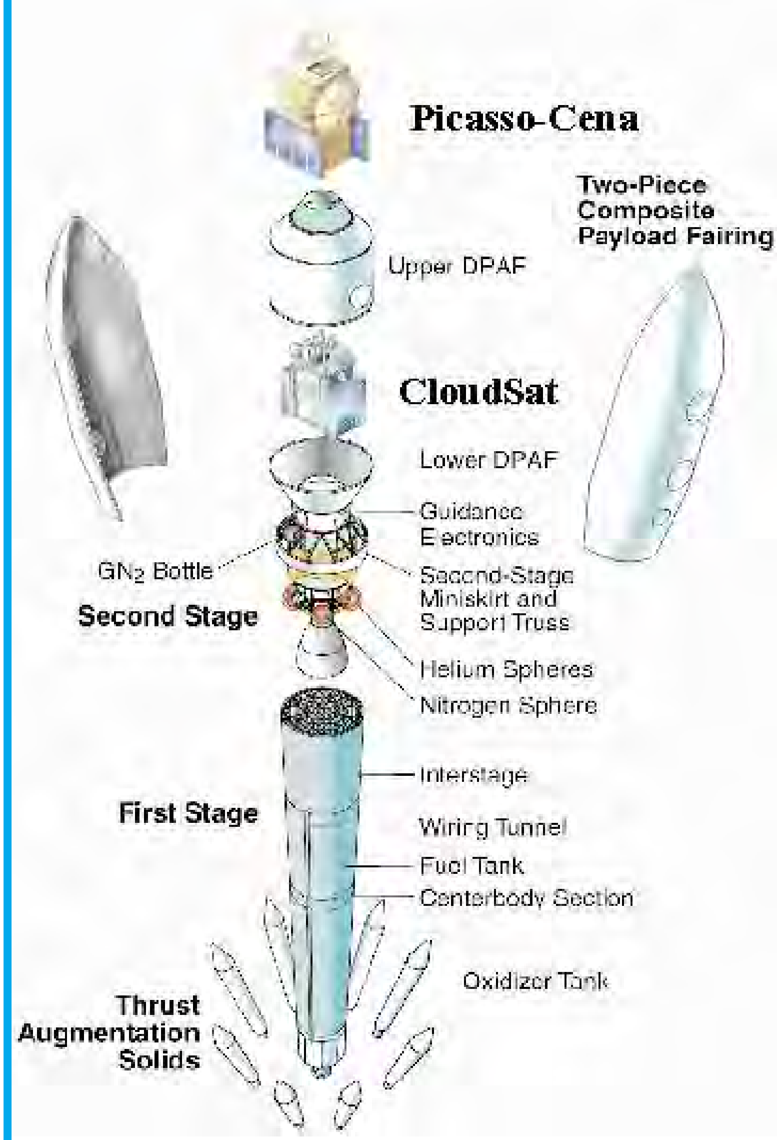
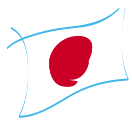


Fig. 5: *The CloudSat launch scenario, based on a Delta 7420-10 launch vehicle.*

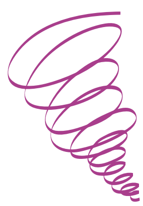
Special Recognition and Events

Dr. Adrian Marroquin, a CIRA scientist working at the Forecast Systems Lab in Boulder, was awarded The Editor's Award for Weather and Forecasting "for highly detailed, logical and critically insightful review" of manuscripts submitted to the Journal of Weather and Forecasting. He received the award at the Awards Banquet of the 80th AMS Annual Meeting that was held in Long Beach, California in January.

Dr. Ken Knapp, a recent Ph.D. recipient studying under Professor Tom Vonder Haar, received 1st prize for the Best Graduate Student Poster at the AMS 10th Conference on Satellite Meteorology and Oceanography held in Long Beach, California in January. Ken's poster discussed the results of his research in the satellite remote sensing of aerosol properties.



Drs. Tom Greenwald and Tom Vonder Haar were recently named by The National Space Development Agency of Japan to the science team for the Global Imager (GLI), an instrument to be flown on Japan's future Advanced Earth Observing Satellite II (ADEOS-II) (see volume 11 of the CIRA newsletter for details). Current plans are to launch ADEOS-II in November 2001.



Dr. Christopher Adams spoke to the national insurance company executives and top government officials at the Institute for Building and Home Safety in Memphis, Tennessee as an invited speaker on October 27th, 1999. Dr. Adams, a sociologist, provided insights from research on how to better prepare for and respond to tornado warnings. He has worked with the National Weather Service, the Federal Emergency Management Agency, and local communities to help them develop better tornado warning communication capabilities. Dr. Adams has also helped develop a national set of weather preparedness training courses for local and state officials.

The AWIPS group at the Forecasts Systems Lab received the National Weather Service Gold Medal for their contributions to the successful implementation of AWIPS at all the NWS forecast offices during the summer of 1999. CIRA employees who were part of the AWIPS team are Joanne Edwards, Tom Kent, Scott O'Donnell, MarySue Schultz, Jim Fluke, Ron Kahn, Phil McDonald, Gerry Murray, Jim Ramer, Frank Tower, Chris Steffen, Chandran Subramaniam, Scott Longmore and Cyril Mehta.

The University of Colorado-Boulder graduated three CIRA staff members with the NOAA/Forecast Space Systems Lab GLOBE Program on May 12. They are David Grimes (BS in Computer Science) Ning Wang (Ph.D. in Computer Science), and Julie Schenk (MS in Computer Science).

CIRA Mission

The Cooperative Institute for Research in the Atmosphere (CIRA), originally established under the Graduate School, was formed in 1980 by a Memorandum of Understanding between Colorado State University (CSU) and the National Oceanic and Atmospheric Administration (NOAA). In February 1994, the Institute changed affiliation from the Graduate School to the College of Engineering as part of a CSU reorganizational plan.

The purpose or mission of the Institute is to increase the effectiveness of atmospheric research of mutual interest to NOAA, the University, the state and the nation. Objectives of the Institute are to provide a center for cooperation in specified research programs by scientists from Colorado, the nation, and other countries, and to enhance the training of atmospheric scientists. Multidisciplinary research programs are given special emphasis, and all university and NOAA organizational elements are invited to participate in CIRA's atmospheric research programs. Participation by NOAA has been primarily through the Oceanic and Atmospheric Research (OAR) Laboratories and the National Environmental Satellite, Data, and Information Service (NESDIS). At the university, the Departments of Anthropology, Atmospheric Science, Biology, Civil Engineering, Computer Science, Earth Resources, Economics, Electrical Engineering, Environmental Health, Forest Sciences, Mathematics, Physics, Psychology, Range Science, Recreation Resources and Landscape Architecture, and Statistics are or have been involved in CIRA activities.

During the past fiscal year, the Institute's research has concentrated on global climate dynamics, local-area weather forecasting, cloud physics, the application of satellite observations to climate studies, regional and local numerical modeling of weather features, and the economic and social aspects of improved weather and climate knowledge and forecasting. The Institute and the National Park Service also have an ongoing cooperation in air quality and visibility research which involves scientists from numerous disciplines. CIRA is playing a major role in the NOAA-coordinated U.S. participation in the International Satellite Cloud Climatology Program (part of the World Climate Research Programme).

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If you know of someone who would also like to receive the CIRA Newsletter, or if there are corrections to your address, please notify us. We can be reached at the phone number and addresses above.