# DEVELOPMENT OF OPERATIONAL MESO-GAMMA-SCALE NUMERICAL WEATHER-PREDICTION SYSTEMS FOR ARMY TEST RANGES

Thomas Warner, Arthur Shantz, Chris Davis, Jennifer Cram, Scott Swerdlin
Research Applications Program
National Center for Atmospheric Research
PO Box 3000
Boulder, Colorado 80307-3000
Voice: 303/497-8411, Fax: 303/497-8401, email: warner@ucar.edu

James Bowers*
U.S. Army Dugway Proving Ground
West Desert Test Center
Dugway, Utah 84022-5000
Voice: 435/831-5101, Fax: 435/831-5289, email: jbowers@dugway-emh3.army.mil

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## OBJECTIVE

The U. S. Army Test and Evaluation Command (ATEC) ranges require a number of weather products to satisfy needs related to test planning, range operations, range safety, and environmental compliance. These required operational products include forecasts of 24-36 h duration, retrospective model-based analyses of weather conditions throughout the previous day for documenting the atmospheric state at the exact location of a test, and a real-time (i.e., current) model-based analysis of the spatial distribution of the detailed weather conditions throughout the range. The model variables that must be accurately predicted and diagnosed are numerous. The quantities that are most critical depend on the range mission, but they may include

- winds and temperatures for ballistic trajectory computations;
- near-surface winds and boundary-layer turbulence for computing movement of a released simulant;
- winds for parachute-drop calculations;
- winds for calculation of trajectories of debris released in the upper atmosphere;
- winds, temperature and humidity for computation of sound propagation across range boundaries;
- rainfall for effects of flooding on range operations; and
- near-surface winds for ensuring safety of range personnel and equipment.

Additionally, model-based realizations of atmospheric structure and processes are required for Virtual Proving Ground (VPG) applications, and the atmospheric model employed to satisfy the above ATEC range needs can be employed for this purpose. There are also requirements for such a model to perform retrospective simulations of atmospheric conditions for various types of forensic analyses.

To satisfy these needs, ATEC funded the National Center for Atmospheric Research to develop the Four-Dimensional Weather (4DWX) system. The specific objectives of the 4DWX system are as follows. The system must provide

- mesogamma scale 24-36 h model-based forecasts of range scale weather;
- mesogamma-scale, model-based analyses of the range weather conditions that prevailed during the previous day's test period;
- real-time (current) mesogamma-scale model-based analyses of range weather;
- an integrated system for displaying local range data, 4DWX model output, NCEP regional model output, global model output, and satellite data;
- world-wide-web-based access to the model products;
- a globally locatable, model-based, system that can provide mesoscale forecasts and real-time mesoscale analyses of current weather conditions, and that can be used for model-based research and development studies;
- an archival system for range data, real-time model-based analyses, and model forecasts;
- interfaces between the meteorological model and special applications models for simulation of transport and diffusion, sound propagation, parachute drift, etc.; and
- a data retrieval system to allow convenient calculation of model-performance statistics and calculation of various types of range climatologies.

The 4DWX system must provide these capabilities and services on a 24 hours per day and 7 days per week basis.

## RESEARCH ACCOMPLISHED

An important message of this paper is that the MM5-based 4DWX system does not simply satisfy a narrowly focussed need of ATEC. Rather, 4DWX currently offers a broad array of capabilities for producing forecasts of all weather variables, retrospective analyses, and real-time analyses. It also represents a foundation for the development of an even wider range of capabilities, such as related to VPG needs, and ATEC needs beyond the continental United States. Considerable resources have also been devoted to providing the ancillary capabilities that are necessary for ATEC forecasters and system administrators to efficiently utilize and manage the system. These capabilities include the following:

- user access to all weather products from a GUI on-site, as well as web-access from off-site locations;
- GUI or web display of the operational status of all components of the system, including input sensors;
- calculation and display of objective validation statistics in real time, to provide the forecasters with insight on model performance;
- archival and retrieval system for model forecasts, data analyses, and observations;
- software for calculation of range climatologies based on archived observations and analyses, with many options for stratifying the information; and
- special application models, such as for dispersion and sound propagation, that are driven by MM5, with graphical output provided.

### *The basic modeling system*

The Penn State/NCAR Mesoscale Model Version 5 (MM5) has been adopted to serve as the basis for the ATEC 4DWX system. For details about the MM5 modeling system, refer to Dudhia (1989, 1993), Grell et al. (1994), Warner et al. (1992) and Davis et al. (1999). The ATEC modeling systems use three or four nested grids, with the finest grid increment being either 3 km or 1 km. The model-based forecast systems, and systems for providing the model-based analyses of yesterday's range weather, have been installed and are presently being employed operationally at the West Desert Test Center at Dugway, Utah; the White Sands Missile Range, New Mexico; and the Aberdeen Test Center, Maryland. An additional system is being installed this year at the Yuma Proving Ground, Arizona. Also under development during the current year is a system that will employ MM5 in a data assimilation mode to produce real-time four-dimensional analyses of current range conditions. In the following year, work will begin to extend this real-time model-based analysis system for world-wide operational-testing applications.

Figure 1 shows the MM5 forecast domain for the Aberdeen Test Center. The grid increments of the interacting nested grids are 30, 10, 3.3, and 1.1 km. A similar configuration is used for Dugway, Utah, but only the three coarser grids are used for the larger ATEC ranges at White Sands and Yuma. Generally, two 24-h forecasts are produced per day using an 8-processor SGI Origin 2000 system. These forecasts, and the 24 hour model-based analysis of the previous day's meteorological conditions, consume virtually all of the processing time on this system. Discussion of the validation of the 4DWX forecasts for Dugway, Utah can be found in Davis et al. (1999), and an analysis of a forecast of a convective-rainfall event at White Sands, New Mexico is found in Warner and Hsu (2000).

### *Examples of special-applications models*

Two special-application models that are now routinely driven by the MM5 output are the Second-order Closure Integrated Puff (SCIPUFF) model for transport and dispersion, and the Noise Assessment Propagation System (NAPS) model for sound propagation. The SCIPUFF model is being implemented at each of the four ranges, and the NAPS system is being used at the Aberdeen Test Center. Figure 2 shows an example of SCIPUFF output using MM5 data from a simulation for Dugway Proving Ground. Figure 3 illustrates the type of output produced by NAPS using wind, humidity and temperature soundings from an MM5 forecast for Aberdeen Test Center as input.

### *Forensic analyses with the 4DWX system*

The modeling system can be utilized for global applications that satisfy a variety of Department of Defense and ATEC-particular needs. In an example described in Warner and Sheu (2000), the 4DWX model is used in a forensic analysis of the atmospheric transport of the toxic material released from the Khamisiyah, Iraq weapons bunker in March 1991 after the Gulf War. The area of the Arabian Desert for which the simulations apply includes northern Saudi Arabia, Iraq, Kuwait and western Iran. There is considerable mesoscale local forcing resulting from the existence of the Persian Gulf, and from the orographic gradients associated with the Zagros Mountains in western Iran, the Tigris-Euphrates Valley in Iraq, and the mountains on the western third of the Arabian Peninsula. In addition, there are modest variations in the vegetation of the desert surface that can influence the PBL through effects on the surface heat and moisture budgets. This study with the 4DWX MM5 complements parallel work in which the Navy Coupled Ocean-Atmosphere Mesoscale Prediction System (COAMPS) and the Navy Operational Global Atmospheric Prediction System were used to produce a re-analysis of the regional and global atmospheric conditions over this area. Both the COAMPS and MM5 simulations were employed to provide an ensemble of realizations of the atmospheric conditions for use as input to transport and dispersion models which supported an analysis of the Gulf War illness. For calculation of the transport and dispersion of material released into the atmosphere at the surface, the correct simulation of the boundary-layer depth is critical. Figure 4, which shows the average daily maximum PBL depth (meters) for a six-day continuous simulation period with MM5, illustrates the boundary-layer modulation that is caused by the local forcing represented by the model. The low values over the Tigris-Euphrates Valley are associated with subsidence from a mountain-valley circulation that suppresses daytime boundary layer growth. Higher values over the western Arabian Peninsula are related to the upward motion over the elevated terrain there, the lower latitude and the dry unvegetated surface. Figure 5 depicts the surface dosage simulation for a release point at Al Muthanna, Iraq based on the SCIPUFF transport and dispersion model driven by MM5 output.

### *An example of the system-management infrastructure of 4DWX*

As noted above, a considerable fraction of the 4DWX development effort has been related to making the operational products as convenient as possible to use, and the system convenient to manage. An example of a system feature that enables managers to easily assess the operational status of various components is shown in Fig. 6. This figure depicts an automatically refreshed monitor display of the various functional elements of the entire 4DWX system. At a glance, a system operator can tell, through the color coding, the status of the various components.

### *The graphical interface to the model products*

Much attention has been devoted to providing model products in a form that can be used effectively by forecasters. A wide variety of static images as well as animations are provided of basic model variables as well as derived quantities for each of the model grids. Figures 7 and 8 show precipitation predictions for the outer grid and an inner grid, respectively. To obtain tabular forecasts for any of a large number of geographic locations, site selection maps such as shown in Fig. 9 are employed. Clicking on each of the inner grids will provide a telescoped view of additional locations for which tabular forecasts are provided. Clicking on a location will produce the forecast table. Figure 10 shows an example of the tabular forecast for Baltimore Washington Airport on Grid 3.

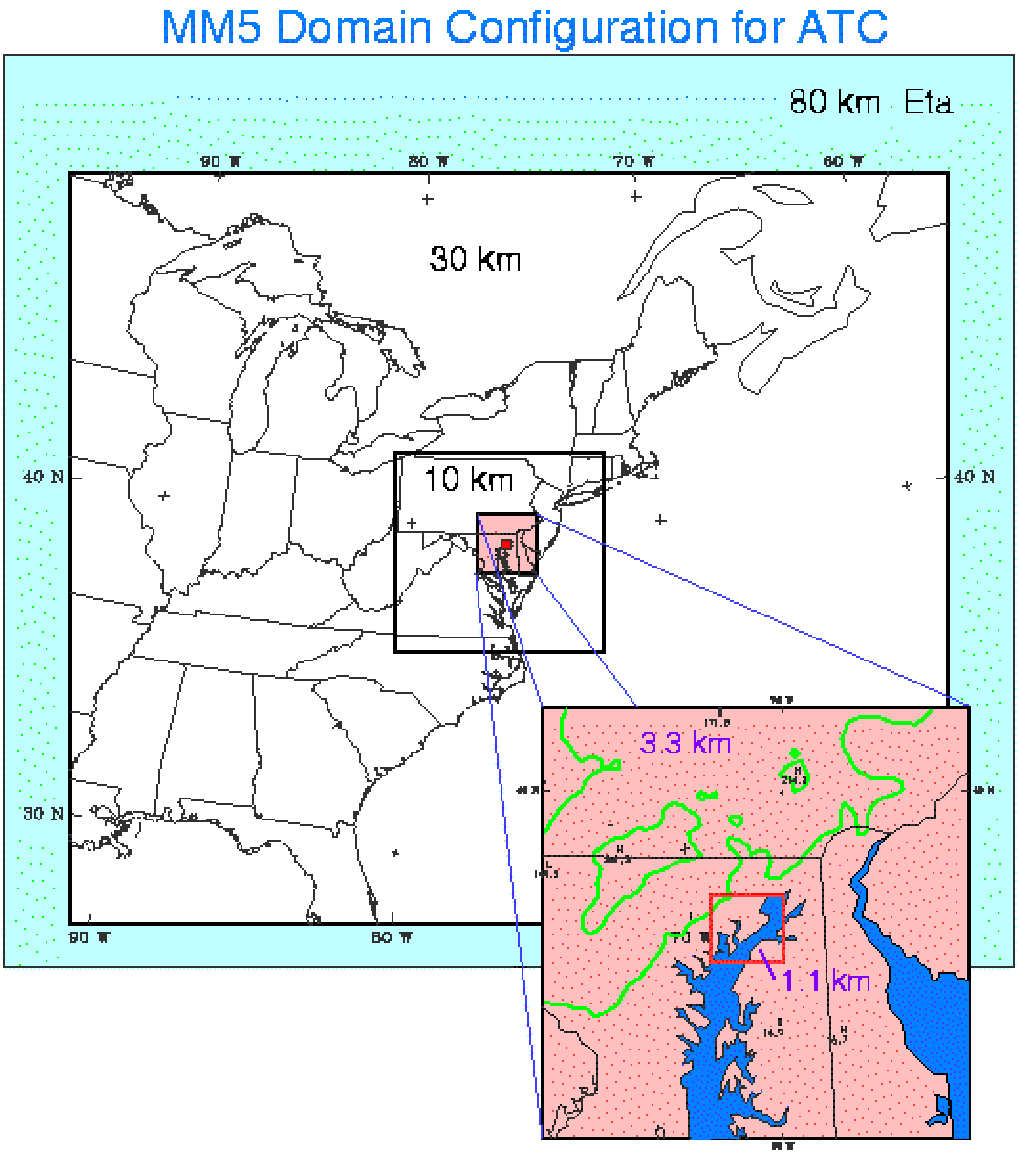


Figure 1. The 4DWX MM5 forecast domain for Aberdeen Test Center. The grid increments of the interacting nested grids are 30, 10, 3.3, and 1.1 km.

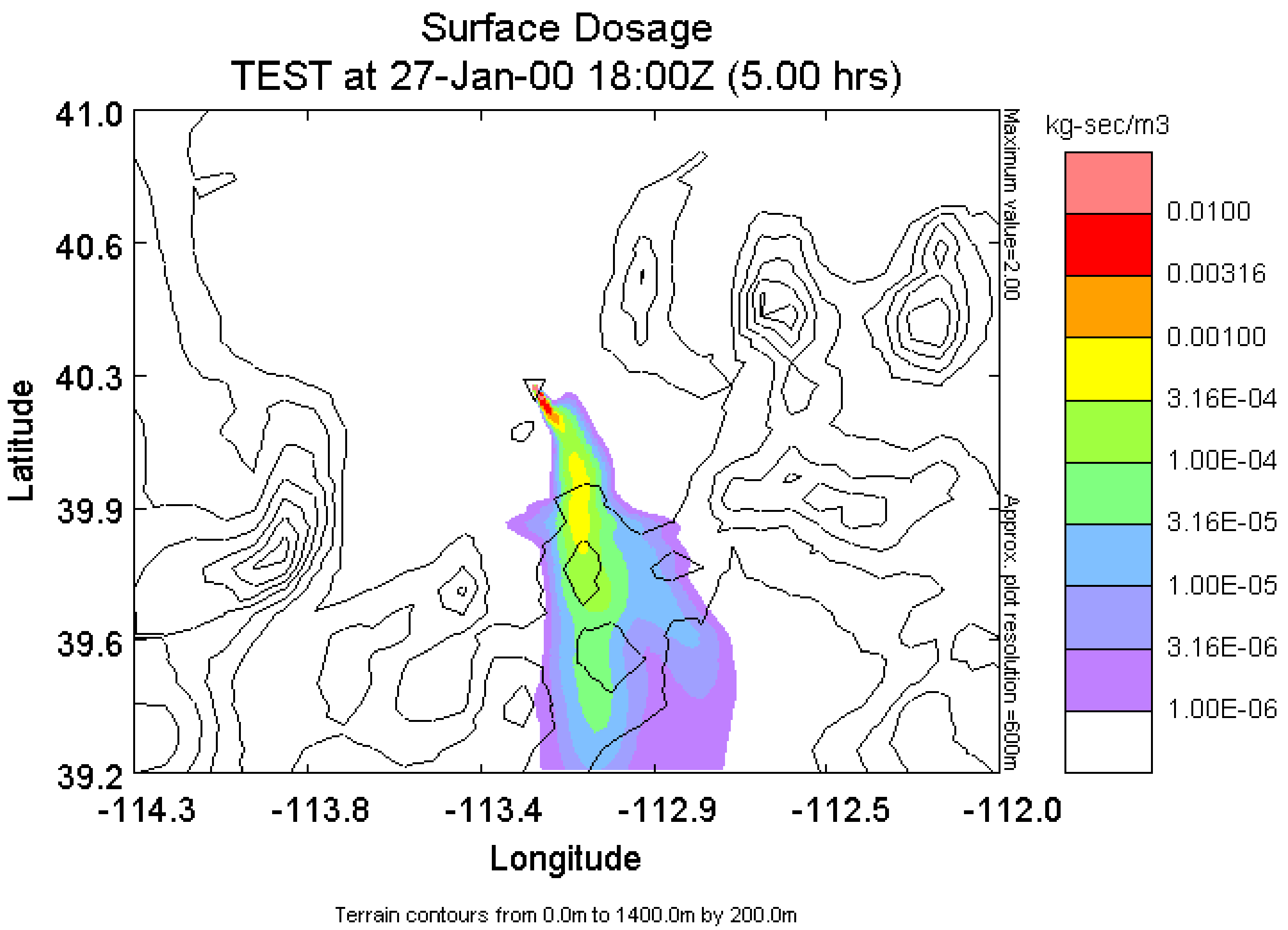


Figure 2. Surface dosage simulation for Dugway Proving Ground, Utah, based on the SCIPUFF transport and dispersion model driven by MM5 output. Solid lines are terrain elevation, drawn with a 200 m interval, and the colors display the dosage.

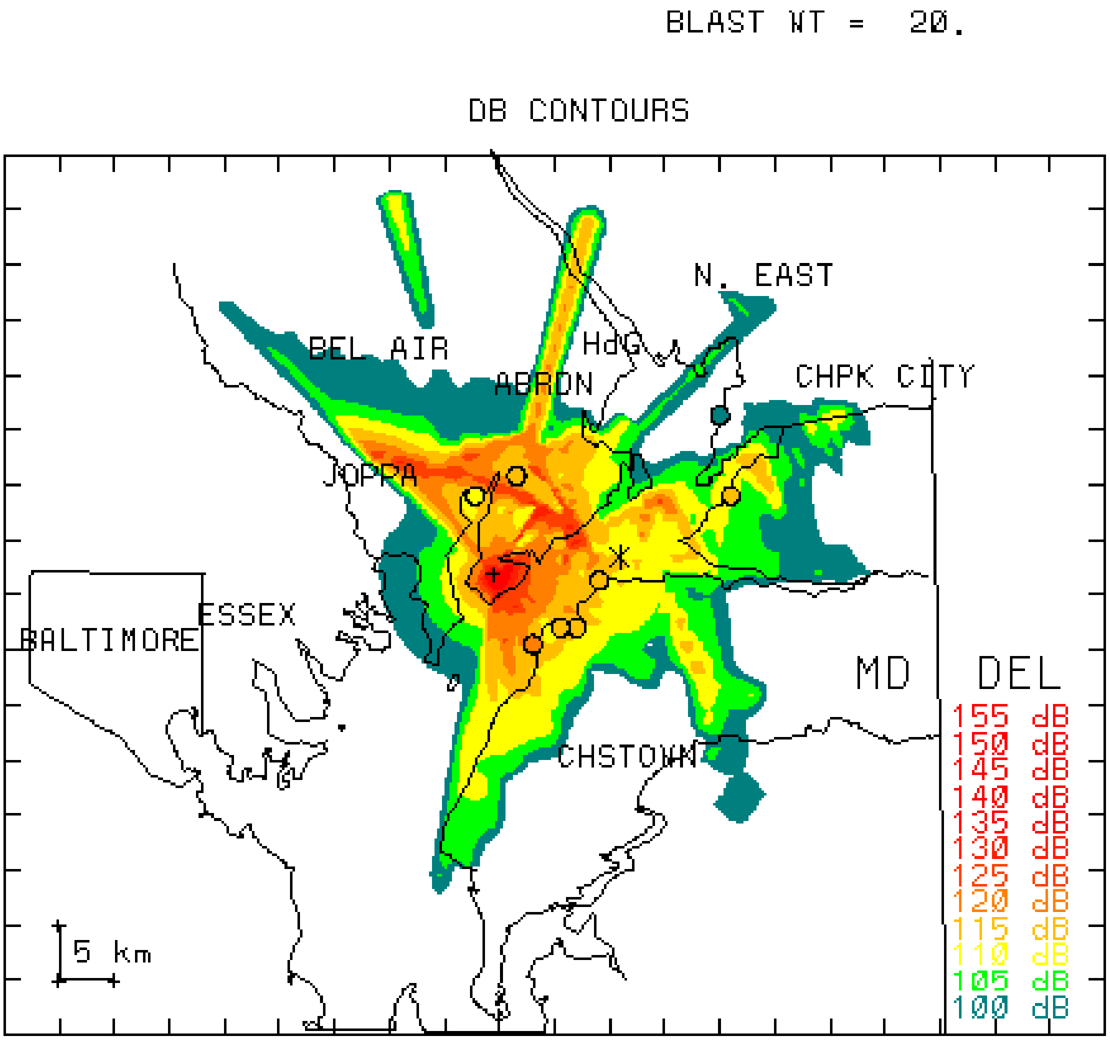


Figure 3. Sound-intensity pattern around Aberdeen Proving Ground, Maryland, as computed by the NAPS model with input from an MM5 forecast sounding of wind, temperature and moisture. The colors indicate sound intensity (decibels) from a blast on the Proving Ground. The blast was 1 m above ground, with a charge weight of 20 pounds.

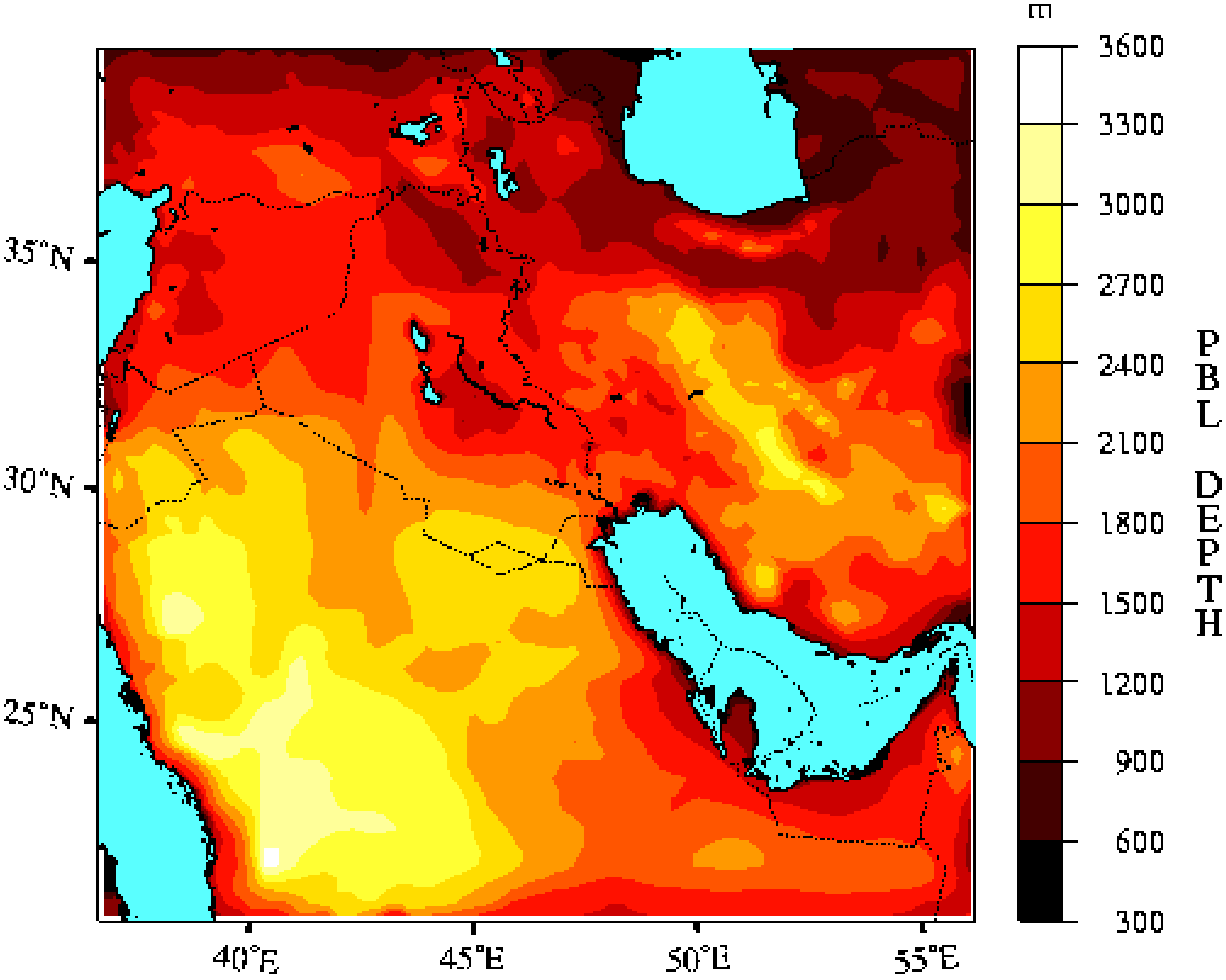


Figure 4. Average daily maximum PBL depth (meters) for a six-day continuous simulation period with MM5. Isopleths are labeled in meters and are plotted at an interval of 300 m.

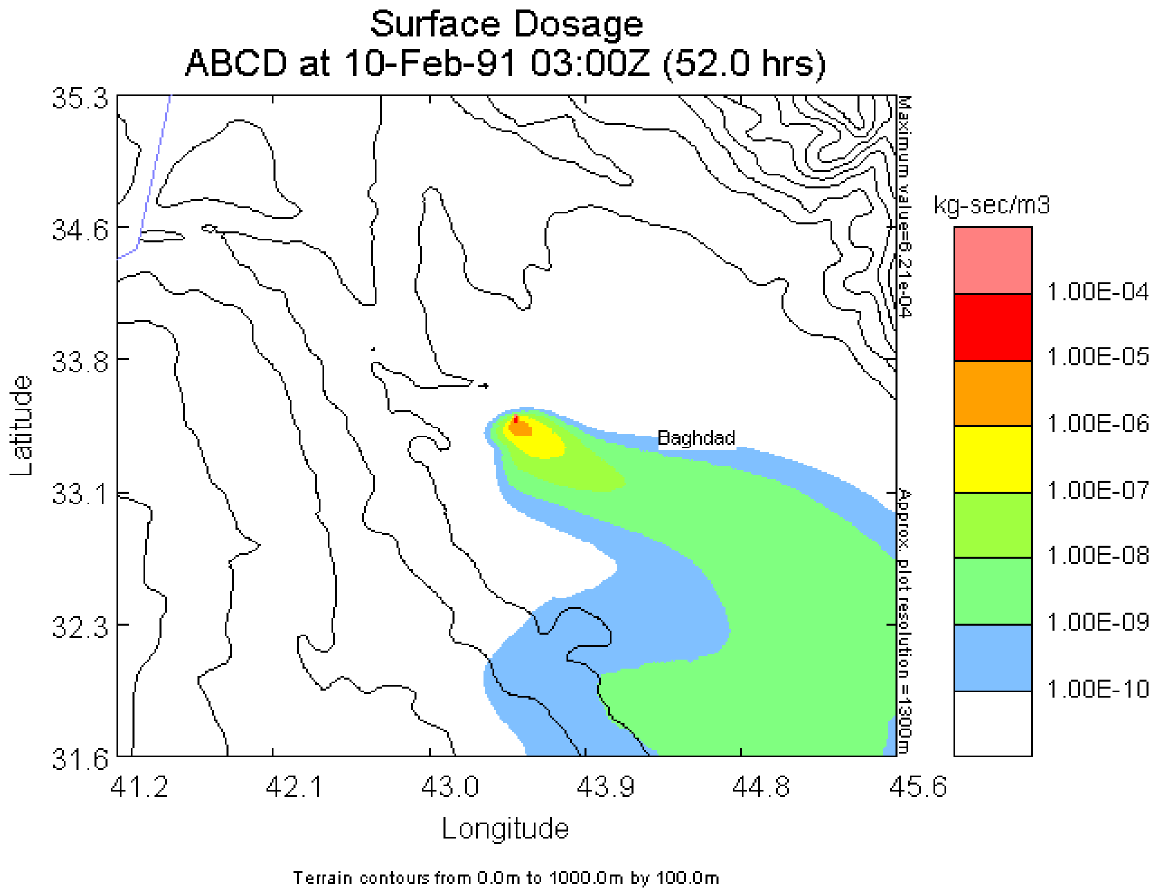


Figure 5. Surface dosage simulation for a release point at Al Muthanna, Iraq, based on the SCIPUFF transport and dispersion model driven by MM5 output. Solid lines are terrain elevation, drawn with a 100 m interval, and the colors display the dosage.

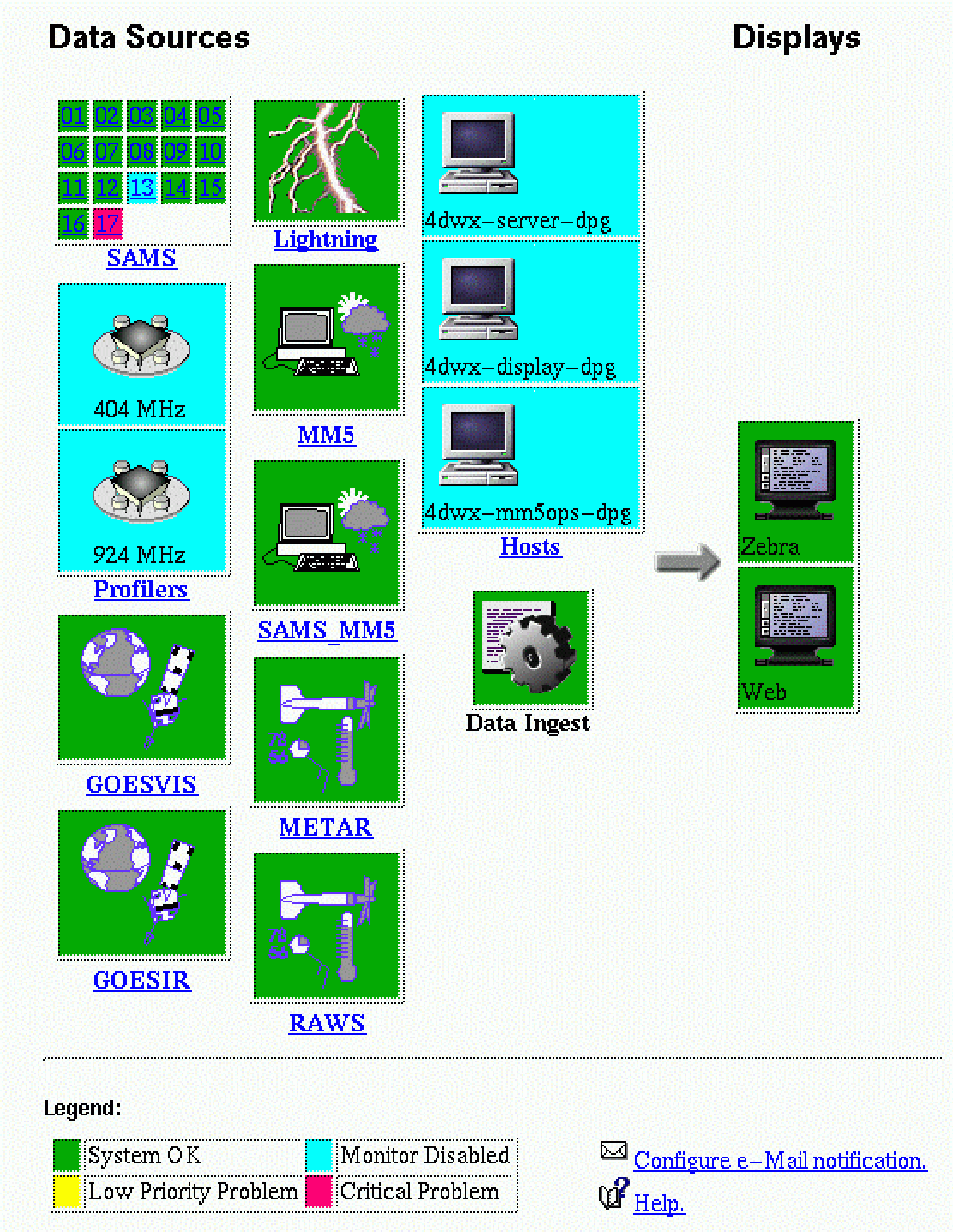


Figure 6. The system-monitoring display that represents the status of various components of the 4DWX system, including the model, graphical displays and data platforms.

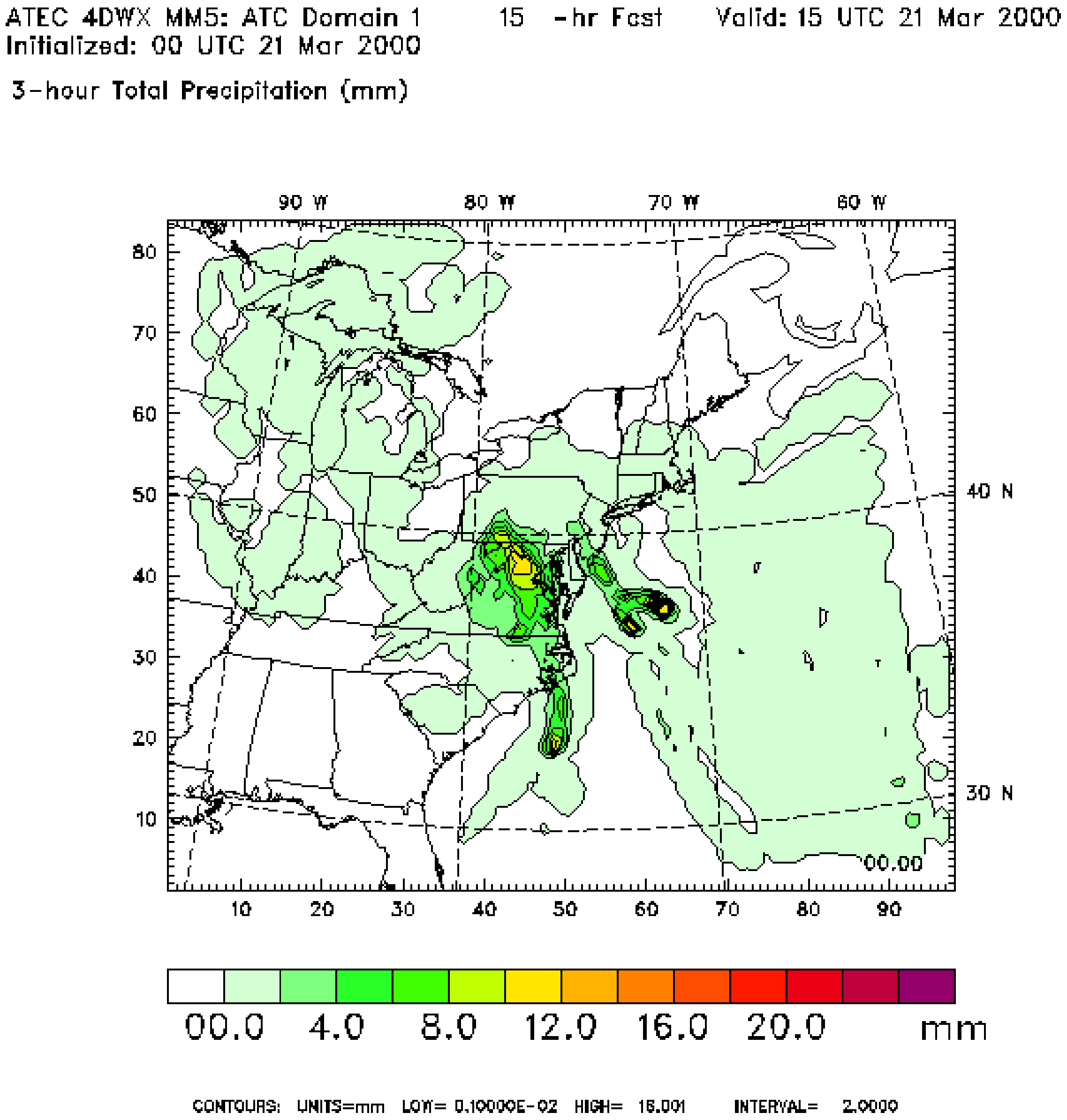


Figure 7. Prediction of coarse-grid rainfall from the Aberdeen Test Center 4DWX MM5 system.

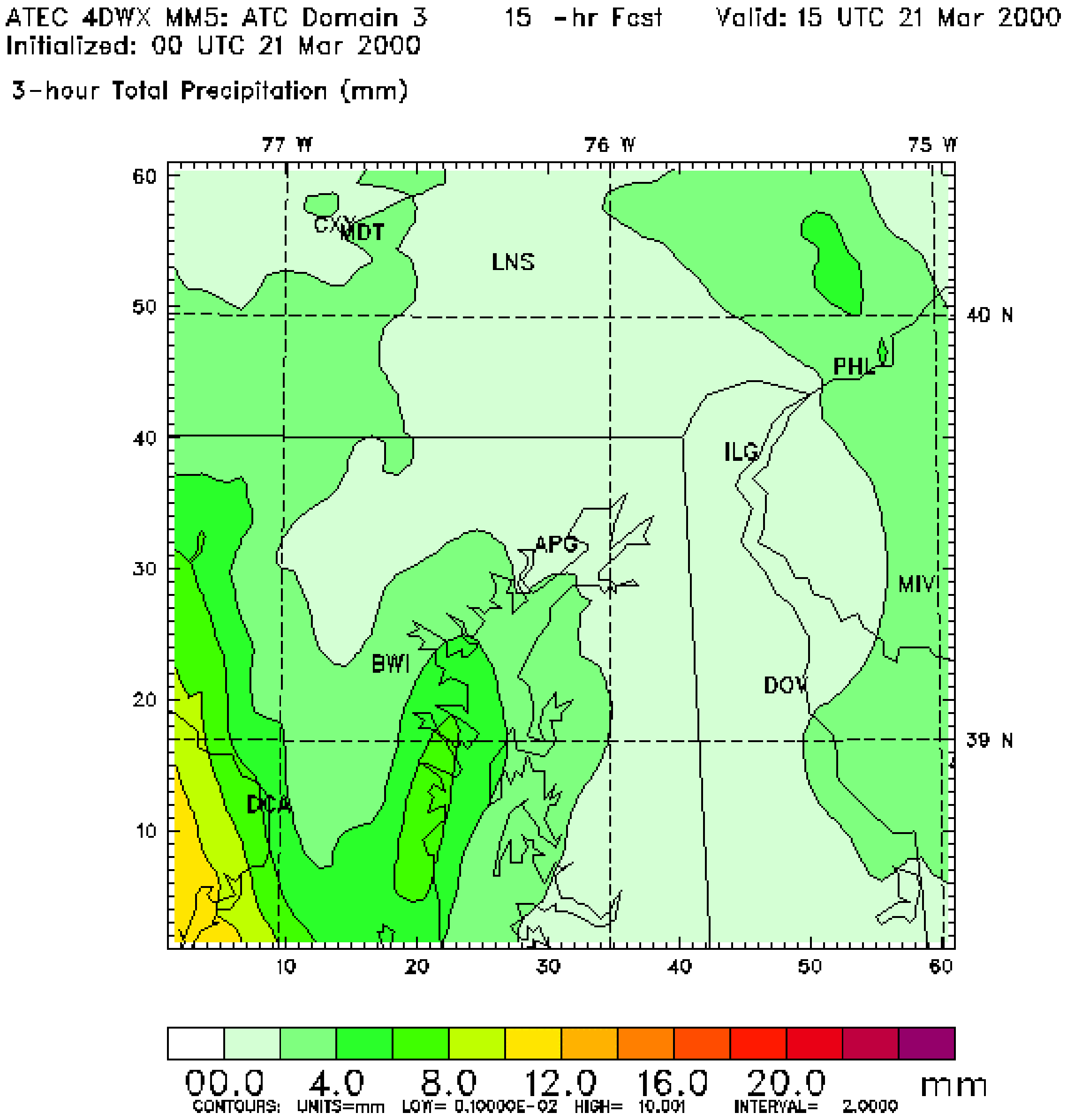


Figure 8. Prediction of fine grid (grid 3 of 4) rainfall from the Aberdeen Test Center 4DWX MM5 system.

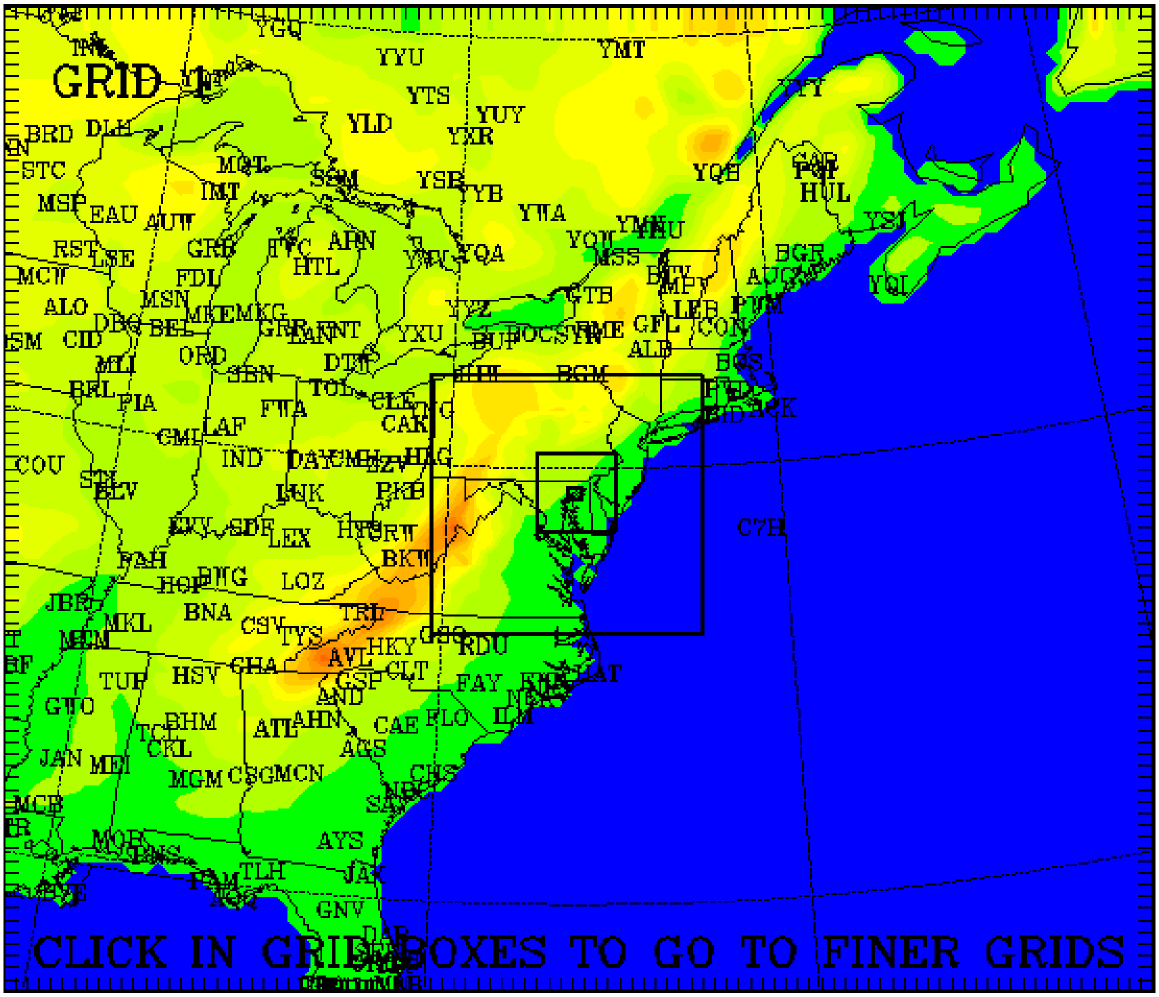
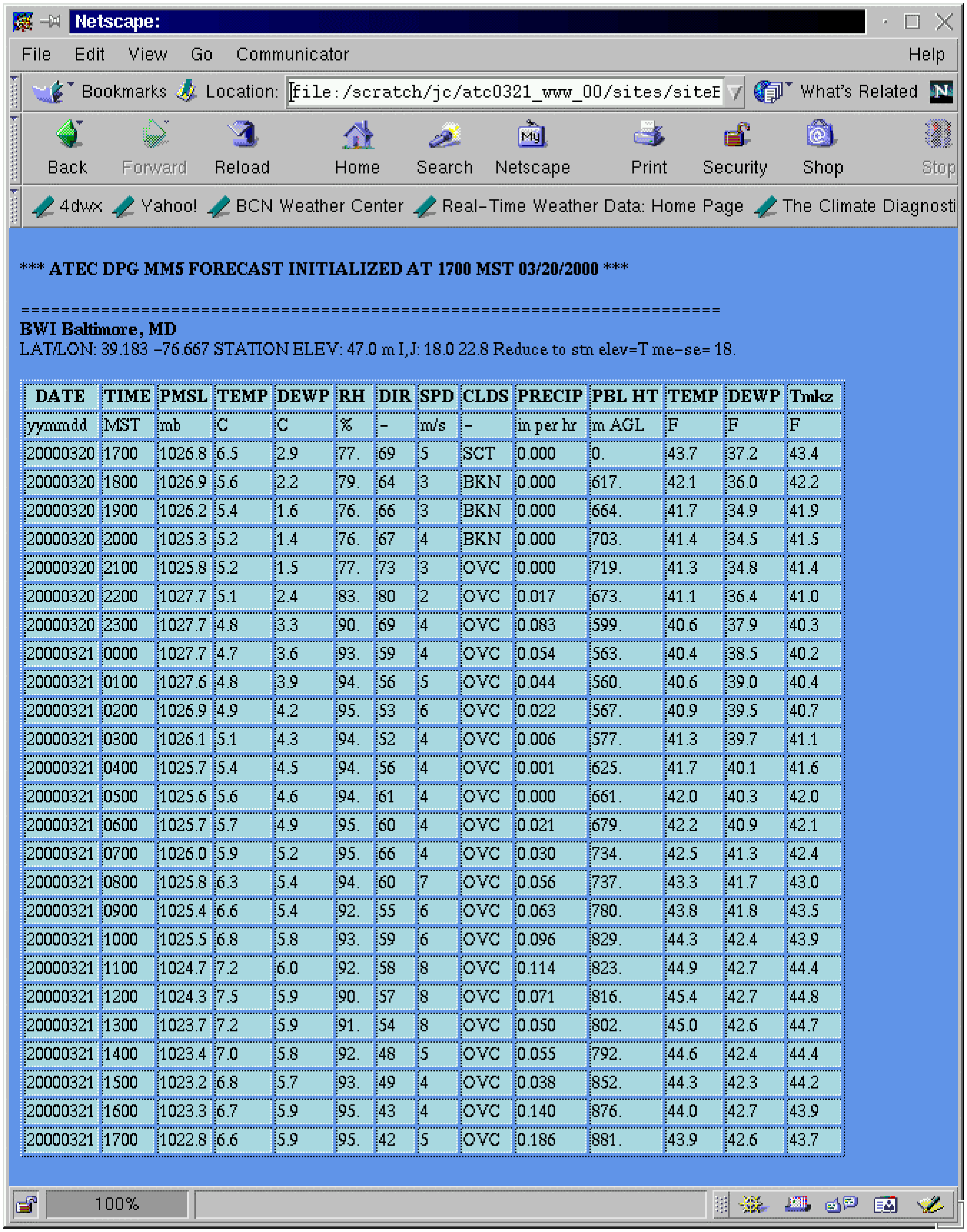


Figure 9. An example of a map on which geographic locations can be clicked to obtain tabulated model forecasts for the location. Clicking on each of the inner grids will provide a telescoped view of additional locations for which tabular forecasts are provided. Figure 10 shows an example of the tabular forecast for Baltimore Washington Airport on Grid 3



***** ATEC DPG MM5 FORECAST INITIALIZED AT 1700 MST 03/20/2000 *****

========================================================================

**BWI Baltimore, MD**

LAT/LON: 39.183 -76.667 STATION ELEV: 47.0 m I,J: 18.0 22.8 Reduce to stn elev=T me-se= 18.

| DATE | TIME | PMSL | TEMP | DEWP | RH | DIR | SPD | CLDS | PRECIP | PBL HT | TEMP | DEWP | Tmkz |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| yymmdd | MST | mb | C | C | % | - | m/s | - | in per hr | m AGL | F | F | F |
| 20000320 | 1700 | 1026.8 | 6.5 | 2.9 | 77. | 69 | 5 | SCT | 0.000 | 0. | 43.7 | 37.2 | 43.4 |
| 20000320 | 1800 | 1026.9 | 5.6 | 2.2 | 79. | 64 | 3 | BKN | 0.000 | 617. | 42.1 | 36.0 | 42.2 |
| 20000320 | 1900 | 1026.2 | 5.4 | 1.6 | 76. | 66 | 3 | BKN | 0.000 | 664. | 41.7 | 34.9 | 41.9 |
| 20000320 | 2000 | 1025.3 | 5.2 | 1.4 | 76. | 67 | 4 | BKN | 0.000 | 703. | 41.4 | 34.5 | 41.5 |
| 20000320 | 2100 | 1025.8 | 5.2 | 1.5 | 77. | 73 | 3 | OVC | 0.000 | 719. | 41.3 | 34.8 | 41.4 |
| 20000320 | 2200 | 1027.7 | 5.1 | 2.4 | 83. | 80 | 2 | OVC | 0.017 | 673. | 41.1 | 36.4 | 41.0 |
| 20000320 | 2300 | 1027.7 | 4.8 | 3.3 | 90. | 69 | 4 | OVC | 0.083 | 599. | 40.6 | 37.9 | 40.3 |
| 20000321 | 0000 | 1027.7 | 4.7 | 3.6 | 93. | 59 | 4 | OVC | 0.054 | 563. | 40.4 | 38.5 | 40.2 |
| 20000321 | 0100 | 1027.6 | 4.8 | 3.9 | 94. | 56 | 5 | OVC | 0.044 | 560. | 40.6 | 39.0 | 40.4 |
| 20000321 | 0200 | 1026.9 | 4.9 | 4.2 | 95. | 53 | 6 | OVC | 0.022 | 567. | 40.9 | 39.5 | 40.7 |
| 20000321 | 0300 | 1026.1 | 5.1 | 4.3 | 94. | 52 | 4 | OVC | 0.006 | 577. | 41.3 | 39.7 | 41.1 |
| 20000321 | 0400 | 1025.7 | 5.4 | 4.5 | 94. | 56 | 4 | OVC | 0.001 | 625. | 41.7 | 40.1 | 41.6 |
| 20000321 | 0500 | 1025.6 | 5.6 | 4.6 | 94. | 61 | 4 | OVC | 0.000 | 661. | 42.0 | 40.3 | 42.0 |
| 20000321 | 0600 | 1025.7 | 5.7 | 4.9 | 95. | 60 | 4 | OVC | 0.021 | 679. | 42.2 | 40.9 | 42.1 |
| 20000321 | 0700 | 1026.0 | 5.9 | 5.2 | 95. | 66 | 4 | OVC | 0.030 | 734. | 42.5 | 41.3 | 42.4 |
| 20000321 | 0800 | 1025.8 | 6.3 | 5.4 | 94. | 60 | 7 | OVC | 0.056 | 737. | 43.3 | 41.7 | 43.0 |
| 20000321 | 0900 | 1025.4 | 6.6 | 5.4 | 92. | 55 | 6 | OVC | 0.063 | 780. | 43.8 | 41.8 | 43.5 |
| 20000321 | 1000 | 1025.5 | 6.8 | 5.8 | 93. | 59 | 6 | OVC | 0.096 | 829. | 44.3 | 42.4 | 43.9 |
| 20000321 | 1100 | 1024.7 | 7.2 | 6.0 | 92. | 58 | 8 | OVC | 0.114 | 823. | 44.9 | 42.7 | 44.4 |
| 20000321 | 1200 | 1024.3 | 7.5 | 5.9 | 90. | 57 | 8 | OVC | 0.071 | 816. | 45.4 | 42.7 | 44.8 |
| 20000321 | 1300 | 1023.7 | 7.2 | 5.9 | 91. | 54 | 8 | OVC | 0.050 | 802. | 45.0 | 42.6 | 44.7 |
| 20000321 | 1400 | 1023.4 | 7.0 | 5.8 | 92. | 48 | 5 | OVC | 0.055 | 792. | 44.6 | 42.4 | 44.4 |
| 20000321 | 1500 | 1023.2 | 6.8 | 5.7 | 93. | 49 | 4 | OVC | 0.038 | 852. | 44.3 | 42.3 | 44.2 |
| 20000321 | 1600 | 1023.3 | 6.7 | 5.9 | 95. | 43 | 4 | OVC | 0.140 | 876. | 44.0 | 42.7 | 43.9 |
| 20000321 | 1700 | 1022.8 | 6.6 | 5.9 | 95. | 42 | 5 | OVC | 0.186 | 881. | 43.9 | 42.6 | 43.7 |

Figure 10. Example of the tabular forecast for Baltimore Washington Airport on Grid 3.

## CONCLUSIONS AND RECOMMENDATIONS

The basic 4DWX modeling system will be fielded at four ATEC ranges by the end of this year, operating with the highest horizontal resolution of any operational model in the world. In spite of the modeling challenges involved in the development of the basic forecast system, this paper has illustrated that considerable effort has also been expended to ensure that the system serves multiple purposes for ATEC. Not only are forecasts produced, but retrospective and real-time analyses are generated by a version of the model that uses data assimilation to ingest available observations. Also, the ATEC operational model will soon be globally relocatable for the support of international field tests. Because ATEC has forecast needs that go beyond the basic weather variables, various specialized application models are linked to MM5 for the production of operational sound-propagation and transport and dispersion forecasts. Other applications models will be fielded in the next 1-2 years.

## REFERENCES

Davis, C., T. Warner, J. Bowers, and E. Astling, 1999: Development and application of an operational, relocatable, mesogamma-scale weather analysis and forecasting system. *Tellus,* **51A**, 710-727.

Dudhia, J., 1989: Numerical study of convection observed during the winter monsoon experiment using a mesoscale two-dimensional model. *J. Atmos. Sci.,* **46**, 3077-3107.

Dudhia, J., 1993: A nonhydrostatic version of the Penn State/NCAR mesoscale model: Validation tests and the simulation of an Atlantic cyclone and cold front. *Mon. Wea. Rev.,* **121**, 1493-1513.

Grell, G. A., J. Dudhia, and D. R. Stauffer, 1994: A description of the fifth generation Penn State/NCAR mesoscale model (MM5). NCAR Technical Note, NCAR/TN 398+STR, 138pp.

Warner, T. T., Y. -H. Kuo, J. D. Doyle, J. Dudhia, D. R. Stauffer, and N. L. Seaman, 1992: Nonhydrostatic, mesobeta-scale real-data simulations with the Penn State University/National Center for Atmospheric Research mesoscale model. *Meteorology and Atmospheric Physics*, **49**, 209-227.

Warner, T. T., and R. -S. Sheu, 2000: Multiscale local forcing of the Arabian Desert daytime boundary layer, and implications for the dispersion of surface-released contaminants. In press, *J. Appl. Meteor.*

Warner, T. T. and H. M. Hsu, 2000: Nested-model simulation of moist convection: The impact of coarse-grid parameterized convection on fine-grid resolved convection through lateral-boundary-condition effects. In press, *Mon. Wea. Rev.*