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EVALUATION AND UTILIZATION OF MESO-γ-SCALE NUMERICAL WEATHER PREDICTION FOR LOGISTICAL AND TRANSPORTATION APPLICATIONS

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1. INTRODUCTION

The effectiveness and efficiency of logistical operations in a number of industries are dependent on the response of local transportation systems (surface and air) to weather conditions. To enable proactive operations, planning and scheduling need to be driven by predictions of weather events that can impact them. Further, those predictions need to be at a temporal and spatial scale consistent with such activities. Consider, for example, the support and execution of operations in and around a major metropolitan area with a number of transportation facilities.

In particular, the Air Force Operations Group (AFOG) Weather Support Division, in addition to its support responsibilities to the Joint Staff (National Military Command Center), Army Operations Center, Secretary of the Air Force (SAF), and Headquarters Air Force (HAF) Operations Center for worldwide situational awareness, gathers near real-time local observations, forecasts, and warnings and tailors this information for senior officers and civilians in HAF/SAF. The sole purpose of this process is to ensure that these senior officials have the information they need to authorize the closure, delayed opening, and early release of over 25,000 personnel in the Pentagon infrastructure (i.e., some personnel work in nearby Rosslyn, VA and Crystal City, VA). This information also drives decision making for the Headquarters US Army, Joint Staff, Pentagon Force Protection Agency and Pentagon Building Management Office. These agencies take any weather updates from the Air Force Weather Office very seriously, and act upon them expeditiously. A group of seven weather forecasters support the President of the United States from their location at Raven Rock Mountain Complex near Gettysburg PA; they coordinate weather forecasts for Washington D.C. with the Pentagon staff.

The AFOG weather forecasters are under tremendous pressure to not only foretell that severe thunderstorm activity or heavy snow is approaching the D.C. area, but also to determine what specific towns and thoroughfares will be impacted by the snow/rain and which communities in and around the Interstate 495 (Washington Beltway) corridor will be hit by large hail, tornadoes or blinding snow. In this regard, the forecasters need tools to help them isolate and define specific precipitation and wind patterns, convective growth and temperature gradients that would enable accurate and timely impact analysis. A past example of this occurred when the Assistant Vice Chief of Staff for the USAF, a two-star general officer, asked about intensity and timing of snow bands for Fredericksburg vicinity during a February 2005 storm. Hence, meso-γ-scale numerical weather models operating at higher resolution in space and time with more detailed physics may offer the appropriate precision and accuracy within a limited geographic region to help address these problems (Mass et al 2002 and Dutton, 2002).

2. PREVIOUS WORK

To begin to explore the relevance of this idea, we build upon the earlier efforts by the IBM Thomas J. Watson Research Center to implement an operational testbed, dubbed "*Deep Thunder*", which has been customized for transportation applications. The original prototype provides nested 24-hour forecasts, which are typically updated twice daily, for the New York City metropolitan area to 1 km. The work began with building a capability sufficient for operational use. In particular, the goal is to provide weather forecasts at a level of precision and fast enough to address specific business problems. Hence, the focus has been on high-performance computing, visualization, and automation while designing, evaluating and optimizing an integrated system that includes receiving and processing data, modelling, and post-processing analysis and dissemination. Part of the rationale for this focus is practicality. Given the time-critical nature of weather-sensitive transportation operations, if the weather prediction cannot be completed fast enough, then it has no value. Such predictive simulations need to be completed at least an order of magnitude faster than real-time. But rapid computation is insufficient if the results cannot be easily and quickly utilized. Thus, a variety of fixed and highly interactive flexible visualizations have also been implemented, including ones focused on support of operational decision-making in transportation. The idea, however, is to have highly focused modelling by geography and application with a greater level of precision and detail than what is ordinarily available (Treinish and Praino, 2004).

Deep Thunder was extended in 2004 to provide forecasts for the Chicago, Kansas City, Baltimore and Washington metropolitan areas at 2 km resolution. All of the operational domains are illustrated in Figure 1, which places the forecast domains in a geographic context of the eastern two-thirds of the continental United States. On the map are three regions associated with each of the aforementioned metropolitan areas. They correspond to the triply nested, multiple resolution forecasting domains used to produce each high-resolution weather forecast. The outer nests are in gray, the intermediate nests are in magenta and the inner nests are in white (1 or 2 km resolution).

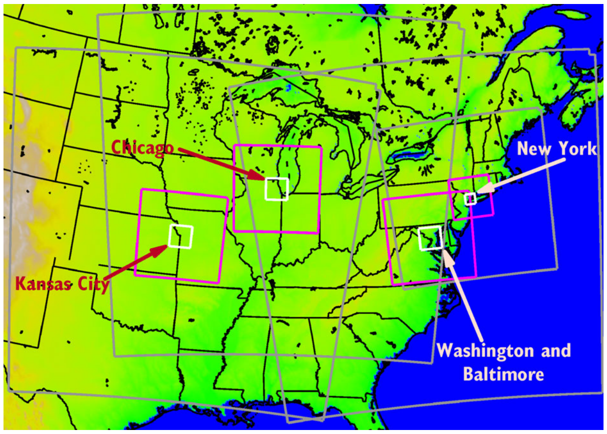

Figure 1. Model Nesting Configurations.

3. FORECAST MODEL AND SYSTEM DESCRIPTION

This particular study focuses on the model runs covering the greater Baltimore and Washington metropolitan areas. It includes a high-resolution nest at 2 km resolution, which is imbedded in a region at 8 km covering all of Maryland and Delaware, and most of Pennsylvania, Virginia and New Jersey. The domain is shown in Figure 2.

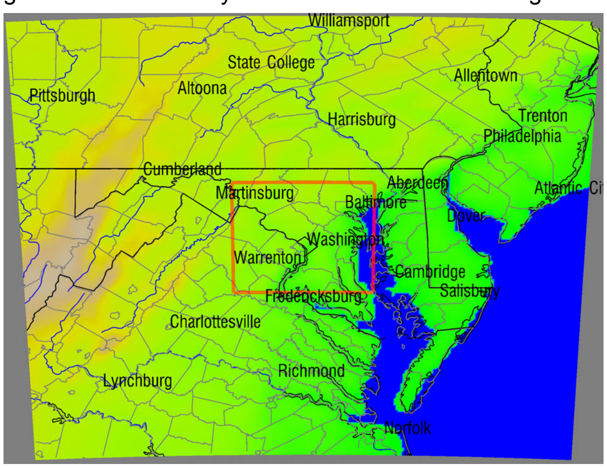

Figure 2. Configuration of 8 and 2 km Nests.

The model used for the *Deep Thunder* system is non-hydrostatic with a terrain-following coordinate system and includes interactive, nested grids. It is a highly modified version of the Regional Atmospheric Modeling System (RAMS, see Pielke et al, 1992), the details of which are described in Treinish and Praino, 2004. It includes full bulk cloud microphysics (e.g., liquid and ice) to enable explicit prediction of precipitation. Operationally, a 3-way nested configuration is utilized via stereographic projection. Each nest is a 66 x 66 grid at 32, 8 and 2 km resolution, respectively (i.e., 2080 x 2080 km^2, 520 x 520 km^2 and 130 x 130 km^2). Figure 2 shows the model orography for the 8 km nest with the boundary of the 2 km nest marked in red. The three nests employ 100, 25 and 6.25 second time steps, respectively. The time steps were chosen to ensure computational stability and to also accommodate strong vertical motions that can occur during modelling of severe convection. Each nest employs the same vertical grid using 31 stretched levels with the lowest level at 48 m above the ground, a minimum vertical grid spacing of 100 m, a stretch factor of 1.12 and a maximum grid spacing of 1000 m. At the present time, two 24-hour forecasts are produced daily, typically initiated at 0600 UTC and 1800 UTC. Additional runs are scheduled with initialization at other times either on-demand or during interesting weather events.

The system was set up to generate a number of customized visualizations viewed via a web browser, which are updated typically twice per day for both the 8 and 2 km nests. (See Treinish, 2002 for a discussion of the approach used for the web-based forecast dissemination.) All of the prerequisite processing is completed in less than an hour on relatively modest hardware to enable timely dissemination of model results at reasonable cost.

4. APPROACH AND RESULTS

In order to evaluate the potential utility of this class of numerical weather prediction, these forecast products were accessed by the AFOG forecasters based in the aforementioned geographic area during 2005, starting in February.

4.1 Winter Events

The winter season of 2004-2005 presented some good challenges for forecasters in the D.C. area. Many large storms missed the National Capital Region (NCR) to the north, east, south and west, and many storms either propagated up the spine of the Appalachian Mountains or intensified as they passed north of the region. Many towns in the D.C. area could have received up to 50 inches of snow but ended up with just a total of 16 inches.

The output of *Deep Thunder* was examined for at least four of the winter systems that impacted the greater Washington metropolitan area in early 2005. The model did very well in predicting the location and intensity of the heaviest snow for two systems, nailing an area of heavy snow showers north of D.C. on 22 February and a band in the Fredericksburg region on 24 February. The setup for the latter event can be seen via GOES visible imagery in Figure 3. It shows the storm developing over the southern Mississippi Valley. Figure 4 indicates the snowfall totals reported to the local National Weather Service Office in Sterling, VA.

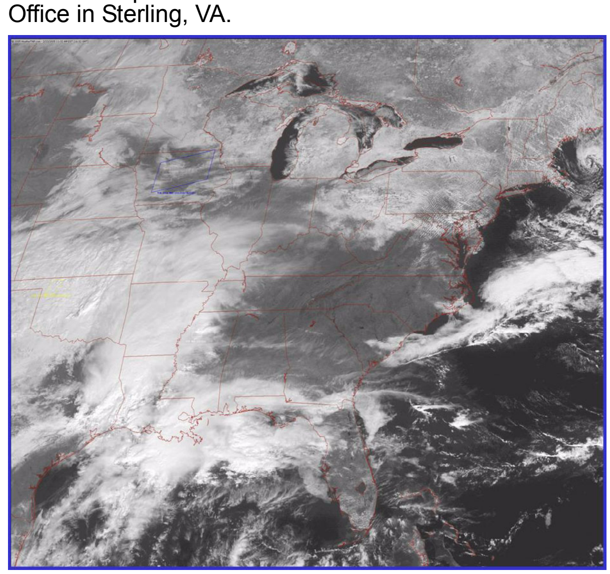

Figure 3. GOES Visible Imagery at 1100 EST on February 23.

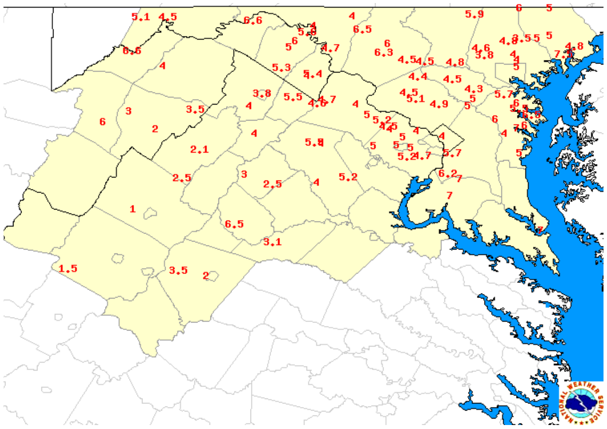

Figure 4. Snowfall Totals for Febuary 24 Storm.

The results for *Deep Thunder* are shown in Figures 5 and 6 from the forecast initiated at 0600 UTC (0100 EST) on 24 February. Figure 5 shows the accumulated total snow from the 8 km (top) and 2 km (bottom) nest, following the legend to the right. For the specific time period (0100 EST on 25 February), the predicted isotherm for the freezing point of water is shown as a light blue line. The maps are also marked by regions of mixed precipitation at that time. The model accurately predicted heavier snow north and west of Washington.

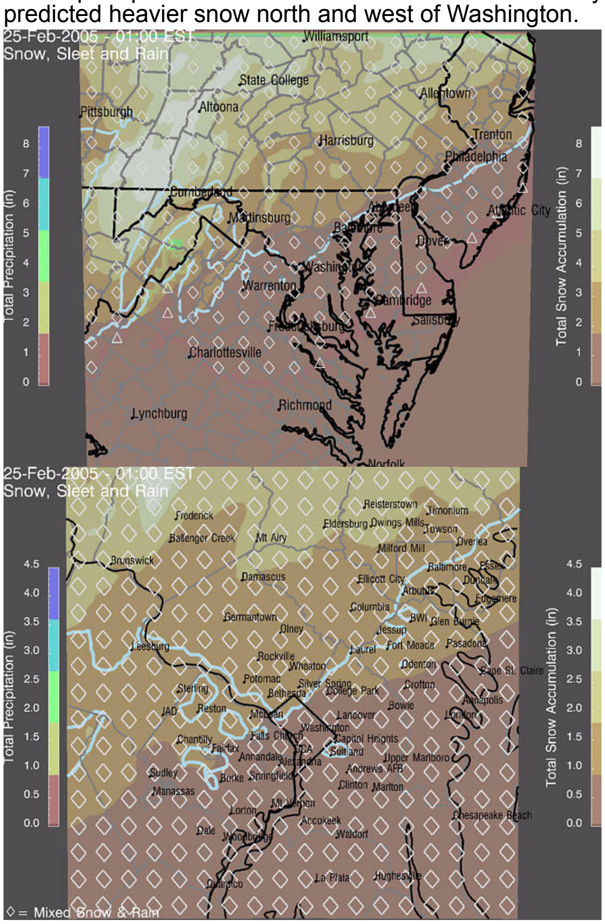

Figure 5. IBM *Deep Thunder* Prediction of Overall Snow Accumulation for February 24, 2005 (8 km Top, 2 km Bottom).

In addition, *Deep Thunder* was the only model that forecasted the area of heavier snow near Fredericksburg, VA. Another view of this event is illustrated in Figure 6 for the 2 km nest. In this case, a simple, "dry" algorithm is used to derive snow totals from the model liquid precipitation. Although this technique results in a positive bias, it does show additional detail concerning the prediction snowfall distribution.

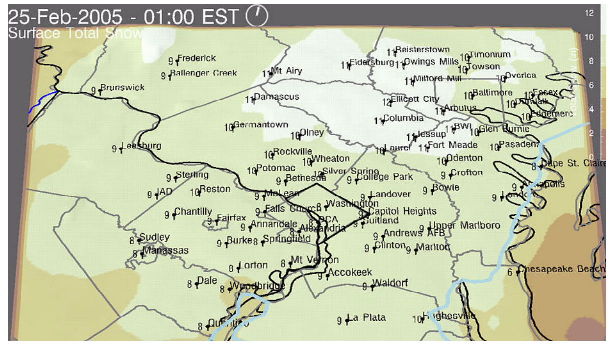

Figure 5. IBM *Deep Thunder* Prediction of "Dry" Snow Accumulation for February 24, 2005.

For comparison on the 24 February event, consider the results on an operational forecast from the Air Force Weather Agency (AFWA), shown in Figure 7. It is a meteogram for Washington, D.C. derived from a model run of the non-hydrostatic Fifth-generation Mesocale Model (MM5) co-developed by the Pennsylvania State University and the National Center for Atmospheric Research (Grell et al, 1993). In this case, a 15 km resolution domain covering the continental United States and southern Canada has been used with data produced every three hours for a 48-hour forecast. This forecast, which was initialized at 0600 UTC on 23 February also showed a slower development of the storm than what actually occurred.

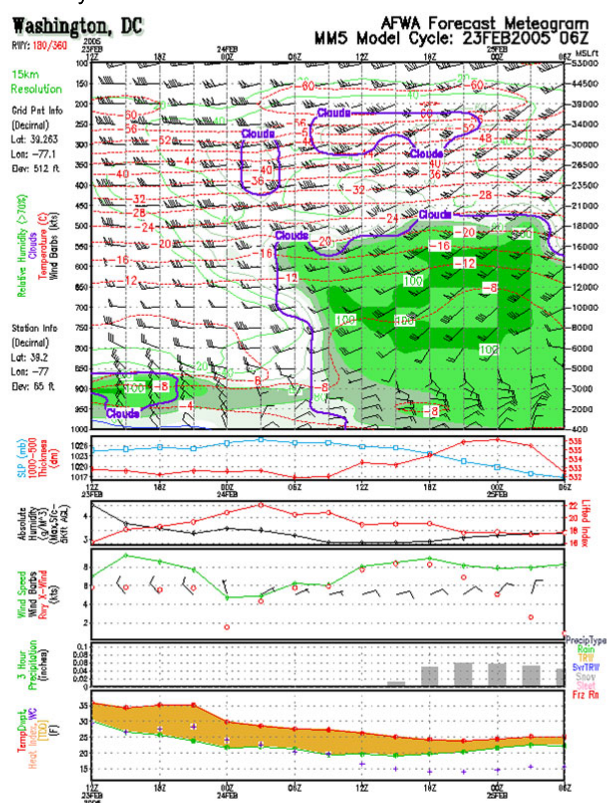

Figure 7. Meteogram for Washington, DC from the AFWA MM5-based Forecasts for February 23.

4.2 Summer Events

The NCR had a relatively dry and hot summer with four of the months having much less precipitation than normal, and September 2005 being the driest September on record (0.11"). In addition, there were 38 days with highs greater than 90 ºF. However, there were a few opportunities to see how the model did during frontal passages and in rain situations. In late June, we noted that the model tended to cool off temperatures in the DC corridor too quickly around sunset, possibly due to inaccurate accounting of high humidity and persistent urban heating. During the frontal passage on 1 July, the model was slightly off on temperatures, but hit the timing of the wind shift at both Ronald Reagan National Airport and Dulles International Airport. The model overdid the precipitation before the frontal passage, missing an area of rain to the south of D.C. (Woodbridge, VA). Unfortunately, the model was also too dry compared to the FROPA itself. Hence, it did not indicate the showers that fired up at night.

The AFOG Weather Office examined the model performance for a decaying tropical system when the remains of Hurricane Cindy flowed across the D.C. area on 7-8 July. The rainfall totals for this event are shown in Figure 8.

The speed of the system was much faster than the model predicted. For example, *Deep Thunder* forecasted rain to start after midnight on 7 July when light rain actually commenced at Dulles Airport at 1700 local time (EDT) and heavy rain fell at Dulles between 2000 and 2200. The model did pick up convection in southern Virginia as verified by reported precipitation amounts, but concentrated too much rain over the Maryland panhandle, well west of the heaviest rain that actually fell just west of D.C. and the Beltway near the eastern slopes of the Appalachians. These characteristics of the model forecast are shown in Figures 9 and 10. It was initiated at 0600 UTC on 7 July. In addition, winds were close with an easterly component of 10 to 15 knots well into 8 July. We also saw that all models had been too slow with Hurricanes Jeanne, Frances and Ivan in 2004 in the DC area. A more comprehensive examination of the results of *Deep Thunder* for extratropical events in the New York area are examined in Praino and Treinish, 2006, including some of these same storm systems.

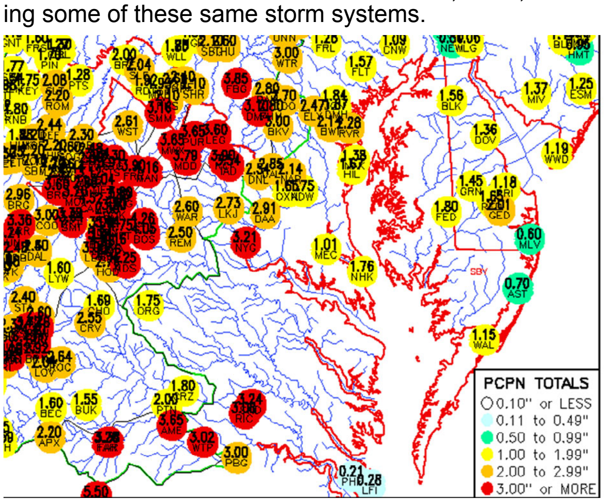

Figure 8. Rainfall Totals for July 7-8, 2005 Storm.

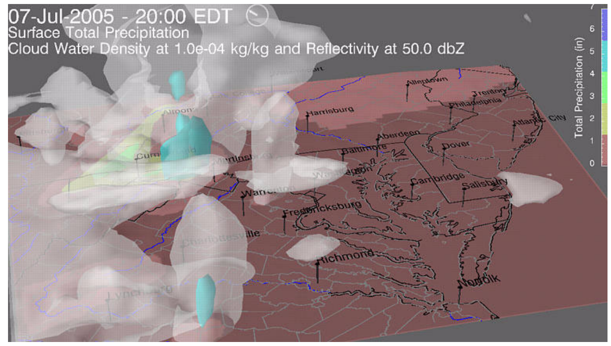

Figure 9. IBM *Deep Thunder* Prediction of Clouds and Precipitation for 2000 EDT along the Middle Atlantic Coast.

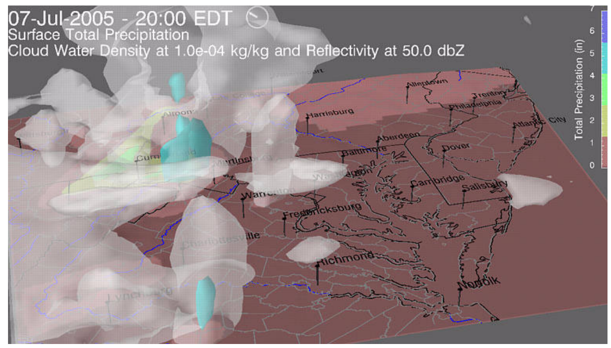

Figure 10. IBM *Deep Thunder* Prediction of Rain for July 7-8, 2005.

From late on 15 August to early on 16 August, *Deep Thunder* predicted an area of light to moderate rain to impact an area extending from the northeast section of West Virginia to just south of Washington, a major rush hour corridor for D.C. A low pressure system propagated from West Virginia to the Chesapeake Bay from 0800 EDT on 16 August to 2000 EDT. Dulles International and Reagan National Airports only received rain from 1000 EDT to 1200 EDT on 16 August with bands of rain running from just north of Cumberland, MD to Lancaster, PA, and from Parkersburg, WV to Fredericksburg, VA. A snapshot of this event is shown in Figure 11 with the composite reflectivity from the local NexRad site in Sterling, VA.

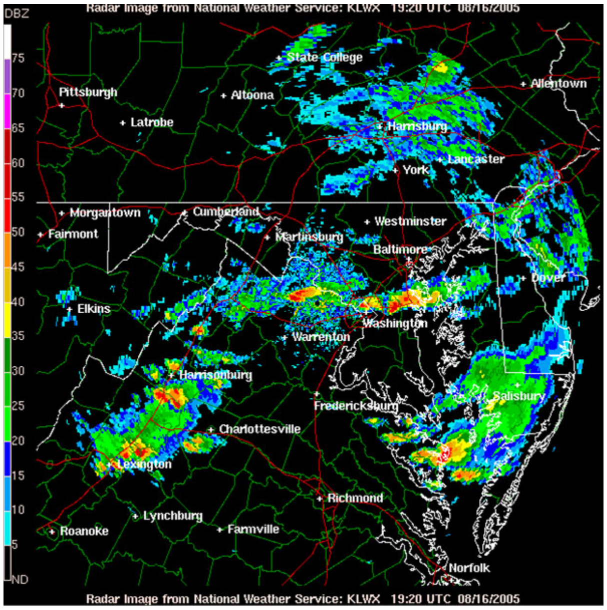

Figure 11. NexRad Compositive Reflectivity for 1520 EDT on August 16, 2005.

The model did pick up on the wind patterns associated with convection (along the Shenandoah Valley) but not over southern Pennsylvania. Temperatures were too cool by at least 5 ºF. over most of the D.C. area, more than likely because the model predicted more cloudiness and rain than had actually occurred. These results are illustrated with Figures 12 and 13.

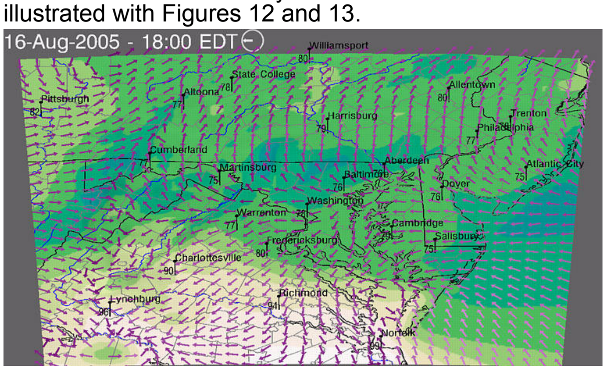

Figure 12. IBM *Deep Thunder* Prediction of Winds and Temperature at 1600 EDT on August 16, 2005.

The forecast was initialized at 0600 UTC on 16 August 2005. Figure 12 shows the convective patterns in the Shenandoah Valley region from Warrenton, VA to Lynchburg, VA

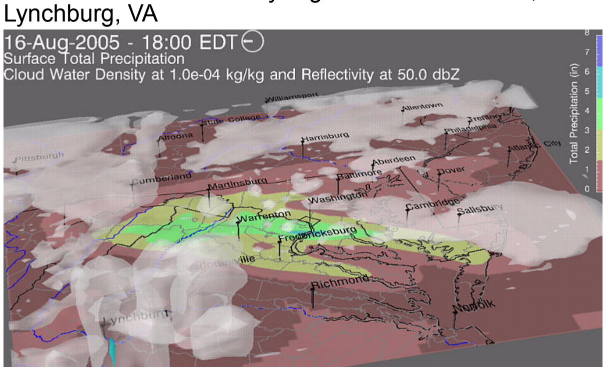

Figure 13. IBM Deep Thunder Prediction of Clouds and Rain at 1800 EDT on August 16, 2005.

4.3 Autumn Events

From late on 6 October to mid-afternoon on 8 October, the remains of Tropical Storm Tammy, along with a persistent frontal boundary, provided the NCR with its first substantial rainfall in at least five to six weeks. Most of the area received well over five to six inches of rain, with a large area west and south of D.C. (Falls Church, Arlington, Alexandria, Annandale, and Vienna in Virginia) getting hit with seven to eight inches of rain. Dulles Airport reported 6.62”, Reagan had 7.34”, and Baltimore-Washington Airport 6.72”. Only a two-hour-drive northwest from D.C., Hagerstown, MD had just 2.94”, while Charlottesville, 2 hours southwest of D.C., had 5.50”. The model under-forecasted the rain by about 1.0” (2.20” vs. 3.20”) for the time period of noon on 7 October to noon on 8 October. This is illustrated with a site-specific forecast for Dulles International Airport shown in Figure 14. However, the model did do well with this event considering it was a record rainfall for 7 October. The model accurately predicted the wind speeds (25 mph) but was slightly off on the overall direction (model had 150º, while the actual was 180º). Temperatures were pretty close, with the model being slightly warmer (77 ºF vs. 75 º F) for highs on 7 October.

5. DISCUSSION, CONCLUSIONS AND FUTURE WORK

Overall, the model showed some promise for forecasting in the challenging region of the greater Washington, D.C. metropolitan area. It did tend to pick up precipitation events in the area, and located the areas where the heaviest rain and snow would take place. There were other issues associated with the timing of the precipitation. Temperatures tended to cool off too quickly on summer evenings, but were close during wintertime events and for major storms.

Some of the biases in the aforementioned forecast results are consistent with earlier studies done in the initial New York forecasts (Praino and Treinish, 2005). This suggests next steps to improve overall forecast quality, especially for storm timing and precipitation totals. While the ability to leverage the availability of full-resolution 12 km North American Model results on the AWIPS 218 grid has been implemented within the current pre-processing tools for background fields and lateral boundaries, additional data such a daily global sea surface temperature will be used to improve initial conditions. In addition, further tuning of the microphysics will also be addressed to reduce its efficiency in aggregation, which can lead to over-prediction of precipitation.

However, the current studies suggest other limitations in the current modelling, which are related to its relatively simple representation of land surface conditions and the planetary boundary layer. This is likely to have impact on the quality of forecasts, which are significantly affected by urban heating in the greater Washington, D.C. metropolitan area. Hence, the long-term, viability of the current modelling component of *Deep Thunder* based upon a highly modified version of RAMS is limited. In addition to gaps in available modelling capabilities, it is unlikely that further optimization of the underlying code for newer computing platforms will be feasible. Therefore, it is expected that the customized version of RAMS will be replaced with the Weather Research and Forecast Model (WRF). The WRF model has reached sufficient maturity in recent months to address some of capabilities of the current *Deep Thunder* system (Michalakes et al, 2004). Hence, the other components of the system will be adapted to utilize WRF to enable the

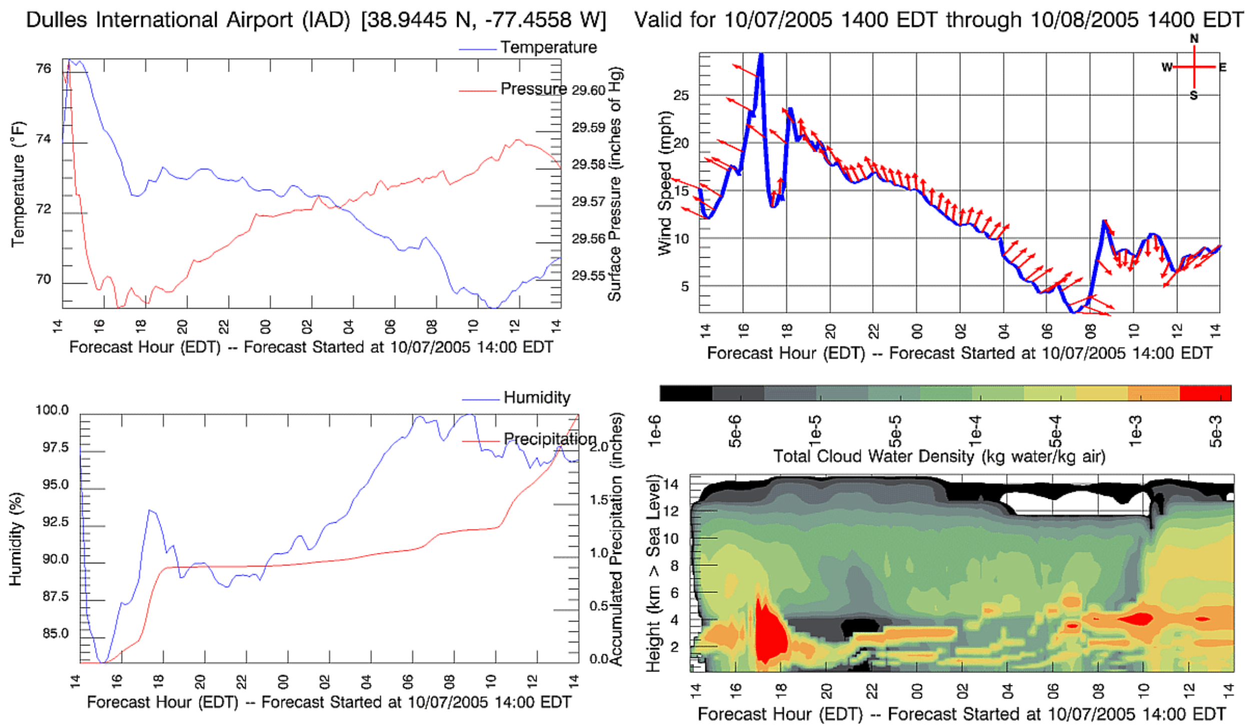

Figure 14. ***Deep Thunder*** **Meteograms of Temperature, Wind, Precipitation and Humidity Forecast for Dulles International Airport at 2 km Resolution for October 7-8, 2005 Initialized at 1800 UTC.**

same class of automated, integrated operations. The next step after enabling parallel operations with WRF with comparable results, will then consider the utilization of more sophisticated physics and parameterization as well as assimilation of available observations to improve initial conditions.

Therefore, the Air Force Weather Operations unit hopes to continue to work with IBM Research to further identify the priorities for improved forecasts as well as to define the additional products that need to be disseminated to support operational forecasting. We hope that this will evolve to include refinements in the model configuration and parameterization, based upon Air Force requirements for both the current utilization of RAMS and the eventual incorporation of WRF. As these customized capabilities are made available to assist in weather-sensitive operations, efforts will also be addressed to determine and apply appropriate metrics for measuring the value to the Air Force. These will serve to provide an evaluation of *Deep Thunder* that is complementary to the traditional meteorological verification.

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