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NWP GOES TO WAR…

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1. INTRODUCTION

Numerical Weather Prediction (NWP) has gone to war in early 2005 in the back of specially equipped Humvees for the U. S. Army. Penn State and Smiths Detection teamed up to design, build and field the Meteorological Measuring Set-Profiler (MMS-P), an automated, relocatable mobile nowcast-prediction system to support Army field artillery operations. Building on the success of this rapidly relocatable nowcast-prediction system (RRNPS, Stauffer et al. 2004, Schroeder et al. 2006), with 45 units fielded/delivered/ordered and a total of 108 units planned through 2011, Smiths Detection, Penn State and other partners are designing and building a new mobile nowcast-prediction system for the U. S. Marine Corps, called Meteorological Mobile Facility Replacement Next Generation (METMF(R) NEXGEN), with delivery of its first prototype in 2008. This system will replace the legacy METMF(R) using current and emerging state-of-the-art technologies to offer smaller size and increased mobility/scalability, which will significantly improve the provision of Marine Air Ground Task Force (MAGTF) meteorological and oceanographic (METOC) support in every clime and place.

The Profiler system (Figure 1) will first be described, including its mesoscale-model nowcast capability and data assimilation system, and its Unified Post Processor System (UPPS) used to further reduce model biases on the fly. Sample graphical and statistical outputs, and photos of its use in the battlefield, are presented. Section 3 will describe the NEXGEN mobile NWP system, including the mesoscale-model nowcast component and local and remote sensors. Finally, examples of this RRNPS technology applied to realtime high-resolution numerical forecasting and fighting terrorism are discussed. This RRNPS is run as a prediction system in realtime at Penn State University, and at the Department of Defense, Defense Threat Reduction Agency (DTRA) for operational reachback support for hazard prediction and consequence assessment (e.g., Stauffer et al. 2007). These NWP systems are easily coupled to tactical decision aids (TDAs) such as HPAC/SCIPUFF (e.g., Deng et al. 2004) for transport and dispersion predictions of chemical / biological / radiological / nuclear (CBRN) threats. Examples of this application of RRNPS are shown in Section 4 for the Torino Winter Olympics and soggy Superbowl XLI in Miami, Florida.

Figure 1. The MMS-Profiler system, housed in a Humvee, on the desert battlefields of Iraq with large guns in the background (top), and with its crew, armed and wearing desert camouflage (bottom). The T-VSAT dish in the foreground of the lower photo provides global model data and WMO regional observations via military satellite communications, and the TACMET weather sensor on the tripod measures surface wind speed and direction, temperature and relative humidity, to be assimilated into the system.

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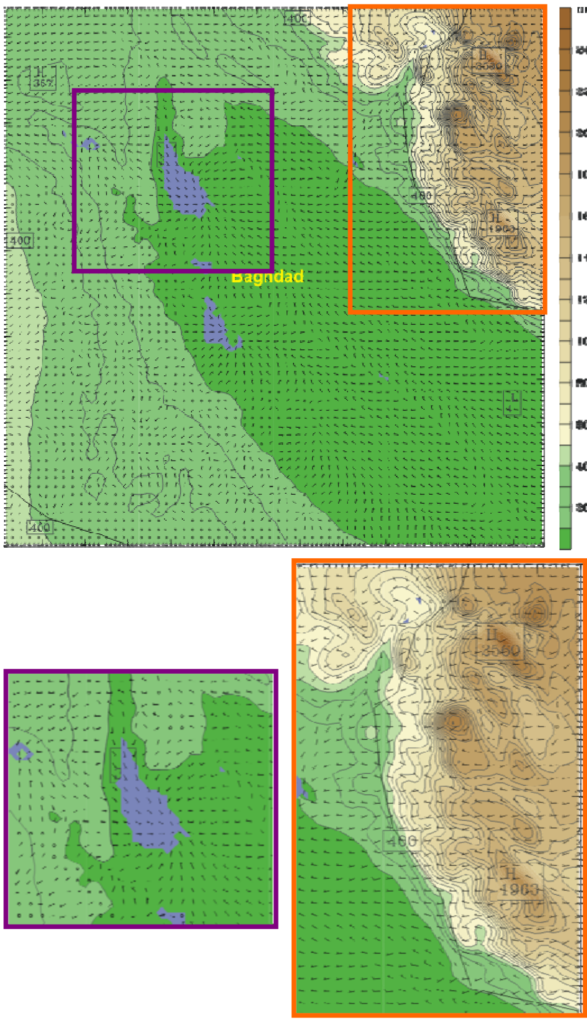

Figure 2. RRNPS sample nowcast output of locally forced flows, shows the Profiler's detailed surface-layer winds (full barb is 10 ms^{-1}) and terrain (color key to right of figure and contour interval of 100 m) over the 4-km domain centered on Baghdad, Iraq, during the afternoon hours when divergent winds over the larger lakes (in blue, left expanded view) and upslope flow into the Iranian Mountains to the northeast (in browns, right expanded view) are predicted.

2. PROFILER SYSTEM

This mobile MMS-P system shown in Figure 1 currently uses a triply nested version of the Penn State University – National Center for Atmospheric Research MM5 (Grell et al. 1995) to produce on-demand meteorological nowcasts, defined here as numerical weather forecasts for the current time, and made available just ahead of the clock. The nowcast assimilates all available data within a running mesoscale model using continuous data assimilation

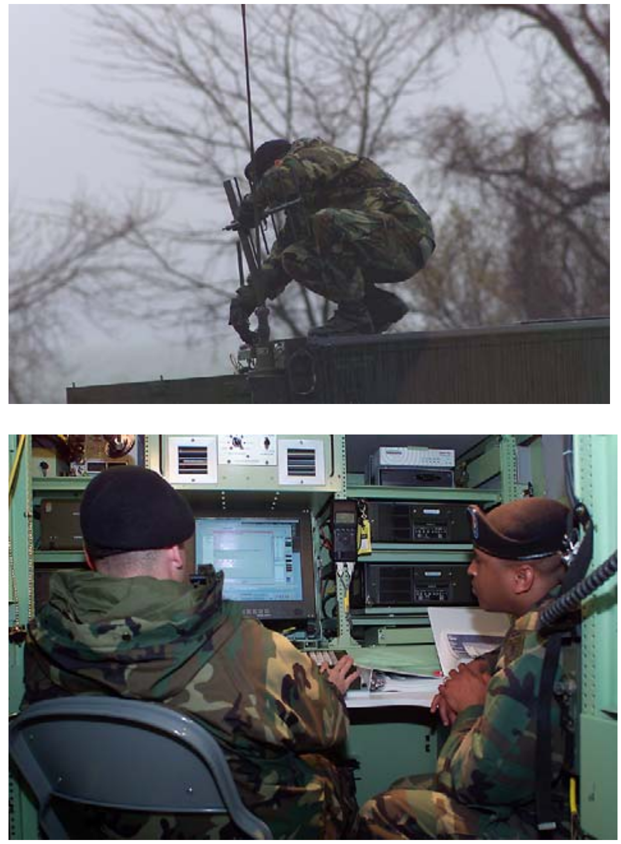

Figure 3. A soldier prepares the MMS-P for operation (top) and then soldiers operate the MMS-P from the back of the humvee (bottom).

(Stauffer and Seaman 1994) to maximize the meteorological (MET) accuracy. The innermost nowcast model data cube, 500 km on a side and extending to 30 km elevation, is updated every 30 minutes at 4-km horizontal resolution. Figure 2 shows sample MM5 nowcast graphical output for Iraq over the 4-km domain, and expanded views of some of the detailed mesoscale flow structures resolved by this system. The Army's MMS-P resides in a Humvee shelter and can be operated worldwide by its crew (Figure 3) in all climates. The results from the MM5 nowcast are used in a newly developed Unified Post Processor System (UPPS) to automatically produce atmospheric profile MET messages that are disseminated to fire support systems over the tactical area by radio communications.

The MMS-P is the successor to the Meteorological Measuring Set (MMS) which is a rawinsonde based system. The MMS has been the field artillery upper-air MET system since 1995, when fielding began. The MMS provides MET updates to the field artillery, but it is unable to provide rapid MET data or target area MET data.

The Profiler expands the field artillery's capability to produce more timely MET updates and target area MET data.

The MMS-P passed extensive Army field testing at White Sands Missile Range in January – April 2004, in addition to virtual worldwide testing, and was fielded to active Army units in early 2005. It was approved for full rate production in June 2005. To date there are 45 units fielded / built / ordered and 108 total units planned. Reports from the battlefield indicate excellent accuracy of the guns when using this system.

The MMS-P uses data from various sources including local MM5 outputs, global model (NOGAPS) outputs, Army deployed measurement systems including ground MET sensors and limited rawinsonde flights to 30 km, and also standard WMO surface and upper-air observations. Nonlocal data are transmitted to the MMS-P via military satellite communications. Multiple MMS-P units can also share their local data among themselves. The MMS-P provides the Field Artillery with the capability to quickly and accurately gather MET data in both the local and target areas.

The U. S. Army Product Manager – Target Identification and Meteorological Sensors (PM-TIMS) sponsors the MMS-P contract with the contracting officer at CECOM, Fort Monmouth, New Jersey. The Directorate of Combat Development, Fort Sill, Oklahoma, represents the user community, which consists of deployed field artillery units.

The MMS-P is required to produce updated nowcast MET messages every 30 minutes to 30 km elevation. The current MM5/UPPS system is able to produce updated MET every 15 minutes. It provides the following fields as vertical profiles: wind speed, wind direction, temperature, relative humidity, and pressure. Table 1, for example, shows the U. S. Army design acceptance threshold criteria for these fields. These criteria are to be met 80 percent of the time for local MET and 75 percent of the time for target MET. In addition to these vertical profile fields, the MMS-P also produces cloud ceiling, visibility, precipitation rate and precipitation type for the target area.

2.1 Mesoscale Model

The system is currently based on an optimized full-physics version of the Penn State University / National Center for Atmospheric Research (PSU/NCAR) mesoscale model MM5 (Grell et al. 1995) utilizing observation nudging four-dimensional data assimilation (Stauffer and Seaman 1994), which is especially attractive for assimilating mesobeta-scale asynoptic data, with its use of terrain-dependent anisotropic weighting functions. Three nested grids of 36-, 12- and 4-km resolutions are currently used. Each grid has 30 terrain following vertical sigma layers extending to the model top at 50 hPa (~20 km above ground level, AGL). The 36-km domain has 101 by 101 horizontal grid points while both the 12- and 4-km domains have 127 by 127 grid points.

Variable	Threshold value
Temperature	2.0 ºC
Mixing Ratio	1.0 g/kg
Wind Speed	At surface and below 2000 m: 2.6 m/s. Above 2000 m, for wind speeds < 30 m/s: 2.6 m/s. 2.6 m/s to 3.6 m/s linear increase for wind speeds from 30 m/s to 60 m/s. 3.6 m/s for wind speeds > 60 m/s.
Wind Direction	At the surface: 45.0º. Below 2000 m: 11.25º + [(45.0º-11.25º)*(1-(z/2000)^1.5)]. Above 2000 m, for wind speeds < 30 m/s: 11.25º. 11.25º to 6.0º linear decrease for wind speeds from 30 m/s to 60 m/s. 6.0º for wind speeds > 60 m/s. Add 2.5º to each of these totals if using WMO data.
Relative Humidity	10.0 %
Sea Level Pressure	3.0 hPa
Vector Wind Difference	[2*V2*(1-cosθ) + 2*V*ΔV*(1-cosθ) + ΔV2]1/2 m/s where ΔV is the allowable wind speed error, V is the observed wind speed, and θ is the allowable direction error
Virtual Temperature	2.0 + 0.061*w_s*T ºC where w_s is the saturation mixing ratio and T is temperature.

Table 1. U. S. Army Profiler design acceptance criteria.

The MM5 modeling component of the system is optimized for parallel performance on a Linux box running C-shell scripts to automate the execution sequence. Pre- and post model data processing is performed on a pair of Sun Microsystem computers. All hardware units have been modified to withstand a wide range of battlefield environmental conditions.

Initial conditions and lateral boundary conditions for the outermost 36-km domain are supplied by real-time fields from the U. S. Navy Operational Global Atmospheric Prediction System (NOGAPS) (Hogan and Rosmond 1991, Rosmond 1992). The three MM5 grids are run in a one-way nested configuration with the inner two domains receiving their lateral boundary conditions from the 36-km and 12-km MM5 domains, respectively. Once initialized, the MM5 continually ingests local and nonlocal World Meteorological Organization (WMO) surface and upper-air data sets in its four dimensional data assimilation (FDDA) system.

The MM5 runs in 30-minute cycles beginning at any arbitrary time the system is turned on and produces a model product valid at the end of the current 30-minute segment and just ahead of the clock. The MM5 then pauses for new data ingest before initiating its next 30-minute cycle. Updated global model fields are automatically loaded on to a data “conveyor belt” for ready use by the system. The conveyor belt and its associated drivers perform quality and completeness checks before making the global model data available to the MM5 and the post processor described in more detail below.

Local and nonlocal observation data are continually processed and quality checked for use by the MM5 FDDA system and the post processor. Local and nonlocal sonde data are ingested continuously by the FDDA system as the balloon is rising. Thus the MM5 FDDA system has ready access to the balloon data as the balloon is in flight. Standard WMO sonde data are usually not available until the balloon reaches 100 hPa or completes it flight. Balloon drift is also accounted for in the FDDA system.

The model preprocessing, execution and post processing is automated so that an operator with minimal meteorological or numerical model training can position the model grids anywhere in the world and initiate the nowcasting system in minutes. By default the Profiler system receives its position information directly from GPS.

The standard MM5 model physics includes explicit prognostic equations for mixing ratios of cloud water/ice and rain/snow (Dudhia 1989). Subgrid scale deep convection on the 36- and 12-km grids is parameterized using the convective parameterization of Kain and Fritsch (1990). All precipitation is assumed to be fully resolved on the 4-km domain so no connective parameterization is used at 4-km resolution. Turbulence is represented on all three domains using a 1.5-order closure which explicitly predicts the turbulent kinetic energy (TKE), (Shafran et al. 2000, Stauffer et al. 1999). Surface fluxes of heat, moisture and momentum are computed from similarity theory (Grell et al. 1995). Ground temperature over land is predicted using a force-restore method based on the surface energy budget equation, while water surface temperature is specified from observations and held constant in time (Grell et al. 1995). The Rapid Radiative Transfer Model (RRTM) is used to parameterize effects of longwave radiation on the temperature tendencies (Mlawer et al. 1997) and shortwave radiation effects are computed following Dudhia (1989).

2.2 UPPS

The MMS-P MM5 interfaces with an automated post processing system that merges the mesoscale model data with the global model data above 100 hPa, to further reduce model biases on the fly as the system is running. This Unified Post Processor System (UPPS), designed by Penn State and the Profiler team for the battlefield, has minimal model and observational data inputs compared to traditional post processing systems used at centralized operational modeling centers. There is no ready long archive of model runs or observational data for these highly localized and remote regions of the world where the system must operate.

The UPPS uses innovations, or observation minus model background corrections, to update the most recent model predictions. This innovation-based objective analysis post processor was designed to further reduce Profiler model biases on the fly based on the most recent observations, MM5 and global model forecast fields. The UPPS uses a 2-hour archive of MM5 and NOGAPS forecasts, the past 2 hours of surface data and the past 6 hours of upper-air data. It is based on widely accepted objective analysis and data assimilation approaches within a highly modular framework so that updated model and post processor components may be used when they become available.

The innovations are computed using the model background field closest in time to the mean time of the observations, and are time weighted to reflect the difference in time between each observation and the model background. Observation mean times for both surface and for upper-air data are computed and used to compute the innovation fields. A running 2-hour observation distribution as shown in Figure 4 is used to determine which MM5 or NOGAPS model background field to use in the innovation calculations. The temperature innovations, for example, are then applied to the most recent MM5 model forecast as shown in Equation 1:

$$T_{UPPS}(i,j,k,t) = T_{MM5}(i,j,k,t) + \sum_{n_{obs}} W(T_{obs}(t_{obs}) - T_{MM5}(\bar{t}_{obs})) \quad (1)$$

The number of observations at each lag time is used to compute a mean time of the observations, $(\bar{t}_{obs})$, and the MM5 model background field closest to this mean time is used to compute the weighted corrections applied to the MM5 temperature to obtain the current UPPS-corrected temperature as in Eq. 1.

The innovations are both time dependent and flow dependent. Figure 5 indicates how observations, represented by small black squares, correct the MM5 model background fields spatially on a given pressure or sigma level within the yellow colored regions as a function of the local wind flow. The direction of the flow is along the streamlines

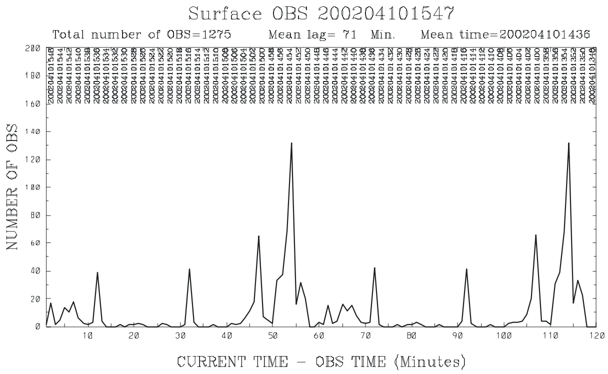

Figure 4. Sample time distribution of surface observations used to compute mean observation time $(\bar{t}_{obs})$, showing number of surface observations within the current 120-minute UPPS time window starting at the current time and extending back in time for 120 minutes.

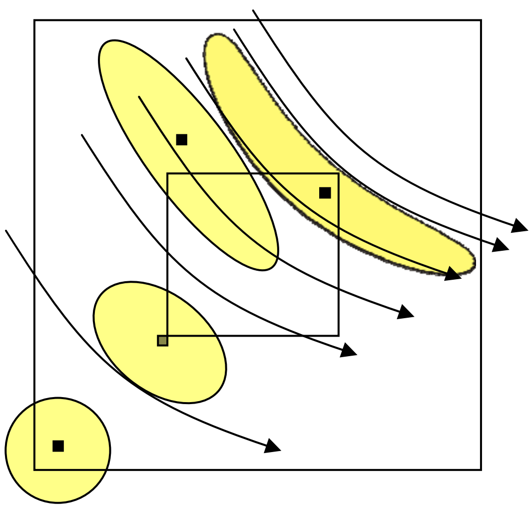

Figure 5. UPPS flow-dependent influence regions for observation corrections to a model background field on a constant pressure or sigma level. Wind speed and direction patterns are denoted by the solid contour streamlines. The outer square outlines the 12-km domain boundaries and the inner square represents the 4-km domain boundaries.

(solid contours) from left to right, and the speed of the flow is proportional to the spacing (or gradient) of the streamlines, where tighter packing of the streamlines indicates faster flow. Where the flow is weak (i.e., the streamlines are spaced far apart), the region of influence for an observation affecting the MM5 model background via the UPPS is circular. Where the streamlines are closer together the flow is stronger and when it exceeds a speed threshold that varies with pressure level, the influence region for that observation correction via the UPPS becomes elliptical and elongated in the direction of the flow.

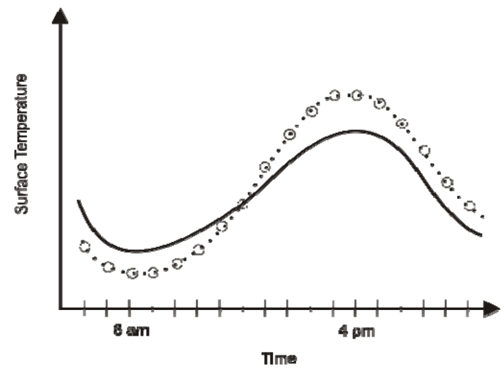

Figure 6. Schematic showing MM5 nowcast surface temperature (solid), surface temperature observations (circles) and UPPS-corrected surface temperature (dashed) as a function of local time at a given grid cell.

There is greater correlation in the MET model background error at the observation site with that at other locations along the flow direction rather than across the flow. Where the flow is sufficiently strong and the curvature of the flow exceeds a pre-determined value, the long axis of the ellipse is bent to reflect the curvature of the flow and the influence region becomes banana-shaped. Thus these influence functions in Figure 5 for observational corrections applied to the MM5 and NOGAPS model background fields within the UPPS are called flow-dependent weighting functions because they depend on the local flow conditions. These flow-dependent weighting functions better represent the model background error structures used to define the observation weights (W in Eq. 1) within the UPPS.

Figure 5 also shows that the UPPS design allows observations outside the inner 4-km resolution model domain (depicted by inner square outline) to influence the region inside this 4-km domain. In this way, observations from friendly nations surrounding a battlespace can still influence potentially data-sparse regions within the battlespace on the 4-km domain. Corrections computed with respect to the outer 12-km domain are interpolated to the 4-km domain area and applied to the most recent 4-km MM5 model output for say temperature, T_{MM5} (i,j,k,t), to compute the UPPS-corrected temperature, T_{UPPS} (i,j,k,t), as in Eq. 1. The finer scale atmospheric structure of the 4-km domain is largely retained while errors in the larger-scale mass-field structures of temperature, relative humidity and sea-level pressure from the 12-km domain are used to correct these same fields on the 4-km domain. Wind fields are not currently adjusted by the UPPS.

Equation 1 shows how the UPPS corrects the MM5 model background value for temperature,

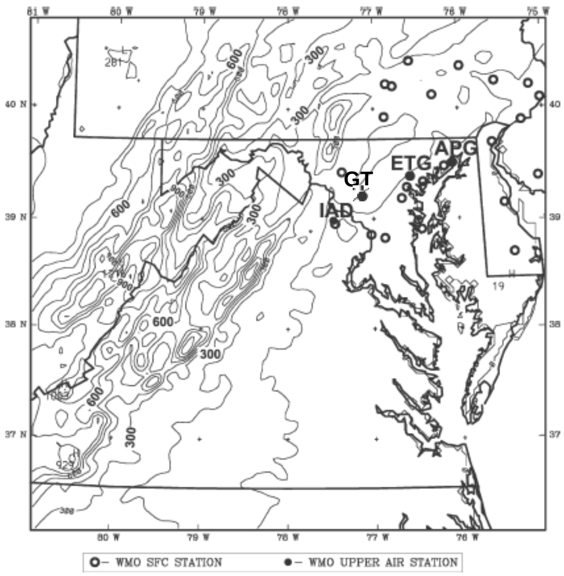

Figure 7. Terrain (contour interval of 100 m) for the 4-km domain winter and summer data gather testing showing the locations of Aberdeen Proving Ground, MD (APG), Edgewood, MD (ETG), Sterling, VA (IAD) and Germantown, MD (GT).

T_{MM5} (i,j,k,t), at a given grid cell (i,j,k) and the current time t, by computing a weighted sum of all of the observation minus model corrections affecting this grid cell. Figure 6 shows that the MM5 model surface temperature, for example, undergoing a diurnal cycle with a maximum surface temperature around 4 pm local time. If the MM5 is underestimating the amplitude of the diurnal range such that the morning minimum temperature is too warm and the late afternoon maximum is too cool, the UPPS corrects the MM5 model values to better reflect the available observations, if they have passed the quality control checks and are retained by the system. The weighted correction term in Eq. 1 uses the MM5 model background field at the mean time of the observations, as determined from Figure 4. For grid cells that are outside the regions of influence of the observations (e.g., Figure 5), no corrections are made and the UPPS sends forward the MM5 model output fields.

The UPPS uses the same model domains as the MM5 to minimize interpolations as it produces MET data at the surface and 82 vertical pressure levels to 10 hPa (~30 km AGL). Both the 12-km and 4-km MM5 domains are used in the post processing. Above the top of the MM5 in the stratosphere, the UPPS uses global model data corrected by available observations to produce the MET messages up to 30 km altitude. When the MM5 nowcast is not running, the UPPS uses the most recent and complete global model data corrected by observations by default. When global model data are unavailable, the system uses local sonde and surface observations in a way similar to that of the MMS, but also accounting for local terrain differences, to produce the MET messages.

2.3 MET Accuracy Testing

Prior to the formal Army Profiler testing at White Sands Missile Range in early 2004, the RRNPS system used within Profiler has undergone extensive testing beginning in August 2001 at the Southern Great Plains ARM-CART site in Oklahoma / Kansas and at the Aberdeen Proving Grounds, Maryland (APG) starting in April 2002 and extending through summer of 2003 (Schroeder et al. 2006). This section documents some of the Army testing of Profiler MM5 nowcast and UPPS for the eastern domain including Aberdeen Proving Grounds (Figure 7) during summer and winter data gathers. Figure 7 shows the terrain on the 4-km Profiler domain and the locations of the sondes at Aberdeen Proving Ground (APG), Sterling, Virginia (IAD), Edgewood, Maryland (ETG) and Germantown, Maryland (GT). A series of twelve 3 – 6 h model nowcast sequences following cold starts were performed during the winter season from 29 January to 15 March 2003 (winter gather) and the summer season from 25 June to 2 July 2003 (summer gather). These 0-6 h nowcast sequences were evaluated both with and without FDDA and also use of the UPPS on the 4-km MM5 FDDA results. For the winter gather, the FDDA system assimilated only WMO observations and special sondes launched at Smiths' Germantown, Maryland location were used for independent verification of the local area. For the summer gather, special sondes from Smiths' Germantown location were assimilated and the Sterling, Virginia sonde (local area) and Edgewood sonde (target area, 60 km away) were used for verification. All verification data in these tests were completely withheld from the system.

The statistical results presented here were produced by Smiths Detection and the U.S. Army prior to the formal White Sand Missile Range testing. These results extend the nowcast results described in Schroeder et al. (2006) by also including the adherence to the Army thresholds (defined in Table 1) and the added value of the UPPS. Figure 8 shows the total percentage of MET message zones between 0 – 30-km exceeding the Army specified thresholds for virtual temperature, vector wind difference and pressure, and the vertically averaged mean absolute error (MAE) for each of these variables during these data gathers. The results generally show that for the local and target areas, FDDA increases the MET

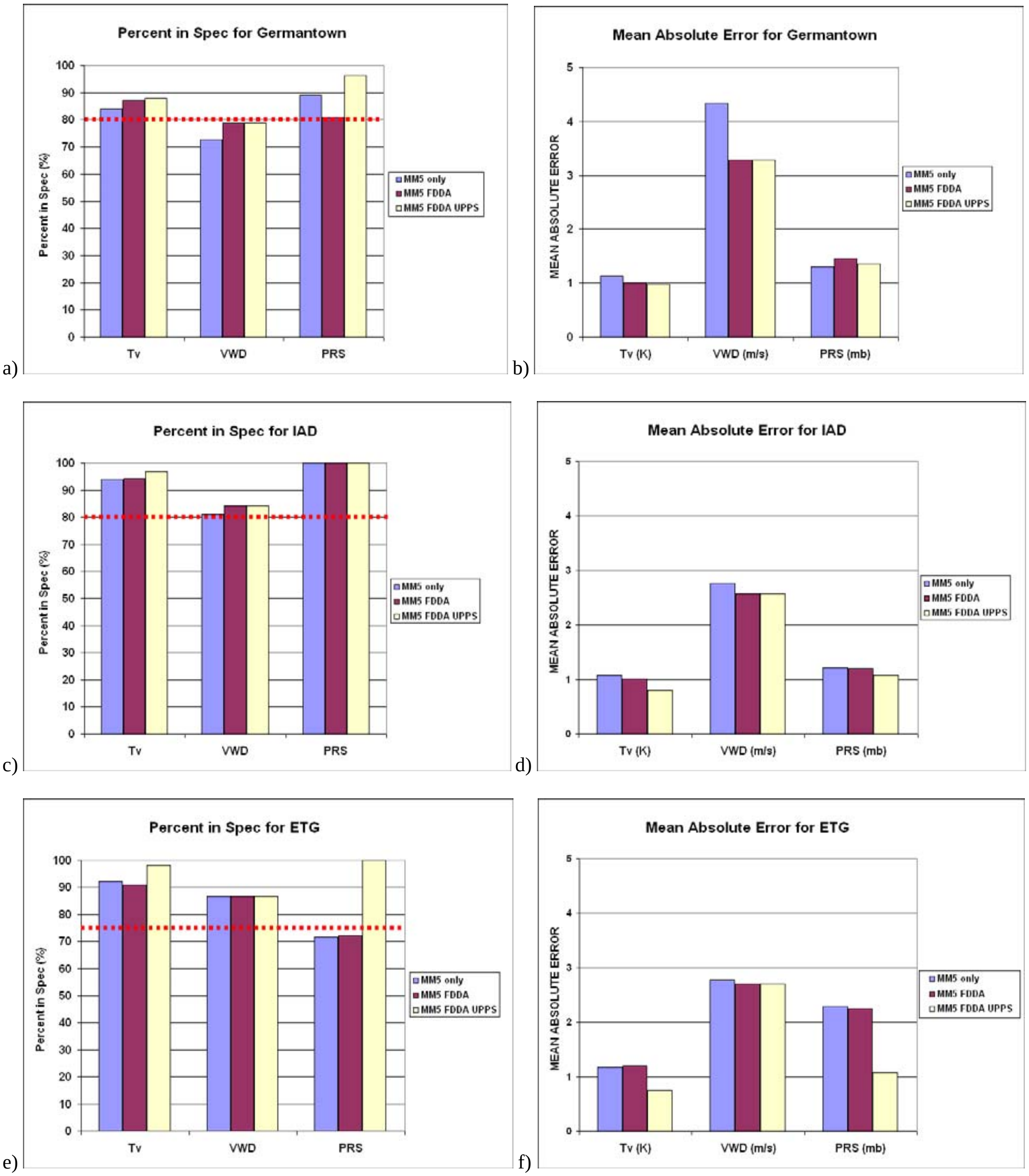

Figure 8. Percentage of MET message zones passing the Army acceptance criteria, and vertical averaged MAE for virtual temperature, vector wind difference and pressure. a) and b), winter data gather results for local area at Germantown, MD (GT), c) and d) summer data gather results for local area at Sterling, VA (IAD), and e) and f), summer data gather results for target area at Edgewood, MD (ETG).

accuracy of the system, and that with FDDA plus UPPS further increases the MET accuracy, and that the Army acceptance thresholds are exceeded. These results proved that the system could meet the Army MET accuracy requirements, and that there was added value from FDDA and UPPS under these very limited data scenarios typical of the battlefield, and that the system was capable of passing the formal testing at White Sands Missile Range, which the system formally passed in 2004. The MMS-Profiler generally outperformed the current balloon based MMS in the local area with the gap increasing as the cases became more challenging. Target area MET 60 km away was also produced and verified at White Sands.

Further real data testing of the MMS-Profiler system was conducted over the eastern U.S. by the U.S. Army and Smiths Detection to characterize Profiler's ability to generate target area MET throughout the 4-km resolution domain's 500-km X 500-km area, at distances much greater than the original threshold target range of 60 km. On-demand target area MET is a significant advantage of the MMS-Profiler mesoscale model nowcast over its predecessor MSS system since the balloon-based MMS provided no target area MET.

3. NEXGEN

The Navy has endorsed a next-generation METMF(R) system to detect weather on the battlefield, which will have more mobility and flexibility to support Marines downrange and may be deployed with intelligence battalions. The next-generation Meteorological Mobile Facility Replacement, known as METMF(R) NEXGEN, will replace the existing METMF(R), which reached full operational capability in 2002.

Currently, the Marine Corps has 12 METMF(R) systems in service, including five in Iraq, according to an information paper provided to *Inside the Navy* by Space and Naval Warfare Systems Command. The system was originally designed in the 1960s -- and twice updated in 1988 and 1998 -- to provide the Marine Corps with an expeditionary meteorological capability to support aviation assets. However, lessons learned in Iraq support a more mobile and tactically flexible system to support the Marine Corps at large.

The next generation system will be built into a standard shelter mounted on a humvee with a towable trailer (Figure 9). The system will utilize commercial-off-the-shelf software and sensors including the Profiler nowcast mesoscale model described in the previous section, and local and

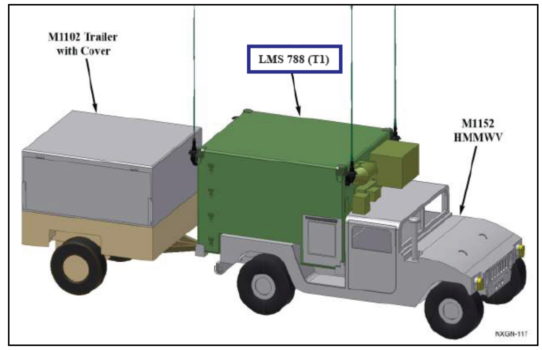

Figure 9. NEXGEN HMMWV vehicle and trailer with only fixed equipment in the shelter and all stowable equipment (deployable sensors and antennas) in trailer.

remote surface data, tactical Doppler radar, an upper air rawinsonde system, and meteorological satellite GOES/POES. It will also require remote and standalone operations of the Doppler radar and the upper air system.

The NEXGEN will generate a nowcast every 30 minutes, on the same size 4-km, 12-km and 36-km domains as Profiler, but the 3D data will also be provided to wXstation Forecaster's Tool Kit (FTK) for graphical display and analysis for battlespace awareness by the NEXGEN weather-trained crew members, and also be used to generate ARTY MET messages. The FTK will provide simultaneous real-time display of multiple layers of data, advanced in-depth analysis functions, a very capable forecaster toolkit, and a family of single data type exploration and looping tools. It will automatically maintain up-to-date and accurate fused weather and tactical situation visualizations. The NEXGEN will also support tactical decision aids (TDAs) such as HPAC (e.g., Stauffer et al. 2007) and use an integrated suite of tranceivers to provide a full spectrum of local and global communications. A web server will be provided to disseminate MET products to the two NEXGEN analyst workstations within the system and to other users via SIPRNET.

4. RRNPS IN FORECAST / HAZARD-PREDICTION MODE

The RRNPS is also run in prediction mode by the Department of Meteorology at Penn State University to provide twice-daily high resolution weather forecasts as a public service (http://www.met.psu.edu/weather/). A version of this system was developed by Penn State under the L-3 Titan team contract for the Department of Defense, Defense Threat Reduction Agency (DTRA), for use in the war against terrorism and to support the global warfighter and provide reachback support for the

MET used for hazard prediction and consequence assessment (HPAC) in the HPAC toolkit (e.g., Stauffer et al 2007).

The RRNPS was run in realtime mode for the 2006 Torino Winter Olympics, and 24-h forecasts were produced in realtime twice daily at 36-km, 12-km, 4-km and 1.3-km resolutions. A running-start dynamic initialization is used to provide spun-up cloud / precipitation fields and local circulations at the initial time (t = 0 h, Stauffer et al. 2006). The 24-h forecasts at all four resolutions were generally improved by using higher horizontal model resolution and the running start FDDA for model initialization (Stauffer al. 2007).

Figure 10 shows an example of how model resolution affects the numerical prediction of downslope flow and channeled winds at the surface overlaid on top of the terrain field of each resolution domain. Red winds are observations from the special ARPA-Piemonte mesonet. The narrow Alpine valleys containing highways leading to the mountain venues are well represented in the 1.3-km terrain field, and somewhat less resolved but visible in the 4-km terrain field. There is channeling and drainage flow coming out of one of these valleys towards the plain to the west of Torino and meeting a weak northeasterly flow from the plain, and these local, terrain-forced flows were generally better resolved at 1.3-km resolution. In contrast to the 1.3- km and 4-km domains, the coarser 12-km and 36-km domains do not resolve these valleys, and the 36-km domain actually shows Torino in the mountains. The 18-h 1.3-km and 4-km resolution forecasts showed excellent agreement with the special mesonet wind

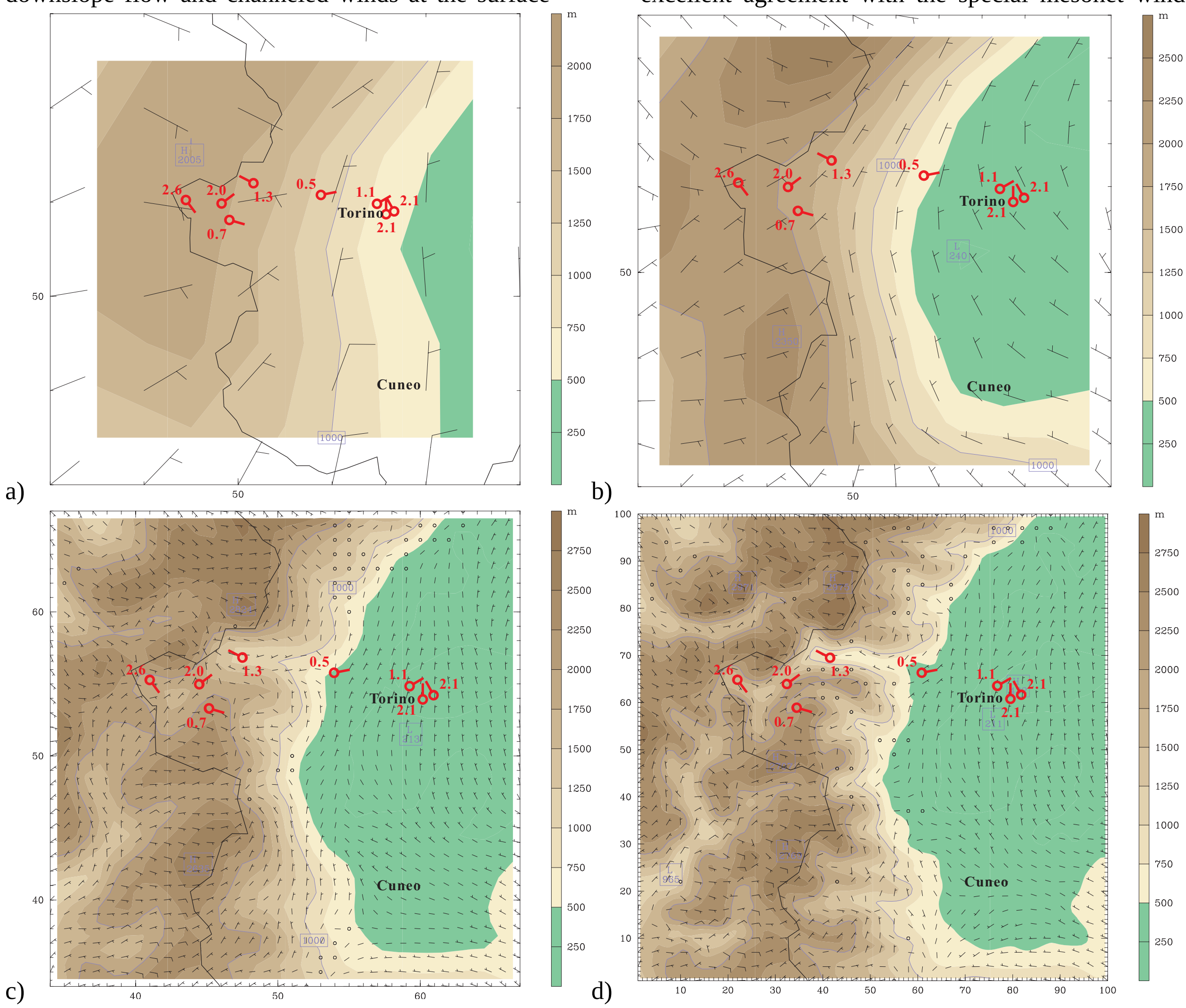

Figure 10. MM5 running-start FDDA, 18-h surface wind prediction and special mesonet observations at 18 UTC 21 February 2006 over the 1.3-km Winter Olympics domain area for each model resolution forecast. Surface winds (ms^{-1}) are overlaid on the terrain field (m, color code on right of figure) for each model resolution domain. a) 36-km domain, b) 12-km domain, c) 4-km domain, d) 1.3-km domain. One full barb is 10 ms^{-1}. Dark line is France – Italy border.

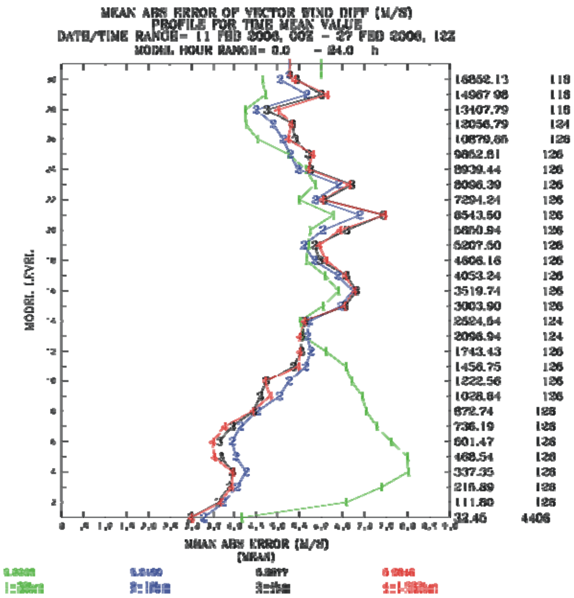

Figure 11. Vertical profile of vector wind difference (VWD) errors for 36-km, 12-km, 4-km and 1.3-km 24-h forecasts averaged over the 1.3-km domain area (see Figure 10d) for the entire 16-day Olympics period.

observations at this time, and the 1.3-km domain showed somewhat closer agreement to the observations than the 4-km domain.

The average vertical wind profile statistics for all 24-h forecasts for the entire 16-day period are shown in Figure 11. They also suggest that the finer resolution domains produce more accurate wind fields near the surface and within the boundary layer, but the difference between the 4-km and 1.3-km domains appears to be quite small. Note that in this complex terrain, there is a clear advantage of 4-km resolution forecasts compared to 12-km and 36-km resolution forecasts (also see figure 10), but the differences between the finest two model resolution grids are quite small. However, hypothetical mountain releases and their 1-h HPAC plume predictions are shown in Figure 12 over the same 1.3-km domain area using the 12-km, 4-km and 1.3-km MET data sets. Note that the shape and orientation of these plumes are distinctly different, and that the 1.3-km HPAC prediction is most consistent with the observed wind fields during this period.

The RRNPS system was also run in forecast mode for soggy Super Bowl XLI on 4 January 2007. The radar composite at 1900 EST 4 January 2007 (00 UTC 5 January 2007), during the game, is shown in Figure 13. The 12-h RRNPS forecasts for this time, following a running start dynamic initialization, are shown in Figure 14 for a 5-km and 1.7-km domain over this region. The model correctly predicted wet conditions during the game, and these predicted MET fields were used to drive HPAC forecasts for a

a)
b)
c)

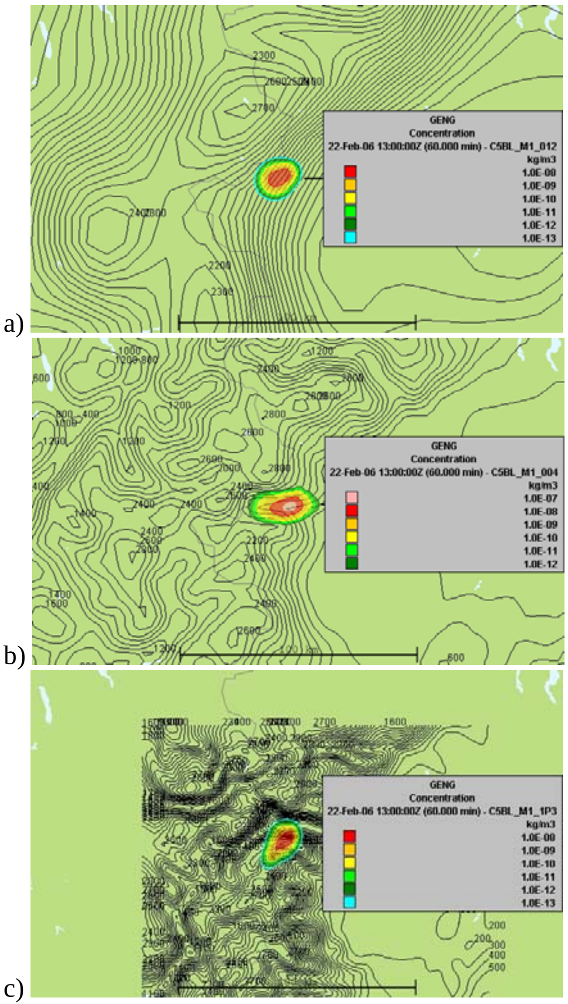

Figure 12. HPAC/SCIPUFF 1-h plume predictions and model terrain from the RRNPS forecasts valid at 13 UTC 22 February 2006 over the 1.3-km domain area. a) 12-km resolution, b) 4-km resolution, c) 1.3-km resolution

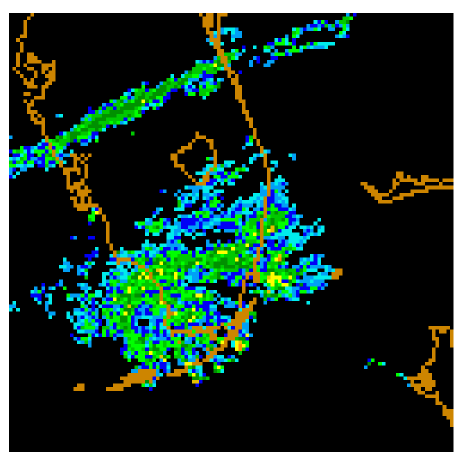

Figure 13. Radar composite over Florida at 0000 UTC 5 January 2007 during Super Bowl XLI.

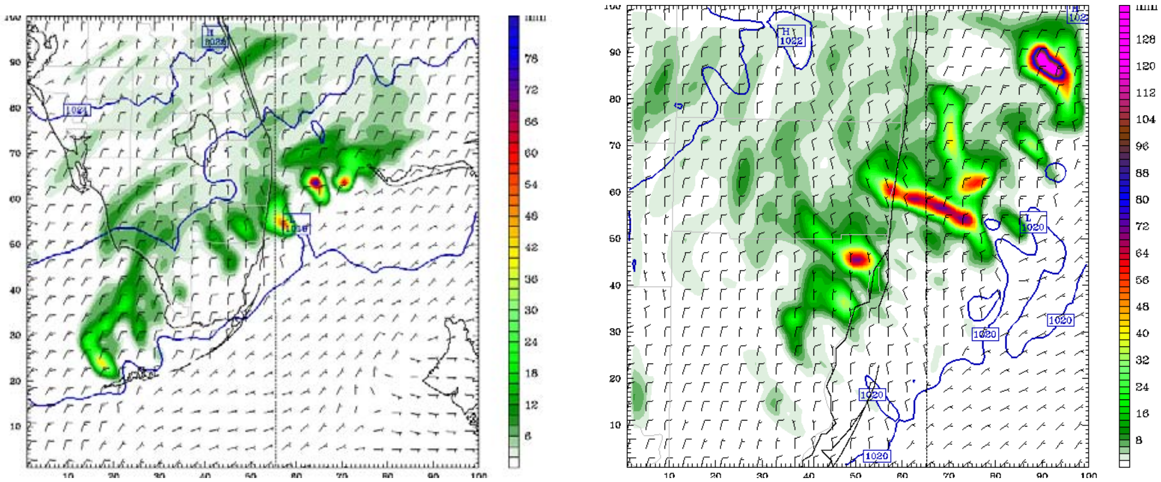

Figure 14. 12-h RRNPS realtime forecast for 3-hourly precipitation ending at 0000 UTC 5 January 2007 during Super Bowl XLI. a) 5-km domain, b) 1.7-km domain.

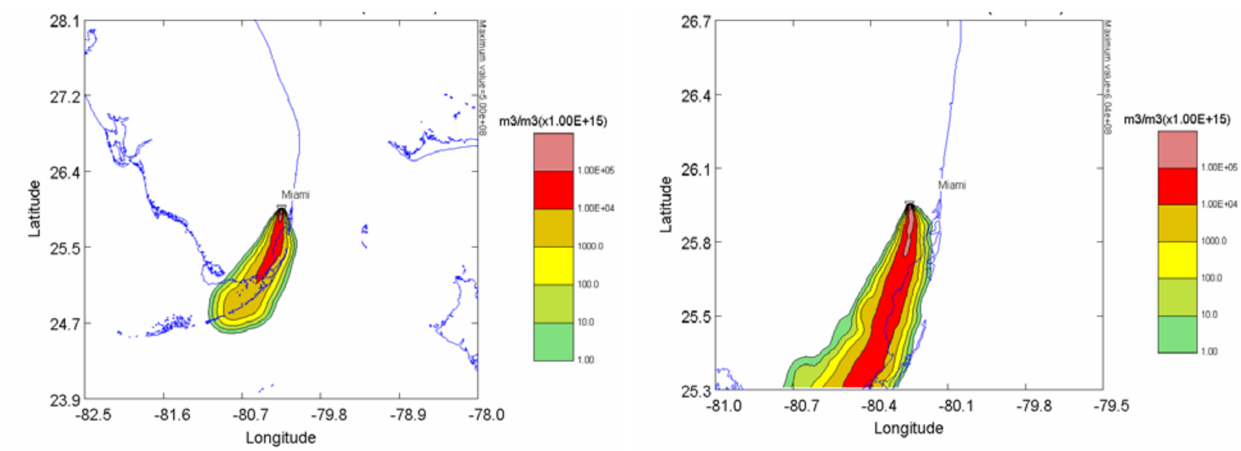

Figure 15. HPAC-predicted plume at 0300 UTC 5 January 2007 after a hypothetical release of a tracer during Super Bowl XLI using RRNPS MET forecast data. a) 5-km domain, b) 1.7-km domain.

hypothetical tracer release during the game (Figure 15). This realtime capability to predict the MET and simulate the effects of a CBRN release is a prime example of how modern NWP systems are being used in the war against terrorism.

5. SUMMARY

In many regions of the world, there is a vital need for accurate, up-to-the-minute meteorological information, for example, in remote mountainous areas where there is a military conflict, or in populated regions where there is the potential threat of bioterrorism. Use of current global or regional model products for this purpose may be very limiting in terms of addressing specialized needs and providing on-demand data sets that resolve mesobeta / mesogamma- scale meteorology and effectively use local data sets.

Penn State's rapidly relocatable nowcast-prediction system (RRNPS) described by Schroeder et al. (2006) and used as the basis for the various NWP systems described above, can run on large, massively parallel computers or on less expensive, more modest computing platforms (e.g., a dual-processor PC) with potentially very limited data resources and non-standard data communications. It can be operated on a regular schedule, or on-demand using arbitrary start and end times. Its nowcast products are immediately available at the current time and thus, are somewhat unique compared to those produced by others who delay the system to use current data directly in the analyses. It must be emphasized that unlike typical operational analysis systems, none of the current data are used in the nowcasts since the nowcasts are made available just ahead of the clock for immediate use. Because none of the verification data are assimilated into the

RRNPS at the time of verification, the evaluation of the nowcast system in Schroeder et al. (2006) is a true test of the time-integrated effects of previous FDDA on current model solutions. Furthermore, the statistical evaluations in Schroeder et al. (2006) also utilize independent data completely withheld from the system at all times. These statistics show that the use of continuous FDDA in a high-resolution mesoscale model improves the accuracy of the RRNPS nowcasts, and that this unique nowcast-prediction system provides immediately available forecast-analysis products that are comparable or superior to those produced at operational centers, especially for the surface and the boundary layer

The development of RRNPS for the Army's MMS-Profiler and Marines' METMF(R) NEXGEN nowcast-prediction systems represents a new generation of mobile NWP and observation systems, which by virtue of their positioning on the battlefield, ease of use, and ready access to special data, offer our military forces up-to-the-minute, high-resolution weather information for their special needs. These mobile NWP systems can also be coupled to tactical decision aids (TDAs) such as the HPAC/SCIPUFF transport and dispersion model in a way similar to that used for MET forecasting, and hazard prediction and consequence assessment by DTRA. These modern NWP and observation systems provide necessary capabilities on site for protecting our troops and citizens on today's "battlefields" wherever they may be.

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