PENN STATE-DTRA HIGH-RESOLUTION METEOROLOGICAL MODELING FOR THE TORINO WINTER OLYMPICS

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## 1. INTRODUCTION

The 2006 Winter Olympic Games in Torino, Italy represented a potential high-value target for disruption by terrorist individuals and organizations. As part of security operations for the Olympics, an international team of consequence assessment analysts was assembled to predict the atmospheric transport and diffusion (AT&D) of chemical, biological, radiological and nuclear (CBRN) agents in the event of an actual release. The United States Defense Threat Reduction Agency (DTRA) was an integral part of this effort providing modeling and simulation support for users of its Hazard Prediction and Assessment Capability (HPAC) AT&D toolset. Figure 1 shows some HPAC output for hypothetical releases of Seron over Olympics venues using the Penn State-DTRA 1.3-km realtime forecast system.

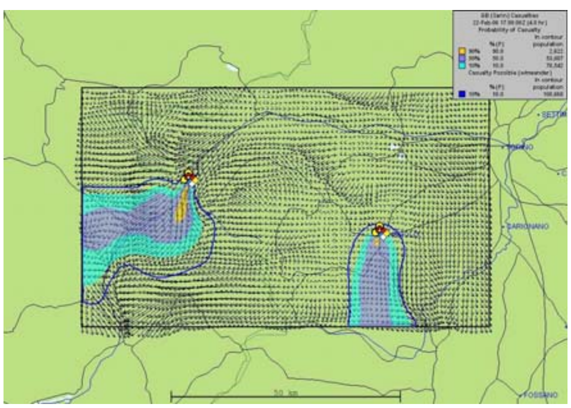

Figure 1. HPAC output showing hypothetical plume predictions over Olympics venues for February 22 / 13-17 UTC using PSU 1.3-km forecast from February 22 / 00 UTC with February 22 / 14 UTC wind-field forecast overlay.

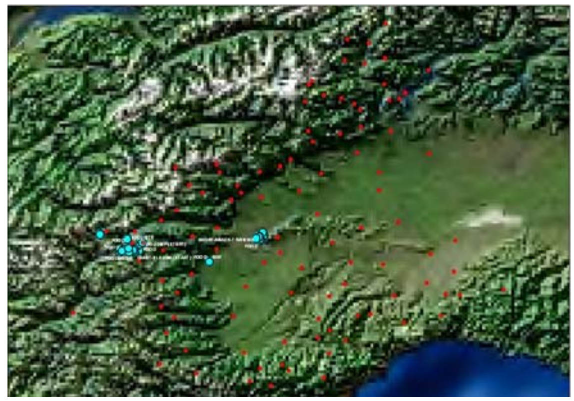

Figure 2. Locations of Winter Olympics venues (blue dots) and special ARPA-Piemonte mesonet data (red dots). Torino, Italy is located on the plain at the easternmost cluster of blue dots, and the Alps border the plain to the west and north.

Local and regional scale atmospheric conditions strongly influence AT&D processes in the boundary layer, and the extent and scope of the spread of dangerous materials in the lower levels of the atmosphere. Therefore, managing the consequences of CBRN incidents requires detailed knowledge of current and future weather conditions to accurately model potential effects. The meteorology team took advantage of Italy's ARPA-Piemonte special weather observation mesonet available within the mountains and over the plains, and in and around the Winter Olympics venues (Fig. 2), and undertook a project to improve numerical weather prediction (NWP) at high resolution. The varied and complex terrain provided a special challenge to the modelers on the meteorology team. Some of the Olympic venues were located in the mountains to the west of Torino, while the rest were located on the relatively flat plain in and around the cities of Pinerolo and Torino to the east.

The MM5 model results from the Olympics period 10 – 27 February 2006 will be presented, and for a subset of these case days representing various combinations of dry, wet, misty or windy conditions in the mountains and/or plains, comparable baseline MM5 and WRF-ARW model runs will be performed for direct comparison. Statistics will be computed for all model resolutions over the finest-resolution Olympics domain area using standard and the special Italian mesonet data. The importance of model resolution and the model initialization strategy for 24-h forecasts over this region of complex terrain will be explored.

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## 2. METHODOLOGY

The DTRA-Penn State Titan team provided twice-daily realtime MM5 high-resolution meteorological model forecasts using a 42-CPU cluster running a four-nest configuration down to 1.3-km resolution over all the Olympics venues (Fig. 3). Model physics options were the same as those used in the MB2 baseline experiment in Deng and Stauffer (2006). A "running start" four-dimensional data assimilation (FDDA) strategy using a 3 – 12-h pre-forecast period assimilation of standard and special data over all four domains was used to improve model initialization and spinup during the subsequent 0 to 24-h forecasts (Fig. 4). This dynamic initialization allowed model cloud and precipitation fields to be already spun up on the various scales at the initial time, when weather was potentially causing delays, cancellations and challenges for AT&D.

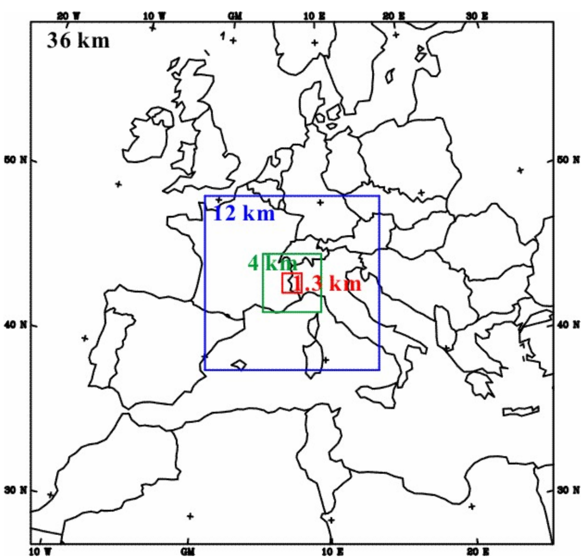


Figure 3. MM5/WRF four-domain configuration for 2006 Winter Olympics

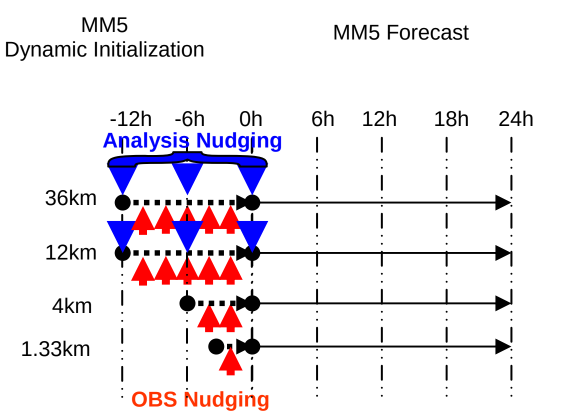


Figure 4. "Running start" model initialization FDDA strategy used for DTRA Olympics modeling support.

Parallel baseline MM5 and WRF runs using the running start (Fig. 4) but without nudging FDDA will be performed over the same -12 to 24-h time periods on the selected case days, and compared with dynamically initialized MM5 forecast results. Both models will use the same domain configurations, gridded data inputs and comparable model physics.

## 3. PRELIMINARY RESULTS

Some subjective analysis of the realtime MM5 predictions will be presented here, and the statistical results including the MM5 and WRF baseline comparisons will be shown at the workshop.

The Penn State-DTRA MM5 system predicted the very localized mountain flows in and around the Olympics venues when large-scale weather conditions were weak, and also the complex interactions of the terrain with the larger scale weather-producing systems when stormy conditions prevailed. Figure 5 shows an example of the former in an 18-h, 1.3-km domain prediction of downslope flow and channeled winds at the surface overlaid on top the 1.3-km domain terrain field and local observations. The highways between the mountain venues are reflected in the fingers of lower terrain shown in this 1.3-km terrain field. Note the drainage flow coming out of one of these fingers towards the plain to the west of Torino. A zoomed-mountain view of the 12-h predicted surface streamlines when upslope flow was occurring over the mountain venues is shown in Fig. 6. These local, terrain-forced circulations are better-resolved at 1.3-km resolution, compared to those based on coarser model resolutions of 4 km to 12 km, and these differences in the resolved meteorology fields may greatly affect the AT&D predictions in this region. This study will further analyze the role of model resolution on meteorological accuracy over the Olympics venues using the special Italian mesonet data.

Figure 7 shows an example of local variations in predicted weather caused by the terrain in a 12-h forecast of 3-hourly precipitation ending at 12 UTC 18 February 2006 on the same zoomed-mountain view of the 1.3-km domain. At this time weather had caused postponement of the women's combined downhill event, and the 12 UTC 18 February 2006 satellite cloud, sea-level pressure and fronts analysis from Met Office, Bracknell (Fig. 8) confirmed cloud and likely weather over the Alps region. The 1.3-km model forecast precipitation ending at 15 h (not shown) indicated that the precipitation would stop, and it did end during this period and the Olympics event was once again resumed. Short-term forecast skill especially for precipitation is greatly affected by the quality of the model initialization.

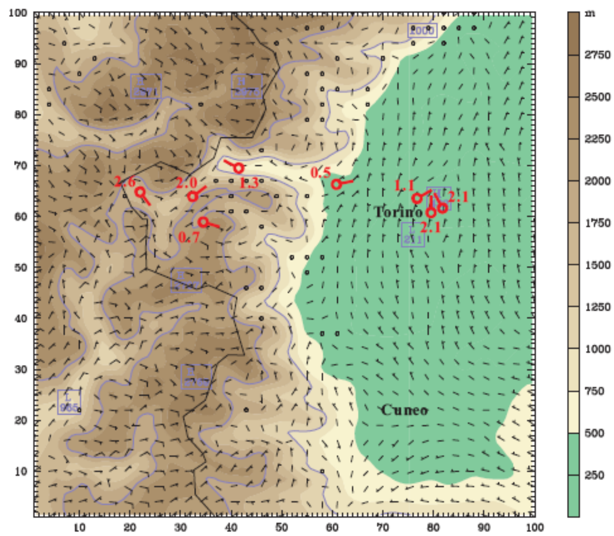

Figure 5. MM5 18-h surface wind prediction and surface observations (red station model with speed values in $ms^{-1}$) at 18 UTC 21 February 2006 showing downslope flow and channeled winds ($ms^{-1}$), overlaid on the 1.3-km domain terrain field (m, color code on right of figure). One full barb is 10 $ms^{-1}$. Dark line is France – Italy border

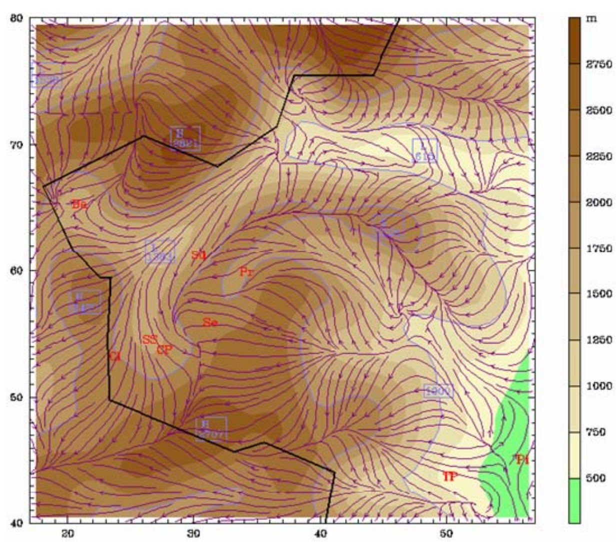

Figure 6. MM5 12-h surface wind prediction at 12 UTC 21 February 2006, showing upslope flow over terrain (m, color code on right of figure) using surface streamlines in a zoomed-view over the mountainous venue areas on the 1.3-km domain. Olympics venues are denoted by red letters.

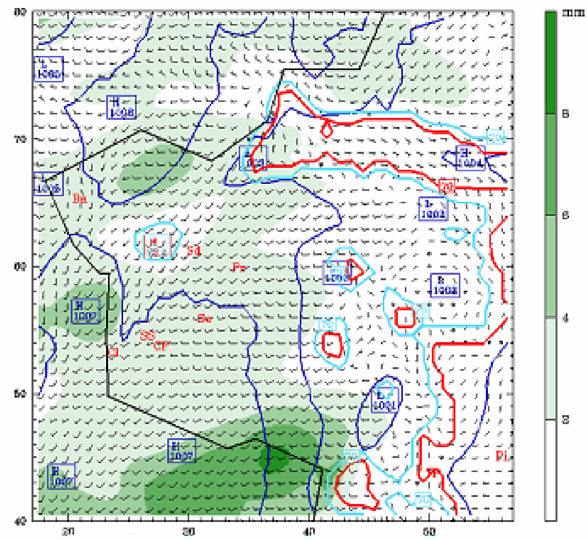

Figure 7. The 1.3-km domain 3-hourly precipitation field ending at 12 UTC 18 February 2006 and shown with a zoomed-view over the mountainous venue areas on the 1.3-km domain. Note the local upslope enhancements in precipitation due to the terrain shown in Fig. 6. Red and blue lines denote liquid and frozen precipitation boundaries.

Figure 9 shows the corresponding t = 0 h initial-condition surface winds, sea-level pressure and column-integrated cloud hydrometeors resulting from the "running start" dynamic initialization for the outermost 36-km domain at 12 UTC 18 February 2006. Note the excellent agreement of the large-scale model initial-condition fields with those in the analysis (Fig. 8). The model already has realistic cloud and precipitation fields at the initial time (t = 0 h), and the corresponding finer-resolution domain forecasts already have spun up grid-resolved cloud and precipitation fields. This "running start" NWP strategy was better able to forecast many of the adverse weather conditions that postponed or cancelled Olympics events.

The 1.3-km resolution model domain was especially skillful predicting the local variations, and start and end times of precipitation in and around the Olympics venues in the mountains and on the plains. The high-resolution weather model was often able to discern those days when precipitation and adverse weather conditions appeared only in the mountains, as compared to other days when it occurred mainly on the plains, and on other days when weather was occurring both in the mountains and on the plains, or not at all. The subset of cases used for the MM5 and

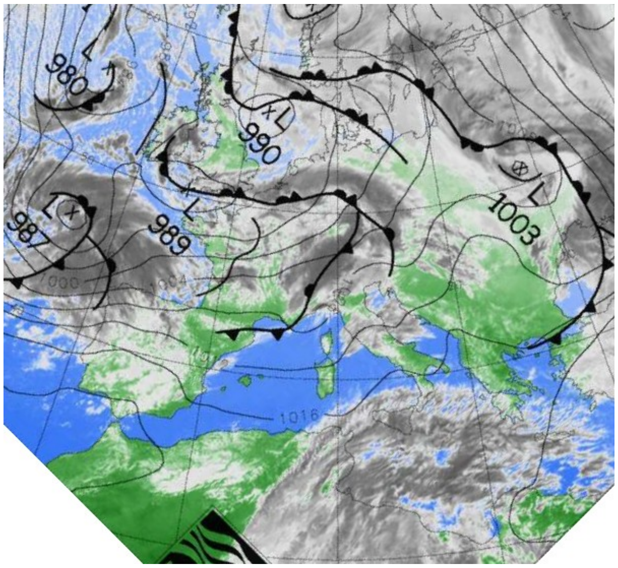


Figure 8. Analysis of satellite cloud, sea-level pressure (contour interval of 4 hPa) and fronts for 12 UTC 18 February 2006 (from Met Office, Bracknell, http://www.polarorbiter.co.uk/Bracknell.htm)

WRF baseline statistical comparisons covers each of these conditions

## 4. CONCLUSIONS

The 1.3-km Penn State-DTRA NWP forecasts were the highest resolution realtime meteorological model products available for the Olympics, and the MM5 NWP model was up and running 100 percent of the time. Model 24-h forecasts for all four domains, and their pre-forecast periods, were completed in less than four hours wall clock on our 42-CPU cluster. Model forecasts were produced every 12 hours throughout the 10 – 27 February 2006 Olympics period for DTRA use (hazard prediction and consequence assessment), and also displayed interactively via the internet for general use.

A “running start” nudging FDDA strategy was used to improve model spinup of cloud, precipitation and terrain-forced local circulations on all four domains in the model-initial condition fields and short-term forecasts. Cold-started mesoscale model predictions interpolated from relatively coarse global model data place the mesoscale prediction model at an immediate disadvantage for nowcasting or short-term forecasting, especially in complex terrain. The hypothesis that higher-resolution model forecasts contain greater skill will be further tested by verifying MM5 and WRF-ARW against the ARPA-Piemonte mesonet data for a diverse subset of Olympics case days without FDDA, along with some evaluation of the role of model initialization. The

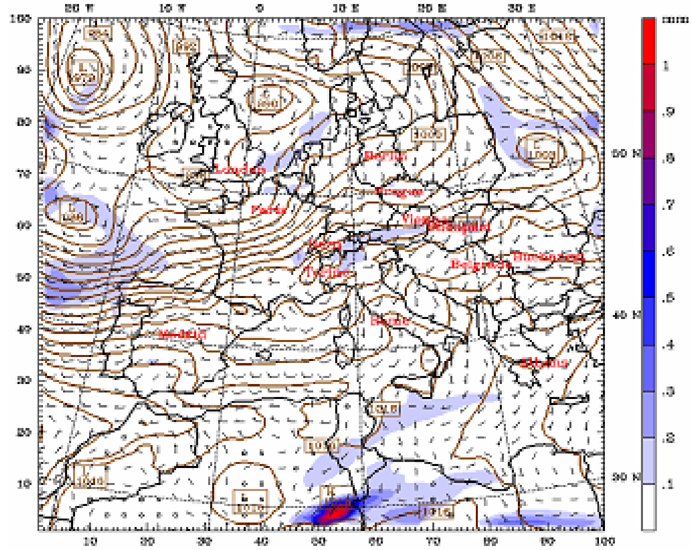

Figure 9. The corresponding t = 0 h (12 UTC 18 Feburary 2006) initial-condition surface winds (ms$^{-1}$), sea-level pressure (contour interval of 2 hPa) and column-integrated cloud water (mm) resulting from the “running start” dynamic initialization on the outermost 36-km domain.

statistical analysis of the MM5 and WRF model forecast fields against the WMO and special Italian data on the 1.3-km domain will be presented at the workshop.

## 5. ACKNOWLEDGMENTS

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