J9.3 MESOSCALE CIRCULATIONS OVER THE ATHENS METROPOLITAN AREA DURING THE 2004 SUMMER OLYMPIC GAMES

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1. INTRODUCTION

During the 2004 Summer Olympic Games, NCAR/RAL operated a real-time mesoscale data-assimilation and forecast system that provided analyses and forecasts of meteorological fields on a variety of scales, from the area of the eastern Mediterranean down to the urban scale. The purpose of this modeling effort was to provide the Defense Threat Reduction Agency (DTRA) with wind and other boundary-layer data to be used for transport and dispersion calculations in the event that terrorists released hazardous material into the atmosphere during the Athens Olympics. The data-assimilation system and forecast model employed were similar to the system developed by NCAR/RAL for Army test-range support using the PSU-NCAR Mesoscale Model, MM5 (Liu et al. 2005).

The cities of Athens and Piraeus (and their suburbs) are situated on the Attic plain on the Greek mainland. They are surrounded by mountains on three sides with elevations up to 1400 m. In addition, there are three hills up to 200 m inside the basin. Because of the topographic, land-water distribution, and land-cover characteristic of the area, local circulations such as sea and land breezes, drainage, and upslope flows usually develop. In addition to the topographic factors affecting the local circulation, the urban area of Athens (with an estimated population of 3.1 million in 2000) is large enough to influence the dynamics and thermodynamics of the atmosphere over the region. High horizontal resolution of the model domain is thus expected to be a prerequisite for accurate numerical simulation of the local circulation. This paper will describe the Athens modeling system, examine preliminary results from the model forecast validation, and explore the model sensitivity to aspects of its lower boundary conditions.

2. MODEL DESCRIPTION AND SIMULATIONS

The MM5 (version 3.6) is a non-hydrostatic primitive equation model using terrain-following coordinates (Grell et al. 1994). The MM5 version used in this study is part of a rapidly deployable, operational, weather analysis and forecast system that has been developed by NCAR for various U.S. Army Test and Evaluation Command facilities (Davis et al. 1999; Warner et al. 2004). Two principal components make up the modeling system: MM5 used in four-dimensional data assimilation (FDDA) mode, where observations are nudged into the model solution, and MM5 used as a forecast model. These two components are run in a rapid cycle of 3 hours where every cycle is composed of a 3-hour FDDA period and a variable (6–36 hours) forecast period. We refer to this system as real-time FDDA, or RTFDDA. More details of the system design, model and observational data used can be found in Liu et al. (2005) and on the web at http://www.4dwx.org/atec.

In the MM5, land surface processes are represented by the Noah land surface model (Chen et al. 1996). This land surface model includes a bulk treatment of processes found in the urban environment. The parameters of the urban land-use class include large values of surface roughness length, large heat capacity, and modified soil characteristics to emulate a surface with high runoff and reduced evaporation.

The model setup used in this application was configured with a 30-km outer domain and three nested, two-way-interacting, computational grids with horizontal grid spacing of 10, 3.3, and 1.1 km, respectively. Figure 1 shows the location of these domains and the topographic elevation of the innermost grid. All grids used 36 unevenly spaced vertical computational levels, extending from the surface to about 17 km AGL, with greatest resolution in the boundary layer and near the tropopause.

The Athens model setup used high-resolution sea surface temperatures (from the Mediterranean Forecasting System Toward Environmental Prediction, Bologna, Italy) and a satellite-derived (MODIS) estimate of the region covered by the Athens metropolitan area. To augment the data from conventional observations, several other data types were merged into the model analysis during the FDDA period. These include data from aircrafts, from retrievals of surface winds over the oceans, and from a local mesonet that cover the Athens Metropolitan area.

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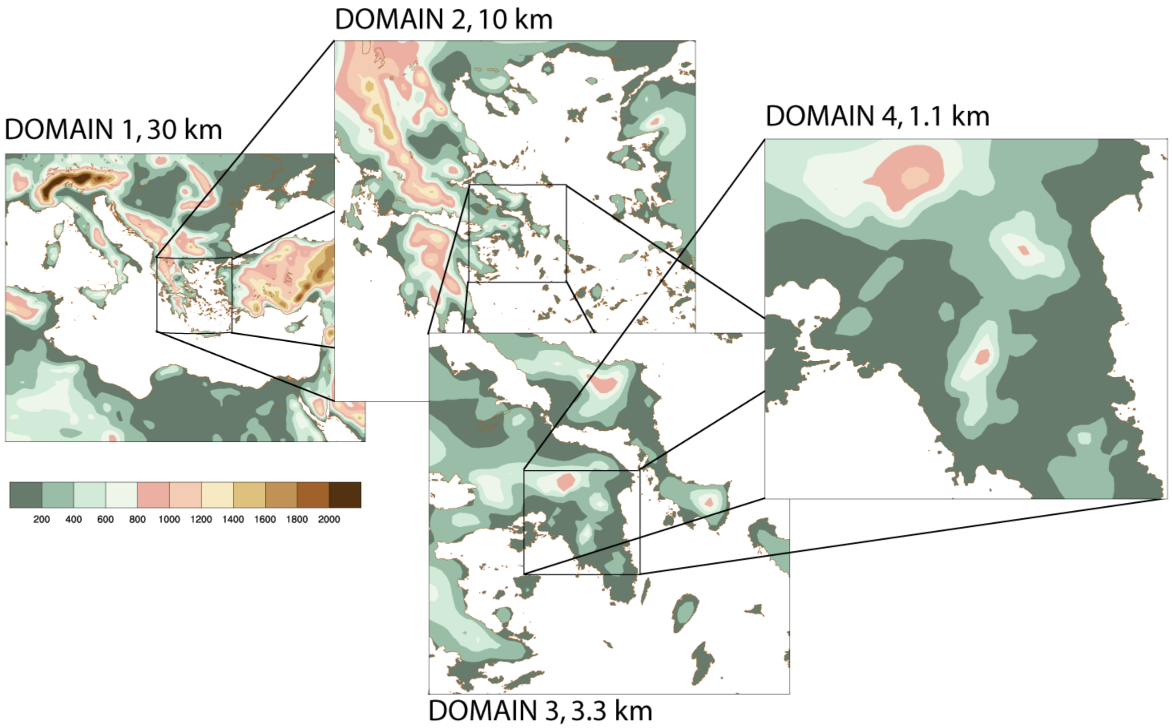

Figure 1: Athens MM5 model configuration (Domains 1–4) and terrain elevation (meters).

During the 2004 summer Olympic games, the RTFDDA system ran in a continuous FDDA and forecast cycle for the period August 12 to September 16, 2004. The model data used in this paper comes from a continuous time series of model analyses (every 3 hours) and 24-hour forecasts, starting at 2300 GMT (0200 LST), for each domain and for each day.

3. RESULTS

3.1. Verification of MM5 forecasts

Figure 2 shows the evaluation of the model FDDA analyses and forecasts of surface winds for the period August 12 – September 16, 2004. Results are averaged over all available days in the model and the observations. The model values have been interpolated to the observation locations from the values at the four neighboring model grid points. Both the model FDDA (top) and 13-hour forecast (bottom) winds are very close to those observed during the period and show the dominance of the N-NE (known as Etesian) winds over the area during this time of the year. The RMSE in the model wind speed at 12 hours is of the order of 2.5 m/s. Other surface variables such as 2-meter temperature and specific humidity (not shown) are similarly well-forecasted in the model. However, the model forecast surface temperatures are underestimated (cold bias at 12 hours of 1.5 – 2.0 K), especially at night .

3.2. Sensitivity experiments

To understand the added value to the quality of the model forecast of the high-resolution model and lower boundary conditions, a series of sensitivity experiments was conducted. Individual days in the period August 12 – September 16, 2004 were classified according to their dominant 850 HPa wind direction into: sea breeze days (with weak large-scale flow) and Etesian days (with strong large-scale N-NE flow). Two sea breeze days (August 13 and August 26) were selected for the initial sensitivity experiments. To assess the impact of the high-resolution land-use specification to the quality of the model analysis and forecast, we have degraded the model land-use map. In the model innermost domain, all grid-boxes classified as “urban” were replaced by the local natural vegetation (or shrubland). The two sea breeze day cases were rerun with the original (URBAN) and the new degraded land-use (NONURBAN) classification map. The simulations were started on the day before the sea breeze day case and consisted of 24 hours of FDDA, followed by 36 hours of forecast. Here we will focus on the August 13 sea breeze case; similar results were obtained in the August 26 experiment.

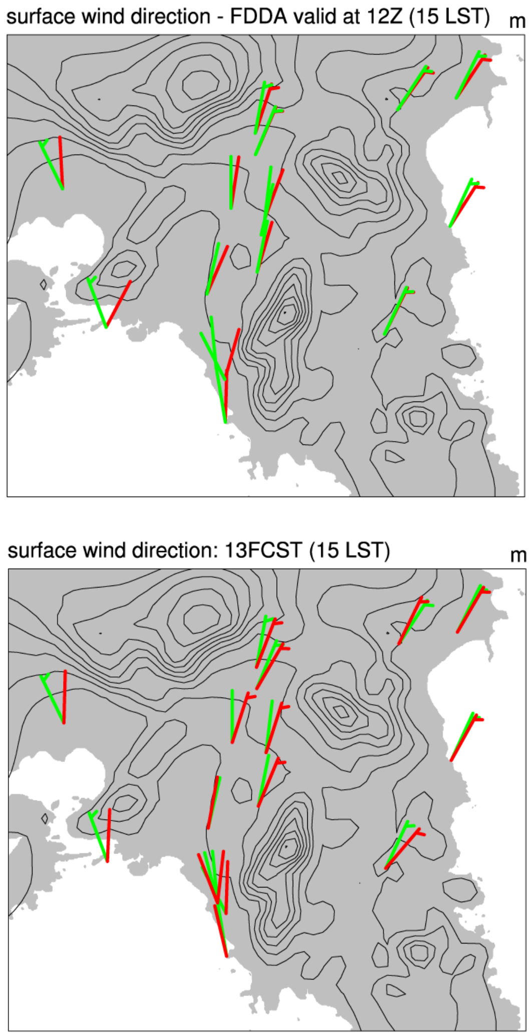

Figure 2: Comparison of observed and interpolated model forecasts (from FDDA and 13-hour forecast) surface winds over the model 1.1 km innermost domain. Green barbs represent the observed wind; the horizontally interpolated model analyses (top) and 13-hour forecasts (bottom) are in red. Model and observation values are valid at 1200 GMT (1500 LST) and have been averaged over all days in the period 12 August – 16 September 2004. The background lines represent the model's local topography with a contour interval of 100 meters.

The results of the first sensitivity experiment are presented in terms of NONURBAN - URBAN differences in 2-meter temperature and surface winds (Figure 3). Maps are drawn for 1300 LST (top) and 1500 LST (bottom) 13 August 2004. The temperature differences show lower temperatures (by 2–3 K) over the region where the urban area was located in the control experiment. This result is a manifestation of the expected urban heat island effect; mainly a consequence of larger heat capacity and reduced evaporative cooling over the urban area.

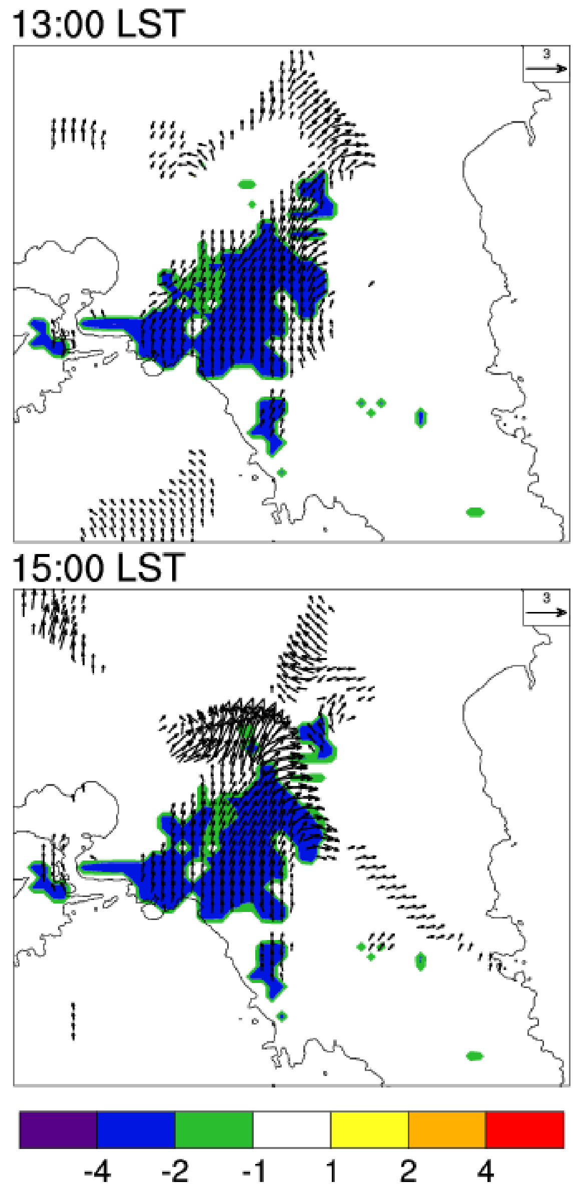

Figure 3: Differences in 2-meter temperature (color scale; degrees) and surface winds (vectors; arrow on right upper corner represents a wind speed of 3 m/s) between sensitivity experiment (NONURBAN) and control (URBAN) valid at 1300 and 1500 LST 13 August 2004.

The main driver of the sea breeze circulation is the existence of a horizontal difference in temperature, and induced pressure gradient, between neighboring ocean and land areas during the day. With the reduction in surface temperature over the previously defined urban area in the NONURBAN experiment, a decrease in the low-level winds associated with sea-breeze circulation was expected. Surprisingly, the wind vector differences in Figure 3 show an increase in wind speeds (wind vector differences pointing NE) over the Athens urban area when the city is replaced by natural vegetation. A few hours later (1500 LST), the stronger SW winds are located further inland with an increased cooling effect at their leading edge. This is a manifestation of the “sea-breeze front” (i.e., the leading edge of the sea-breeze circulation) penetrating further inland and earlier in the NONURBAN than the control experiment. Examination of the atmospheric response upward in the column (not shown) reveals that the thermal effect of the city extends only in a very shallow layer (about 1–2 model levels above the surface).

The wind differences in the NONURBAN minus URBAN experiment suggest that, at least in this case and region, the “aerodynamic” effect of removing the characteristics of the urban zone dominates over the “thermal” effect in enhancing the sea-breeze circulation. The replacement of the urban land-use region by shrubland reduces the surface roughness length from 1.0 to 0.03 meters; which makes the region where the city was located “smoother” and allows for stronger winds and further inland penetration of the sea-breeze circulation. Nevertheless, these results are highly dependent on the details of the land surface model used, the sea surface temperatures offshore, and the dominant large-scale flow. Repeating these experiments using varying surface parameters and under weak sea breeze and Etesian flow regimes could help to understand the mesoscale processes occurring in this region.

4. SUMMARY AND FUTURE WORK

During the Athens Olympics in the summer of 2004, NCAR operated a real-time mesoscale data-assimilation and forecast system that provided analyses and forecasts of winds on a variety of scales, from the area of the eastern Mediterranean down to the urban scale. The meteorological situation was challenging in that the highly complex coastline produced interacting sea and land breezes that were significantly affected by the local topography and land-use characteristics. The initial evaluation of the model analysis and forecast showed that the high resolution provided by the model's innermost grid was indeed necessary for a proper representation of the thermal and dynamic effects of the Athens urban area.

A sensitivity experiment was introduced that was designed to explore the added value of the various lower boundary conditions to the quality of the model forecast of the surface temperatures and winds. The experiment focused on the sensitivity of the model forecast to the urban-related parameterizations and to the parameters used in the land surface model. The results of the sensitivity experiment show that the model forecast over this region and under this type of large-scale forcing is most sensitive to changes in the aerodynamic characteristics of the surface rather than its thermal properties. Further experiments are required to test this hypothesis under various synoptic regimes and land surface characteristics.

A series of other experiments are also planned. These will address model forecast sensitivities to high-resolution sea surface temperature, orientation of the coastline, correct specification of the local terrain, and the various observation types used in the FDDA portion of the modeling system.

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