5.2 MESOSCALE AND URBAN-SCALE MODELING SUPPORT FOR THE OKLAHOMA CITY JOINT-URBAN 2003 FIELD PROGRAM

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1. INTRODUCTION

The Joint Urban 2003 (JU03) Field Experiment on Atmospheric Dispersion was held in Oklahoma City (OKC), Oklahoma, during July 2003. The focus of the JU03 experiment was to characterize the flow of a tracer gas (SF6) in an urban environment. Over one hundred government, university, and private sector participants supported high resolution atmospheric measurements, and other instrumentation during the experiment. The field program consisted of six day time and four night time intensive observation periods (IOP)s that lasted approximately eight hours each. The Forecasters that supported JU03 required model guidance on winds and other conditions in order to help field- program managers schedule intensive observation periods.

The primary model used for this purpose was the MM5-based 4DWX system that has been jointly developed by NCAR and the Army Test and Evaluation Command (ATEC). The 4DWX mesoscale modeling system has been operating at ATEC test ranges, and at other locations for various high visibility events (such as the 2002 Olympic Winter Games) under the sponsorship of the Defense Threat Reduction Agency (DTRA). The version of the 4DWX modeling system that was used for JU03 support employed 5 nested grids with horizontal grid increments of 500 m, 1.5 km, 4.5 km, 13.5 km, and 40.5 km, with the fine meshes centered at and simulating the urban meteorology of OKC (Fig.1). This is the highest resolution version of the system that has been used to operationally forecast weather on the scale of metropolitan areas. To better meet the special requirement of JU03, enhancements with local data resources and urban physics were put into the system. In addition, embedded within the innermost MM5 grid was the DTRA Urban Wind Module (UWM), with a horizontal grid increment of 100 m. This paper describes the modeling system employed, explains how the model products were used by the JU03 forecasting team and demonstrates the model capability with some example products from the model.

2. THE NCAR/ATEC RTFDDA SYSTEM

The NCAR/ATEC 4DWX modeling system is a real-time Four-Dimensional Data Assimilation (RTFDDA) system that can be operated in real-time to generate four-dimensional, dynamically and physically consistent, multiscale analyses and forecasts. The system can be cycled at time intervals of 1-12 hours, and 0 - 48 hour forecasts can be generated in each cycle. Readers may refer to Cram et al. (2001), and Liu et al. (2002, 2004) for more thorough descriptions of the system. Briefly, the system incorporates all available observations, obtained at regular and irregular times and places, into a continuously running full-physics MM5 system. The standard data sources used by the RTFDDA include the conventional twice-daily radiosondes; hourly surface, ship and buoy observations, and special observations from GTS/WMO; the NOAA/NESDIS hourly satellite winds derived from VIS, IR and Water Vapor images; NOAA/FSL aircraft reports and NPN and Multi-agency profilers; and the high-density and high-frequency observations from a large number of public and private agencies/companies over the western states, gathered by Mesowest of the University of Utah. The high-resolution, accurate, real-time analyses and forecasts from the RTFDDA system developed at the five Army testing ranges have become a dependable tool in the daily operational meteorological support for tests at these ranges. In addition, in last three years, seven other RTFDDA systems also employed to support various field missions of other DOD and government agencies, with typical deployment periods of a few months.

The system was carefully designed for users to easily and quickly chose and use the real-time model products from a large volume of RTFDDA analyses and forecasts. The system performance is monitored with real-time verification. Interfaces to generate and display user's application products are provided. In addition, a global-locatable capability has been built into the system, which allows the RTFDDA system to be quickly (in 1 - 5 minutes) launched globally. This capability is referred as to GMOD (Global Meteorology on Demand) and the RTFDDA JU03 system was controlled with the GMOD system.

3. ENHANCEMENTS FOR JU03 OPERATION

3.1 Incorporation of Local Data Sources

One of the major factors that controls the performance of the RTFDDA system is ingested data sources. Generally,

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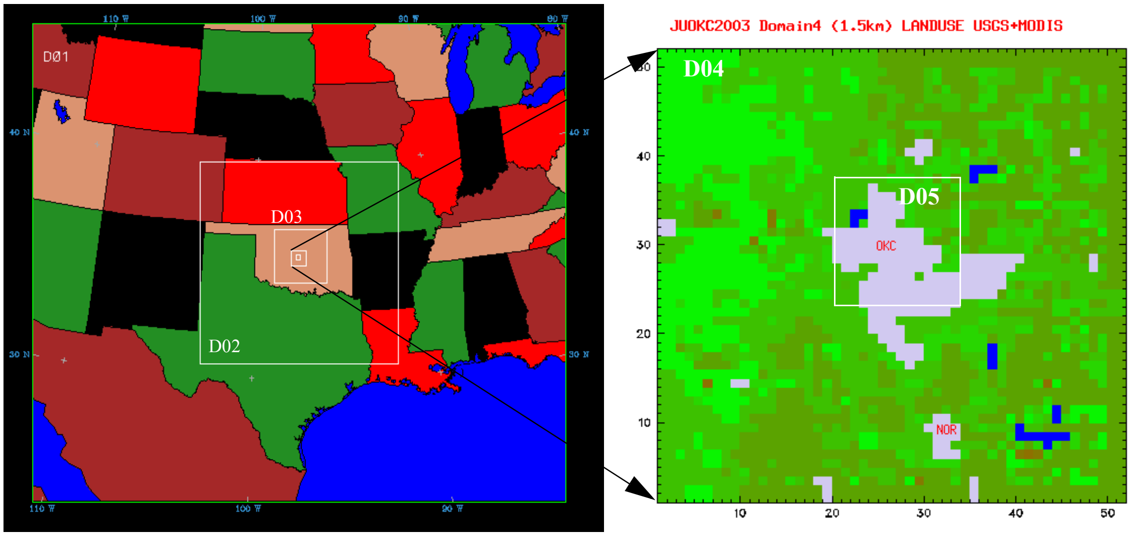

Fig.1 JU03 RTFDDA domain configuration and land use on Domain 4

mesoscale analysis and forecast suffer from lack of sufficient observations. Thus, one important task is to incorporate various local observations in real-time, in addition to the data sources that RTFDDA commonly uses. Two special data sources were incorporated into the JU03 operations. One is the Oklahoma Climatology Survey Surface Mesonet, which provides a very high time- and space coverage over the state of Oklahoma. The other one is a radiometer operated by the ARM program in northern Oklahoma. The radiometer measures vertical temperature and moisture profiles every few minutes.

3.2 Modification to Noah Urban Scheme

Correctly modeling urban effects on the atmosphere in the RTFDDA system is crucial for the success of realtime support for the JU03 field experiment for a few reasons. First, Oklahoma City (OKC), with its larger area, has a strong impact on the dynamic and thermal structures of the Planetary Boundary Layer (PBL), and, hence, on the dispersion. Second, RTFDDA analysis and forecasts were used as input for atmospheric dispersion models and for planning field experiment. Third, in the high- resolution RTFDDA configuration, the urban area occupies roughly 20% of the 1.5-km grid and ~ 70 % of the 0.5 km domains (see Fig.1).

Two important enhancements were incorporated into the JU03 RTFDDA urban simulation. The first was to refine the OKC urban land use with the recent (2002) MODIS satellite data. The result (Fig.1) reflects significant OKC urban expansion and water body changes during last two decades. The second enhancement is to the Noah land surface model (LSM). The standard Noah land surface model in MM5 has a simplified urban representation, which merely increases the roughness length and reduces surface albedo for urban landuse. However, accurate urban simulations need a much more-complete physical representation of the urban effects. Given the time constraints for preparing for the JU03 field program, an intermediate approach was adopted to enhance the current Noah LSM by providing for a larger heat-trapping and storage and a smaller water storage capacity for the urban area. More details on the Noah urban LSM modification can be found in Liu et al. 2004.

3.3 Wind Refinement with the UWM Model

Embedded within the innermost MM5 grid was the DTRA Urban Wind Module (UWM). The DTRA UWM model solves a set of spatially-averaged equations of mass conservation, momentum and thermal energy, with parameterization of turbulent kinetic energy and drag forces due to the presence of obstacles. It is configured as a 2-domain nested run. The coarse domain corresponds to the 1.5-km grid of the RTFDDA configuration. The meteorological conditions from the model run on this grid provide lateral boundary and initial conditions for the nested grid, which has 100 m grid spacing on a 10 km by 10 km urban domain. The vertical resolution near the surface is about 5 m.

4. OPERATION SUPPORT

The decision to conduct an IOP during JU03 had to be made at least 24 hours in advance because of the time required to deploy and set up the SF6 samplers and IOP-specific meteorological instrumentation. Conditions favorable for an IOP included boundary layer winds upwind of the central business district that were from the southwest through southeast, with speeds of less than 10 ms^{-1} and no precipitation or thunderstorms. Because of the 24-hour lead-time for IOP go/no-go decisions, only the 48-hour forecasts on RTFDDA domains 1, 2, and 3 could be considered in making the IOP decision. However, the shorter-forecasts and analyses from the inner domains were used to assist with last-minute revisions in IOP plans and for real-time experiment-conduct decisions.

The RTFDDA forecast and analysis output included a number of graphical products that were made available to the JU03 forecast team and experiment participants on a web site. These graphical products included surface and upper-air maps, vertical cross-sections, and vertical profiles of winds, temperature, humidity, and other variables. RTFDDA output also included gridded meteorological files in the format required for input to the Defense Threat Reduction Agency's (DTRA)'s Hazard Prediction and Assessment Capability (HPAC) modeling system. Additionally, the graphical products available on the RTFDDA web site for each hour included the surface dosage pattern predicted by HPAC's Second-order Closer Integrated Puff (SCIPUFF) dispersion model for an instantaneous SF6 tracer release from one of the typical dissemination locations. During the last week of JU03, output from domain 4 was used as input to the Urban Windfield Module (UWM), a low-resolution computational fluid dynamics (CFD) model that will be available in the next HPAC release.

5. EXAMPLE RESULTS

One of the major advantages and goals of using the real-time RTFDDA system is to produce high-quality "spin-up-free" dynamically consistent mesoscale analyses that incorporate all available observations. This dynamic constraint allows the model to fit the observation, while producing dynamically and physically meaningful analyses in data-void regions. Furthermore, from these balanced analyses, reliable nowcasts and short-term forecasts can be generated. Fig.2 shows an example of the RTFDDA surface wind and temperature analyses. The observations, valid at the same time, are shown for comparison. Obviously, the analysis not only fits the observations nicely, but also produces dynamically-consistent circulations and many detailed structures over "data-void" areas.

To illustrate the urban-scale simulation of the JU03 RTFDDA system, Fig. 3 presents the average 06 UTC 2-m temperature, wind vectors and surface sensible heat fluxes on 9 clear-sky days from the RTFDDA analyses on Domain 4 during JU03. The "urban heat island" effects are prominent in the 9-day average on this 1.5-km grid, in that the OKC area is roughly 2 - 3 C warmer than the rural regions (Fig. 3a). Note that, in Fig. 3b, this nocturnal urban heating is able to keep the lower boundary layer slightly unstable (with heat transferred from the surface to the atmosphere), while the surrounding rural areas are mostly in the stable regime because of a surface inversion.

Although the 9-day mean night-time winds in Fig.3 show relatively small variations over the urban regions, the winds are perturbed quite significantly by the urban area in each individual case, especially during the daytime. One example is given in Fig.4. It is interesting to see that, in this case, flows appear to deflected around the urban area. The incoming flow diverges in the upstream and converges in the downstream

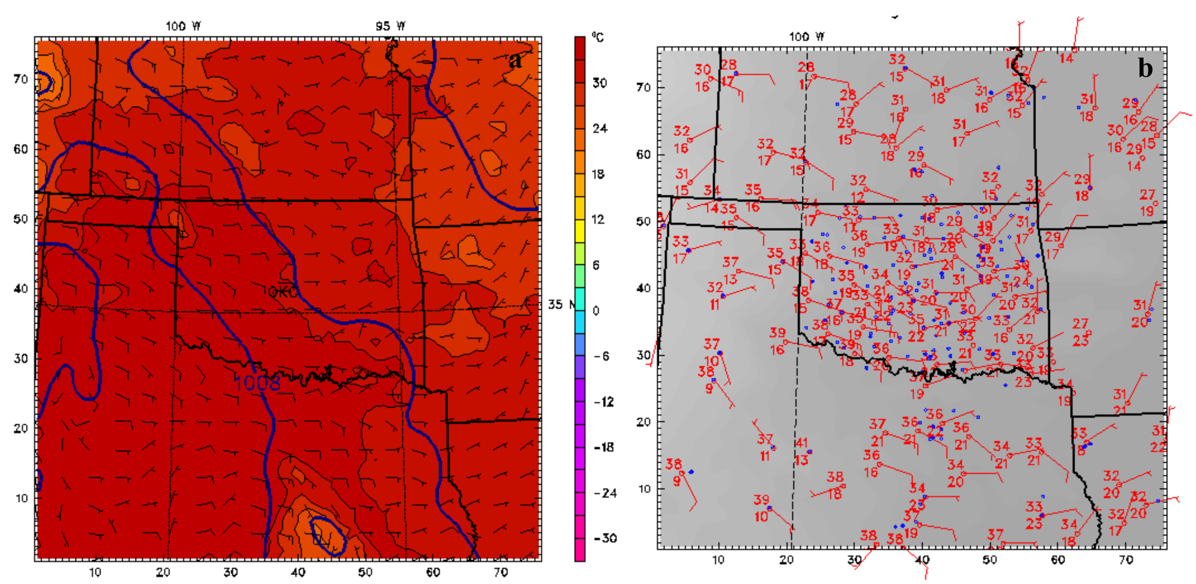

Fig.2 Comparison of the RTFDDA surface wind and temperature analyses (a) with surface observations (b) on Domain 2, valid at 00 UTC, August 9, 2003.

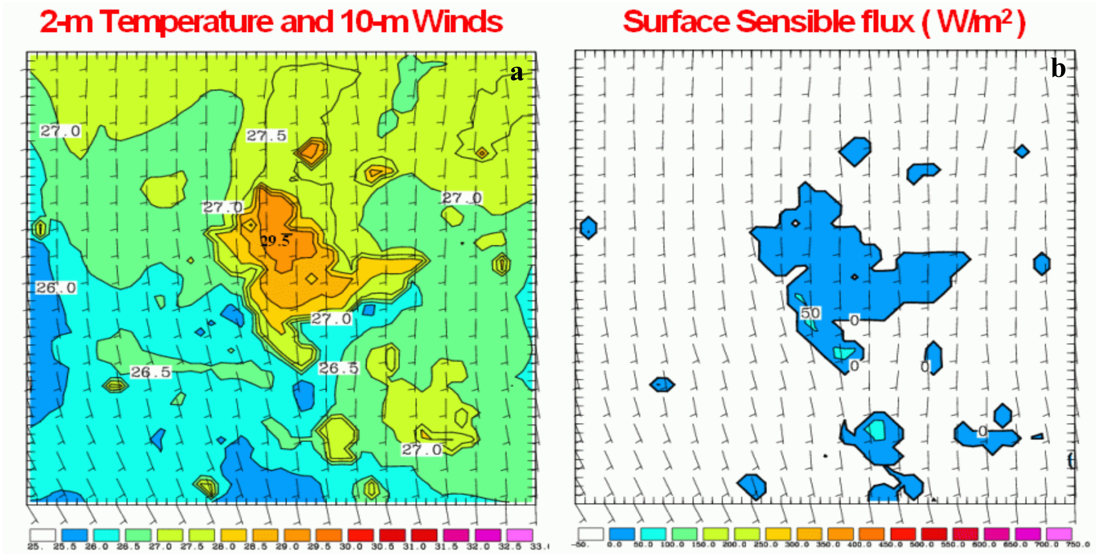

Fig.3 2-m temperature (a) and surface sensible heat flux (b) on Domain 4, valid at 06Z, averaged for 9 clear-sky weather days during JU03 operation in July, 2003

areas. It also seems that the urban-heated air advects significantly toward the downwind side of the OKC.

On most days, RTFDDA simulations showed that the OKC heat-island effect enhanced PBL development during day-time, and also the mixing in the night-time. Fig. 5 displays the PBL structure on Domain 4 of the RTFDDA analysis at 18 UTC (11 LST) July 5, 2003, a clear-sky day. One can see that the PBL over OKC and the nearby downwind regions are 300 - 500 m deeper than in the surrounding rural region (Fig. 5a). Deeper and stronger eddies and the overall buoyant PBL convective rolls (Fig. 5b) appear to be responsible to the stronger PBL development in the urban area. In contrast, the PBL in the surrounding rural regions was mostly characterized by weak descending motion.

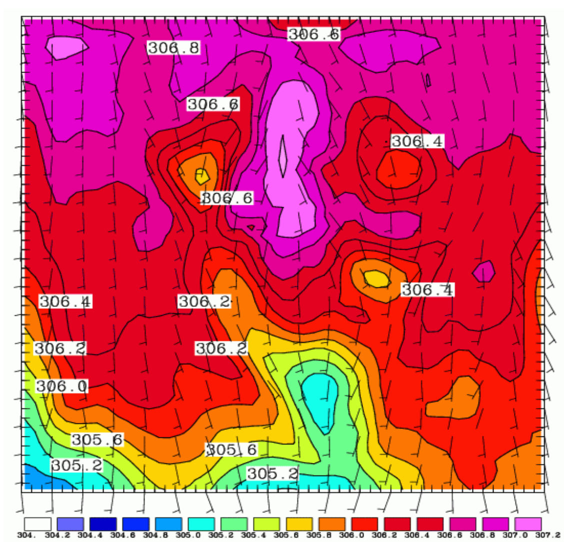

Fig.4 RTFDDA analysis surface winds and 950-hPa potential temperature on Domain 4, at 18Z, July 5, 2003.

Finally, an example of the UWM output is given in Fig.6a. The UWM refined the RTFDDA wind structure according to the local building distribution. The UWM diagnostic results are subsequently used to drive SCIPUFF, which simulates the plume using an instantaneous release of SF6. Fig. 6b shows the SCIPUFF-simulated plume, after 35 minutes of transport by the UWM winds.

6. SUMMARY

The NCAR/ATEC RTFDDA system proved to be an ideal nowcast/forecast system during the JU03 field program. It provided the forecasters with timely high-resolution forecasts, insight into four-dimensional (4D) urban meteorology, and the ability to produce transport and dispersion calculations. The success of the NCAR/ATEC RTFDDA system relied on 1). the ability to incorporate conventional, non-conventional and local JU03 observations, 2). the augmented Noah land-surface model that captured urban land use, and 3). the computing resources needed to run the model down to 0.5 km grid increment. All of these factors were necessary to generate forecasts and model the structure of the urban atmospheric environment. The forecast web site was found to be easy to use by forecasters, and had most of the required forecast products. The meteorologists forecasting for JU03 heavily depended on the system, and, most of time, the RTFDDA system was the only one used for planning test operation.

With the enhancements to the Noah LSM urban physics, the RTFDDA system appears to successfully capture many urban-induced features, including the nocturnal heat-island

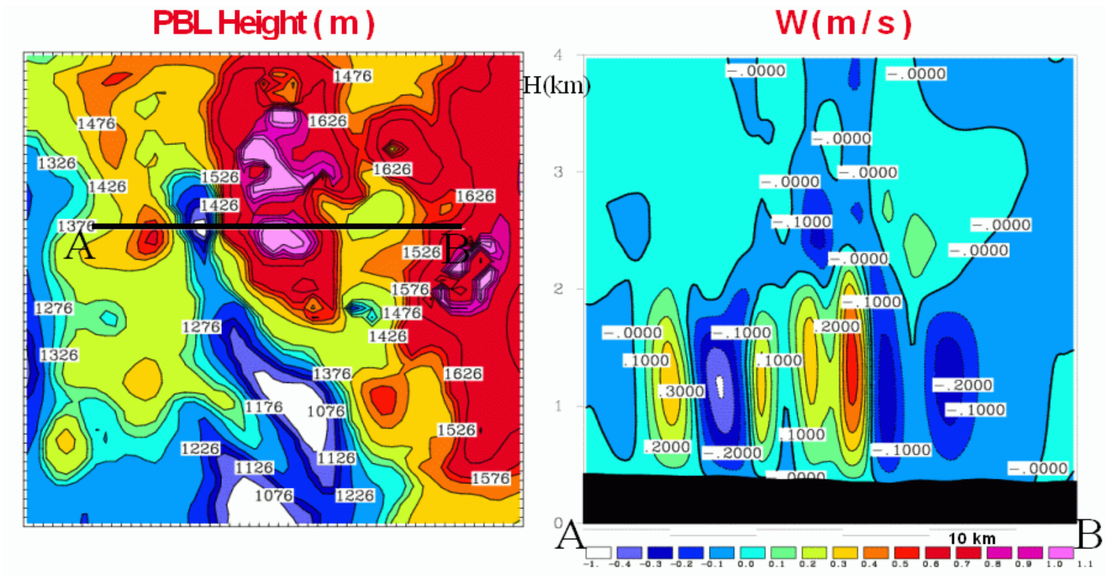

Fig.5 The same as Fig.4, but for PBL height and vertical cross section of vertical motion along the line AB

effect, the increased daytime PBL growth with strengthened eddy mixing, and many local wind perturbations produced by the urban heat-island and the enhanced urban friction.

While the RT-FDDA model output coupled with the UWM was not fully utilized during JU03, this system did provide information on micro-scale wind structures produced by urban building clusters.

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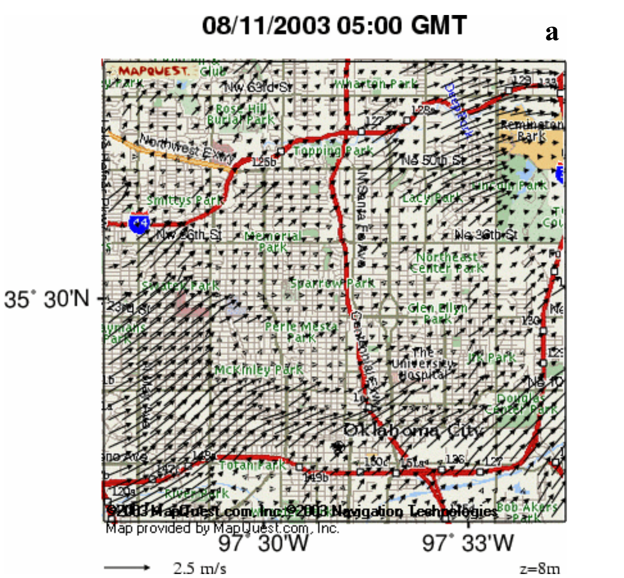

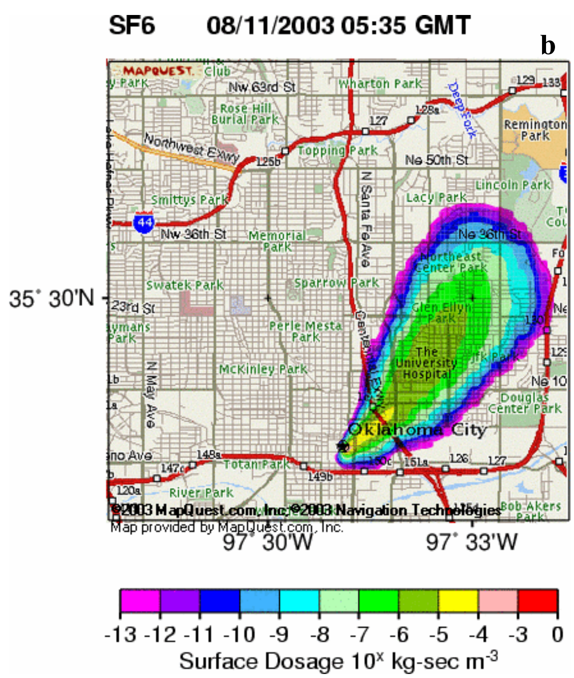

Fig.6 UWM diagnostic winds at 8 m AGL (a) and the surface dosage distribution 35 minutes after a point release of SF6 (b), simulated with SCIPUFF