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MM5 FDDA EXPERIMENTS USING THE WEST TEXAS MESONET DATA

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1. Introduction

At Texas Tech University in Lubbock, Texas, the atmospheric scientists and wind engineers are developed and assembled an array of advanced fast-response high-resolution atmospheric monitoring systems and the state-of-the-art mesoscale models for research in vaious aspects of atmospheric boundary layer (BL) and surface processes. The central component of the array is the West Texas Mesonet including both fixed and mobile observation platforms. The Mesonet surface data can be used to initialize mesoscale models, to provide high-frequency observations for data assimilation, or to validate model simulations. One expected result is to have a better understanding of how mesoscale numerical model and high resolution data sets may be best used in regional numerical weather forecasting.

The mesoscale prediction system MM5 (Grell et al., 1994) is employed in this study. The focus is on the model predicted surface conditions. The MM5 Model is a three-dimensional dynamical prediction system cast on terrain following sigma coordinates in the vertical. The model provides a number of dynamical and physical options. Here we invoke non–hydrostatic dynamics with the full three-dimensional Coriolis effect and 24 sigma levels in the vertical. The upper radiative and lateral relaxation boundary conditions are imposed to close the model. Also, the following BL-related physical options are selected for the simulation experiments.

- Grell moist-convection parameterization
- Atmospheric radiation with the effects of clouds (Dudhia et al. 1998).
- MRF (Hong and Pan 1996) planetary boundary layer
- Surface heat and moisture fluxes from the ground
- Surface energy budget to calculate the ground temperature
- Multi-layer soil thermal diffusion

The model works well in simulating various meteorological settings such as relatively quiescent conditions and intense storms over West Texas (Gill et. al. 2003). The results of two real-data case studies including four-dimensional data assimilation (FDDA) experiments using the Mesonet observations are summarized in Section 3. The FDDA parameters selected in the experiments are as follows:

- Nudging factors for wind, temperature, and humidity: 4×10^{-4} s^{-1}.
- Horizontal radius of influence: 100 km from the observation sites.
- Vertical radius of influence: 0.002 (about 20 m) from the level of sigma = 0.995.
- Time window: 60 min centered at the observation time

2. West Texas Mesonet

The West Texas Mesonet is an automated surface network operated. The network providing continuous coverage of a region centered on Lubbock consists of thirty-five fixed 10-m instrumented towers, several boundary layer towers of height ranging from 70 to 200 m, two 3-m and three 10-m portable mesonet towers, and five 3-m mobile mesonet platforms. The average spacing of the fixed towers is about 40 km. The site locations were selected depending on both geographic availability of sites and considerations made for communications purposes. Three of these sites have atmospheric profilers capable of sampling wind and stability measurements of the lowest several kilometers of the atmosphere. The tower observations include five-minute data on temperature (T), humidity, barometric pressure, wind speed, wind direction, precipitation, and solar radiation. In addition, data on soil moisture and soil temperature are collected every 15 minutes. The complete Mesonet tower specifications and locations are available at www.mesonet.ttu.edu.

During 2002, quality control procedures were developed for application to the Mesonet data sets. These procedures consisted of a suite of tests that check the data for a variety of problems. Tests were developed to 1) check that data were within expected normal ranges, 2) check that the data was within the range limitations of the instrumentation, 3) check the temporal continuity of the data, 4) check the spatial continuity of the data, and 5) check the collected data against other like instruments on the same platform. In cases where data points failed range tests, such data points were flagged as bad points and removed from the archive. In cases where tests could not conclusively rule out that the data was correct, the data were flagged with a warning for the users to consider. Using these procedures, the appended data archive for 2002 was developed. In the current study, only the fixed 10-m tower observations were used. The Mesonet hourly data files created for the MM5 FDDA experiments were based on the 5-min data.

3. Results

Within the confines of the Mesonet, we have performed finer scale observational studies. These studies provide a more detailed look at pertinent

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mesoscale features such as the dryline, boundary layer winds, and thunderstorm environments. Overall, there exist within the data sets collected in 2002 a wide variety of phenomena. Two cases presented in this study are a) relatively quiescent meteorological conditions and b) an oscillation dryline. Being able to model conditions in period of quiescent weather will be a necessary first test of model performance. The outcomes are useful in defining the base line for interpretations of more dynamic cases such as severe convective weather outbreaks, which often require more information on the larger (synoptic) scale. As stated earlier, we are most interested in the model BL wind simulations over the Mesonet area. Thus, only the simulated surface conditions on the proximity of the Mesonet are presented.

3.1 The 23 November 2002 (Case 1)

Case 1 represented relatively tranquil conditions. Three 24-h (00 UTC 23 to 00 UTC 24 November) one-grid MM5 simulations were conducted. There were 67 by 67 horizontal grid points with a resolution of 15 km. The initial state and lateral boundary conditions were generated from the NCEP ETA model analysis. Real-data FDDA experiments by observation nudging of the West Texas Mesonet data into the model were carried out. The MM5 FDDA package (PSU/NCAR Mesoscale Modeling System, 1998) was not designed to assimilate temperature and humidity in the convective BL, which could be 1 to 2 km deep in the daytime. The forecasting time period starting at late afternoon local time was intended to maximize the impact of FDDA during night when the convective BL vanished. The question being investigated was whether the Mesonet data can improve the model performance in short-range (6-12 h) surface wind forecasting. The FDDA input data included the hourly Mesonet 10-m tower wind, T, and relative humidity (RH).

Over West Texas, the model initial state (not shown) is dominated by primarily weak southerly flow, below 10 m/s. The surface air is dry and cool with weak T and RH gradients. Three 24-h MM5 simulations are a) one without FDDA (r1), b) one with 6-h FDDA between 6-h and 12-h model time (r2), and c) one with 9-h FDDA between 3-h and 12-h model time (r3). In both r2 and r3, FDDA ends at 12-h model time at 12 UTC 23. Figs. 1 and 2 depict the 12 h r1 surface winds, and T and RH, respectively. In the vicinity of the Mesonet (see Fig. 3), westerly and southwesterly flows with speeds close to 10 m/s are predicted and the air remains dry and cool. The corresponding Mesonet observations are shown in Fig. 3. It appears that the model winds have more westerly but less southerly component near the Texas-New Mexico boarder, and somewhat higher speeds. The model over-predicts the surface T by a few degrees at 12 UTC. Observations reveal strong warming occurring between 12 UTC 23 and 00 UTC 24 by about 10 ^{o}C at most Mesonet sites. The warming trend is well predicted by the model. In consistent with observations, there is no accumulated precipitation predicted by the model during the 24-h period.

The difference fields (r2-r1) at 12-h model integration are presented in Figs. 4 and 5. The corresponding (r3-r1) fields (not shown) are very similar to those of (r2-r1). As expected, notable discrepancies with the highest magnitudes close to 3.5 m/s and 0.5 ^{o}C in the surface winds and temperatures, respectively, only occur over the Mesonet area. FDDA enhances the cyclonic flow in the vicinity of the Mesonet. However, the differences dissipate rapidly after FDDA is turned off. In three hours, the maximum differences are less than 1 m/s in wind speed, while 0.3 ^{o}C in temperature.

3.2 The dryline of 14-16 April 2002 (Case 2)

The quiescent dryline is a common weather feature in West Texas from April to June. As it oscillates east and west across the region, moisture convergence and cyclonic vorticity associated with the boundary may aid in the development of isolated deep convection. It is well known that local surface effects such as elevation changes, soil moisture, land use, and vegetation variations influence the morphology of the boundary layer and thus the quiescent dryline's motion (e.g. Peckham and Wicker, 2000). Previous studies such as Sun and Wu (1992) and Grasso (2000) have demonstrated the usefulness in employing mesoscale models to investigate the quiescent dryline. In this section we will examine if the addition of surface data from a mesonetwork will increase the skill of the MM5 mesoscale model in prediction of the quiescent dryline of 14-16 April 2002

On the morning of 14 April, a weak shortwave trough moved north of the forecast area and precipitated the generation of a sharp dryline that was positioned approximately in the middle of the domain by 00 UTC 15 April. The dryline began its diurnal retreat and was located west of the domain by 12 UTC 15 April. The dryline advanced eastward during the day sweeping east of the domain by Apr 16-0Z. During the evening the dryline retreated again until it became located in the western half of the domain by 12 UTC 16 April.

The MM5 model was initialized with the 00 UTC 15 April NCEP ETA model analysis. A nested domain was used that was centered over the West Texas Mesonet. The grid spacing was 6-km for the inner grid and 18-km for the outer grid. A 24-h control simulation was run without FDDA. A similar simulation with 18-h (06 UTC 15 to 0) UTC 16) FDDA observation nudging based on the Mesonet data was then performed. Only the results of the inner grid simulations are presented.

Figure 6 shows the analysis of the dryline from West Texas mesonet data. Fig. 7 shows the 12-h simulated surface wind field from the control (non-FDDA) experiment. The predicted wind fields show large deviation from the actual wind fields. Fig. 8 is the model prediction with observation nudging. It is difficult to discern any quantitative difference between the control and the fdda wind fields. Fig. 9 shows the vector wind differences between the control and FDDA runs. The FDDA run does predict the higher winds speeds more accurately than the control run. At 00 UTC 16, no organized improvement can be seen. Overall, neither simulation accurately represents the actual wind field. Further examination of this event will be shown including an evaluation of the moisture field prediction.

4. Conclusions

The mesoscale (MM5) modeling systems in conjunction with the West Texas Mesonet are used to investigate how the high-resolution surface data provide by the West Texas Mesonet may impact regional numerical weather prediction. Two relatively quiet synoptic cases are examined. In Case 1, MM5 performs equally well in reproducing the observed surface flow with and without FDDA using the Mesonet data. In Case 2, both runs, with and without FDDA, fail to accurately reproduce the actual wind field. Comparisons of the model simulations with observations suggest that FDDA with the Mesonet data have very little impact on the outcomes of the two non-precipitation cases. The model responses to data assimilation are likely to be a function of weather scenarios. Since the model performance is not expected to be uniform, more studies should be done to examine which conditions are most likely to be affected by surface data assimilation. For example, the FDDA approach may have significant impact on local convective activities.

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Acknowledgements

We wish to acknowledge that the data are provided by the West Texas Mesonet personnel, Dr. Tim Doggett, Mr. Wes Burgett, and Mr. Bruce Haynie at Texas Tech University, and the programmatic and management assistance and support of Mr. Chris Pepper and others at The Institute for Environmental and Human Health at Texas Tech University; and Dr. William Lagna and Mr. Raymond Jablonski of Soldier Biological and Chemical Command (SBCCOM), Department of the Army, by the Defense Threat Reduction Agent.

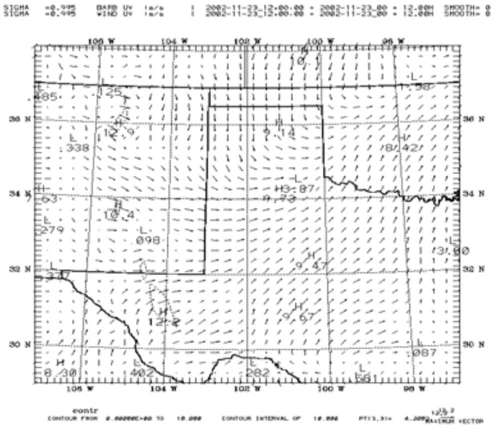


Fig. 1: MM5 12-h simulated surface winds at 12 UTC 23 November.

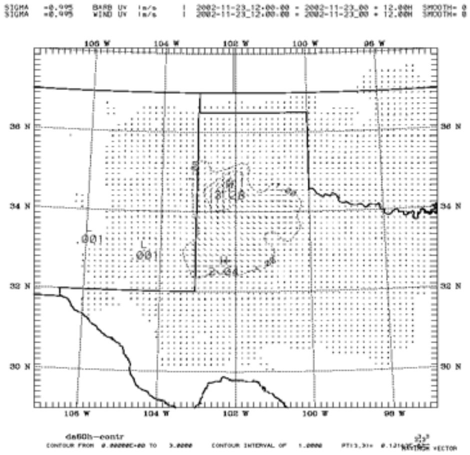


Fig. 4. Surface vector wind differences (r2-r1) at 12 UTC 23 (12 h model time).

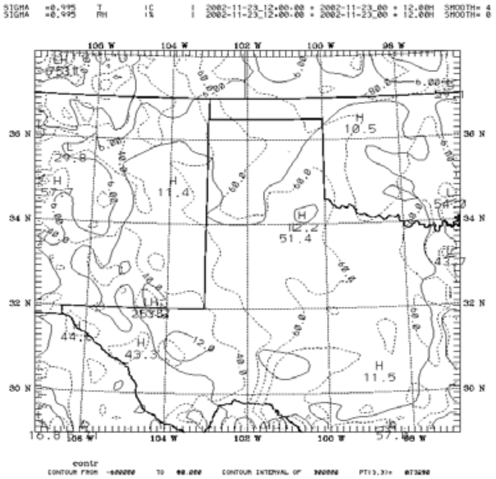


Fig. 2: MM5 12-h simulated surface T (solid lines) and RH at 12 UTC 23..

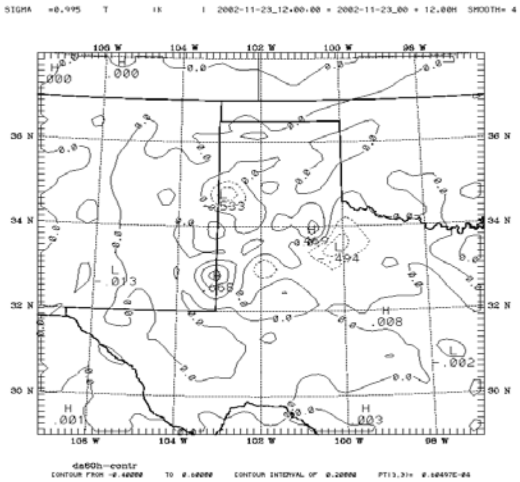


Fig. 5. Surface temperature differences (r2-r1). at 12 UTC 23.

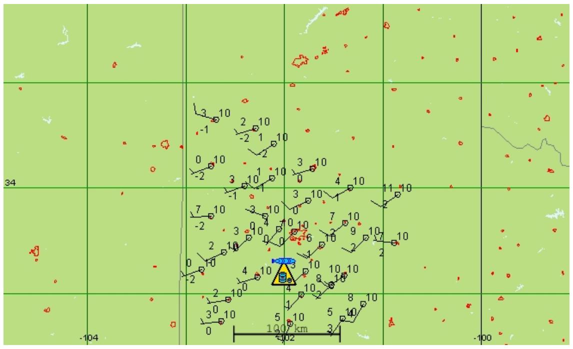
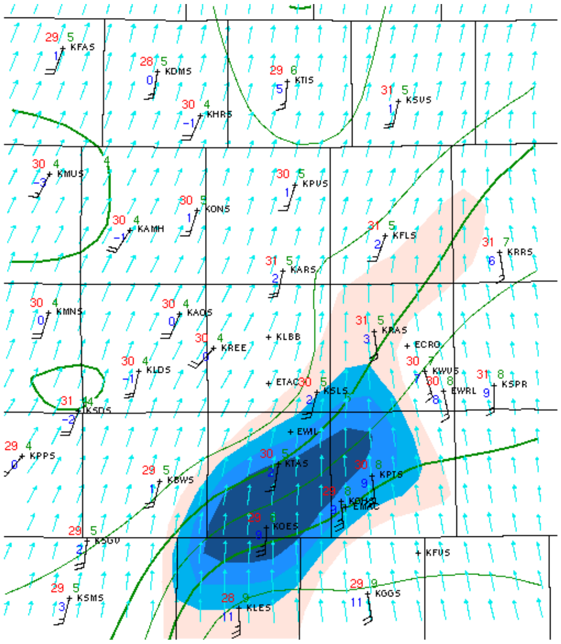


Fig. 3: Mesonet observations at 12 UTC 23 November.



020416/0000 Moisture and wind field analysis

Fig. 6. A surface objective analysis of the dryline at 00UTC 16 April 2002 using data from the West Texas Mesonet. The green contours are mixing ratio (g kg^{-1}). Region of moisture convergence is shaded. A full wind barb equals 5 m/s.

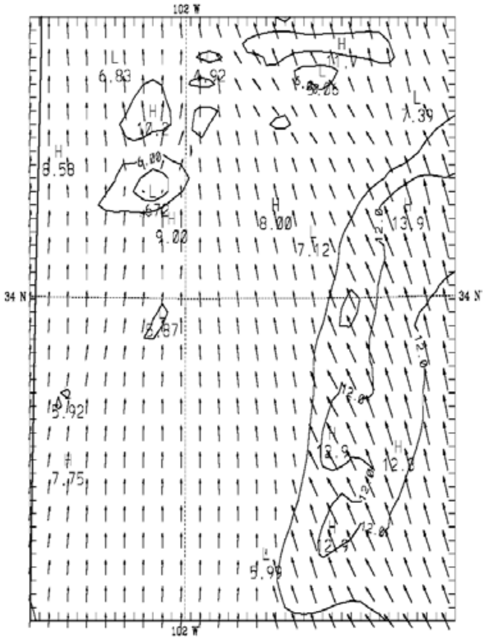


Fig. 7. Simulated 24 h surface winds (Control run) at 00 UTC 16 April.

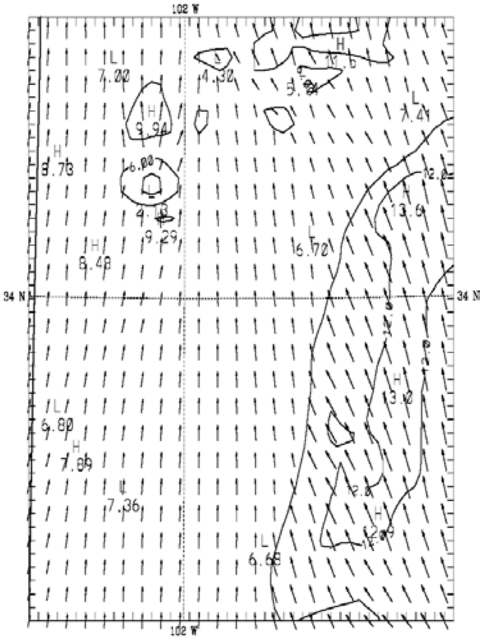


Fig. 8. Simulated 24 h surface winds (FDDA run) at 00 UTC16 April.

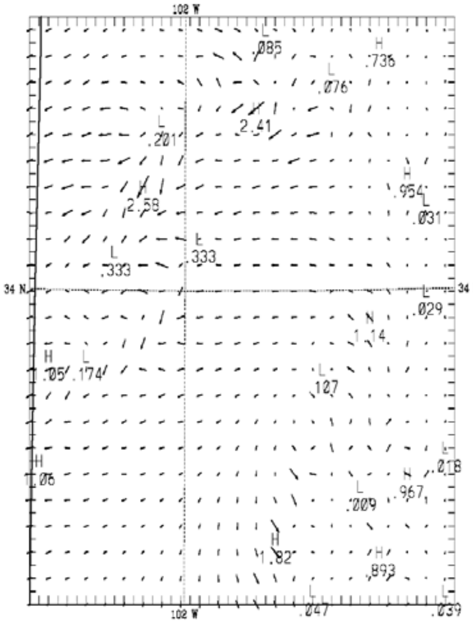


Fig. 9. The vector wind differences (Control - FDDA) at 00 UTC 16 April.