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USE OF LOWER ATMOSPHERIC PROFILERS AND AUTOMATED SURFACE MEASUREMENTS TO INVESTIGATE MESOSCALE STRUCTURE AND PREDICTABILITY

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1. INTRODUCTION

A special field program was conducted at White Sands Missile Range (WSMR) during the summer of 2000. Three 924-MHz Lower Atmospheric Profilers were operated continuously for a two-month period to obtain wind and temperature profiles within the atmospheric boundary layer. Profiler measurements from this field program include the horizontal and vertical wind components which can be used to validate predictions by the Penn State/NCAR Mesoscale Model Version 5 (MM5) in the WSMR Four-Dimensional Weather (4DWX) system. The profiler measurements of vertical velocities are not directly comparable to the grid cell-averaged vertical velocities predicted by MM5. However, because the profilers were configured in a triangular array, it is possible to compute volume-averaged vertical velocities for comparison with MM5 forecasts of the vertical motion fields. In addition to providing data for MM5 model validation, the results of the WSMR profiler field study may provide insight into how best to deploy and operate wind profilers in the field for use in data assimilation and real-time mesoscale weather prediction that have been applied to synoptic-scale systems (Smith and Benjamin, 1993).

The wind structure of the middle and upper troposphere and lower stratosphere at WSMR has previously been studied. Nastrom and Eaton (1995) investigated hourly wind profiles at 150-m intervals from 2 to 20 km above the ground (AGL) with measurements from a 50-MHz profiler. Weber et al. (1990) used a 404-MHz profiler to study hourly wind profiles at 250-m intervals from 500 m to 14 km. Astling (2000) compared WSMR MM5 forecasts and with 404-MHz profiler measurements of horizontal winds in the mid- and upper-tropospheric levels. The observations from the summer 2000 field program provide the first detailed information about the wind fields in the lowest 2 km AGL.

2. AREA OF STUDY

The 924-MHz profiler data were collected in a mountain basin at WSMR that is surrounded by prominent orographic features. Figure 1 is a topographic map showing the locations of the profilers (A, B, and C) and Surface Atmospheric Measurement System (SAMS) in this WSMR field program. The mountain basis, which is within the Chihuahuan Desert, is oriented in a north-south direction with lowest elevations (< 1200 m ASL) extending along its western side. The 1500-m AGL contour in Figure 1 outlines the location of the San Andres Mountains on the west side of the basin, with peak elevations at 2078 m, and the Sacramento Mountains on the

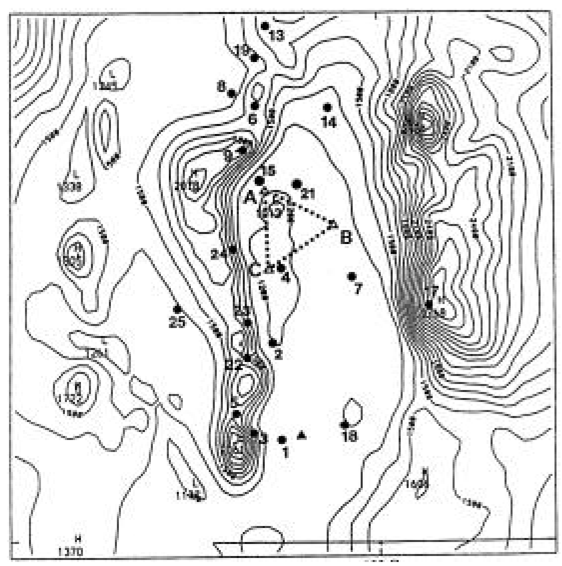

Figure 1. Map of the topography in the WSMR region. The contour interval is 100 m. Triangle symbols with labels A, B, and C denote locations of the 924 MHz profilers. The large dots show locations of the SAMS stations.

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east side, with elevations above 2700 m. The mountain basin is open at the south end and bounded by high terrain at the north end. These orographic features influence mesoscale wind fields and diurnal variations in precipitation events (Tucker, 1993; Huck, 1998).

The profilers were deployed over a sufficiently small spatial domain at WSMR to investigate the mesoscale flow structure over complex terrain. Figure 1 shows the locations of the three profilers relative to the main orographic features and Surface Atmospheric Measurement Systems (SAMS). The northern most location was at Jallen (A) near the San Andres Mountains. The second profiler was located approximately 33 km southeast of A at Tula_g (B). The third profiler was located 33 km south of A at NW30. The terrain was relatively flat with elevations varying from 1179 ASL at site B to 1254 m at site C. This profiler array extends over a sufficiently small spatial domain to capture the detailed flow structure of the atmospheric boundary layer in complex terrain. Spacing of the profilers is large enough so that, in addition to the temporal averaging period, influences by thermals and individual downdrafts are minimized.

3. PROFILER DESCRIPTION

The 924-MHz profiler is an important means of obtaining profiles of winds and, with the addition of a radio acoustic sounding system (RASS), virtual temperature in the atmospheric boundary layer. Profilers transmit a vertical beam and two tilted orthogonal beams, to derive the three-dimensional wind vector within the radar's resolution volume. The WSMR profilers use a consensus average approach in which the distribution of first moments for each beam is accumulated over a 25-min period to create a mean for the period. This approach generally produces acceptable mean wind field measurements, but at the cost of relatively coarse time resolution. Second moment data (width of peak centroid for velocity variance) were not collected in this study due to the large data volume that is generated and because the main focus was on the wind field forecast by MM5 rather than on turbulence phenomena. Each WSMR profiler is equipped with a RASS and provides virtual temperature profiles for two 5-min periods during each hour. RASS measurements were collected during the field project and will be reported in a separate study. During the 2000 field study, the profilers were operated in a low-mode configuration to obtain measurements for 55-m layers from 120 to nearly 3000 m AGL.

4. ANALYSIS PROCEDURE

The profiler data collection began on 1 June 2000 and continued through 31 July 2000. Careful inspection of the profiler wind data for each 25-min period revealed missing observation times and partial data files with missing range-gate measurements at one or more of the profilers. Missing observations were attributed to weak signal returns during some brief periods with extremely dry conditions (especially at the higher range gates), measurements failing to meet the consensus averages (less than 10 radar returns), and occasional power outages. Only days with complete sets of data files at all three sites were included in the analyses. Two additional quality control criteria were applied to these complete data files. Measurements were deleted when signal-to-noise levels were less than –20 dB. Wind data were also excluded whenever the magnitude of the vertical velocities exceeded 2 m s^{-1}. This last criterion was applied in order to reduce errors in the horizontal wind components when the radial velocity correction from the vertical beam is applied to the tilted beams. The comparison of profiler measurements with MM5 forecasts was limited to nine days in July when MM5 forecasts and observations from all three profilers were available concurrently. The hourly wind profiles from WSMR Domain 3 MM5 forecasts were bi-linearly interpolated to each profiler location and vertically interpolated to each of the 40 measurement levels between 120 and 2000 m.

For validation purposes, the MM5 forecasts of the boundary layer wind profiles were stratified according to time of day and level above ground. There were 17,359 sets of hourly MM5 forecasts and profiler measurements that passed all of the quality control criteria. MM5 validation statistics (bias and RMSD) were calculated at 1-h intervals for the U- and V-horizontal wind components and the vertical component (W). The bias and RMSD values were averaged together for the three profiler sites and were grouped into 3-h periods and 5 layer subsets. The bias and RMSD values also were averaged for the levels between 120 and 400 m AGL and for four 400-m deep layers between 400 and 2000 m AGL. Winds within the lowest layer used in the analyses (120 to 400 m) are strongly influenced by diurnal variations and orographic effects, while terrain influences are less important in the upper-most layer (1600 to 2000 m), which extends above the highest mountain peak. Winds in the layers between 400 and 1600 m may be influenced by mountain-barrier effects, depending on the flow direction and atmospheric stability (Smith, 1979). The average ridge-top height above the basin floor is 700 m for the San Andres Mountains and 1500 m for the Sacramento Mountains.

5. COMPARISONS OF VERTICAL VELOCITIES

Vertical velocity is an important quantity in understanding the three-dimensional structure of boundary layer circulations. The magnitude of W in the vertical velocity in mesoscale circulations is generally two orders of magnitude smaller than that of the horizontal wind components and within the measurement accuracy of the 924-MHz profilers. Also, studies have noted erroneous vertical velocities in the 924-MHz profiler measurements due to hydrometeors, insects, and vertical-beam pointing (Angevine, 1997). The 3-h averages of vertical velocity measured by the WSMR profilers during the period of study indicated sinking motion ranging from 7 to 40 cm s^{-1} throughout most of the 24-h period and were considered to be erroneous. For these reasons, vertical velocities were calculated from the horizontal wind measurements by the triangular array of WSMR profilers for comparison with MM5 forecasts of vertical velocity.

The horizontal wind measurements from the triangular array of wind profilers were used to calculate vertical velocities following the method previously applied to radiosonde measurements at Dugway Proving Ground by Astling et al. (2000). The 3h averaged wind components for each of the five layers described in the previous section were used to calculate the divergence of the horizontal wind field within the triangle bounded by the profilers for each layer. The vertical velocity in each layer was then calculated from the negative of the integral of the divergence from the surface through that layer.

Figure 2 compares vertical velocities computed from the profiler measurements at each of the five layers with the averages of the vertical velocities forecasts by MM5 for the three profiler locations. Figure 2 shows a good agreement between the sign and the magnitude of the vertical velocities estimated from horizontal divergence and forecast by MM5. Figure 2 also shows the second-order line of best fit, which has a correlation coefficient of 0.81. The vertical velocities ranged from –13 to +10 cm s^{-1}. Smallest absolute values occur in the two lowest layers and the largest values appear in the two highest levels. The vertical velocities were mostly downward at night (W<0) and upward during the day (W>0). Figure 2 indicates that MM5 forecasts of sinking motions tend to be stronger than sinking motions computed from the profiler array, while MM5 forecasts of rising motions tend to be less than rising motions as estimated from the profiler array.

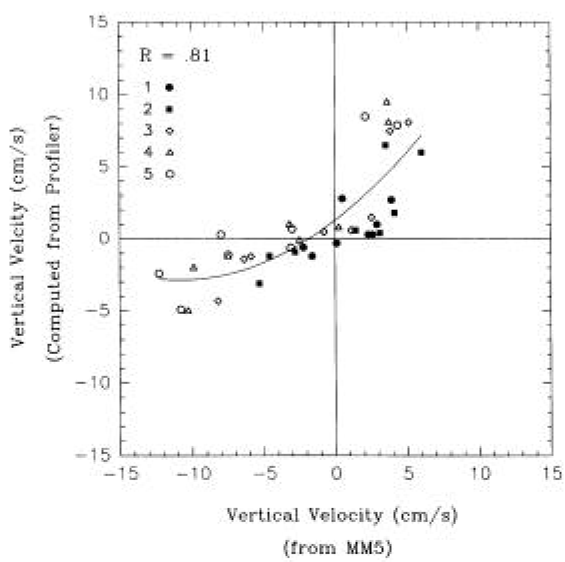

Figure 2. Comparisons of vertical velocities computed from 924-MHz measurements with MM5 forecasts for the five layers described in the text (1= lowest layer, 5=highest layer).

6. SUMMARY

Comparisons of 924-MHz profiler wind measurements at WSMR with MM5 forecasts for a 9-day period in July 2000 showed that model performance exhibited a diurnal variability. MM5 tended to underpredict the boundary layer winds in the afternoon and overpredict the winds at night. Comparisons of vertical motions calculated from the profiler measurements of horizontal winds with MM5 forecasts displayed good agreement in terms of sign and magnitude. Both MM5 and profiler derived vertical motions showed rising motions at night and sinking motions during the day. The results suggest that 924-MHz profiler data may be used to validate MM5 forecasts and enhance FDDA analyses.

8. ACKNOWLEDGEMENTS

The author acknowledges Stan Parsons for operating the three 924-MHz profilers at WSMR and collecting the data, Daran Rife of NCAR and Greg Dodd of H.E. Cramer Co. for assistance in processing the MM5 output files and profiler data.

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