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SINGLE AND DUAL-DOPPLER RADAR OBSERVATIONS OF A MESOVORTEX IN THE 28 MAY 1985 MESOSCALE CONVECTIVE SYSTEM OBSERVED DURING PRE-STORM

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1. INTRODUCTION

The PRE-STORM (Preliminary Regional Experiment for Stormscale Operational and Research Meteorology) project in May-June 1985 documented a number of Mesoscale Convective Systems (MCSs) in considerable detail. One such event occurred on 28 May 1985 when a nocturnal MCS passed through the PRE-STORM network. In this paper we emphasize some surface characteristics of the storm as obtained from the NCAR PAM II (Portable Automated Mesonet) network and describe kinematic features of the mesoscale flows within the storm as obtained from the NCAR CP-3 and CP-4 Doppler radars. An overview of PRE-STORM, including a description of the field facilities can be found in Cunning (1986).

2. SYNOPTIC SETTING AND STORM OVERVIEW

This MCS formed near 03Z (2200 local) along a strong outflow boundary generated by severe isolated convection along the southern Nebraska border. The convection formed in association with a weak trough in the lee of the Rockies. The trough was followed downstream by a longwave ridge with weak middle and upper-level winds. Significant advection of Gulf of Mexico moisture occurred in the PRE-STORM network during the observable period of this storm. This synoptic pattern is conducive to the formation of MCCs (Maddox, 1983). Fig. 1 shows the radar reflectivity pattern obtained by the Wichita National Weather Service (NWS) WSR-57 radar during the mature phase of the storm. Note the intense line of convection, trailed by stratiform precipitation. The convective and stratiform regions are noticeably disjoint, the stratiform region being shifted from a position directly behind the convective line to a position behind the northern portion of the line. This pattern results from the presence of a well-defined mesoscale vortex within the stratiform region, which permitted strong rear inflow (flow entering the storm from the rear) to erode the stratiform cloud along the main portion of the convective line, while at the same time injecting ice from the convective region into the more northern portion of the stratiform cloud through front-to-rear flow. Evidence of this circulation is seen from the reflectivity pattern alone (Fig. 1). Note the hook like appendage along the northern portion of the stratiform region. The square overlay denotes the region within which dual-Doppler data of the mesoscale vortex will be presented later.

3. PAM II OBSERVATIONS

Forty PAM II stations were deployed in Kansas for PRE-STORM. Pressure data were corrected to sea level assuming an average station height of 518 m. Data were objectively analyzed using GEMPAK. The sea level pressures and surface winds (ground-relative) obtained from the PAM II network at 12 Z are presented in Fig. 2. The radar reflectivity pattern from the Wichita WSR-57 radar is also shown for this time. A continuous line of convection oriented roughly north-south was present at this time, although it is not indicated in the figure as a result of data elimination over Wichita. A region of stratiform rain associated with the convective line was situated to the north of Wichita. The most obvious pressure feature at this time is a mesohigh situated just behind the convective line. This mesohigh (or thunderstorm high as described by Fujita, 1955) is associated with convective-scale descent and evaporative cooling. The lowest surface pressures were situated at the rear of the stratiform rain region, but were rather poorly defined at this particular time. This low pressure region was transient in time, and constituted a "wake low" as discussed by Johnson and Hamilton (1988). Later we present PAM II data at a single station which illustrates the intensity and small size of the wake low. The most notable feature in the wind field is the intense divergent outflow centered within the stratiform rain. This outflow is evidently linked to the mesoscale subsidence driven by evaporation and melting in the stratiform region. The strength of the outflow may have been reinforced by a plunging rear inflow jet that sloped sharply to the surface in this area (shown below). This outflow was responsible for the generation of new convection along the southern flank of the convective line. Strong convergence along the interface between the divergent outflow and southeasterly flow ahead of the new convection is very apparent (Fig. 1). This illustrates a clear feedback process between mesoscale subsidence producing divergent outflows and the generation of new convection.

A time series of PAM II data from station 6 is shown in Fig. 3 (the approximate location of PAM 6 is shown in Fig. 2). Inspection of a time series of plots like Fig. 2 (not shown) indicated that the wake low intensified with time and passed over station 6 near 14Z. PAM 6 experienced a rather weak convective line passage near 1130Z. Approximately 10 mm of rainfall was recorded in a 30 min period after 1130Z, coinciding in time with modest pressure rises associated with the mesohigh. Stratiform rain then occurred over the next two hours where an additional 8 mm of rain were recorded. Hence nearly 50% of the total rainfall at PAM 6 was attributed to stratiform rain. The pressure abruptly dropped at the back edge of the stratiform rain region (note the correspondence to the precipitation trace), dropping nearly 6 mb in a 20 min period. The pressure drop was accompanied by a 50 kt wind gust. Although sunrise (and hence the diurnal temperature increase) was near in time to the passage of the wake low, the initial rise in temperature was likely associated with subsidence warming in the vicinity of the wake low (Johnson and Hamilton, 1988). Indeed the wake low is a manifestation of the rear inflow aloft, resulting from subsidence warming inducing hydrostatic pressure falls at the surface . The wake low "hugs" the rear of the stratiform precipitation as within the stratiform rain evaporative cooling by evaporation offsets the subsidence warming.

4. SINGLE-DOPPLER OBSERVATIONS

Doppler radar observations were collected throughout a 5 hour period during the passage of this storm. A radar reflectivity and storm relative flow cross-section is shown in Fig. 4. This cross-section was obtained at the CP-3 radar along the 290 and 110 degrees radials at 1148Z. The structure of leading convection (vertically erect) trailed by a narrow region of stratiform

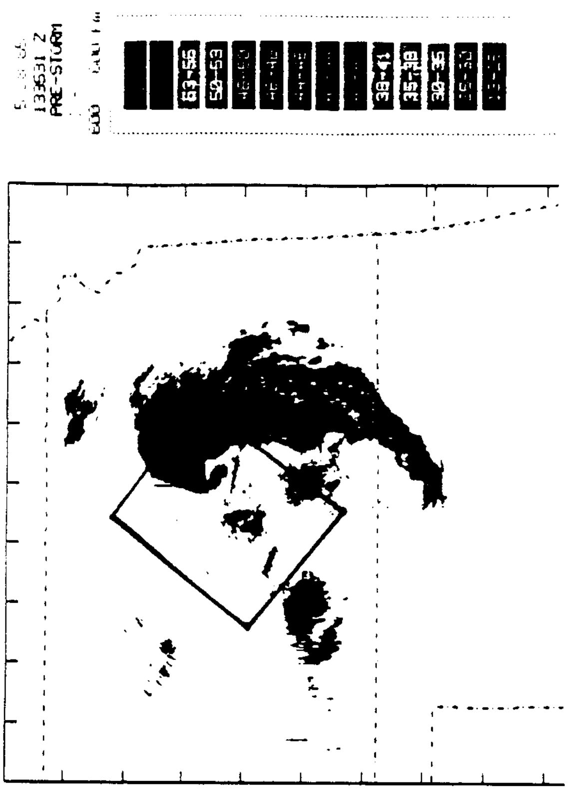

Figure 1. Radar reflectivity map from the Wichita NWS WSR-57 radar at 1335 Z. Box denotes the dual-Doppler domain.

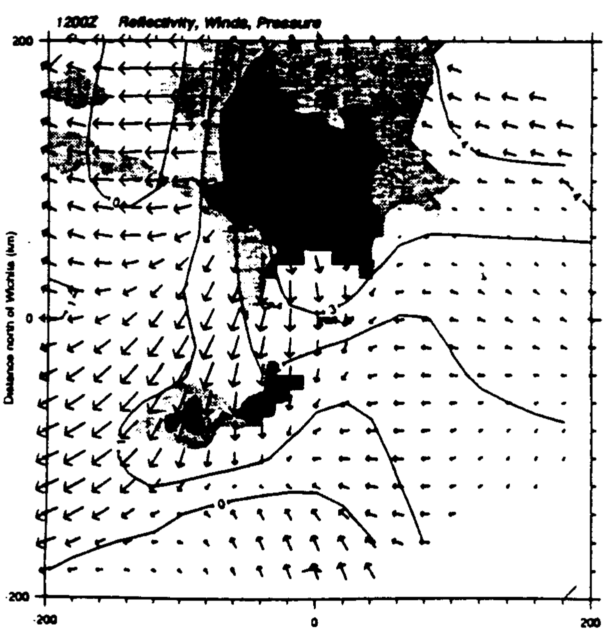

Figure 2. Surface pressure field (pressure - 950 mb) and ground relative flow at 1230 Z obtained from the PAM II network. Maximum vector length corresponds to 12 m/s.Isobar contouring is at 1 mb intervals. Radar reflectivity is from the WSR-57 in Wichita. Reflectivity levels are shaded at 10-20, 20-30, 30-40, and >40 (black). PAM station 6 is located at (-30,140).

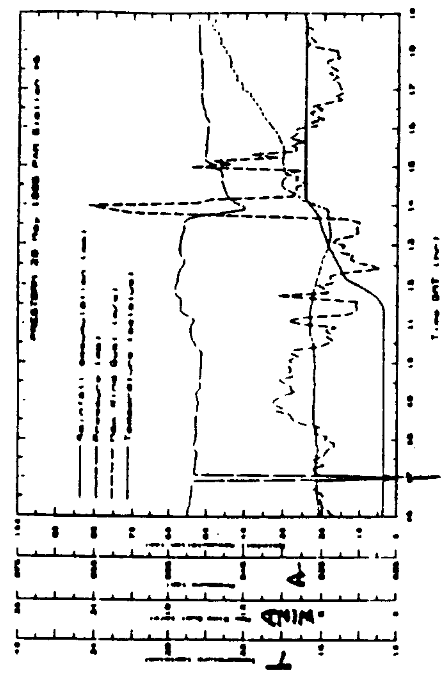

Figure 3. Time series of meteorological parameters from PAM station 6. The pressure drop at 07Z is erroneous.

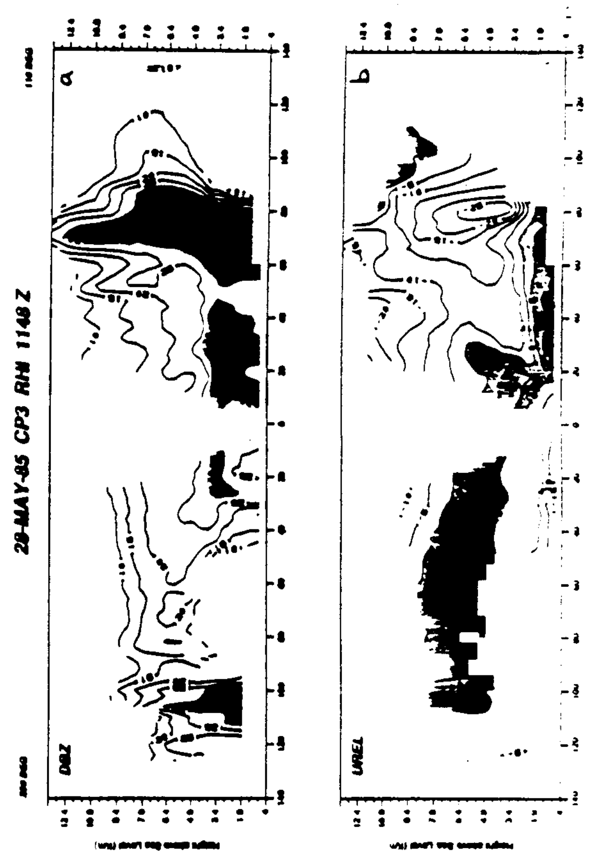

Figure 4. Cross-section from CP-3 at 1148Z. a) Radar reflectivity in dBZ. Reflectivities greater than 30 are shaded. b) Storm relative flow in m/s. Shaded values represent flow from left to right, or rear inflow as discussed in the text.

rain is clearly seen (Fig. 4a). The weak convection to the rear of the stratiform region was associated with convergence into the wake low region (this type of convection has been documented in several past cases). A very interesting rear inflow pattern was seen at this time (Fig.4b). The rear inflow plunged to the surface some 60 km rearward of the convective line and was evidently instrumental in generating the strong surface divergence beneath the stratiform cloud. A plunging rear inflow was not present in the 10-11 June case, with the exception of immediately behind the convective line (Rutledge et al., 1988). Comparison between these two cases suggests the plunging rear inflow in this case may have been related to stronger and deeper front-to-rear flow emanating from the convective line as compared to the 10-11 June storm. The intense front-to-rear could essentially acted as an obstacle to the rear inflow. A time series of radar cross-sections spanned the development of the radar reflectivity transition zone in this storm. From these data (not shown) we suggest that the transition zone development was linked to the intensification and deepening of the front-to-rear flow, which increased the advection distance of hydrometeors being carried out from the convective line. Rearward of the position where the rear inflow plunged toward the surface, a notably deep rear inflow existed. The rear inflow entered the storm at high levels (10 km), as was seen in the 10-11 June case (Rutledge et al., 1988).

Several profiles of mesoscale vertical motion were obtained from single-Doppler radar using the method discussed by Srivastava et al. (1986). These profiles (from CP-3) were obtained in the broadest portion of the stratiform region. The divergence profile was integrated downward using the continuity equation with a upper level boundary condition of $w=0$. [The profile shown in Fig. 5a can be considered representative of conditions in a cylinder of 20 km radius centered at $x=0$ km in Fig. 4.] The later profiles (Figs. 5 b,c) represent conditions further to the rear in the storm. At 1130Z the vertical motion profile contained both mesoscale upward and downward motions with peak values of 50-100 cm s^{-1}. However the later profiles were considerably different, indicating deep mesoscale subsidence in the absence of any mesoscale upward motion. Note the deep convergence extending throughout the depth of the data. These profiles evidently resulted from the upper-level penetration of the rear inflow jet into the rear of the storm, causing upper-level convergence (with the front-to-rear flow) and downward motion. The deeper subsidence at the rear of the stratiform region in this case compared to 10-11 June is consistent with a stronger wake low in this case (more subsidence warming).

5. DUAL-DOPPLER OBSERVATIONS

Dual Doppler observations were analyzed at 1314Z within the domain shown in Fig. 1. The single-Doppler data from each radar were interactively edited using the NCAR/RDSS software. The interpolation and synthesis steps were performed using the NCAR SPRINT and CEDRIC software packages. The storm relative vector winds and radar reflectivity pattern for two levels are shown in Fig. 6. The most notable feature in the analysis is the mesoscale vortex located near the back edge of the stratiform region. The vortex was undoubtedly responsible for the hook-like reflectivity pattern as hydrometeors were transported in a cyclonic pattern by the vortex. The southern portion of the vortex constituted strong rear inflow which lead to a notch in the reflectivity structure. Notches have been previously related to strong rear inflow into storms by Smull and Houze (1985). The horizontal scale of the vortex is at least 60 km. The vortex tilted very little with height as the center at 5.9 km (Fig. 6b) was nearly directly over the center at 2.9 km. [The vortex circulation was weakly evident up to the 7.9 km level and extended downward to about the 1.9 km level.] This vortex is similar to those seen in tropical MCSs (Gamache and Houze, 1982) and at middle-latitudes (Leary and Rappaport, 1987). This is the first clear documentation of such a well-defined vortex circulation by dual-Doppler radar. A vortex of this type is thought to be related to the generation of a mid-level mesolow in the stratiform region associated with upper level diabatic heating and low-level cooling through evaporation and melting.

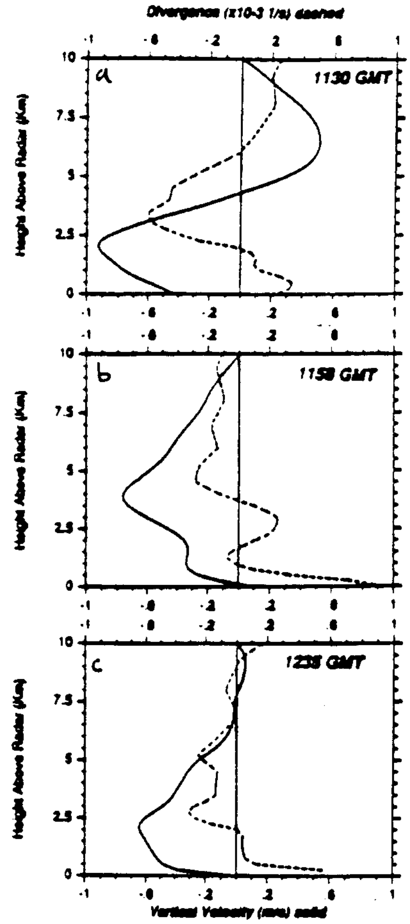

Figure 5. Vertical profiles of mesoscale divergence and vertical motion obtained from single-Doppler data in the trailing anvil cloud. Divergence dashed, vertical motion solid.

6. CONCLUSIONS

PAM II data indicated distinct surface features associated with this storm. A strong mesohigh was present immediately behind the convective line whereas an intense mesolow was situated at the back edge of the stratiform region. Outflows beneath the stratiform cloud apparently triggered new convection along the southern flank of the storm. The strong outflow in this case was likely enhanced by the plunging of the rear inflow to the surface some 60 km behind the convective line. A well-defined mesoscale vortex was situated in the stratiform region. The vortex was approximately 6 km deep.

7. ACKNOWLEDGEMENTS

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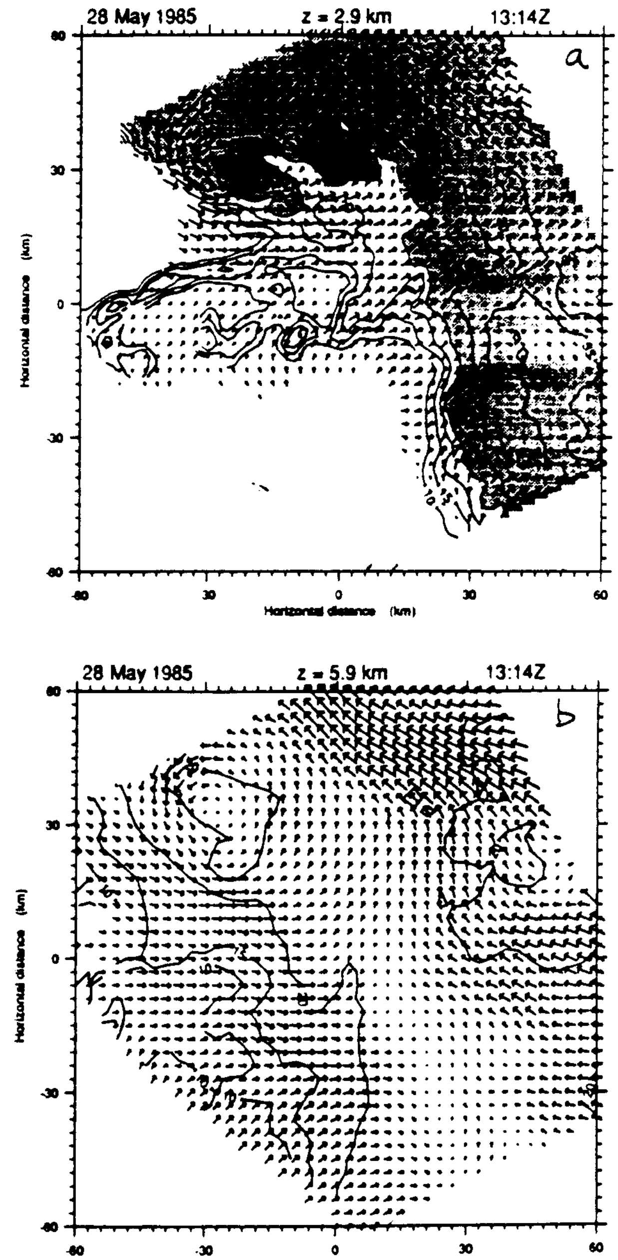

Figure 6. Storm-relative winds and radar reflectivity in dBZ from the dual-Doppler synthesis at 1314Z. a) z=2.9 km MSL. Maximum vector length corresponds to 12 m/s. Reflectivities are contoured at 5 dBZ intervals and > 25 dBZ is shaded. b) As in a) except for 5.9 km MSL.