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VERTICAL DRAFTS IN THE CONVECTIVE REGIONS OF MESOSCALE CONVECTIVE SYSTEMS IN KANSAS

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1. Introduction

Several mesoscale convective systems (MCS'S passed through the observational network of the Stormscale Operational and Research Meteorological Program—Central Phase (PRE-STORM). These storms were typically characterized by a line or region of convection, an associated area of stratiform precipitation and distinct mesoscale motions. Two cases, which passed over Kansas on 10-11 June and 28 May 1985, were examples of midlatitude squall lines with trailing regions of stratiform precipitation. The general structural features and single-Doppler radar kinematic analyses emphasizing the mesoscale circulations of these two cases have been presented by Smull and Houze (1987) and Rutledge *et al.* (1988). The third case (3-4 June 1985) contained a more varied pattern of convection which formed into lines for only a brief period and had stratiform rain confined mainly to the northern portion of the system. In this paper, we focus on the convective-scale motions and present results derived by dual-Doppler analysis of the PRE-STORM radar data in these three observed mesoscale systems. We investigate specifically the spatial arrangement and intensity of the updrafts and downdrafts in the convective regions of these storms.

2. Data and method of analysis

All data were obtained with two National Center for Atmospheric Research (NCAR) 5-cm wavelength Doppler radars (CP3 and CP4), which were deployed near Wichita, Kansas, with a 60 km north-northwest/south-southeast baseline. The radars were operated in coordinated sequences of elevation angles, either over 360° in azimuth or over smaller limited area sector scans (Rutledge *et al.*, 1988). We use only the 360° scans in this paper. Several sector scans were also analyzed but led to no significant differences in results. The 360° scans provided regions of dual-Doppler analysis both east and west of the baseline.

For both the 28 May and 10-11 June cases, radar data were collected from 0.2 to 58.0° in elevation. Convective cells were well sampled at the tops, thus allowing an upper boundary condition to be applied in integrating the anelastic continuity equation downward to obtain the vertical velocity. A boundary condition of 0.1 to 0.25 m/s in the convective region and zero elsewhere was used for all of the volumes analyzed for these two days. Values ranging from zero to 2.0 m/s in the convective region and zero to 0.5 m/s elsewhere were tested. The results were not very sensitive to the choice of boundary condition except for the extreme cases. Also, "sponge depths" (in which the initial vertical velocity is determined by multiplying the upper most measured divergence by the depth of the sponge—Knupp, 1987) have been tested for depths of 0.1 to 1.0 km . The mean vertical velocities were relatively unaffected by sponge depths < 0.5 km, but large vertical drafts at upper levels appeared as a result of the boundary condition calculation. This method thus tends to overemphasize the role of the upper-level divergence, which is generally not well sampled and could be affected by sidelobes. By using a near zero but slightly positive vertical velocity as the boundary condition, any significant drafts that are computed are the result of integrating over a fairly deep layer rather than overemphasizing the upper-level divergence.

During 3-4 June, the radars scanned to only 28.0°. For that case, we used between 0.25 and 0.50 m/s in the convective region and zero elsewhere.

As a further check on the vertical velocity calculation, a lower boundary condition was applied to the data after the divergence had been integrated. Since none of the analyses contained data extending to the ground, we took 67% of the residual mass flux in grid columns extending to 500 m above the ground and 33% of the residual mass flux in grid columns extending to only 1 km above the ground. No adjustment was made in columns terminating before 1 km above ground. Thus, only about 70% of the data was adjusted. The divergence was recomputed with the amount of adjustment increasing with height. Then, the adjusted convergence was integrated to obtain the adjusted vertical velocity. The net result of this adjustment scheme was to reduce the strength of the low-level downdrafts. The upper-level downdrafts were less sensitive to the adjustment. But in some cases they were slightly increased to compensate for low-level updrafts. Since there is evidence that a significant amount of divergence can occur within the lowest 500 m of the atmosphere in convective systems (e.g., Wilson *et al.*, 1984), we consider those results to be less realistic than those shown in here. Moreover, the basic strucutre of vertical drafts were relatively unaffected by this adjustment scheme.

All data were adjusted in position according to the observed mesoscale system motion to a central analysis time to account for the time interval required to collect a full 360° scan. The data were thus shifted a maximum horizontal distance of about 4 km. Horizontal velocities were filtered to remove wavelengths less than 6 km to ensure that this data "advection" did not bias our results. The filtering is also consistent with the upper-level horizontal resolution of the data. The time interval required to complete a full 360° elevation-angle sequence ($\approx$ 10 min) is a major limitation in the data set. However, since results using the smaller sector scans, which took only 6 min to complete did not show any major differences in the structure of vertical drafts, we are confident in the results obtained from the 360° scans.

3. Results

Figures 1 and 2 show typical cross sections normal to the convective line for the two squall-line cases. In both of these systems, a mesoscale area of ascent 20-40 km across and hundreds of kilometers long was observed ahead of and in the zone of highest reflectivity. Fairly continuous enhanced updrafts (>3 m/s) were located within this region and were confined mainly to the area defined by the reflectivity cells. These updrafts generally increased in area and usually tilted upshear with height. Within this fairly continuous sloped convective updraft, separate cores of stronger vertical motion were observed. These cores formed a stair-stepped pattern within the general updraft. The maximum vertical velocities of these cores tended to increase with height. Peak updraft speeds from 10-20 m/s were typically found between 8 to 10 km MSL, although strong updrafts were also found at mid-levels probably associated with the development of new cells at the leading edge of the convective line (e.g. x = 26 km, Figure 2).

Figure 3 shows a vertical cross section through a convective cell in the 3-4 June case. The absence of a broad region of ascent at low to mid levels in Figure 3b may be due to the more varied organization of the convective cells in this storm compared to the 28 May and 10-11 June squall line systems. However, the general structure of the updraft from mid to upper levels was similar to that of the other two cases. The same stair-stepped structure of the enhanced updraft cores was evident.

Each of the systems also exhibited mid to low level convective downdrafts, probably associated with precipitation loading and evaporative cooling, usually within or upshear of the maximum reflectivity core. As illustrated in Figs. 1-3, these low-level downdrafts were several kilometers across and had peak values between 3 and 5 m/s, located within one or two km from the ground. The characteristics of similar low-level downdrafts have been documented by Knupp (1987).

In addition to downdrafts at low levels, convective downdrafts were also observed at upper levels on both sides of the peak reflectivity cores in all three of these systems. These upper-level downdrafts were usually weaker and shallower than the low level downdrafts. Speeds from 1 to 3 m/s and depths from 2 to 4 km were typical. The strongest of these upper-level downdrafts tended to be located ahead of reflectivity cores that tilted downshear with height (Figures 1 and 3). Apparently similar behavior has been seen in recent model simulations of Rotunno *et al.* (1988). Occasionally, upper and lower downdrafts would appear to be vertically aligned (e.g., x = 12 km, Figure 2b), creating columns of downdrafts extending throughout the depth of the troposphere. This result does not imply that the trajectories of air parcels in these columns extended from upper troposphere to the ground. The horizontal velocities (not shown) were about three times as large as the vertical velocities in this region and the widths of these superimposed downdrafts were usually quite narrow.

4. Conclusions

In the three PRE-STORM cases considered here, the structure and types of vertical convective drafts were

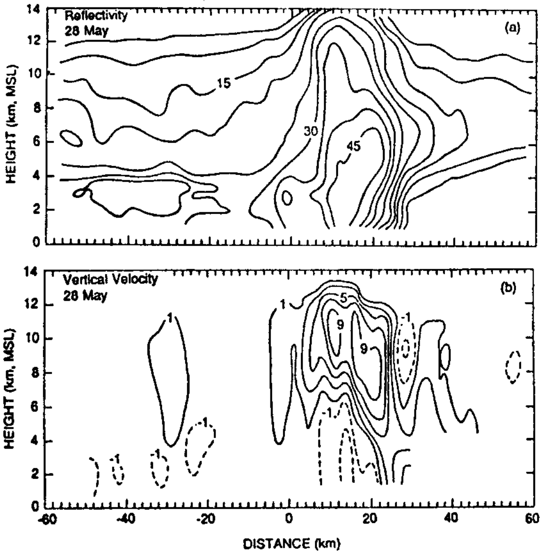

Fig. 1 Vertical cross section through 28 May 85 squall line at 1153 UTC. (a). Reflectivity every 5dBZ starting at 5dBZ. (b). Vertical velocity every 2 m/s from -11 to 11 m/s. Positive values are solid and negative values are dashed.

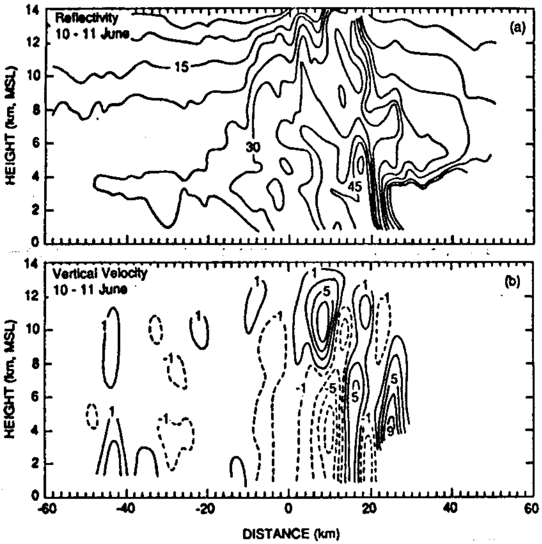

Fig. 2 Same as Fig. 1 except for 10-11 June 85 squall line at 0144 UTC.

very similar. In each case, three basic types of vertical drafts were observed in the convective region: a somewhat continuous tilting updraft, a low-level downdraft and an upper-level downdraft. The strengths and sizes of the vertical drafts varied from case to case and were three-dimensional in character. However, the tendency for the peak updraft to be between 8 and 10 km MSL and the peak low level downdraft to be within 2 km of the ground was common among all three systems.

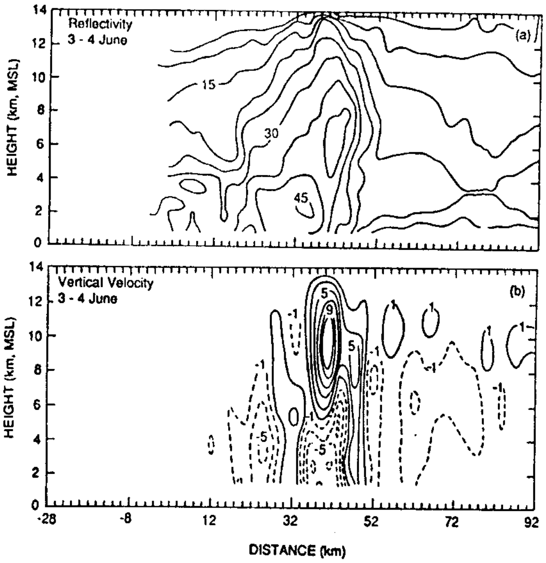

Fig. 3 Same as Fig. 1 except for 3-4 June 85 system at 0109 UTC.

Furthermore, the tendency for upper-level downdrafts to be located adjacent to and immediately ahead of downshear tilting reflectivity cores and for the deepest, strongest low-level downdrafts to be located within upshear tilting reflectivity cores was observed in all three systems.

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REFERENCES

Knupp, K.R., 1987: Downdrafts within High Plains cumulonimbi. Part I: General kinematic structure. J. Atmos. Sci., 44, 987-1008.

Rotunno, R., J.B. Klemp and M.E. Weisman, 1988: A theory for strong long-lived squall lines. Submitted to J. Atmos. Sci..

Rutledge, S.A., M.I. Biggerstaff and R.A. Houze, Jr., 1988: The Oklahoma-Kansas mesoscale convective system of 10-11 June 1985: Precipitation structure and single-Doppler radar analysis. Submitted to Mon. Wea. Rev..

Smull, B.F. and R. A. Houze, Jr., 1987: Rear inflow in squall lines with trailing stratiform precipitation. Mon. Wea. Rev., 115, 2869-2889.