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A SQUALL LINE WITH TRAILING STRATIFORM PRECIPITATION OBSERVED DURING THE OKLAHOMA-KANSAS PRE-STORM EXPERIMENT

Robert A. Houze, Jr.
Department of Atmospheric Sciences
University of Washington
Seattle, WA 98195

Steven A. Rutledge
Department of Atmospheric Science
Oregon State University
Corvallis, OR 97331

1. Introduction

The Oklahoma-Kansas PRE-STORM experiment was conducted in May-June 1985. The goal was to obtain a mesoscale data set that would prepare the way for future field studies aimed at understanding the interactions between mesoscale weather systems and larger scales of motion. Field studies of these scale interactions are evisioned for the late 1980's and 1990's under the auspices of the National STORM Program. The objectives of PRE-STORM were both to test observational techniques being considered for the STORM program and to collect data that would focus more sharply the scientific objectives of the later scale-interaction experiments.

This paper describes data obtained in a storm that passed over two PRE-STORM Doppler radars, the NCAR CP-3 and CP-4 C-band units located as shown in Fig. 1. This storm was a mesoscale system that closely resembled the Oklahoma storm studied by Ogura and Liou (1980) and Smull and Houze (1985, 1986a). It consisted of a 20 km wide leading line of convective storms trailed by a 75 km wide region of stratiform precipitation.

The leading convective line, oriented northeast-southwest, can be seen in the low-level reflectivity pattern of the Wichita National Weather Service WSR-57 shown in Fig. 2. The line was moving from the northwest at a speed of 14 m/s (its component in the plane of the cross section was 11 m/s). The band of convection was followed by a noticeable minimum of reflectivity and, subsequently, by a secondary maximum of reflectivity in the heart of the trailing stratiform rain area. This secondary reflectivity maximum in the stratiform region formed a band of rather uniform moderately intense echo parallel to the leading convective line. Model calculations (Rutledge, 1986) indicate that, as suggested by Smull and Houze (1985), this secondary band can be explained by the fallout of ice particles that are carried rearward to the stratiform region after being released from the upper levels of the convective cells (Rutledge, 1986). At the time of Fig. 2, the mesoscale system was moving through the region of dual Doppler radar coverage shown in Fig. 1.

This case is of interest because one of the objectives of the first STORM field phase (STORM-Central) is to determine the relationship of the stratiform regions of mesoscale convective systems to their convective regions (Interagency Team for STORM-Central, 1984). The thorough documentation of the convective line and stratiform region of the 11 June PRE-STORM case as it passed over Kansas affords an opportunity to sharpen the scientific objectives of STORM-Central by making an intensive study of the data for this case. In particular, we seek to determine and interpret the mesoscale air motions and precipitation growth processes that develop in the stratiform region. The following sections describe some preliminary results of our examination of the radar data for this case. In Sec. 3, a sample of vertically pointing radar data obtained in the stratiform region immediately behind the convective line are shown, while in Sec. 4 the horizontal airflow synthesized from dual-Doppler data collected in the same part of the storm are presented.

2. Vertically Pointing Data

A time section of vertically pointing measurements of reflectivity from the CP-4 radar are shown in Fig. 3a. The back edge of the convective line is in evidence on the left edge of the figure, where the reflectivity is a maximum at all heights. The remainder of the figure depicts the stratiform echo immediately to the rear of the convective line. As in the case studied by Smull and Houze (1985, 1986a), the transition zone, characterized by relatively low values of reflectivity (from ≈ 0240 to 0300 GMT), separated the back of the line from the secondary maximum of reflectivity in the stratiform region, which became well defined after 0300 GMT. The bright band marking the melting layer of the stratiform region (at about 2.7 km) is particularly well defined in the region of the secondary maximum.

Displayed in Fig. 3b are the vertically pointing Doppler velocity data corresponding to the reflectivity pattern shown in Fig. 3a. The vertical velocities in this figure are the net result of vertical air motion and the terminal fallspeeds of precipitation particles. Positive values indicate regions where updrafts are so strong that the upward air motion locally overbalances the particle fallspeeds. Several such regions are seen aloft in the transition zone. Similar structure was seen in the case studied by Smull and Houze (1985, 1986a) and indicates that convective scale updrafts were located at upper levels in the transition zone. These drafts were probably the high-level remnants of cells previously located along the convective line and subsequently advected rearward by the horizontal flow relative to the system (see next section).

In the region of the secondary reflectivity maximum (after 0300 GMT), the velocity data in Fig. 3b show an abrupt increase in downward velocity at the height of the bright band, where ice particles were melting to form more rapidly falling raindrops. In this region, vertical air motions were probably upward above the melting level, probably enhancing the growth of the falling ice particles but not strong enough to carry them upward. Such a mesoscale updraft was present in the case studied by Smull and Houze (1985, 1986a) as well as in a similar Illinois squall line studied by Srivastava et al. (1986) and in tropical squall lines studied by Gamache and Houze (1982, 1983, 1985) and Houze and Rappaport (1984). If the similarity to other cases is borne out, then mesoscale downdraft motion was occurring at and below the melting level in the stratiform region. Analysis of VAD data collected at the CP-3 radar while the vertical incidence data in Fig. 3 were being collected at CP-4, is underway to test the hypothesis that an upper-level mesoscale updraft and lower-level downdraft occupied the stratiform region of the 11 June storm.

3. Dual-Doppler Winds

One of the main results of the studies of Smull and Houze (1985, 1986a) was the finding that the horizontal flow relative to the mesoscale convective system was characterized by a strong current (or "jet") of front-to-rear motion at mid-levels, just above the 0 °C level, and a descending rear-to-front jet below this level. The latter is the "rear inflow jet" discussed further by Smull and Houze (1986b). Figures 4 and 5 confirm that this flow structure was present in the 11 June storm. The first of these figures is a PPI presentation of the unfolded radial velocities observed on the CP-4 radar at 0345 GMT at elevation angle 5.3 °. The prominent cores of inbound radial velocity northwest of the radar and outbound velocity to the southeast clearly mark the presence of the low-level rear inflow jet over the radar. The mid-level front-to-rear jet is more difficult to see in Fig. 4 because the velocity of the storm has not been subtracted from the velocity data. Its presence can, however, be deduced from the region of negative radial velocities seen southeast of the radar at ranges of 40-85 km just beyond (i.e., above) the location of the rear inflow jet maximum.

The mid-level front-to-rear jet is more clearly evident in the vertical cross section of horizontal flow relative to the system at 0202 GMT shown in Fig. 5. This cross section was derived from a dual-Doppler synthesis of the CP-3 and CP-4 radar observations obtained at this time. Front-to-rear motion (positive in the cross section) is seen throughout the upper part of the domain of the cross section. Maximum positive values define the jet core at ≈ 7.5-8.0 km altitude. The rear-to-front flow is sparated from the lower-level rear inflow jet by a sharp isotach gradient that slopes upward toward the rear of the stratiform region. The rear inflow appears to descend as it penetrates inward, finally penetrating into the convective region at low levels. The extension of the mesoscale rear inflow into the convection line region was suggested by Smull and Houze (1985) as a mechanism to enhance the gust front.

4. Conclusions

The limited sample of results presented here indicates that the structure and air motions of one mesoscale convective system observed over Kansas in PRE-STORM was consistent with observations of similar mid-latitude systems obtained in earlier field programs. However, those previous studies were in fact highly restricted to brief snapshots of storm structure as the earlier programs were not organized to obtain comprehensive data sets on the mesoscale. The PRE-STORM data for the case presented here as well as for numerous others not shown, extend over the whole storm period and the data cover as large an area as is possible with two Doppler radars. When combined with the surface mesonet, mesoscale sounding network, profiler, satellite, aircraft and lightning-network data that were also obtained, the PRE-STORM radar data will have documented mid-latitude mesoscale convective systems far more extensively than any past data set.

Acknowledgements

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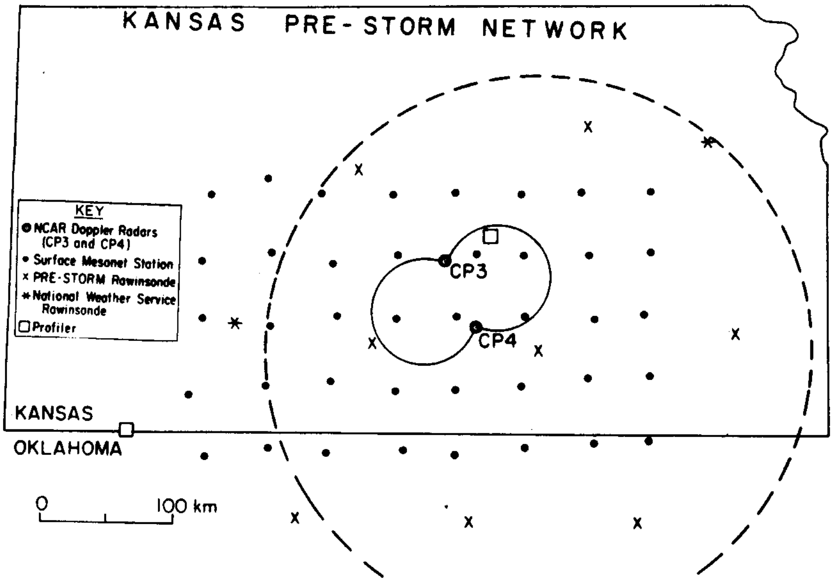

Figure 1. Kansas portion of PRE-STORM data network. The dashed circle is the 200 km range ring of the National Weather Service Wichita WSR-57 radar. Locations of other instrumentation are as indicated in the key. Also shown are the lobes of dual-Doppler radar coverage by the NCAR CP-3 and 4 radars.

Figure 2. Low-level PPI scan of the National Weather Service Wichita WSR-57 radar at 0352 GMT 11 June 1985. Range marks are at 50 km intervals.

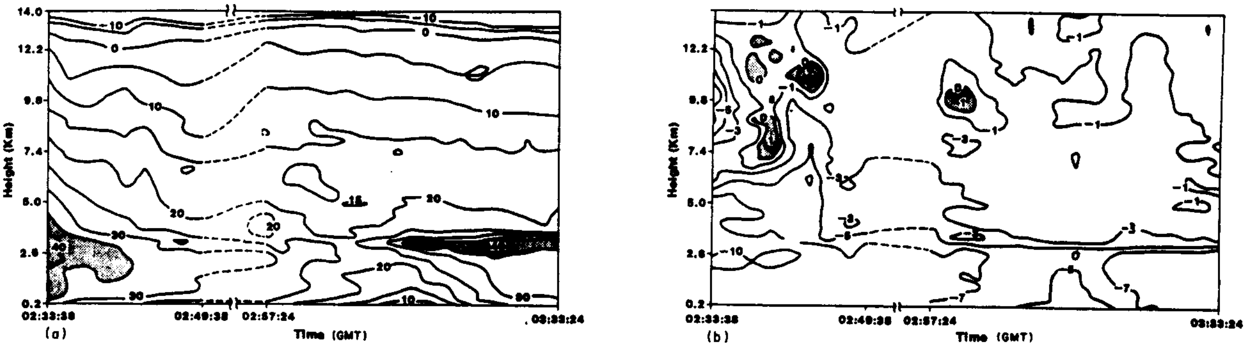

Figure 3. Sequence of vertical-incidence radar data obtained at CP-4 radar on 11 June 1985. (a) Reflectivity [dB(Z)]. (b) Radial velocity (m/s).

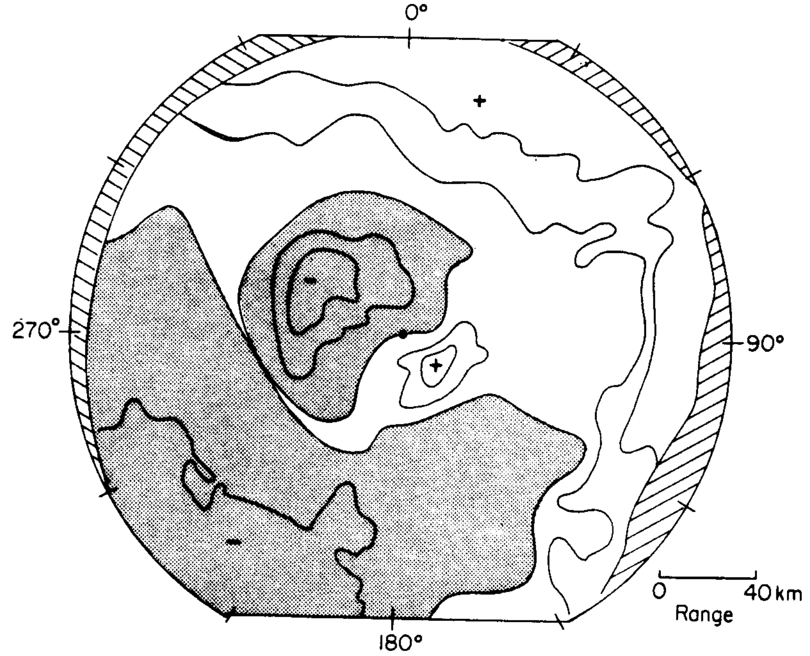

Figure 4. PPI presentation of unfolded radial velocity observed by the CP-4 radar. The elevation angle is 5.3 °, so height increases with range. Areas of negative velocity (shaded) indicate motion toward the radar. Positive velocities are away from the radar. Contours are for -25,-16,0, 11 and 20 m/s.

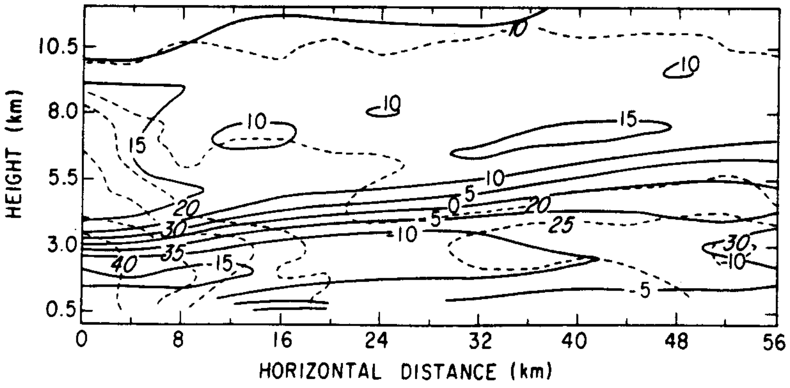

Figure 5. Cross section of reflectivity [db(Z), dashed] and horizontal velocity (m/s, solid) in the plane of the cross section for 0202 GMT 11 June 1985. The horizontal velocity was derived by dual-Doppler synthesis of data from the NCAR CP-3 and 4 radars. The cross section is approximately normal to the leading line of convection seen in Fig. 2.