J5J.4 QUAD-DOPPLER AND MICROPHYSICAL OBSERVATIONS OF THE BAMEX 29 JUNE 2003 MCS

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1. INTRODUCTION

Squall lines are a common occurrence during the late spring and early summer across the central United States, although they may occur during any season (Johns 1993). When a squall line or squall line segment forms into a bow-shaped line of convective cells, this is termed a bow echo (e.g., Nolen 1959). From pioneering studies of Fujita (see review by Weisman 2001) and subsequent observational and numerical studies (e.g., Weisman 1993), it is known that the strong straight-line surface winds often associated with bow echoes originate in part within downdrafts generated along and behind convective lines. These strong winds are also often enhanced by the descent of the rear inflow jet (RIJ), a jet of accelerated air that flows from the rear to the front of the squall line system.

Observational and numerical studies show that the RIJ develops in tandem with the formation of one or possibly two mid-level low pressure centers, one generated by a hydrostatically induced negative pressure perturbation immediately under the upshear-tilted warm convective updrafts (e.g. Smull and Houze 1987) and another, near the back edge of the stratiform region, the result of combined effects of latent heat release in the mesoscale updraft above and evaporative cooling enhanced by melting in the mesoscale downdraft below (Klimowski 1994).

Microphysical processes, particularly sublimation, melting of ice, and evaporation of rain, can exert a strong influence on both the strength and descent rate of the rear inflow once it develops (e.g., Zhang and Gao 1989), and may strongly influence whether or not severe winds occur at the surface. In an observational study, Rutledge et al. (1988) found that the mesoscale downward motion in the stratiform region was greatest just beneath the 0 °C isotherm, where the effects of melting, evaporation and sublimation all work in tandem to provide the greatest amount of cooling. This was further confirmed in modeling studies (e.g., Gallus and Johnson, 1995). Numerous other numerical simulations (e.g., Hjelmfelt et al. 1989) have shown that the presence of hydrometeors can influence the development of low-level downdrafts through changes in buoyancy due to condensate loading and ambient heat loss associated with water phase changes. In some studies (e.g., Klimowski 1994) the RIJ descended to the surface; however, in others it did not (e.g., Chong et al. 1987).

This study focuses on the dynamical and microphysical forcing of the RIJ and its descent. Results from the 29 June 2003 Kansas squall line observed during the Bow Echo and Mesoscale convective vortex Experiment (BAMEX) are presented. Quad-Doppler analyses have been obtained from two radar-equipped P-3 aircraft to examine the structure and evolution of the RIJ. The aircraft flew on opposite sides of the squall lines and were each equipped with a dual-Doppler radar system. Dynamic retrieval routines were used to retrieve the perturbation pressure patterns associated with the flow within the system. In addition, microphysical probe data from quasi-Lagrangian spirals will be used to estimate precipitation mass, and subsequently, microphysical cooling from sublimation, evaporation, and melting of precipitation particles. These spirals were designed to follow the motion of falling precipitation particles and slowly descended from generally -10 to 10 °C, providing profiles of precipitation particle size distributions, temperature, and moisture.

2. QUAD-DOPPLER OBSERVATIONS

During the overnight hours of 28 to 29 June 2003, an east-west oriented squall line developed over northern Kansas and propagated southward into the central part of the state. Before 0500 UTC, the system was characterized by scattered convective cells embedded within a stratiform region (Fig. 1a and b). However, by 0600 UTC, a marked bow echo had suddenly developed and bowed southward along the southern edge of the system (Fig. 1c and d). After pushing southward for a short time, the propagation of the bow echo stalled, followed shortly after by a rapid weakening of the leading convective line (not shown).

Quad-Doppler analyses were obtained prior to, during, and after the first microphysical spiral and are

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shown in Figs. 1 and 2. An elevated RIJ was present within the cross-section from the flight leg centered on 0453 UTC (Fig. 2a). The analysis shows that it descended slightly toward the front of the system, but only to around 3 km. Front to rear flow was present at low levels behind a downdraft present near the leading edge of the system.

Shortly thereafter the rear inflow lowered to midlevels and descended to near the surface along the leading edge of the system (Fig. 2b). This descent to near the surface was coincident with an ignition of leading convection. It was also coincident with and near the same level as a sharp reflectivity gradient (not shown). It is obvious that latent cooling was occurring from the combined effects of sublimation, melting, and evaporation and was likely contributing to the rate of descent of the RIJ.

By 0605 UTC, a strong updraft had developed within the leading convective line (Fig. 2c). The RIJ was still present, centered at about 4 km above ground level, but had also become elevated once again. This may explain why the leading convection quickly dissipated after this time, since the lifting of warm, moist surface air was no longer as intense.

Dynamic retrieval routines were used to retrieve the perturbation pressure patterns associated with the flow within the system (not shown.) During the time of development of the RIJ, a general positive gradient in derived pressure was present from the stratiform region toward the rear edge of the convective line at the level of the RIJ. This suggests that this pressure gradient may have been responsible for forcing the flow of the RIJ toward the front of the system.

3. MICROPHYSICAL OBSERVATIONS

The first microphysical spiral was flown during the developmental stage of the bow echo (Fig. 1c). The spiral descended from the anvil into a dry layer (~55-75% relative humidity; Fig. 3) below, resulting in a sharp decrease in reflectivity. This gradient in reflectivity occurred above the 0 °C wet-bulb isotherm, which indicated that sublimation was the primary microphysical cooling mechanism in the gradient zone. Frozen precipitation, mainly in the form of aggregates of multiple types of smaller ice crystals, was observed down to as warm as 7 °C (Fig. 3). The

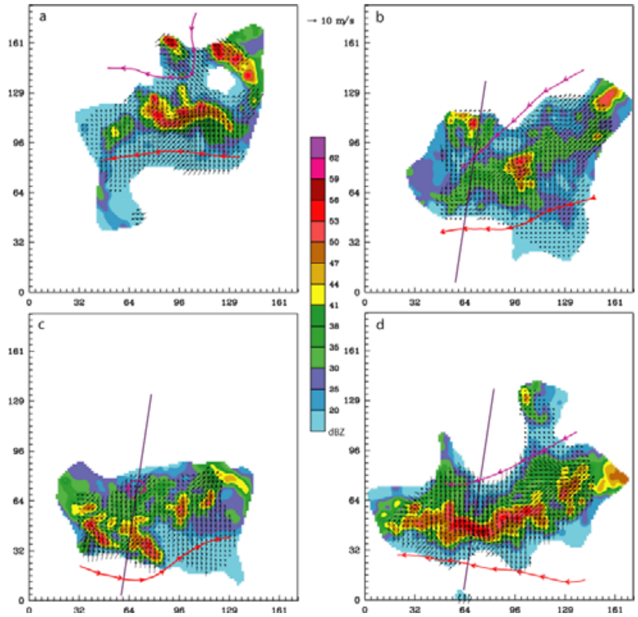

Figure 1: Radar reflectivity (shaded), quad-Doppler wind field (arrows) at 3.5 km from the NOAA P-3 and ELDORA radar systems, and flight tracks (NOAA P-3 – lavender; NRL – red) for the four flight legs of a) 0334 – 0347 UTC, b) 0446 – 0500 UTC, c) 0527 – 0542 UTC, and d) 0559 – 0616 UTC 29 June 2003. The black line denotes the location of the cross-sections shown in Figure 2. The x- and y- axes show the distance (in km) from the lower-left corner point at 38.3N, 99.3W.

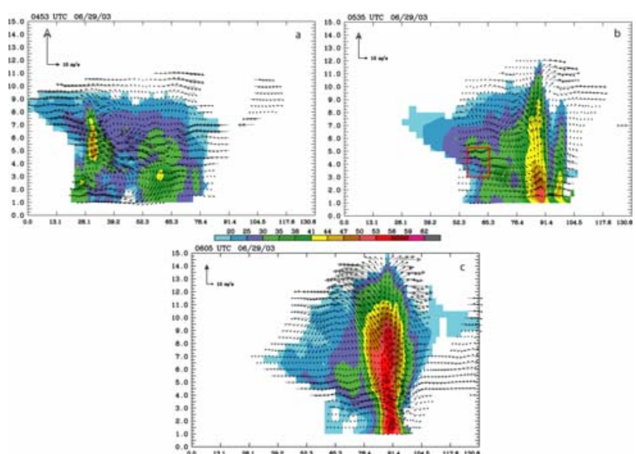

Figure 2: Radar reflectivity (shaded), quad-Doppler wind field (arrows) from the NOAA P-3 and ELDORA radar system for the cross-sections depicted in Fig. 1. The x- and z- axes show the distance (in km) from the lower-left corner of the cross-section. The red box in panel b) denotes where the spiral measurements were made.

data were also obtained within a downdraft (Fig. 2b), which may have enabled the ice particles to descend more rapidly to such warm temperatures. Since the air was well below saturation throughout most of the spiral, it is clear that sublimation, along with evaporation, were resulting in a significant amount of latent cooling, in addition to the melting that was occurring down to 7 °C.

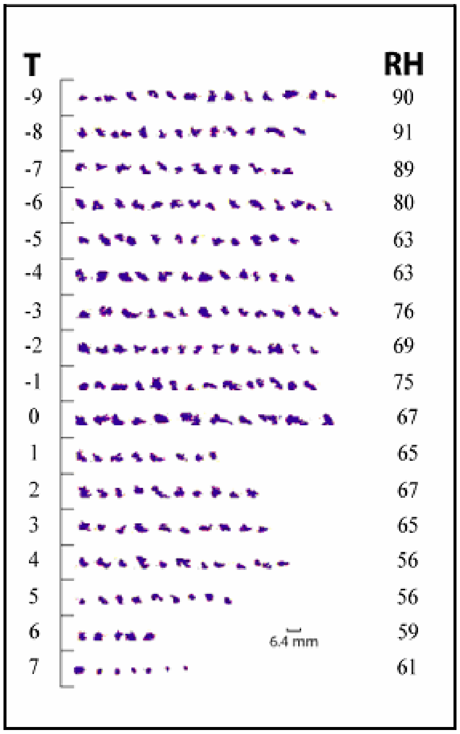

Figure 3: Examples of 2D-P precipitation particle images for every one degree Celsius during the spiral descent. The aircraft-measured relative humidity with respect to water (%) is listed along the right of the figure.

In order to obtain estimates of latent cooling due to melting, sublimation, and evaporation, a good estimate of precipitation mass must first be obtained. Due to the irregular shapes of ice crystals, aggregates, and graupel particles, the estimation of particle mass can be particularly difficult. Particle mass can be derived from the equation

$$M = a\,D^{b}$$

where, a and b are parameters that represent the particles' general shape and density. We determined the a and b parameters directly by comparing the reflectivity retrieved from the particle size distributions and the radar-retrieved reflectivity (which is proportional to the square of the mass.) Fits were made using a Levenberg-Marquardt fitting technique. Close fits are evident between the radar-observed and probe-observed reflectivities for both spirals in the 29 June 2003 case (Fig. 4).

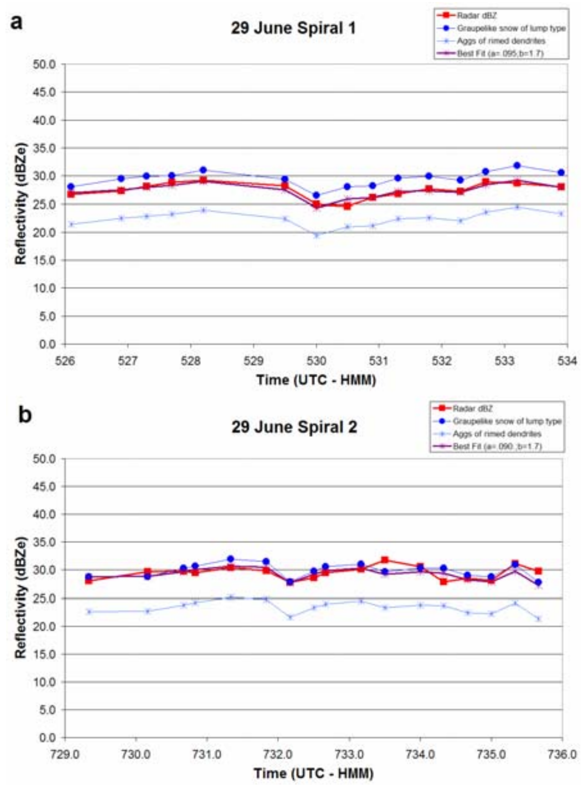

Figure 4. Comparisons of reflectivity for microphysical (a) spiral 1 and (b) spiral 2 on 29 June 2003. The graupelike snow of lump type, and aggregates of rimed dendrites use a and b parameters from Locatelli and Hobbs (1974). The best fit lines use a and b parameters listed in the key in the upper-left-hand corner of each panel.

Figure 5 presents the retrieved values of these parameters in the context of all 18 BAMEX microphysical spirals, and compares the retrieved values with those from observations from Locatelli and Hobbs (1974). These results show that the spirals were likely dominated by rimed aggregates and crystals. These types of particles are generally denser than pure aggregates or crystals and therefore fall faster and melt more slowly, therefore increasing their cooling impact within the melting level.

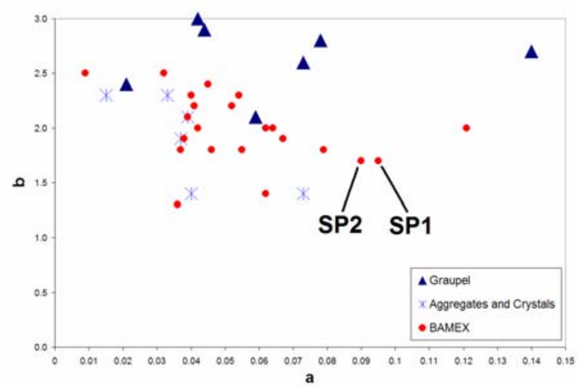

Figure 5: Plot of a and b parameters used in the calculation of mass from the 18 BAMEX microphysical spirals (red circles), with the spirals from the 29 June 2003 case labeled SP1 and SP2. Some spirals had more than one set of values, due to habit changes within the spiral. Blue stars and triangles depict parameter values from observational studies by Locatelli and Hobbs (1974).

4. SUMMARY

The development of the 29 June 2003 Kansas bow echo coincided with the strengthening and descent of the RIJ within this system. Dynamic pressure retrieval revealed that a front-to-rear pressure gradient was present at the level of the RIJ, providing dynamical forcing for the strengthening of the RIJ. Later, the RIJ was still present, but was no longer descending. This coincided with the rapid dissipation of the strong convection after this time, since the lift of warm, moist surface air was no longer as intense.

In addition, the RIJ was situated within precipitation in a subsaturated region, both above and below the melting level, indicating that there was latent cooling from sublimation, melting, and evaporation. Evidence for this strong latent cooling is the presence of ice down to 7 °C. This latent cooling may have led to the descent of the RIJ. In order to better quantify the forcing from latent cooling, a 1-D microphysical and thermodynamical model will be developed. This model will incorporate the size distribution obtained from the microphysical probes within the quasi-Lagrangian microphysical spirals.

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