JP5J.4 EXPLAINING THE VARIABILITY OF CLOUD MICROPHYSICS IN STRATIFORM REGIONS OF BAMEX MCSs USING HIGH-RESOLUTION RADAR OBSERVATIONS

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1. INTRODUCTION

Mesoscale Convective Systems (MCSs) are responsible for much of the summertime rainfall in the central United States and frequently generate damaging straight-line winds, tornadoes, and flooding. Studies by Smull and Houze (1985) and others have shown that most MCSs consist of a leading convective line followed by a more expansive region of stratiform rain. Oftentimes, a transition zone of light precipitation exists between these two regions.

The trailing stratiform region develops as a result of rearward hydrometeor advection within the front-to-rear flow aloft (Rutledge and Houze 1987, Smull and Houze 1987a). Processes in this region have been shown to play a significant role in controlling MCS evolution. Weisman and Rotunno's (2004) modeling efforts showed that the strength of the cold pool generated below the stratiform region impacts the strength and longevity of the MCS itself. Weisman's (1992) numerical simulations demonstrated that the descent of rear-to-front flow, or the rear-inflow jet, within the stratiform region is also an important factor in determining the strength and longevity of MCSs. However, Weisman notes that one major limitation to his study is the lack of ice-phase microphysics in his model. Studies by Rutledge and Houze (1987), Fovell and Ogura (1988), and Tao and Simpson (1989) demonstrated that ice-phase microphysics are crucial to the production of a realistic stratiform region. Furthermore, studies by Zhang and Gao, Yang and Houze (1995a) and Braun and Houze (1996b) suggested that ice-phase microphysics are important to the intensity and descent of the rear-inflow jet.

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During the Bow Echo and Mesoscale Vortex Experiment (BAMEX), the NOAA-P3 aircraft executed sixteen Lagrangian spiral descents advecting with the ambient wind, collecting in-situ microphysical data to characterize the vertical variability of hydrometeor shapes, sizes and phases in the stratiform regions behind mesoscale convective systems (MCSs). The NOAA P-3 aircraft was also equipped with an X-band Doppler radar, which yielded high resolution measurements of reflectivity and Doppler velocity for all cases. This presentation focuses on understanding the observed variations in vertical microphysical profiles in the context of airborne radar data. Specifically, we examine how derived microphysical quantities such as total number concentration and the slope of fits to size distributions change with respect to the spirals' locations within the three precipitation zones, the rear inflow jet, and the time evolution of an MCS.

2. METHODOLOGY

In order to better compare and contrast the information garnered from the spiral descents, each spiral was examined in the context of a general trailing stratiform MCS evolution, as outlined by the works of Smull and Houze (1985, 1987), Parker and Johnson (2000) and others. As described in these studies, a very common MCS evolution is one in which the system begins as a line of convective cells that then develop into a continuous line of convection in which precipitation begins to spread rearward to form the trailing stratiform region. As the system matures, a transition zone emerges and the trailing stratiform region widens to several times that of the convection. Eventually, the convection dissipates and a weak stratiform region remains. The majority of BAMEX cases in which spiral descents were performed followed this general pattern of evolution.

When examined in this manner, it is evident that the spiral descents were performed in a variety of different locations and times within the MCS life cycle. Figure 1 shows the locations of all sixteen spirals relative to a "typical" MCS evolution (in this example, the 4 July 2003 bow echo represents the general MCS with trailing stratiform precipitation). As shown in panels C and D, two spirals were performed in the early stages of an MCS. Two more spirals were executed during the formation of bow echoes (panel E), and several more spirals occurred during the mature and dissipating stages of MCSs, as depicted by panels G and H. It is also important to note that in five MCSs, two spirals were flown at different times, allowing for an examination of microphysical changes across time within the same case.

Figure 1 also illustrates the variety of locations of the spiral descents. Many were executed quite close (only 15km from high reflectivity cores) to the convective line (panel C), while others were performed well rearward within the stratiform region (panel F). Figure 2 depicts these variations within a conceptual cross section of a trailing stratiform MCS.

These variations in spiral timing and location allow for an examination of microphysical trends across the MCS lifetime, which is discussed in the following section, as well as the development of a conceptual model of the microphysical structure of the trailing stratiform region, which is part of our future work.

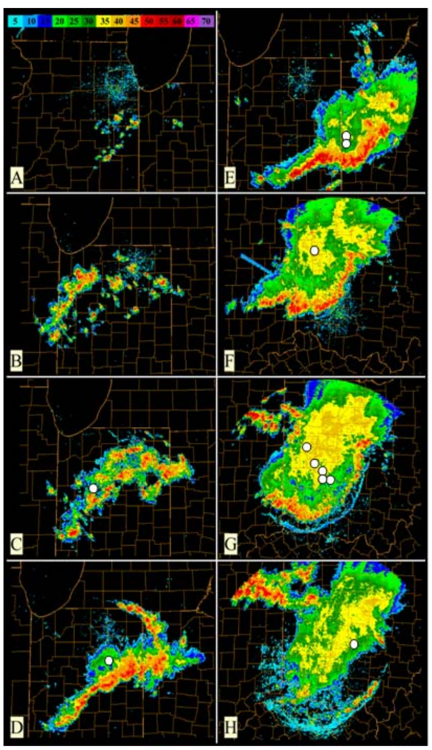

Figure 1: Radar representation of a typical trailing stratiform MCS evolution (actual 4 July 2003 MCS radar). Panel A is time of convective initiation. White circles denote the approximate areas in which BAMEX spiral descents were performed within MCSs.

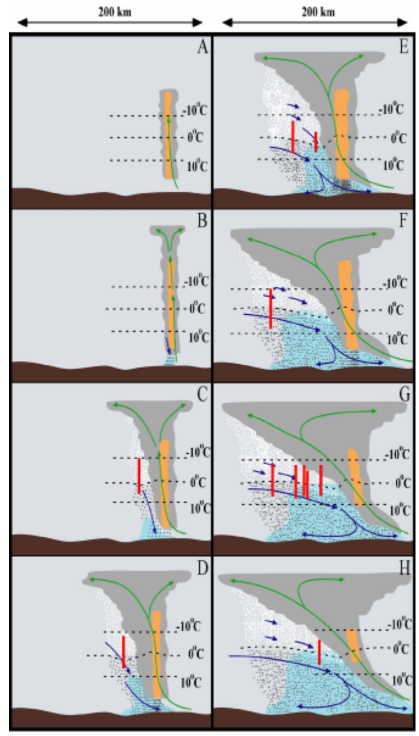

Figure 2: Conceptual cross section of a typical trailing stratiform MCS. Panels correspond to those in figure 1. Red rectangles denote the approximate areas in which BAMEX spiral descents were performed within MCSs. Gray shading denotes cloud, orange shading denotes convective cores, white stippling denotes ice, black stippling denotes rain and arrows denote general flow.

3. MICROPHYSICAL OBSERVATIONS

The in-situ microphysical data have been processed to show the vertical variation of phase, particle shape, total mass content, total number concentration and the shape of the size distributions. Most spiral descents yielded relatively comparable values (between 1.4 g m^{-3} and 2.2 g m^{-3}) of total water content, regardless of their timing relative to the age of the MCS and their proximity to the convective line. The first spiral conducted on 29 June 2003 was different, with a total water content of only 0.69 g m^{-3}. All values were significantly larger than those obtained from measurements in tropical squall lines and tropical cyclones, and may be due to the proximity of the measurements to the convective line. Total number concentration was also comparable (between .04 m^{-3} and .09 m^{-3}) between all spirals except, again, for the first spiral from the 29 June 2003 case, which was an order of magnitude less than all others. The uniqueness of the 29 June case is due to the position of the spiral descent (see panel C above) within a downdraft with highly sub-saturated conditions. This case is examined in-depth by Grim et al (2005).

While the aforementioned bulk properties did not show a great amount of variation between spirals, there is an evident change in the slope of the gamma fits to the size distributions across the MCS lifetime. The slope parameter generally increased with the age of BAMEX MCSs. As can be seen in figure 3, the value of the slope parameter was only around 5 for those spirals conducted early in the MCS lifetime (panels C – F). Except for the first spiral from IOP17, the spirals in these panels were conducted in subsaturated conditions, where small crystals evaporated. The removal of small crystals flattened the slope of the distribution, leading to the low values values. As the MCSs matured, the relative humidity increased in the trailing stratiform regions, preventing small crystals from sublimating/evaporating and increasing the slope parameter. Changes in the relative humidity and hence, the slope parameter, may also be tied into the location of the spirals within the rear inflow jet, where entrainment of drier air may be occurring. Investigations using P-3 dual and quad-Doppler scans are ongoing to determine the placement of the spirals with respect to the axis and elevation of the rear inflow jet.

A		E	
		7s1	4.78
		17s1	15.8
B		F	
		7s2	4.61
C		G	
14s1	4.90	9s1	7.44
		16s1	10.38
		17s2	10.60
		18s2	10.11
		18s3	15.5
D		H	
4s2	6.64	13s1	6.67

Figure 3: Panels correspond to those in figures 1 and 2. IOP number followed by the spiral number (1 denoting the first spiral conducted during the case, and 2 the second) are listed in the left-hand column, while the corresponding values of the slope parameter averaged between the top of the spiral and 0°C are listed to the right.

In addition to microphysical variations due to spiral timing and location, there are significant microphysical variations *within* many of the spirals. Figure 4 depicts the inhomogeneity of the total number concentration in the second spiral conducted on 02 June 2003. Upon examination of the color-shaded concentration, it is obvious that there is a regular pattern in which the concentration maxima appear followed shortly thereafter by minima. This corresponds approximately to a 5-minute cycle, which is the time it takes for the NOAA-P3 to complete one turn of a 5km radius spiral descent. These variations are almost certainly due to the aircraft spiraling into heavier precipitation close to the convective line and out of it again toward lighter stratiform precipitation. Future work involves examining all intra-spiral inhomogeneities against P-3 radar reflectivity cross sections to determine the magnitude of the change in microphysical parameters between the stratiform region and heavier convective areas.

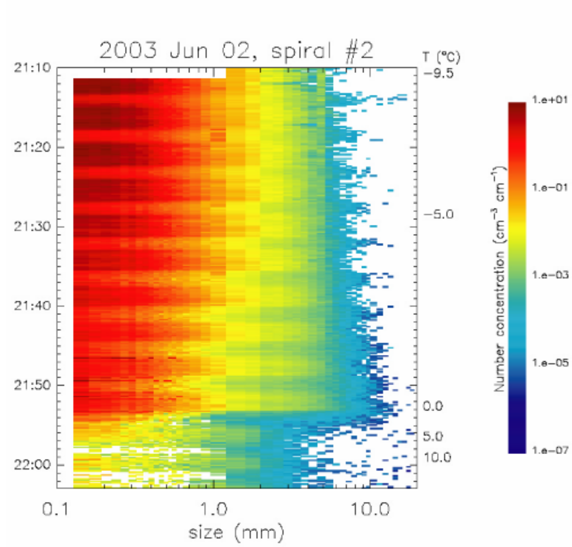

Figure 4: Number concentration from 2DC (D < 1200 μm) and 2DP (D > 1200 μm) as function of time and temperature for second spiral conducted on June 2, 2003 between 2110 and 2203 UTC.

4. SUMMARY AND FUTURE WORK

A majority of the BAMEX MCSs in which spirals were conducted were similar to trailing stratiform MCSs documented by the previous works of Smull and Houze (1985, 1987), Parker and Johnson (2000) and others. Spiral descents were executed during a variety of times in MCS lifecycles and in a variety of locations throughout the trailing stratiform regions of those BAMEX cases that followed the typical patterns of the aforementioned studies. These variations in spiral timing and location revealed that total water content and total number concentration were roughly comparable across all of the spirals. The values of the slope of gamma fits to size distributions generally increased across the MCS life cycle due to increasing relative humidity as the stratiform region became more established. This prevented small crystals from evaporating and sublimating, and steepened the slopes of the distributions. Microphysical trends within localized areas were also expressed, as number concentrations changed while the aircraft spiraled into and out of regions of heavier precipitation near the convective line. These and other variations and their causes will be investigated more closely in the future through the examination of P-3 tail radar cross sections and dropsonde data.

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REFERENCES

Braun, S. A., and R. A. Houze, Jr., 1996b: The Heat Budget of a Midlatitude Squall Line and Implications for Potential Vorticity Production. *J. Atmos. Sci*., **53**, 1217–1240.

Fovell, R. G., and Y. Ogura, 1988: Numerical simulation of a midlatitude squall line in two dimensions. *J. Atmos. Sci*., **45**, 3846–3879.

Parker, M. D., and R. H. Johnson, 2000: Organizational modes of midlatitude mesoscale convective systems. *Mon. Wea. Rev.,* **128**, 3413–3436.

Grim, J.A., Rauber, R.M., McFarquhar, G.M., Jorgensen, D.P., Timlin, M.S, Jewett, B.F., and Smith, A.M., 2005: Quad-Doppler and Microphysical Observations of the BAMEX 29 June 2003 MCS. Preprints*, 32nd Conference on Radar Meteorology,* Albuquerque, N.M., USA, Amer. Meteor. Soc.

Rutledge, S. A., and R.A. Houze, Jr., 1987: A diagnostic modeling study of the trailing stratiform region of a midlatitude squall line. *J. Atmos. Sci*., **44**, 2640-2656.

Rutledge, S. A., R. A. Houze, M. I. Biggerstaff, and T. Matejka, 1988: The Oklahoma-Kansas mesoscale convective system of 10-11 June 1985: Precipitation structure and single-Doppler radar analysis. *Mon. Wea. Rev.,* **116,** 1409-1430.

Smull, B. F., and R. A. Houze, Jr., 1985: A midlatitude squall line with a trailing stratiform region of stratiform rain: radar and satellite observations. *Mon. Wea. Rev*., **113**, 117-133.

Smull, B. F., and R. A. Houze, 1987: Dual-Doppler radar analysis of a midlatitude squall line with a trailing region of stratiform rain. *J. Atmos. Sci.,* **44,** 2128–2149.

Tao, W.-K., J. Simpson, 1989: Modeling study of a squall-type convective line. *J. Atmos. Sci*., **46**, 177-202.

Weisman, M. L., 1992: The role of convectively generated rear-inflow jets in the evolution of long-lived mesoconvective systems. *J. Atmos. Sci.,* **49,** 1826-1847.

Yang, M.-H., and R. A. Houze, 1995: Sensitivity of squall-line rear inflow to ice microphysics and environmental humidity. *Mon. Wea. Rev.,* **123,** 3175–3193.

Zhang, D.-L., and K. Gao, 1989: Numerical simulation of an intense squall line during 10 – 11 June 1985 PRE-STORM. Part II: Rear inflow, surface pressure perturbations and stratiform precipitation. *Mon. Wea. Rev.,* **117,** 2067-2094.