P3.5 22 JUNE 2003 BAMEX OBSERVATIONS OF A CONVECTIVE LINE WITH PARALLEL PRECIPITATION

Eve A. Halligan* and Matthew D. Parker
University of Nebraska-Lincoln, Lincoln, Nebraska

1. INTRODUCTION AND BACKGROUND

Linear Mesoscale Convective Systems (MCSs) are an important source of precipitation and severe weather in the Plains. Unlike individual thunderstorms, MCSs impact a large geographic region, and the degree of severe weather and amount of precipitation that they produce is related to their organizational modes and speeds. Previous research by Parker and Johnson (2000) identified three commonly-observed linear MCS organizational modes, consisting of a main convective line with either leading (LS), parallel (PS), or trailing (TS) stratiform precipitation regions (Figure 1).

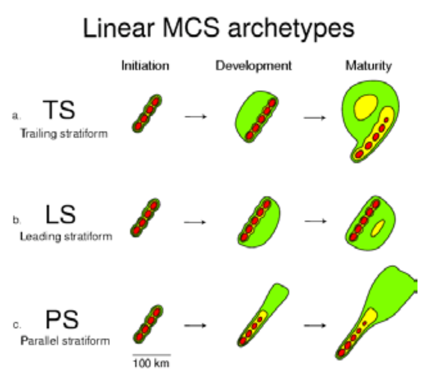

Figure 1. Schematic reflectivity drawing of idealized life cycles for three linear MCS archetypes: (a) TS, (b) LS, and (c) PS (Parker & Johnson, 2000).

Very few detailed studies of PS systems have been undertaken. It is extremely important that these systems are studied more thoroughly in order to better understand their processes and to improve prediction. On June 22, 2003 from approximately 0215 UTC to 0700 UTC a PS system which evolved into a TS system was sampled by the Bow Echo and MCV Experiment (BAMEX) over North and South Dakota. The system consisted of three distinct regions along its convective line during its lifespan (Figure 2). Region A, located in North Dakota, was an area of older convection, with a distinctly TS mode of organization. Region B, which was most extensively sampled by BAMEX, consisted of a mature convective line with little to no attendant stratiform precipitation and displayed some PS characteristics. Finally, region C consisted of the southernmost area of the MCS, which also possessed TS precipitation. This study focuses on region B, which had characteristics of the PS archetype.

Previous observational work by Parker and Johnson (2000) provided insight into the environments associated with PS MCSs (Figure 3). These flow structures include a large line-perpendicular component at the low levels, and increasing line-parallel flow throughout the troposphere, with a large line-parallel and small line-perpendicular component in the upper levels. Despite these advances, the dynamics and flow structures within the PS mode of linear MCS are still poorly understood.

In order to address the structure of the PS mode of MCS, airborne radar and soundings will be used. These observations will also be used to evaluate causes for the evolution of the PS mode into the TS mode, as this is a common occurrence for PS systems. This paper will focus on the storm's evolving structure from 0245 UTC to 0450 UTC, the time during which the system had PS characteristics and was well-sampled by BAMEX.

2. DATA

The NRL P-3 ELDORA airborne radar was utilized on the day under investigation. These data provide high temporal and spatial resolution of the storm flow structure through dual-doppler analysis. The following three distinct flight legs are utilized by this study: 0257-0320 (0310) UTC, 0320-0350 (0320) UTC, and 0435-0450 (0440) UTC. These three time frames display the evolution of Region B from PS to TS system.

GLASS soundings were released from one primary location in the system's path during the times of interest (denoted by 'G' in Figure 2). The soundings were taken approximately hourly. These data are used to depict the storm-relative flow and vertical wind shear near the system, as well as the thermodynamic environment. The 0000 UTC operational sounding from Aberdeen, South Dakota was also utilized for this study. For more information about data available from BAMEX, see Davis et al. (2004).

3. BACKGROUND ENVIRONMENT

During the late hours of 21 June 2003, a cold front advanced eastward across North and South Dakota

* Corresponding author address: Eve A. Halligan, 210 Bessey Hall, University of Nebraska – Lincoln, Lincoln, NE 68588
email: halligan3@earthlink.net

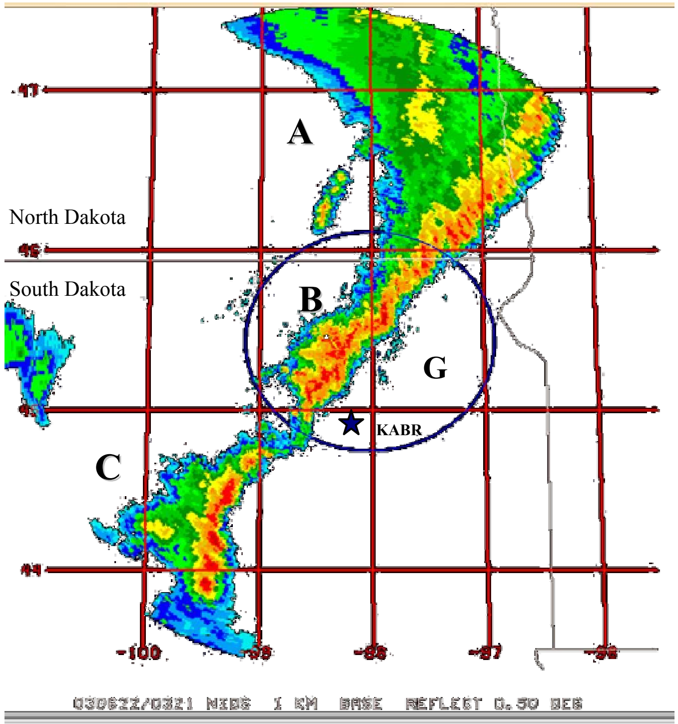

Figure 2. Composite radar reflectivity (dBZ) at the time period 0310 UTC from WSR-88D radars. A, B (circled), C represent the MCSs' three distinct regions, G represents the approximate location of the GLASS soundings, and the star represents the location of Aberdeen, South Dakota (KABR).

ahead of an upper level shortwave trough and in a region of low level warm air advection (not shown). Supercell storms formed along the frontal boundary by 2030 UTC, with the main convective line forming over ND and SD by 2230 UTC. The system developed into a PS linear MCS around 2230 UTC, and by approximately 0000 UTC the northern part of the system, region A, had evolved into a TS MCS with a significant area of stratiform precipitation developing by 0230 UTC.

The environment was quite unstable ahead of the system, with convective available potential energy (CAPE) of 4559 J kg^{-1} and a lifted index (LI) of -13 based on the 0000 UTC Aberdeen sounding (KABR, Figure 4a). There was a moderate amount of wind shear in the environment prior to MCS passage with a 0-3 km line-perpendicular vector wind difference of 14 m s^{-1} (0000 UTC KABR sounding). Thus, the environment was very unstable, with a moderate amount of wind shear to aid in the organization of the MCS along the cold front.

4. STORM STRUCTURE AND SHEAR

By 0245 UTC 22 June 2003, the linear MCS comprised several distinct regions. North of approximately 46ºN latitude, the system had TS structure with a large stratiform region following the bowing convective line (Figure 2), whereas south of 46ºN in region B, the MCS retained PS characteristics. By the 0440 UTC flight leg, the entire system was displaying a TS mode of organization. Observations of region B during its mature and transitional stages are used to illustrate its basic structure and evolution. In this section, data from 0310, 0320, and 0440 UTC are examined and related to the observed environmental conditions, with particular interest in the environmental shear and pre-system flow during its evolution.

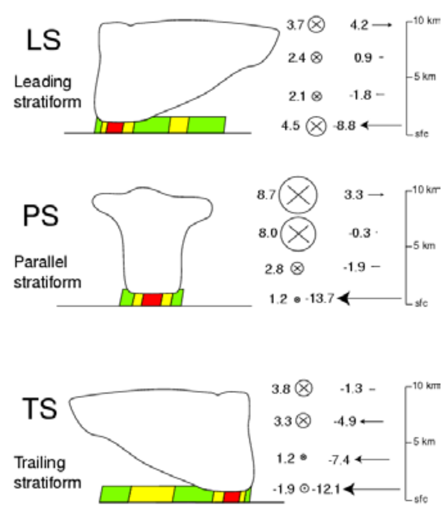

Figure 3. Vertical profiles of layer-mean storm-relative pre-MCS winds for linear MCS classes. Wind vectors depicted as line parallel (circled x's) and line perpendicular (arrows) components in m s^{-1}. (Parker & Johnson, 2000).

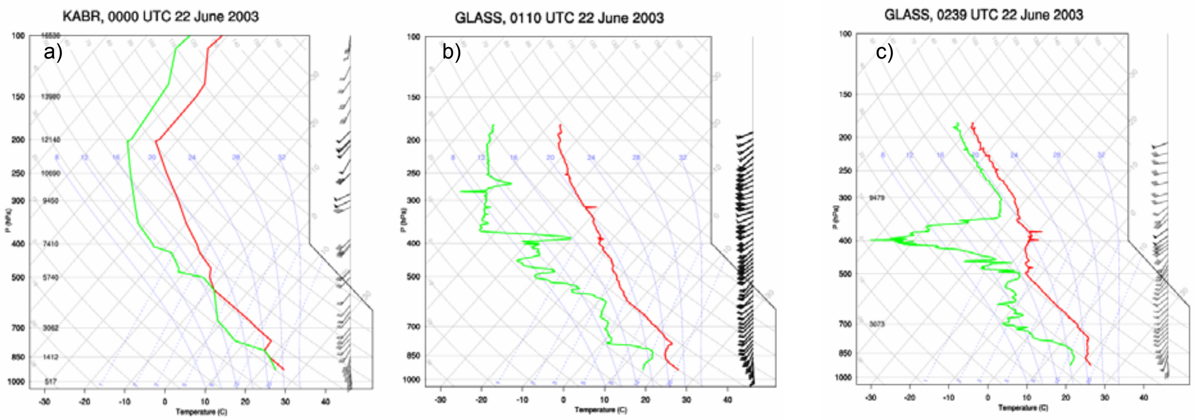

Figure 4. Skew T-ln p plot of rawinsonde observation from: (a) 0000 UTC 22 June 2003, KABR; (b) 0110 UTC 22 June 2003, GLASS; (c) 0239 UTC 22 June 2003, GLASS: flag=25 m s^{-1}, full barb=5 m s^{-1}, half barb=2.5 m s^{-1}.

4.1 STORM-RELATIVE PRE-SYSTEM FLOW

Environmental shear and pre-system flow values were computed from the 0000 UTC KABR, 0110 UTC GLASS, and 0239 UTC GLASS soundings (Figure 4). These soundings were located within region B of the system.

The along-line flow becomes more dominant the higher in the system that one goes. Central to the development of a stratiform region of precipitation in a linear MCS is the layer of bulk hydrometeor transport within the system, which Rutledge and Houze (1987) found to be focused in the 5 – 8 km layer. Within this layer, the 22 June MCS displays a combination of line-perpendicular and line-parallel flow with the line-parallel flow becoming more dominant within the 5 – 8 km layer (Table 1). This may account for the lack of trailing stratiform precipitation during the 0310 and 0320 UTC flight legs in region B.

4.2 0310 & 0320 UTC NRL P-3

The NRL P-3 radar sampled region B of the system during the 0310 UTC and 0320 UTC flight legs (Figure 7 a & b). The 0310 UTC flight took place from 0257 to 0320 UTC, and the 0320 leg from 0320 to 0350 UTC. Unfortunately, the aircraft did not reach the system until approximately 0215 UTC, thus data were not collected for the MCS earlier in its development. For this reason, the 0310 and 0320 UTC legs display very similar structure. At low levels, the system experienced front-to-rear inflow ahead of the convective line, with significant convergence along the convective line below 5 km AGL (Figure 7 a & b). Vertical cross sections were taken perpendicular to the convective line in order to examine the storm structure and flow (Figures 8 & 9).

The fact that the environment possessed deep along-line flow in addition to moderate low-level line-perpendicular shear on 22 June 2003 (Figures 5 & 6) suggests that the PS archetype should have been the

Table 1. Pre-MCS storm-relative line-parallel & perpendicular wind averages for a) 0000 UTC KABR, b) 0110 UTC GLASS, and b) 0239 UTC GLASS.

	Layer (km AGL)	Perpendicular (m s^{-1})	Parallel (m s^{-1})
a)			
	8 – 10 km	-2.5	17.9
	6 – 8 km	-2.5	16.2
	4 – 6 km	-1.5	9.8
	2 – 4 km	-7.3	6.9
	0 – 2 km	-16.2	12.4
b)	Layer (km AGL)	Perpendicular (m s^{-1})	Parallel (m s^{-1})
	8 – 10 km	5.0	15.3
	6 – 8 km	-2.6	12.9
	4 – 6 km	-4.4	6.2
	2 – 4 km	-5.6	5.3
	0 – 2 km	-15.6	11.4
c)	Layer (km AGL)	Perpendicular (m s^{-1})	Parallel (m s^{-1})
	8 – 10 km	-0.8	10.0
	6 – 8 km	-3.4	14.5
	4 – 6 km	-4.5	4.6
	2 – 4 km	-5.2	4.6
	0 – 2 km	-14.3	13.1

favored mode of linear MCS on this day. PS MCSs generally exhibit significant low-level line-perpendicular shear, as observed by Parker and Johnson (2000, Figure 3). This suggests that, if a PS system is to evolve toward TS structure, a strong surface cold pool must develop in order to overcome the low level shear (e.g., Rotunno et al., 1988).

The updrafts during the mature phase of development exhibit both a jump and an overturning updraft (Figures 8 & 9). The updrafts within the line exhibit significant depth. This is not surprising considering the extreme instability (high CAPE) of the environment. The flow within the updrafts has both a line-perpendicular and a line-parallel component, such that the system is quite 3-

dimensional (Figure 8). Interestingly, the cell motion during the time frame is primarily along the convective line. Therefore, precipitation moves along the line and falls through the active low-level updrafts. Because of this structure, the cold pool would be expected to strengthen quickly. Due to the high values of CAPE and dryness of the pre-storm environment (Figure 4), the potential to develop a strong cold pool rapidly is high. The rapid development of a strong surface cold pool would suggest a rapid evolution of the original PS system into a TS MCS, which indeed occurred as time progressed.

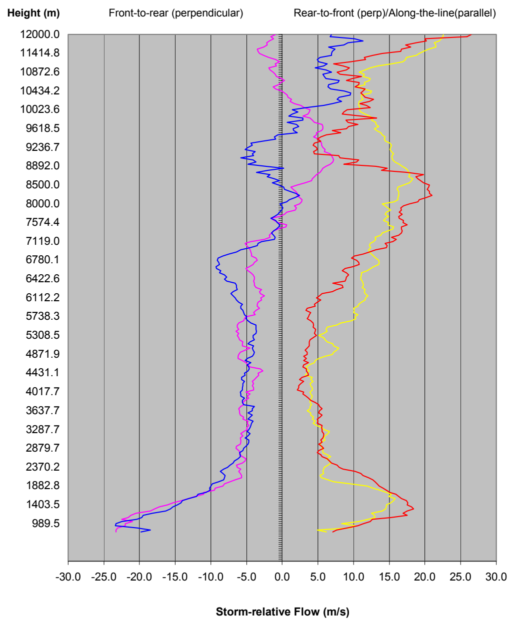

Figure 5. Vertical profile of storm-relative line-perpendicular (light purple – 0110 UTC; blue – 0239 UTC) and line-parallel (yellow – 0110 UTC; red – 0239 UTC) winds.

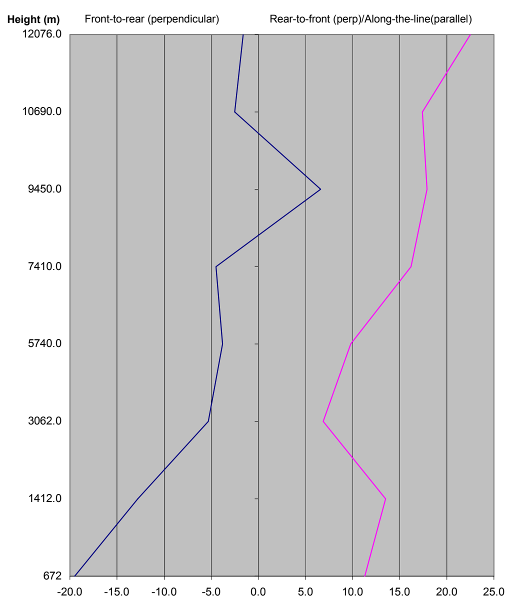

Figure 6. Vertical profile of storm-relative line-perpendicular (blue) and line-parallel (light purple) winds for 0000 UTC KABR.

4.3 0440 UTC NRL P3

The NRL P-3 radar again sampled region B over western Minnesota from 0435 – 0450 UTC (0440 UTC leg) (Figures 7c, 10). The small, bow-like features within the line were much less pronounced by 0440 UTC, and the entire system had evolved toward the TS mode of organization. The updrafts' common feature during this time is a pronounced jump updraft, with little overturning (Figure 10). The updrafts are much more 2-D at this stage of development. The cell motion still exhibits a significant along-line component, but the system-relative winds are primarily front to rear. Two separate reflectivity cores are present in cross section G. This is likely due to the advection of older updrafts rearward over the cold pool over time, as newer updrafts developed on the leading edge of the outflow. As a result of this structure, the TS precipitation region continued to develop. Future research will concentrate on differences in the observations at 0310, 0320, and 0440 UTC in order to better understand and explain the governing dynamics of the PS system, as well as the frequently-observed evolution of this linear MCS archetype into the TS mode. As mentioned earlier, rapid intensification of the surface cold pool seems a likely culprit, and may be especially important in PS systems because much of their precipitation falls in close proximity to their outflow boundaries. Therefore, our ongoing work will also examine the influence of the along-line cell motion, especially the implications of precipitation falling through the updrafts of cells other than its cell of origin.

5.0 CONCLUDING REMARKS

On 22 June 2003, a PS linear MCS was sampled by BAMEX as it evolved into a TS system. The high spatial and temporal resolution, as well as quality of the data allowed for the structure of the system to be examined and described during its transitional and dissipating stages. The conceptual model for long-lived squall lines proposed by Rotunno et al. (1988) seems to explain the observed system quite well. The evolution of the system appears to rely on the rapid development of a strong surface cold pool in the high-CAPE environment. The movement of cells along the line caused the precipitation to fall and evaporate in close proximity to the surface outflow boundary, thereby intensifying the cold pool where it matters most. Although there was significant line-parallel flow throughout a large depth of the troposphere (Figure 4), the PS mode was not likely to be long-lived because the low level line-perpendicular shear was insufficient to balance the rapidly strengthening cold pool. Our ongoing work will focus on a detailed understanding of the unique convective scale dynamics in this quasi-PS system, as well as the possible causes for system evolution toward the TS archetype.

ACKNOWLEDGEMENTS

The authors would like to acknowledge Dave Jorgensen for his assistance with the airborne radar data. The research reported here is supported by the National Science Foundation under grant ATM-0349069.

REFERENCES

Davis, C., and coauthors, 2004: The Bow Echo and MCV Experiment (BAMEX): Observations and opportunities. *Bull. Amer. Meteor. Soc.*, in press.

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

Rotunno, R., J.B. Klemp, and M.L. Weisman, 1988: A theory for strong, long-lived squall lines. *J. Atmos. Sci.,* **45,** 463-485.

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.

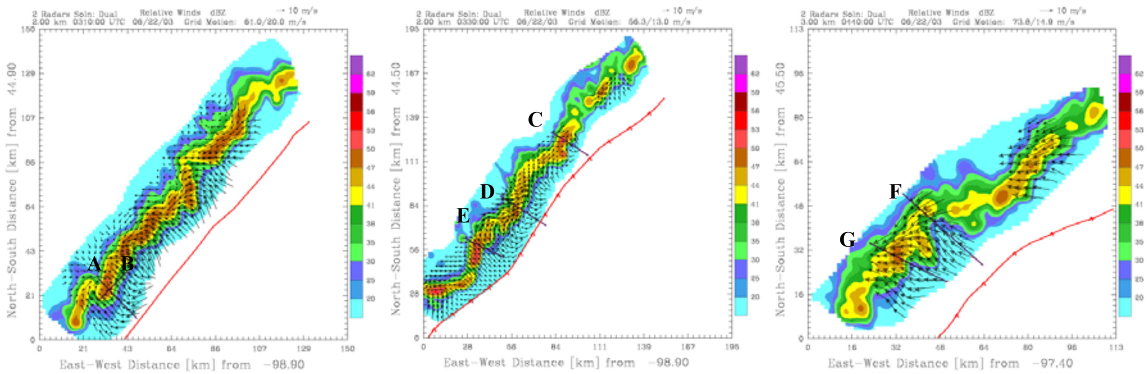

Figure 7. Horizontal analysis of radar reflectivity and system-relative wind flow for (a) 0310 UTC at 2 km, (b) 0320 UTC at 2 km, and (c) 0440 UTC at 3 km.

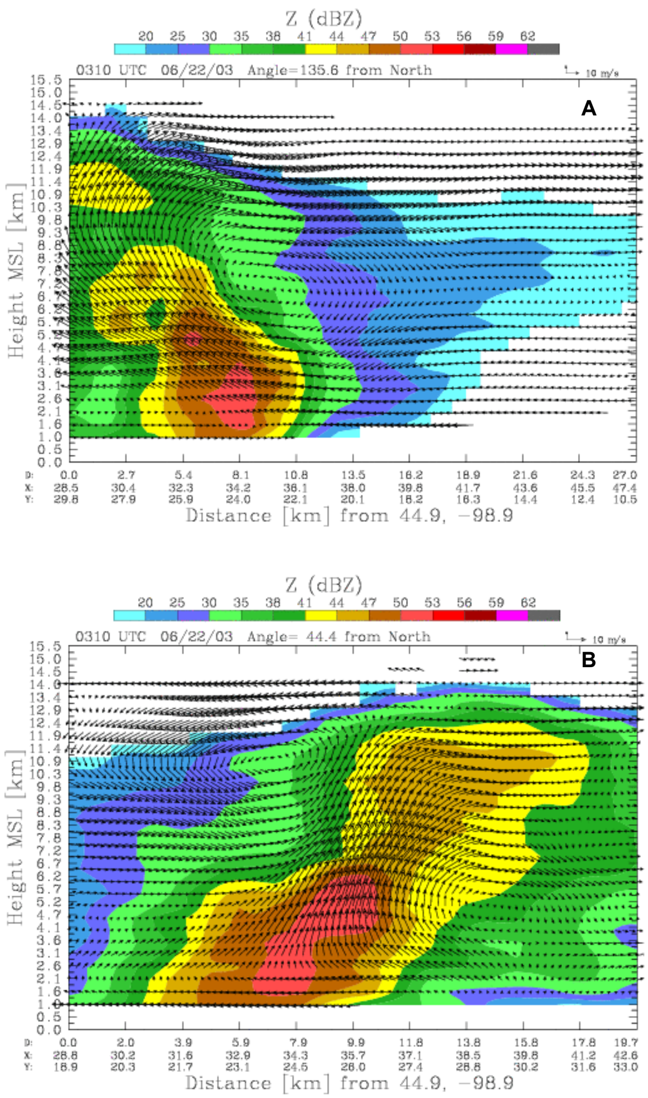

Figure 8. Vertical cross section of reflectivity and system-relative wind through corresponding lines in Figure 7*a* for 0310 UTC. A) line-perpendicular section; B) line-parallel section.

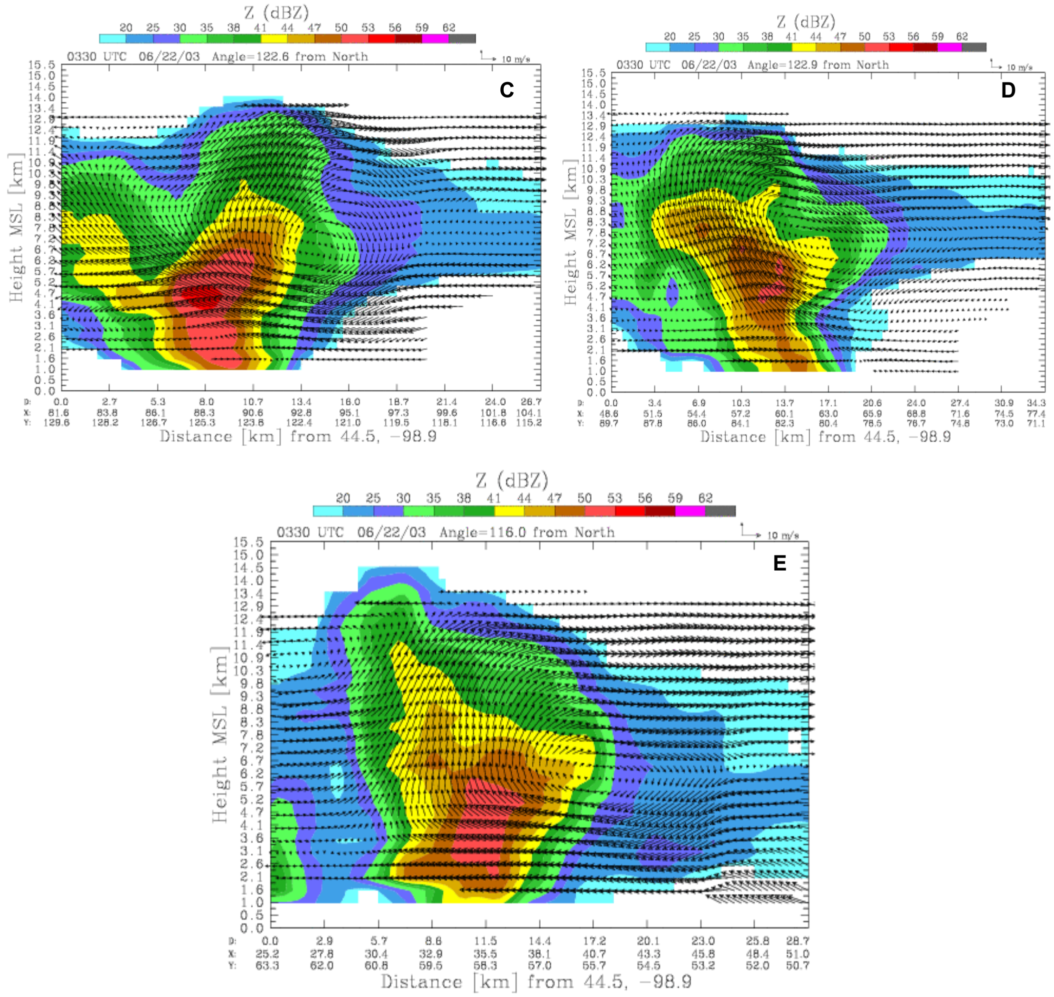

Figure 9. Line-perpendicular vertical cross sections of reflectivity and system-relative wind through corresponding lines in Figure 7b for 0320 UTC.

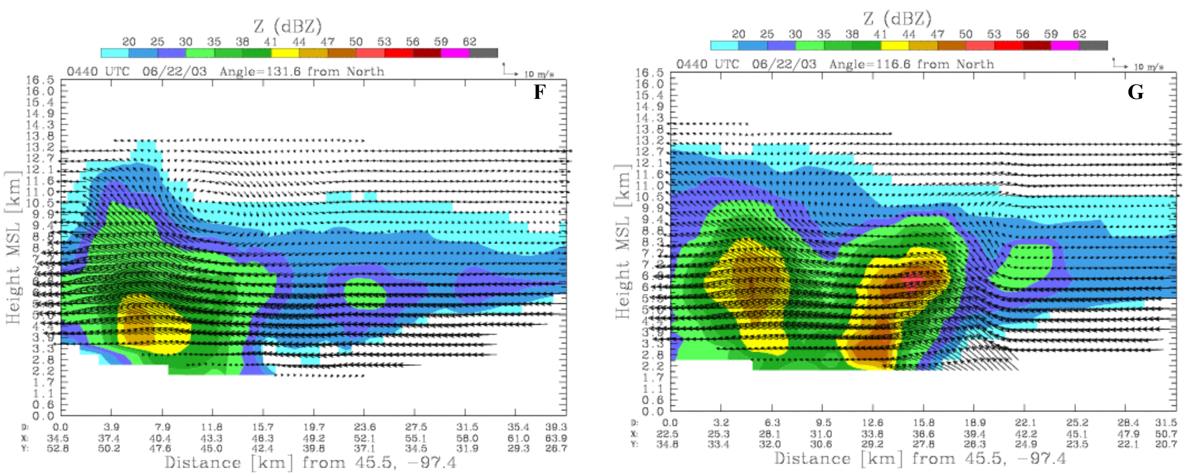

Figure 10. Line-perpendicular vertical cross sections of reflectivity and system-relative winds through corresponding lines in Figure 7c for 0440 UTC. Reflectivity and vertical air motion contour scale and the 10 m s⁻¹ scaling vector for winds are shown above.