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A SINGLE DOPPLER ANALYSIS OF A MIDWESTERN QUASI-LINEAR MESOSCALE CONVECTIVE SYSTEM ACROSS CENTRAL IOWA ON 29 JUNE 1998

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1. INTRODUCTION

During the early afternoon of 29 June 1998, a severe quasi-linear (QL) squall line traversed central Iowa producing widespread straight-line wind damage (gusts exceeding 50 m s^{-1}) and several weak to moderate tornadoes (F0--F2) (Fig. 1). During the mesoscale convective system's (MCS) beginning stages, the overall storm complex contained several embedded hybrid high-precipitation (HP) supercells.

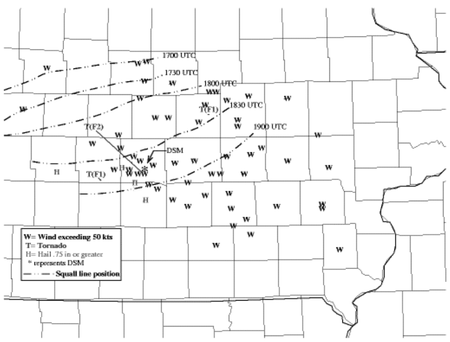

Figure 1. Damage map illustrating the locations of severe weather events and squall line position across central Iowa.

This study examined high-resolution level II reflectivity and single-Doppler velocity data from the Des Moines, Iowa WSR-88D radar site (KDMX). The first part of this paper focuses on the complex storm morphology and velocity structures as the system approached the Des Moines metropolitan area. Specifically, the evolution of one particularly intense portion of the convective line that contained a hybrid HP supercell will be examined in detail. This embedded hybrid HP supercell and its associated storm-scale cyclonic circulations were responsible for a nearly continuous swath of severe straight-line wind damage and a moderate intensity tornado (F2).

The second part of this paper will capitalize on the proximity of a tornadic mesocyclone to the KDMX radar site. The low-level velocity structure of the tornadic mesocyclone was examined in detail and the observations will be compared with those documented by Burgess and Magsig (1998; hereafter BM98) who examined several tornadic vorticies at close ranges to a WSR-88D Doppler radar.

2. PAST STUDIES

Much of the recent research involving the evolution of QL convective reflectivity structures and circulation characteristics has focused on the mature stage of MCS evolution (e.g., Heinlein et al. 1998; Van DeWald et al. 2000). Other studies have examined bow echoes during both the intensifying and mature stages (e.g., Schmocker et al. 1998). The present study examines the reflectivity structure and circulation evolution during the intensifying and early part of the mature stage of MCS evolution (pre-bow echo and early stages of bowing). Thus far, there are a limited number of studies that focus primarily on this portion of QL MCS evolution.

3. PRE-CONVECTIVE ENVIRONMENT

The 1200 UTC 29 June pre-convective environment played an important role in the initiation and sustenance of the convective system line. The mid- and upper-level flow was nearly zonal with a 60 m s^{-1} 300 hPa jet streak located over South Dakota and Minnesota. The flow at 850 hPa was southwesterly, with an 18 m s^{-1} low-level jet extending from the Oklahoma panhandle into south-central Nebraska. This low-level jet was responsible for the transportation of high θe air northward into the region of severe convection (See Fig. 2).

Convection initiated in northeast Nebraska underneath the right entrance region of the 300 hPa jet streak and just north of a surface warm front. The large convective system moved east-southeastward along a nearly stationary surface boundary that stretched from east--central Nebraska through central Iowa and into northwest Illinois. Surface dew points of 20 to 25 $\circ$C pooled alongside and to the south of this boundary, thus resulting in a region of highly unstable air. The 1200 UTC upper-air sounding taken from Valley, Nebraska (OAX) depicted the max θe CAPE to be 3325 J kg^{-1} (not shown).

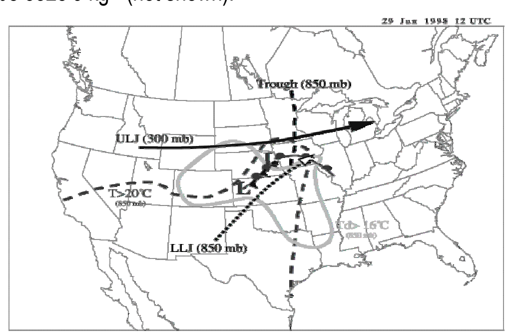

Figure 2. Composite map indicating important synoptic and mesoscale features in place at 1200 UTC 29 June 1998.

The Slater, Iowa wind profiler (Fig. 3) indicated that between 1200 and 1700 UTC, the vertical wind shear (VWS) evolved into a broadly--curved, strongly--sheared profile that suggested the convective mode may be supercellular in nature. During this same time period, the 0-3 and 0-6 km bulk shear magnitudes had increased to 12 and 30 m s^{-1}, respectively.

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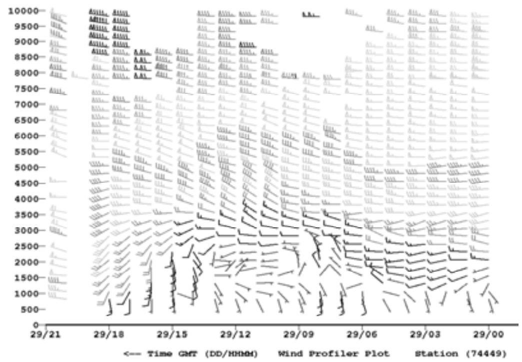

Figure 3. Slater, Iowa wind profiler for 29 June 1998.

4. STORM SCALE STRUCTURE AND EVOLUTION

Examination of the overall QL MCS reflectivity structure at 1716 UTC revealed a cluster of organized deep convective storms stretching from 120 km northeast of KDMX to 80 km north of OAX (Fig. 4). At this time, three discrete cells located to the west and northwest of KDMX were found to contain persistent rotating centers (Storms A, B, and C labeled in Fig. 4). In each of these storms, the mesocyclones (Andra 1997) originated at mid-levels, similar to observations recorded by Burgess et al. (1982). The remainder of this paper will focus on the evolution of one particularly intense portion of the convective system (Storm B) and its associated circulations as it approached KDMX from an initial range of 100 km.

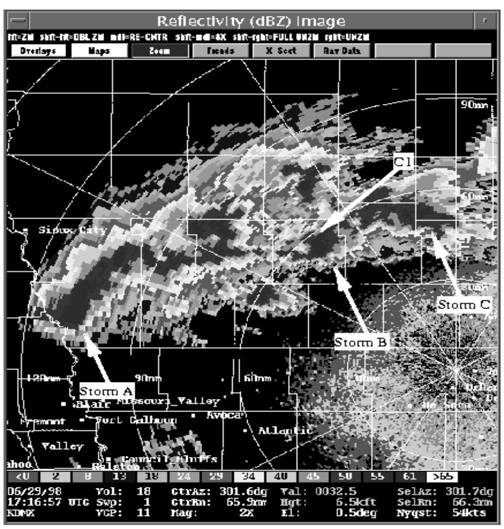

Figure 4. WSR-88D PPI reflectivity display at the 0.5° elevation angle for 1716 UTC 29 June 1998.

At 1716 UTC, a reflectivity cross section, which was oriented perpendicular to the leading edge of Storm B (not shown), revealed a nearly vertical convective tower extending to a height of approximately 15 km. This observation is consistent with those made by RR93 during the intensifying stage of MCS evolution, as well as Weisman's Stage II of bow echo evolution (tall echo stage). RR93 noted that during this stage of MCS evolution, the cells at the leading edge grow to their greatest vertical extent and the convective updrafts attain their highest updraft speeds. Weisman (1993) found that during Stage II, strong, erect updrafts are produced as a result of the balance attained between the cold outflow and the ambient VWS.

Figure 5 depicts the durations and documented paths of three of the storm-scale cyclonic vortices associated with Storm B that were examined in detail for this study.

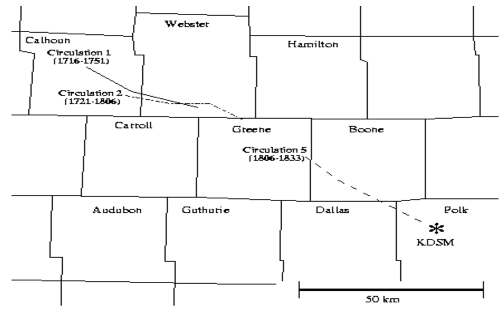

Figure 5. Map of central Iowa designating the tracks of C1, C2, and C5.

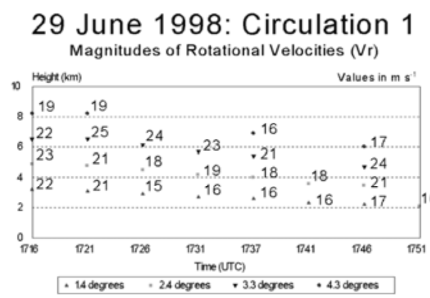

Figure. 6 Plot of height (in km) versus time of Vr values for C1.

The first storm-scale cyclonic circulation associated with Storm B (C1) was detected at 1716 UTC between 3.5 and 8 km above ground level (AGL) (see Fig 4). At this time, C1's maximum Vr of 23 m s^{-1} was located approximately 5 km AGL and it maintained a consistent diameter of 5 km throughout its depth (Fig. 6). At an initial range of 100 km, C1 immediately met the criteria of a strong mesocyclone (Andra 1997). These observations are consistent with Burgess et al. (1982) who showed that vortices associated with supercells originated at the storm's mid-levels. C1 was initially detected in the vicinity of a weak echo region (WER) on the leading edge of the Storm B. Between 1716 and 1737 UTC, C1 maintained a diameter of approximately 5 km as well as consistently stronger shear magnitudes between 5 and 7 km AGL. After 1741 UTC, the vortex became embedded near Storm B's high reflectivity core and weakened. It was indistinguishable after 1751 UTC.

The second cyclonic vortex linked to Storm B (C2) was initially identified at 1731 UTC, 3 km south of the path of C1 (Fig. 5). Consistent with observations of C1, C2 also revealed a mid-level origin with its strongest cyclonic shears (23 m s^{-1} located near 5 km AGL. At this time, C2's depth was 3 km and its diameter was approximately 3.5 km.

Between 1731 and 1746 UTC, C2 expanded to its greatest vertical depth of approximately 8 km and largest diameter of 6 km. C2 maintained its strongest shear magnitudes between 3.5 and 6 km AGL until 1756 UTC. Then, the cyclonic shear associated with C2 weakened considerably and became uniform throughout its decreasing depth. C2 appeared to take a similar trajectory to C1, where it gradually advected rearward into Storm B's high reflectivity core and weakened. Between 1716 and 1806, numerous severe straight-line wind occurrences were documented in the vicinity of the paths of both C1 and C2 (Storm Data 1998).

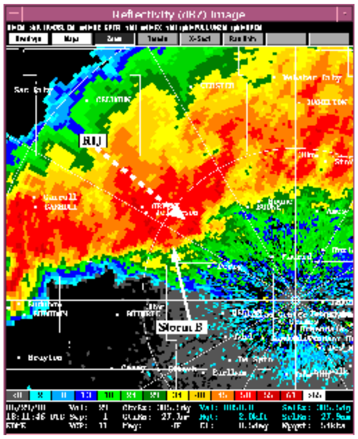

Figure 7. WSR-88D PPI reflectivity display at the 0.5◦ elevation angle for 1811 UTC 29 June 1998.

By 1811 UTC, the QL MCS had solidified into a line that was nearly 200 km long and orientated east-northeast--west-southwest across west--central and central Iowa (Fig. 7). At this time, Storm B was located approximately 50-80 km northwest of KDMX.

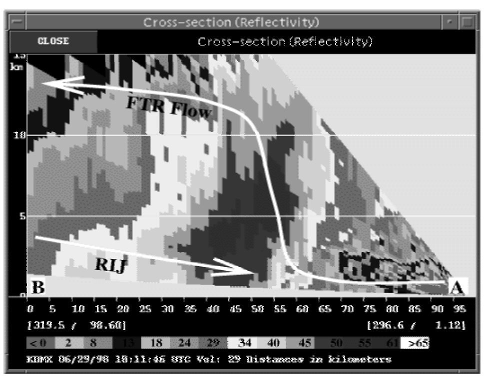

Figure 8. WSR-88D RHI reflectivity display for 1811 UTC 29 June 1998.

The RHI reflectivity cross-section (orientated perpendicular to Storm B's leading edge) taken at 1811 UTC revealed a WER along the HP storm's forward flank associated with new cell development between 4 and 7 km AGL (Fig. 8). At this time, the 50 dBZ core extended to a height of approximately 11 km. The convective towers remained nearly vertical, similar to observations recorded by RR93 during the later part of the intensifying stage and early part of the mature stage of QL MCS evolution. During this time, surface gusts associated with Storm B exceeded 35 m s^{-1} over southwest portions of Boone county Iowa (50 km northwest of KDMX; Storm Data 1998). The corresponding velocity cross-section (Fig. 9) showed a steep ascending branch of the front-to-rear flow (FTR), as well as the gradual descending rear inflow. This type of kinematic flow structure appears to be common during the "early part" of the mature stage of linear MCS evolution. The existence of a steep ascending branch of the FTR at this time is in contrast to the gradual ascending branch shown in the later part of the mature stage (RR93) and Weisman's Stage III (Weisman 1993).

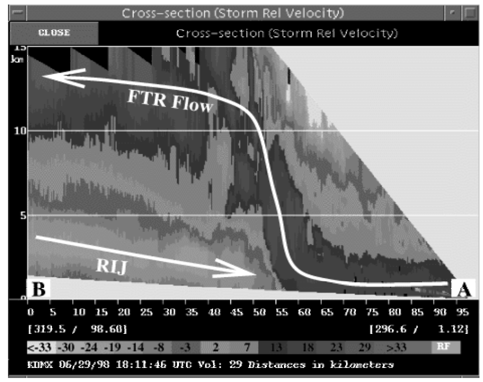

Figure 9. WSR-88D RHI SRM display for 1811 UTC 29 June 1998. Storm velocity was calculated as 11.0 m s^{-1}, from 270.0 ◦.

5. EXAMINATION OF A TORNADIC MESOCYCLONE AT CLOSE PROXIMITY TO THE KDMX WSR-88D

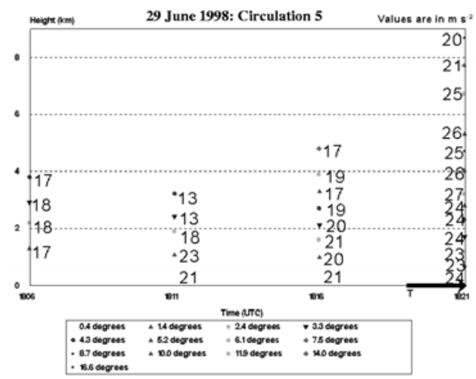

Fig. 10 Plot of height (in km) versus time of Vr values for C5.

A recent study (BM98) examining tornadic vortices at close ranges to a WSR-88D has revealed a fairly consistent pattern of vortex evolution prior to and during tornadogenesis. They noted that before tornado formation, storm relative velocity (SRV) plan projection indicator (PPI) detected the existence of strong rotation well above the cloud base (assumed to be 750 m) and strong convergence below the cloud base. *Just before* tornado formation, SRV PPI indicated strong rotation well above the cloud base (to near cloud base) as well as strong convergence near and below the cloud base. Finally, at tornado formation, strong rotation was present through a deep column, including below the cloud base, with maximum rotation located at a height just above the cloud base.

At less than 30 km from the KDMX WSR-88D, the close proximity of circulation 5 (C5) allowed for a detailed examination of its vortex characteristics (Fig. 10). C5 was initially detected along the leading edge of Storm B at 1806 UTC. At this time, C5 revealed an overall depth of 3 km and a core diameter of 2.5 km. In contrast to observations of non-tornadic vorticies C1 and C2, C5 originated in the lower-levels of Storm B and was completely contained within 4 km of the surface. Between 1811 and 1821 UTC, C5 rapidly deepened and intensified. At 1821 UTC, the magnitude of the Vrs associated with C5 exceeded 23 m s^{-1} between 200 m and 7 km AGL. The first report of a tornado associated with this mesocyclone occurred at approximately 1820 UTC southeast of Berkley, Iowa in southwest Boone county (Storm Data 1998). Tornadogenesis occurred just prior to when C5 attained its greatest vertical depth (8 km) and strongest Vr values (25-28 m s^{-1}). This is consistent with findings in other cases examined in the Mid-Mississippi Valley region (Przybylinski et al. 2000).

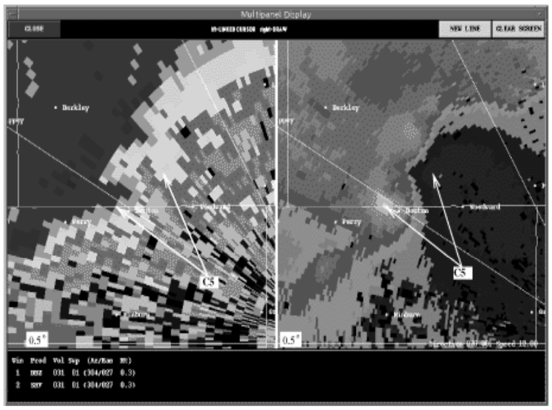

Figure 11. WSR-88D PPI Reflectivity and SRM display at the 0.5◦ elevation angle for 1821 UTC 29 June 1998.

At 1821 UTC, C5 was located at a range of approximately 26 km from KDMX (Fig. 11). At this time, C5 revealed a cyclonic-convergent velocity signature at the 0.5◦ elevation angle (0.4 km AGL) and a symmetrical vortex structure at the 1.5◦ elevation angle (1.0 km AGL) and above. Although the first tornado was occurring at this time, a purely convergent velocity signature was not detected at the lowest elevation angle. This observation slightly contrasts with those made by BM98.

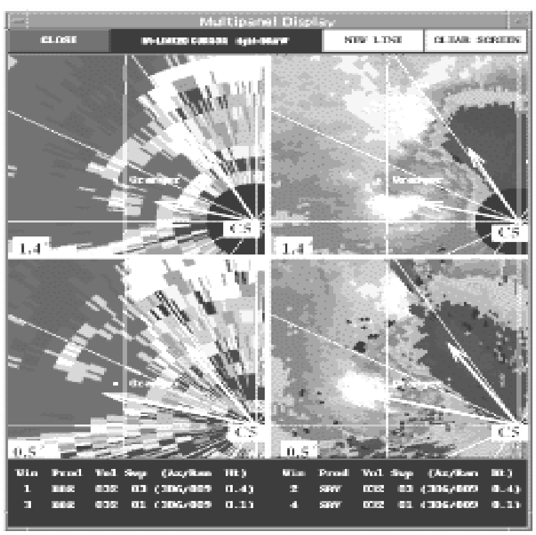

Figure 12. Reflectivity and SRM display at the 0.5 and 1.5◦ elevation angles for 1833 UTC 29 June 1998

Due to a power outage, the next volume scan recorded from KDMX did not occur until 1833 UTC, at which time the velocity structure showed a nearly symmetrical vortex at the lowest two elevation slices (0.5 and 1.5◦; 0.1 km and 0.2 km AGL) and above (Fig. 12). These observations are in agreement with those recorded by BM98. However, it is interesting to note that strong convergence (ΔV ~58 m s^{-1}) was detected along the northern periphery of C5's core, 8 km northwest of KDMX. Subsequent elevation slices above the convergent velocity signature (i.e., above 1 km AGL) exhibited a cyclonic-convergent velocity couplet. The overall velocity pattern at this time is very complex and the loss of data and limited sampling resulted in obtaining only a partial understanding of the overall vortex structure of C5. However, the velocity structure at it is 1833 UTC does suggest the possibility of a "double core" vortex structure.

6. SUMMARY

An QL MCS responsible for several swaths of damaging straight-line winds and several weak to moderate tornadoes traveled across most sections of central Iowa during the early to mid afternoon of 29 June 1998. The complex evolved in a highly-unstable, strongly deep-sheared environment. The Slater, Iowa wind profiler at 1700 UTC revealed a broad, curved deep-layer shear profile suggesting the potential for supercell development. From 1700 to 1730 UTC, a cluster of severe storms across central and eastern Iowa gradually evolved into a nearly solid linear convective line similar to the intensifying stage shown by RR93. Several portions of the line exhibited hybrid HP supercell characteristics, as rotating cyclonic centers were initially detected at mid-levels. Damaging winds were reported with all of the HP storms. One storm (Storm B), and its associated circulations, was closely examined between 1716 and 1833 UTC. Characteristics of the first two mesocyclones (C1 and C2) showed that the strongest cyclonic shears generally remained within the 4 to 6 km layer of Storm B's mid-level region. These vortices rapidly weakened at mid-levels as they traversed into the high-reflectivity core region of the HP storm. C1 and C2 were non-tornadic, and associated primarily with severe straight--line wind damage across much of central and southern Calhoun county, as well as southern Webster county. The fifth mesocyclone (C5) formed along the forward flank of the Storm B, originating within the lowest 4 km, and deepened and intensified during the subsequent volume scans. This vortex was responsible for the tornadic damage over parts of southern Boone and Dallas counties in central Iowa. Tornadogenesis occurred just prior to when C5 attained its greatest depth and strongest magnitudes of rotational velocities.

Low-level mesocyclone structure of C5 at ranges below 30 km was compared to observations by BM98. During the period of tornadic activity, C5's core structure appeared to be similar to observations recorded by BM98, as strong rotation was observed through a deep column. A vast amount of understanding has been gleaned through the study of the mature stage of MCS evolution. However, much work is still needed to fully understand MCS evolution from its infancy through its dissipation.

7 REFERENCES

References will be made available upon request.