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# The Impact of Surface Boundaries on Tornadogenesis during the Northwestern Minnesota Event of 20 July 1998

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## 1. INTRODUCTION

The interaction between surface-based discontinuity lines and tornadogenesis in supercell thunderstorms has been examined in detail for many years (e.g. Purdom 1976, Maddox et al. 1980 and Weaver and Nelson 1982). Over the past decade, a number of severe weather researchers have focused on trying to solve the mystery of tornadogenesis by examining case studies (e.g. Davies et al. 1994, Weaver and Purdom 1995, and Browning et al. 1997) or conducting field experiments (Rasmussen et al. 1994). During the Verifications of Rotation in Tornadoes Experiment (VORTEX), up to 70% of the significant tornadoes (F2 or greater intensity) that were observed were found to occur near low-level boundaries (Markowski et al. 1998a). Such boundaries may be formed by such mechanisms as a forward flank downdraft (FFD) or cirrus anvil cooling creating baroclinity (Markowski et al. 1998b). They found that low-level boundaries appear to enhance the baroclinic, horizontal vorticity present in the storm environment. Vertical motions in the thunderstorm environment can then tilt and stretch the vorticity to promote tornadogenesis. Intersecting surface boundaries have also been shown to enhance low-level convergence and aid in tornado formation (Purdom 1993). Atkins et. al (1999) have shown that a stronger more persistent low-level mesocyclone was generated in simulations which have a pre-existing boundary present, than those without a boundary in their simulation. In addition, mesocyclones with a boundary in the simulation formed sooner and were more persistent than those without a boundary present.

This paper will examine a minor outbreak of 8 weak (F0) tornadoes which occurred during the afternoon hours of 20 July 1998 in northwestern Minnesota (Table 1). These tornadoes were believed to be associated with intersecting surface discontinuities across the region. In this analysis, an examination will be done on the potentially critical role that surface boundaries may have played in tornado formation for this event.

## 2. SYNOPTIC OVERVIEW

The large-scale surface pattern for 1800 UTC 20 July 1998 (Fig. 1) showed a low pressure center propagating eastward across southern Canada with an associated triple point feature entering the western Red River Valley in extreme eastern North Dakota. Weak differential positive vorticity advection, implied by a 500 hPa shortwave, tracked across northern Minnesota during the afternoon hours of 20 July 1998 and enhanced synoptic scale lift over the region (not shown). The vorticity advection was associated with the exit region of a 50 m $s^{-1}$ 250 hPa jet maximum tracking along the U.S.-Canadian border. In the lower troposphere, a 23 m $s^{-1}$ low-level jet (LLJ) at the 850 hPa level passed through northern Minnesota during the outbreak period enhancing speed and directional wind shear (Fig. 2). The LLJ advected abundant moisture into the region with a ridge of high surface equivalent potential temperature extending into the outbreak region. A forecast for a 1000 hPa ridge of 356K equivalent potential temperature air into the outbreak region was also progged (not shown). A modified afternoon sounding for northern Minnesota indicated convective available potential energy (CAPE) values ahead of the frontal system in excess of 5000 J $kg^{-1}$ .

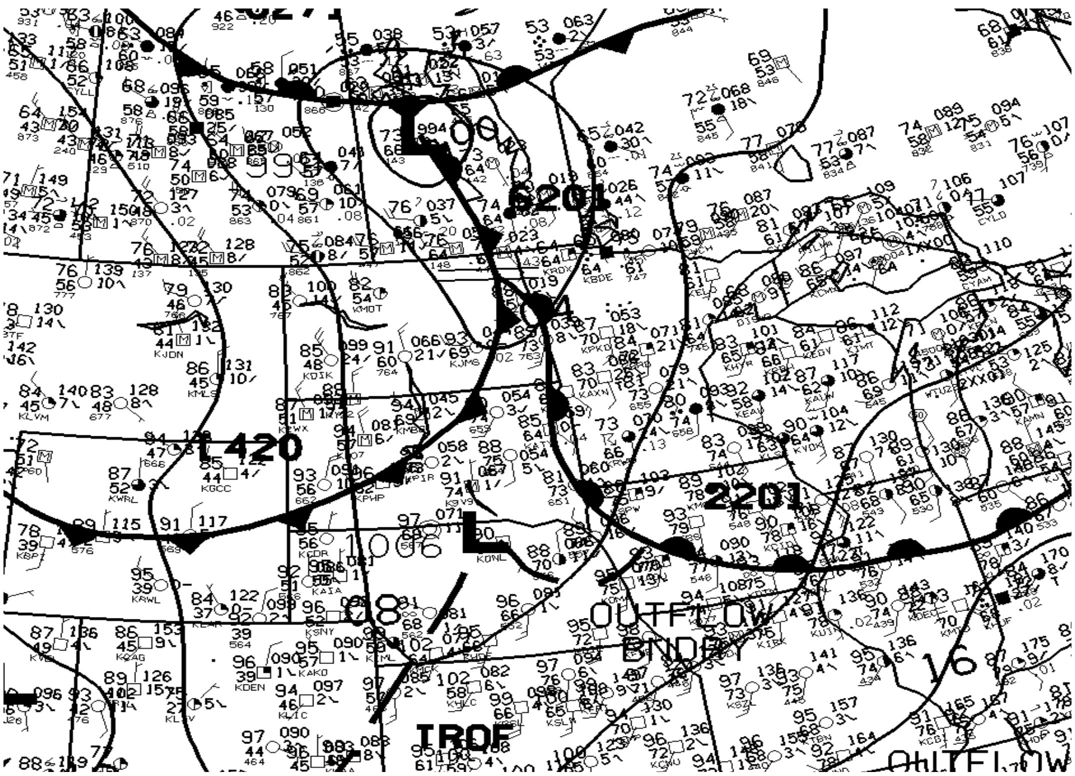


**Figure 1:** Surface Map for 1800 UTC 20 July 1998.

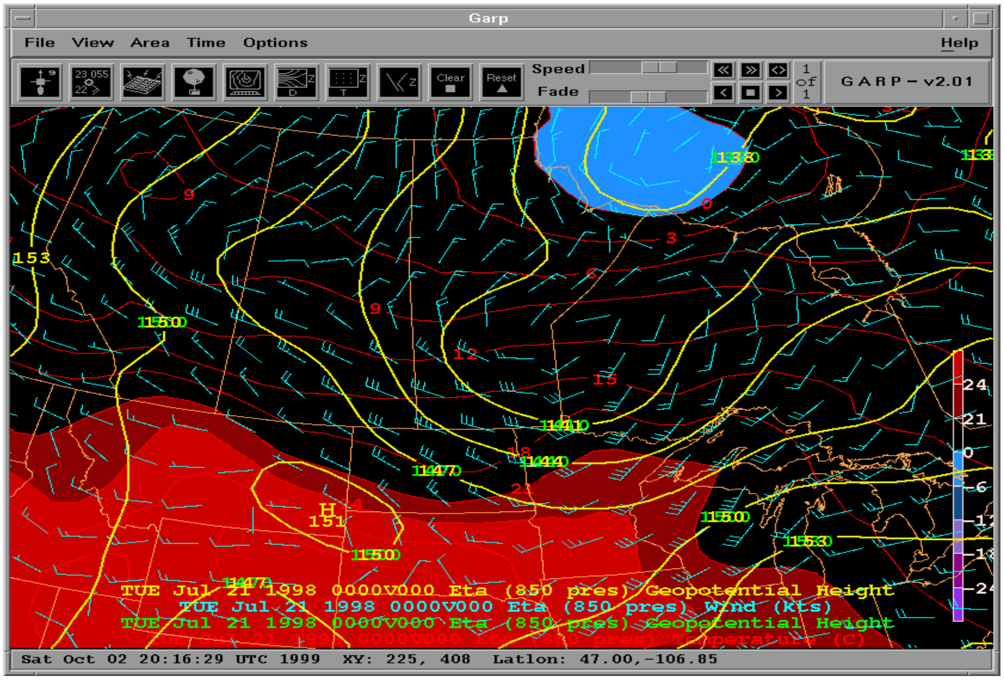


**Figure 2:** ETA 850 hPa analysis for 0000 UTC 21 July 1998.

The synoptic-scale wind profile was also conducive for tornado development in the vicinity of the surface boundaries. The soundings from International Falls, MN (INL) indicated a dramatic rise in 0-3 km and 0-2 km Storm-Relative Helicity (SRH) values. Standard SRH calculations, using the default parameters for the Skew-T/Hodograph Analysis and Research Program (SHARP) at 0-3 km, rose from 72 J $kg^{-1}$ at 1200 UTC 20 July 1998 to 470 J $kg^{-1}$ by 0000 UTC 21 July 1998. The SRH values at 0-2 km rose from 62 J $kg^{-1}$ at 1200 UTC 20 July 1998 to 479 J $kg^{-1}$ at 0000 UTC 21 July 1998.

## 3. MESOSCALE ANALYSIS

The remnants of a morning convective complex that moved across northern Minnesota from 1200 UTC until 1530 UTC produced a number of surface outflow boundaries which persisted into the afternoon hours. During the afternoon hours, a low-level mesolow developed at the intersection of an outflow boundary and a prefrontal wind shift over extreme eastern North Dakota. Such prefrontal wind-shift lines have been shown to be important in the prediction of thunderstorm initiation (Hutchinson and Bluestein 1998). This feature then translated eastward into northwestern Minnesota during the event. The mesolow circulation was quite evident on the Mayville, ND WSR-88D (KMVX) 0.5 degree reflectivity imagery at 1833 UTC (Fig. 3).

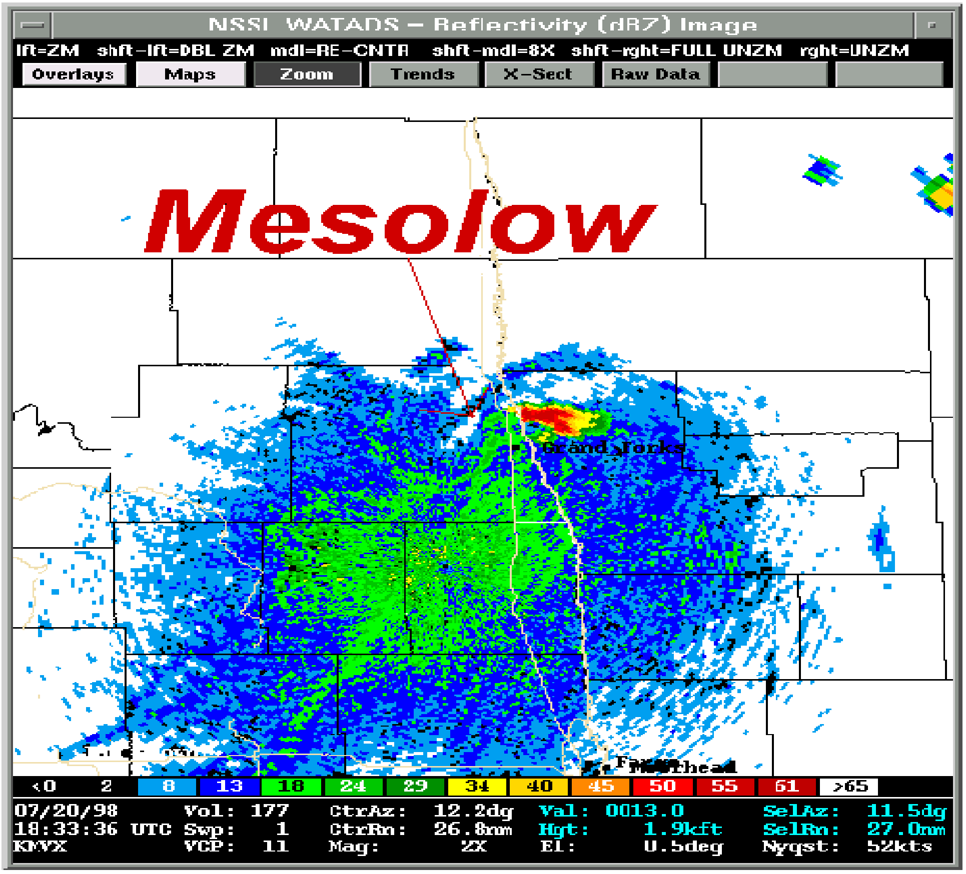


**Figure 3:** Mayville, ND WSR-88D (KMVX) 0.5 degree base reflectivity image at 1833 UTC 20 July 1998. A low-level mesolow circulation is evident with the initial thunderstorm development occurring ahead of it in northwestern Minnesota.

The initial convective cell of the event can be seen just east of the mesolow circulation and was associated with a curved outflow boundary. Animation of the KMVX 0.5 degree reflectivity loop illustrated an additional outflow boundary extended to the south which propagated into the tornadogenesis region. This outflow boundary tracked southward along the pre-frontal wind shift. The wind shift remained south of the mesolow circulation as deep, moist convection developed along it. Interaction with the associated developing flanking line of thunderstorms would aid in apparent cyclic tornado development throughout the event. Table 1 gives the chronology of the tornado touchdowns for this event.

**Table 1**

Times and locations of F0 tornado touchdowns in northwestern Minnesota on 20 July 1998.

| Time (UTC) | LOCATION OF INITIAL TOUCHDOWN | COUNTY |
|---|---|---|
| 2028 | 7 miles (11 km) northeast of Fertile, MN | Polk |
| 2030 | 5 miles (8 km) northeast of Winger, MN | Polk |
| 2050 | Mahnomen, MN | Mahnomen |
| 2055 | 6 miles (10 km) northeast of Mahnomen, MN | Mahnomen |
| 2120 | 2 miles (3 km) north of Waubun, MN | Mahnomen |
| 2130 | Ogema, MN | Becker |
| 2145 | 10 miles (16 km) south of Zerkel, MN | Clearwater |
| 2105 | 5 miles (8 km) northeast of Rochert, MN | Becker |

As the prefrontal wind-shift line propagated eastward, a flanking line developed to the south as it intersected the outflow boundary moving perpendicular to the wind-shift. A series of closely spaced multicell thunderstorms continued to develop in rapid succession to the southwest along the wind-shift in the very unstable air mass. Each subsequent thunderstorm cell produced new outflow boundaries which likely enhanced the low-level convergence. Recent model simulations have shown that pre-existing boundaries enhance low-level vertical velocities and vorticity (e.g. Lee and Wilhelmson, 1997 and Atkins et. al, 1999). Therefore, the intersection between the pre-frontal wind shift and outflow boundary would have likely strengthened the low-level vorticity and resultant vertical motions. As the new outflow boundaries continued to help focus horizontal vorticity in the boundary layer, vertical velocities within the thunderstorms enhanced the tilting and stretching of this vorticity and may have resulted in the subsequent tornadogenesis.

The F0 tornadoes during this event were produced early in the development of each thunderstorm cell. A comparison of the timing of spotter reports with KMVX WSR-88D reflectivity data indicated tornadogenesis occurred quickly after thunderstorm formation. Observations from SKYWARN spotters indicated tornado touchdowns occurred before low-level circulations were evident on KMVX velocity products. Eyewitness accounts for some of the touchdowns reported two rope-like tornadoes at the same time. The only exception to this was the tornado near Winger, MN which had a well-defined mesocyclonic signature on the KMVX WSR-88D (Fig. 4). Thus, some of the remaining tornadoes may have been examples of "landspout" tornadogenesis from the surface layer upward (e.g. Bluestein 1985 and Wakimoto and Wilson 1989). Researchers looking at VORTEX field data found that this may be a more common method for tornado formation than previously thought (Markowski et al. 1998a).

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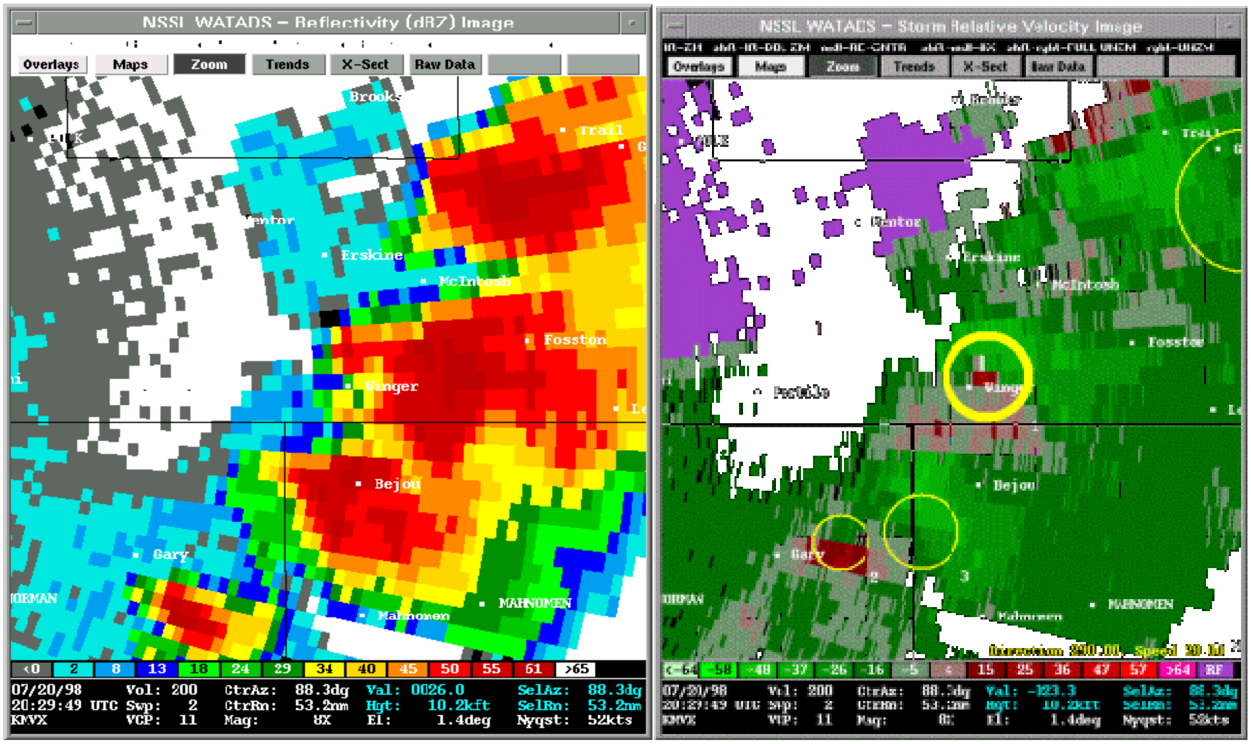


**Figure 4:** KMVX 1.5 degree reflectivity and relative velocity image at 2029 UTC 20 July 1998. A strong mesocyclone circulation is evident associated with the Winger, MN tornado.

To further illustrate the potential importance of surface boundaries to tornado formation for this event, an examination of the development of an isolated thunderstorm away from any outflow boundaries showed a pronounced difference. This severe thunderstorm originated well to the south of the tornadic storms in the same synoptic environment (Fig. 5). This storm developed away from the wind-shift line and in a location where no surface outflow boundaries were present. The thunderstorm produced large hail which was up to 2.25 inches (6 cm) in diameter. However, no tornadic activity was associated with this severe thunderstorm. The reason this severe thunderstorm did not generate any tornadoes was possibly due to the lack of interaction with any surface boundary to focus the low-level horizontal vorticity. In addition, analysis of KMVX velocity data indicated that no mid-level rotation was evident with this thunderstorm.

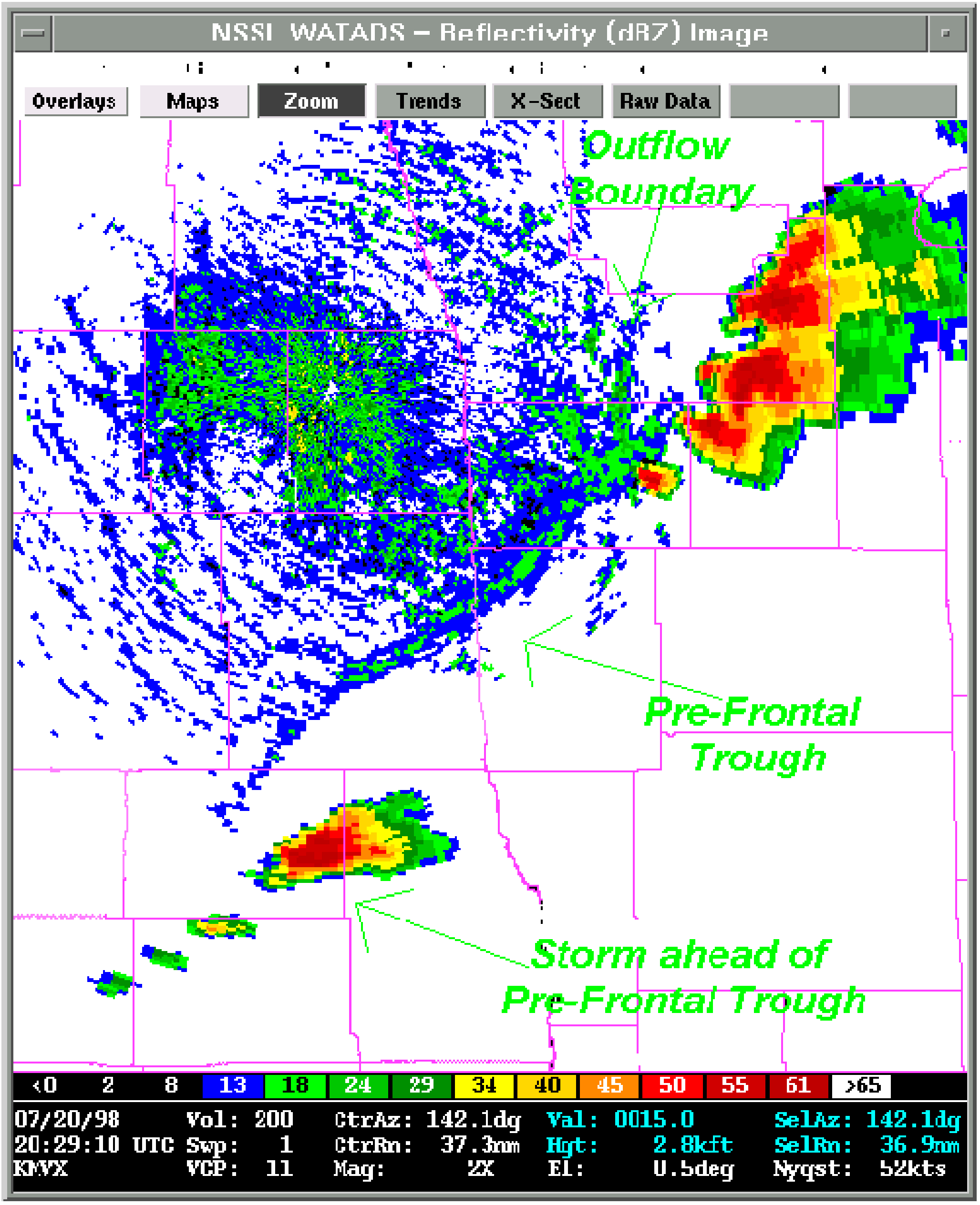


**Figure 5:** KMVX 0.5 degree reflectivity image at 2029 UTC 20 July 1998. Tornadic thunderstorm development occurred near the intersection of an outflow boundary and the pre-frontal trough. An isolated, non-tornadic severe thunderstorm can be seen south of the pre-frontal trough in southeastern North Dakota.

## 4. SUMMARY AND DISCUSSION

Low-level boundaries are an important consideration when attempting to forecast tornado development. The tornadogenesis case of 20 July 1998 illustrated how a minor outbreak of 8 weak (F0) and short-lived tornadoes developed near a pre-frontal trough which intersected pre-existing outflow boundaries. By contrast, an isolated severe thunderstorm over 125 km southwest of any outflow boundaries was not tornadic in nature. This indicates the potential importance of these surface boundaries in concentrating horizontal vorticity in the lower troposphere. It appears only one tornado was associated with a well-defined mesocyclone within the parent thunderstorm. Due to the rapid spin-up and dissipation of these vortices, it may have been difficult for the KMVX WSR-88D to detect a sustained and coherent mesocyclonic signature for the required number of volume scans to be considered an operator defined Tornadic Vortex Signature (TVS). The remainder of the tornadoes may have been generated by a combination of spin-up from the surface layer upward or by stretching and tilting of horizontal vorticity in the boundary layer by vertical motions within the thunderstorm cells.

Another interesting aspect of this case was the fact that none of the tornadoes were rated higher than F0 despite favorable environmental conditions for more intense vortices. Relatively high values of CAPE, wind shear and SRH would generally produce stronger tornadoes on the Fujita scale as previous tornado climatologies have suggested (Kerr and Darkow 1996). Three potential hypotheses may explain this situation. First, the multicell thunderstorms did not have enough time to attain their maximum potential due to the quick cutoff of inflow by rapidly developing storms south along the flanking line. This could have inhibited inflow enough that any individual cell was prevented from reaching its full convective potential. Second, rapid development of outflow from the cold FFD of earlier thunderstorms may have been another possible mechanism for the limited intensity of the tornadoes. The third possible explanation would be the fact that the majority of the touchdowns were on crop-land where an adequate assessment of Fujita scale tornado intensity is more difficult to determine.

The proposed mechanisms which result in weak tornadogenesis have continued to grow in recent years. Interactions between low-level boundaries appears to be a promising area for future research. However, investigations into generation mechanisms without apparent boundaries should also continue to help complete our understanding of the entire spectrum of tornado development. This case study represented another example to illustrate the complex set of circumstances involved in forecasting weak tornado outbreaks when a variety of surface boundaries (rear flank downdrafts, forward flank downdrafts and pre-frontal troughs) interact.

## 5. ACKNOWLEDGMENTS

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