

## 19.2 STORM MODE EVOLUTION FROM A QUASI-LINEAR CONVECTIVE SYSTEM TO A DISCRETE TORNADIC SUPERCELL DURING THE HISTORIC WISCONSIN TORNADO OUTBREAK OF 18 AUGUST 2005: A RADAR PERSPECTIVE

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### 1. INTRODUCTION

During the afternoon and evening of 18 August 2005, the state of Wisconsin experienced its largest one-day tornado outbreak in recorded history, with 27 tornadoes across the central and southern portions of the state. For the warning forecaster, a particularly challenging aspect of this tornadic episode developed early in the event over Vernon County, in southwest Wisconsin. A complex change in storm mode, from a quasi-linear convective system (QLCS), into a hybrid supercell structure, then into a discrete classic supercell occurred. During this evolution, an F1 tornado (Fujita, 1971) touched down near Esofea, WI at 2045 UTC, and an F2 tornado (Fujita, 1971) touched down near Viola, WI at 2115 UTC. Immediately prior to both instances of tornadogenesis in Vernon County, cell mergers with isolated, weak convective activity and the approaching QLCS were noted.

Conceptual models of the evolution of linear convective systems, including QLCSs, don't typically include such a rapid evolution in storm mode into discrete tornadic supercells. However, Burgess and Curran (1985) documented a similar event in Oklahoma (26 April 1984) where a mature linear system transitioned into discrete tornadic supercells due to changes in the overall vertical shear profiles and low-level thermodynamics from a meso-alpha scale upper-air disturbance moving across the area. Lee et al. (2006) have authored the most recent work citing strong evidence that cell merger interactions led to both an increase in cell rotation, and instances of tornadogenesis.

The close proximity of the La Crosse, WI (KARX) WSR-88D provided a well-sampled, high resolution dataset of convective behavior, and associated wind fields, during this evolution in storm mode. The synoptic and mesoscale setup for this event, as well as the evolution to the classic supercell, from the QLCS, will be discussed. The mode change was rapid, occurring across Vernon County within one hour. The role of weak cell mergers immediately prior to both instances of tornadogenesis will be emphasized.

### 2. SYNOPTIC AND MESOSCALE OVERVIEW

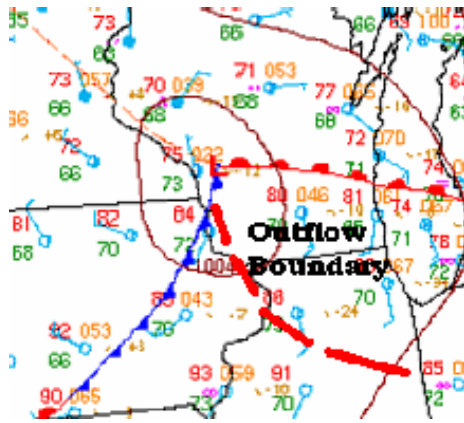
At 1200 UTC on 18 August 2005, the synoptic scale flow over much of the United States could be described as fairly typical for the late summer months. At 250 mb, a broad subtropical ridge, centered in central Texas, extended across much of the southern tier of the country, with a 30 ms<sup>-1</sup> subtropical jet stream extending from California to the Mid-Atlantic region. A 40 ms<sup>-1</sup> jet streak was embedded within the flow from Nebraska through Indiana. By 0000 UTC on 19 August, the center of the subtropical ridge had redeveloped east into Alabama, which resulted in intensification (45 ms<sup>-1</sup>) and reorientation of the jet streak across Iowa and Nebraska. This, in combination with an associated midlevel shortwave trough over central Minnesota, placed southern Wisconsin in a favorable region for large scale ascent.

In response to the approaching shortwave trough, a 15 ms<sup>-1</sup> southwesterly low-level jet maximum was present at 850mb at 1200 UTC across Iowa and Missouri, which focused warm advection and isentropic lift downstream over Wisconsin and northern Illinois. This aided in the development of scattered convection, which congealed into a small Mesoscale Convective System (MCS) which propagated across southern Wisconsin and northern Illinois during the morning hours on 18 August. Maintenance of this low-level wind maximum continued throughout the day due to the proximity of the approaching trough. This resulted in a sustained feed of a higher, low-level equivalent potential temperature ( $\theta_e$ ) airmass into southern Wisconsin in the wake of the early morning MCS.

Surface analysis at 2100 UTC (Figure 1) indicated low pressure near La Crosse, WI with a strengthening warm front east into central Wisconsin. This frontal zone featured convection along, and to its north, where several brief tornadoes were reported. A strengthening cold front extended south of the low into central Iowa, while a northeast propagating outflow boundary from the morning MCS activity extended from the Mississippi River southeast into northern Illinois. From all observational data, the outflow boundary's northern extent seemed to be located just south of Vernon County.

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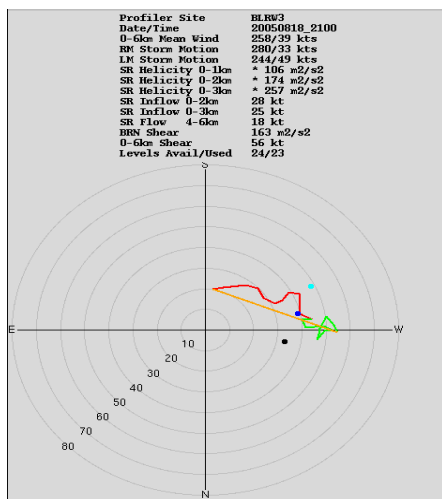
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**Figure 1.** 2100 UTC 18 August 2005 HPC Surface Analysis. Outflow boundary noted by dashed line.

The mesoscale environment over southwest Wisconsin was in a state of rapid transition during the hours immediately prior to the two instances of tornadogenesis, with the rapid return of the outflow boundary. Strong midlevel flow ( $20 \text{ ms}^{-1}$ ) had spread over the area south of the shortwave trough over central Minnesota. Deep layer bulk shear values over the area were sufficient for storm organization as a result of light southeasterly low level flow north of the outflow boundary, veering to westerly aloft south of the midtropospheric wave.

Observational soundings from the Local Analysis and Prediction System (LAPS) across Vernon County at 2100 UTC indicated 0-1 km mixed-layer parcel convective available potential energy (MLCAPE) had risen in excess of  $1700 \text{ JKg}^{-1}$ , while hodographs from the nearby (35 nmi south) Blue River, WI wind profiler (BLRW3, Figure 2) supported the LAPS-indicated 0-6 km bulk shear values around  $28 \text{ ms}^{-1}$ .



**Figure 2.** AWIPS hodograph plot from BLRW3 wind profiler valid 2100 UTC 18 August 2005.

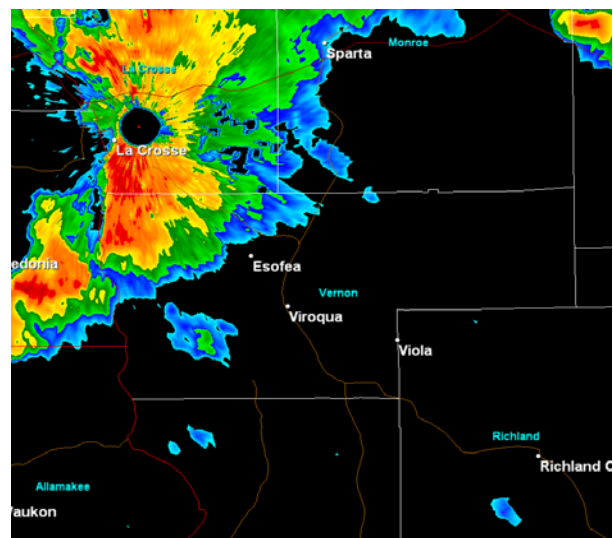
Thunderstorms in southeast Minnesota quickly congealed into a QLCS ahead of the cold front as they crossed the Mississippi River just after 2000 UTC. Once the QLCS moved into Vernon County, WI, proximity to the retreating outflow boundary afforded not only the opportunity to interact with isolated cellular convection, but also a tap into the higher  $\theta_e$  airmass along the boundary.

### 3. RADAR ANALYSIS AND STORM OBSERVATIONS

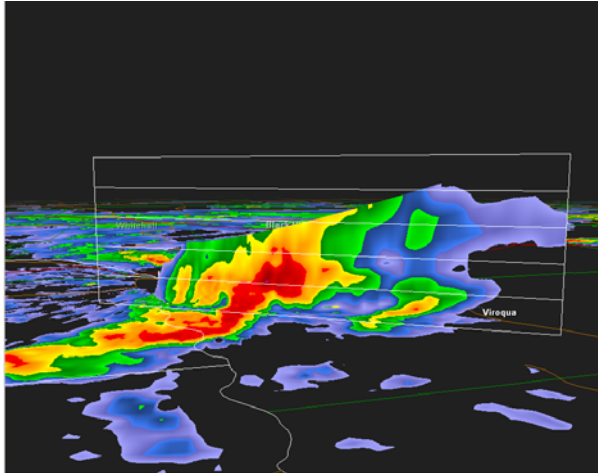
The KARX WSR-88D radar east of La Crosse provided an excellent view of the QLCS as it crossed the Mississippi River into Vernon County. The radar is located 15-30 nmi northwest of Vernon County. It is important to note that as the QLCS crossed into Vernon County from southeast Minnesota, it had not shown any signs of taking on supercellular structure, nor had it shown widely accepted radar signatures of becoming a mature linear convective system (descending rear inflow jet, stratiform rain region, bookend vortices, etc). The convection was sub-severe across southeast Minnesota, and had shown a slow increase in intensity with time.

#### 3.1 The Esofea, WI Cell Merger and Tornadoic Circulation

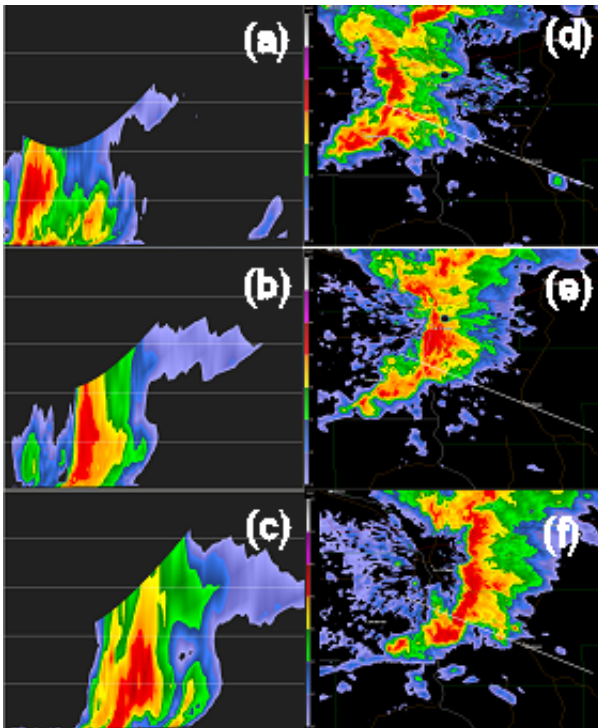
At 2020 UTC, scans from the KARX WSR-88D showed an increase in weak cellular convection about 20 nmi southwest of Esofea, WI (Figure 3). This was most likely a result of isentropic lift and warm advection of the southwesterly low-level jet over the shallow outflow boundary immediately to the south of the QLCS.



**Figure 3.** 2020 UTC 18 August 2005 2.4° base reflectivity from KARX WSR-88D. Image is centered on Vernon County, WI. Note weak cellular convection west of Viroqua.

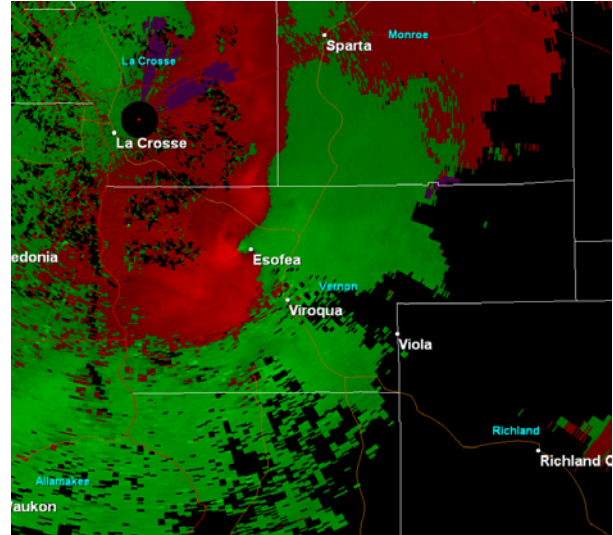


**Figure 4.** 2027 UTC 18 August 2005 KARX WSR-88D 3-D base reflectivity cross section view looking northeast along the QLCS. Note the overhang in the QLCS line and also the isolated cell, prior to cell merger, ahead of the line.



**Figure 5.** KARX base reflectivity cross-section at (a) 2002 UTC (b) 2020 UTC (c) 2032 UTC for the QLCS as it moved east across Vernon County with time matching 0.5° base reflectivity (d-f). Cross section location is shown by white line in (d-f). Horizontal lines on cross section are at 10 kft intervals. Reflectivity overhang and isolated pre-merger cell shown in (c).

Three dimensional cross sections (Figure 4) and two dimensional cross sections (Figure 5) across the QLCS showed the system had become better organized, as it approached the weak cellular convection, over a period of 30 minutes. A distinct trend of the QLCS developing overhang of echo aloft, from

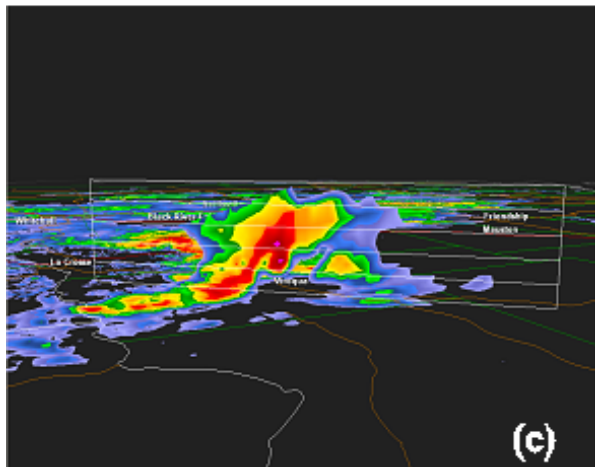
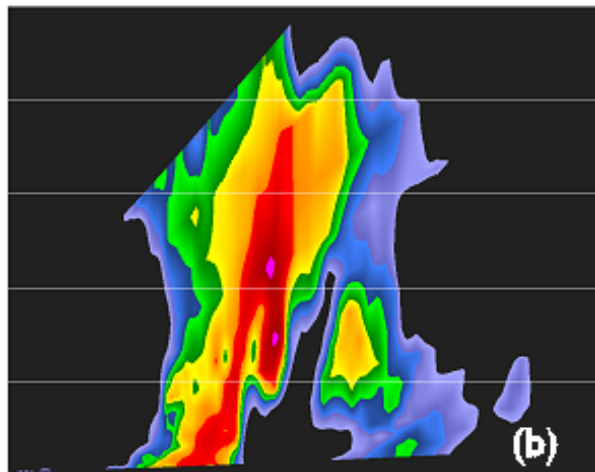
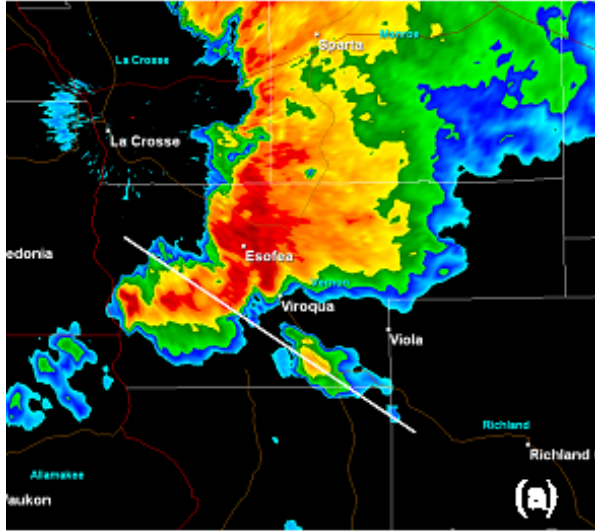


**Figure 6.** 2045 UTC 18 August 2005 0.5° base velocity image from KARX WSR-88D. Note velocity couplet approaching Esofea.

being more upright, was noted in both the three dimensional, and two dimensional cross sections confirming the higher level of convective organization. This was the beginning of the mode transformation. Subsequent KARX base reflectivity imagery (2024 UTC through 2032 UTC) showed this weak cellular convection being ingested into the approaching QLCS. This was coincident not only with an overall increase in coverage and intensity of the storm's reflectivity, but also an almost immediate development of a midlevel (4 km AGL) cyclonic circulation. This is apparent by the 2036 UTC 8.0° base velocity and storm relative motion (SRM) products, which place the broad midlevel circulation about 10 nmi west of Esofea, WI (not shown). In recent work by Lee et. al. (2006), the authors noted that cell mergers led to increases in rotational velocity between 44% and 60% of the time for their dataset.

The next available 0.5° base reflectivity product at 2040 UTC already showed this broad cyclonic shear near the surface immediately west of Esofea, while higher elevation scans (0.9° through 8.0°) showed a continuing rapid increase in the strength of the parent mesocyclone. In fact, the 2040 UTC base velocity at 8.0° (available to the warning forecaster at 2043 UTC) showed  $52 \text{ ms}^{-1}$  of gate-to-gate cyclonic shear, over the city of Esofea, at 4 km AGL. Reflectivity imagery at this same time still showed a QLCS reflectivity structure, with the strong low to midlevel cyclonic circulations deeply embedded in the heavy rain core. The next volume scan's 0.5° base velocity product (2044 UTC, Figure 6), which arrived to the warning forecaster at 2045 UTC, showed the strong low-level mesocyclone ( $46 \text{ ms}^{-1}$  of cyclonic gate-to-gate shear at 300m AGL) clearly. However, by this time, the tornado had formed 3.2 miles west of Esofea, causing F1 damage for 1.2 miles, before lifting by 2050 UTC.





**Figure 7.** KARX 2045 UTC 18 August 2005 base reflectivity (a) at 0.5° showing QLCS and second weak merger cell. (b) 2-D cross section (c) 3-D cross section looking northeast. Cross section for (b) and (c) depicted by white line in (a).

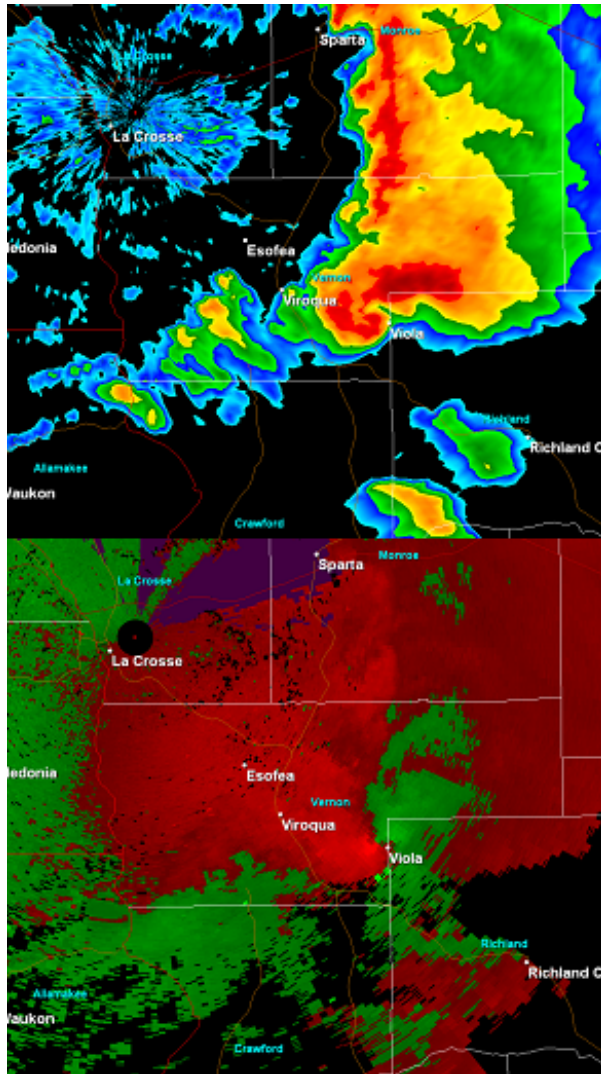
Analysis of the KARX volumetric radar data for the Esofea tornado evolution confirms an instance of a rapidly descending mesocyclone and subsequent tornadogenesis. A weak inbound velocity maximum associated with the cell merger appears to play a significant role in the rapid descent of the developing mesocyclone. From the first hints at broad midlevel rotation ( $28 \text{ ms}^{-1}$  cyclonic shear at 4 km AGL at 2038 UTC) to tornado touchdown (estimated from spotters and radar to be at 2044 UTC), just more than 6 minutes passed during this transformation. As quickly as this low and midlevel mesocyclone developed, it dissipated equally as fast. The next 0.5° base velocity image (2049 UTC) shows a marked weakening in the low level mesocyclone (from  $46 \text{ ms}^{-1}$  to  $23 \text{ ms}^{-1}$  of gate to gate cyclonic shear), which proceeds to diminish almost completely by 2053 UTC.

### 3.2 The Viola, WI Tornadic Circulation

With the dissipation of the Esofea tornadic circulation, volumetric base reflectivity data from KARX showed a number of interesting features. First, the QLCS began a mode change to more discrete cells, with increasing separation between the updrafts. Of even greater interest, was that another isolated convective cell had developed over southeastern Vernon County at 2045 UTC moving toward the forward flank of the evolving supercell structure (Figure 7a). This convective cell, which was stronger than the cell in the Esofea merger, moved northeast and appears to have initiated once again from isentropic lift across the outflow boundary immediately to the south of the current storm.

Two dimensional (Figure 7b) and three dimensional (Figure 7c) cross sections across the QLCS and the weak convective cell showed more classic supercellular storm structure. In comparison with previous storm organization (Figures 4 and 5), a much more pronounced supercellular structure is depicted, with a very pronounced bounded weak echo region (BWER). Base reflectivity products in this time period also confirm a dramatic change in the structure of the supercell, with the 2102 UTC 0.5° elevation slice showing a strong inflow notch and the bounded weak echo region continuing aloft between 2057 UTC and 2102 UTC.

This weak convective cell also merged into the forward flank of the supercell at approximately 2055 UTC roughly 10 miles west of the city of Viola. Low-level velocity imagery at 2045 UTC and 2050 UTC clearly showed an enhanced inbound velocity signature associated with the merger cell, wrapping into the southeastern, forward flank of the supercell. Once this wind field was fully ingested into the supercell between 2053 UTC and 2057 UTC, 0.5° base velocity data indicated another rapid intensification of low-level cyclonic shear immediately west of the city of Viola between 2056 UTC and 2102 UTC. However, failure of



**Figure 8.** 2110 UTC 18 August 2005 0.9° base reflectivity (top) and base velocity (bottom) from KARX WSR-88D. Note velocity couplet northwest of Viola located in the “hook” region of the classic supercell storm.

the radar’s velocity dealiasing algorithm led to some uncertainty on the strength and intensity of the low-level mesocyclone due to anomalous outbound wind signatures.

By 2102 UTC immediately west of the city of Viola, volumetric base velocity data from KARX showed a strengthening low to midlevel mesocyclone. This circulation, increased from  $20 \text{ ms}^{-1}$  of cyclonic shear at 2 km AGL at 2102 UTC, to  $50 \text{ ms}^{-1}$  of gate-to-gate cyclonic shear from 1 to 4 km AGL by 2110 UTC near Viola, WI (Figure 8). The mode transformation was now complete from QLCS to classic supercell. A tornado touched down on the north side of Viola at 2115 UTC causing F2 damage along a broken 20 mile path with no injuries or fatalities.

In contrast with the Esofea parent tornado cyclone, the Viola circulation appeared to be stronger in the lowest elevation scans from its inception, suggesting non-descending (mode II) tornadogenesis as described by Trapp et al (1999). However, as discussed above, significant failure of the velocity dealiasing algorithm immediately prior to tornadogenesis with the Viola circulation lends significant uncertainty on the strength of the wind fields in the lowest elevation scans making this assumption grounds for further research.

#### 4. SUMMARY

An uncommon evolution in storm mode occurred across Vernon County, Wisconsin, on 18 August 2005 as a non-severe QLCS developed into a hybrid supercell, and finally into a classic, discrete supercell. The supercells produced two tornadoes causing F1 and F2 damage.

Several aspects of this evolution were challenging to the warning forecaster, as the typical conceptual model for linear convective systems rarely includes the mode “breakdown” into discrete tornadic supercells. Cell mergers, which have been discussed as to being an instigator of tornadogenesis in previous work, seemed to have played a significant role in this evolution.

Two separate cell mergers occurred as the QLCS crossed Vernon County, Wisconsin. The first, near the city of Esofea, resulted in a rapidly strengthening and descending mesocyclone, which produced a tornado causing F1 damage. The entire tornadogenesis process appears to have occurred in less than 10 minutes. This cell merger also began the mode evolution toward a discrete supercell, which climaxed when the second cell merger occurred 15 minutes later near Viola, WI. This merger again appears to have induced a rapid increase in cyclonic shear and mesocyclone formation. A tornado causing F2 damage quickly followed.

#### 5. REFERENCES

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