8B.4

ANALYSIS OF CELL MERGERS LEADING TO TORNADOGENESIS USING 3D RENDERED RADAR IMAGERY

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1. INTRODUCTION

Convective cell mergers are an ubiquitous aspect of the convective environment. They pose a particular challenge when issuing tornado warnings because mergers occur frequently, but only in a subset of cases do the mergers result in a tornado. Moreover, when a tornado does result, tornadogenesis frequently occurs very rapidly permitting little advance warning or lead time. In some cases, the resultant tornado can cause loss of life and significant damage (e.g., NOAA 2009, Carey et al. 2003, Wolf et al. 1996).

Storm mergers associated with tornadogenesis have been reported in a variety of permutations: two supercells (Wurman et al. 2007, Lee et al. 2006, Wolf and Szoke 1996), a squall line and supercell (Carey et al. 2003, Wolf et al. 1996, Sabones et al. 1996, Goodman and Knupp 1993, and others), a supercell with an ordinary cell (NOAA 2009), a squall line with an ordinary cell (Pryzbylinski and Decaire 1985), and unknown storm types (Westcott 1994, Ray et al. 1981). However, not all mergers constructively impact tornadogenesis. Lindsey and Bunkers (2005) reported a case where interaction from a left-moving supercell appeared to disrupt tornado production in the right moving storm as the left mover crossed into the tornadic storm's inflow.

This study utilizes standard and three-dimensional radar imagery from the WSR-88D to analyze mergers in three tornadic cases. The goal is to (1) learn more about merging storms and subsequent tornadogenesis, and (2) explore the potential for 3D imagery to provide additional value beyond traditional tools in assessing storm mergers.

2. METHOD

Level II WSR-88D radar data for the cases were obtained from the National Climatic Data Center (http://hurricane.ncdc.noaa.gov/pls/plhas/has.dsselect) and viewed using GRLevel2 Analyst software (http://www.grlevelx.com/gr2analyst/). For the purposes of this study, a merger is defined as the overlap of 0.5° reflectivity values of 15-20 dBZ or higher, similar to the approach used by Westcott (1994). Mesoscylone strength is evaluated based on rotational velocity of the circulation using the nomogram described by Andra (1997).

3. CASES

3.1 Picher, Oklahoma EF4 Tornado – 10 May 2008

This event is a supercell – ordinary cell merger resulting in tornadogenesis. The background environmental conditions were quite favorable for tornadic supercells in this case (NOAA 2009).

a) Pre-merger 2139 - 2143 UTC

At 2139 UTC on 10 May 2008, the KINX WSR-88D from Tulsa, Oklahoma indicated several thunderstorms across eastern Oklahoma and southeast Kansas. The cells of interest were located north of the radar, along and just south of the Kansas-Oklahoma border in Nowata County (Fig. 1a). The stronger of the two cells, which straddled the Oklahoma-Kansas border, displayed supercell characteristics including a mesocyclone with moderately strong and deep rotation (Fig.2) and a tilted updraft with an elevated reflectivity core of 60 dBZ. The second cell to the south was notably weaker with lower reflectivities and no rotation evident. The relative size of these storms was well-depicted in the 3D imagery at 2143 UTC (Fig. 3a).

b) Merger initiation 2147 UTC

About eight minutes later at 2147 UTC, the 0.5° reflectivity echoes began to merge in Craig County (Fig. 1b), although it would take another nine minutes at 2156 UTC for this merger to become apparent viewing the elevated 30 dBZ reflectivity cores (Fig 3b). After the merger at 0.5°, the

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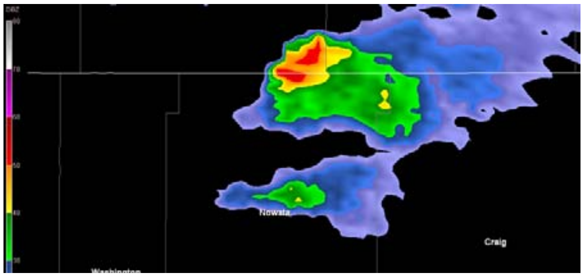
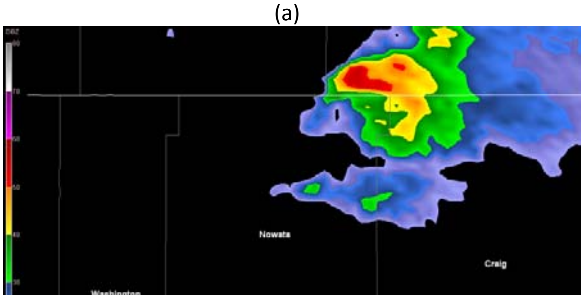


(a)



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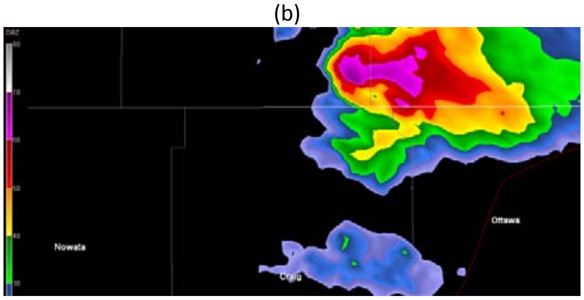


(c)

Figure 1. KINX 0.5° reflectivity images at (a) 2139 UTC, (b) 2147 UTC, and (c) 2217 UTC.

mesocyclone began to intensify in the mid-levels and then strengthen downward, reaching moderate to strong levels during the next 20 minutes (Fig. 2).

c) Merger completion – 2217 UTC

Finally at 2217 UTC, the original weaker echo was almost entirely engulfed by the larger supercell (Fig. 1c). The reflectivity core had increased dramatically in height, size, and magnitude with a very well developed weak echo region (Fig. 3c). Three minutes later a tornado was reported. The rotational velocity (Fig. 2) reached its greatest strength to this point in the lowest part of the storm. As the tornado continued, the mesocyclone continued to strengthen and increase in depth. Twenty-three minutes later at 2240 UTC, the tornado hit Picher, Oklahoma, killing six people while causing EF4 damage (NOAA 2009).

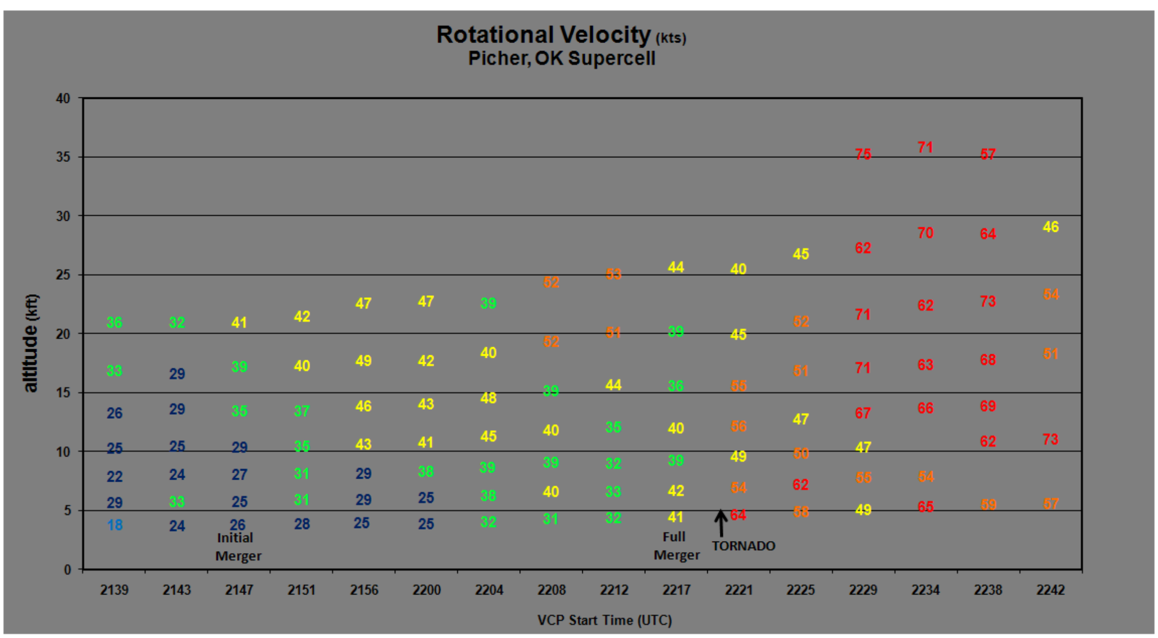
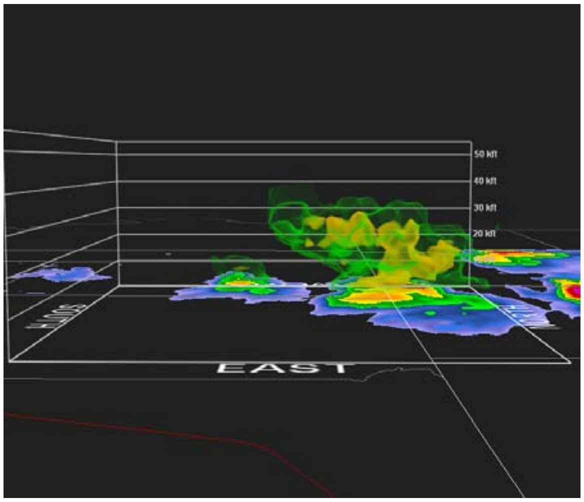


Figure 2. Time-height diagram of rotational velocity values from the Picher, OK supercell's mesocyclone. Shear values (kts) are noted by warmer colors indicating stronger shears and cooler colors weaker shears.



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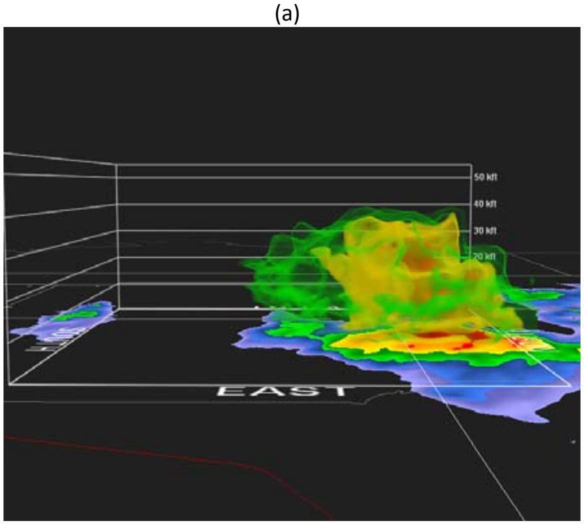

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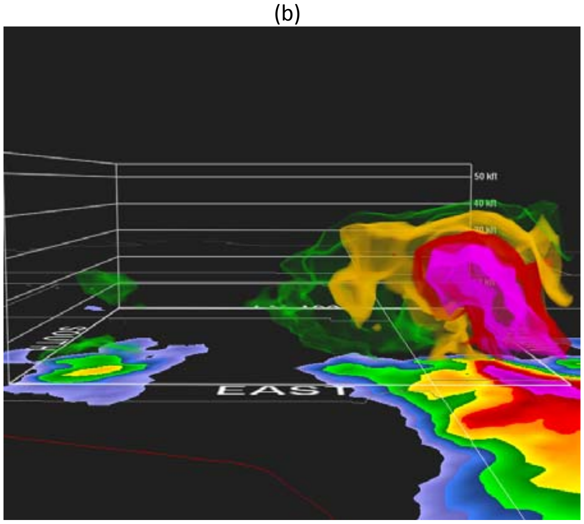


(c)

Figure 3. Three-dimensional view of the ordinary cell supercell storm merger at (a) 2143 UTC, (b) 2156 UTC, and (c) 2217 UTC.

3.2 Eastern Iowa – 19 August 2009

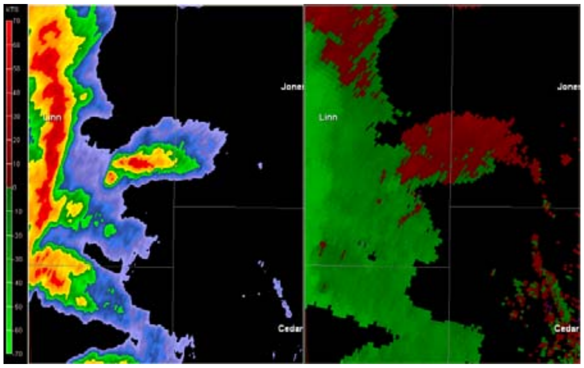
This case is a squall line – supercell merger resulting in a brief tornado which caused EF0 damage (NCDC 2009), uprooting and snapping trees during its brief lifetime. Storm tops were below 30 kft and no lightning or thunder was observed or reported with these storms. The background environment was supportive of tornadoes with low instability (surface-based CAPE < 1000 Jkg^{-1}) but high bulk shear (0-6 km of 50 kts and 0-1 km of 25 kts), more characteristic of a transition season severe weather environment in the Midwest rather than what is typically observed during the summer.

a) Pre-merger 2150 -2155 UTC

Fig. 4a depicts the 0.5° reflectivity and base velocity images at 2155 UTC. The KDVN Davenport, Iowa WSR-88D is located southeast of the storms. A small supercell with a shallow, weak mesocyclone is apparent ahead of the squall line in Linn County. Line movement was to the east while the supercell was moving slowly north. This differential motion allowed the squall line to overtake the supercell beginning around 2159 UTC.

b) Merger 2159 – 2230 UTC

Initial merger of the 0.5° reflectivity echoes began around 2159 UTC with the merger process continuing for the next 30 minutes. At 2213 UTC, the reflectivities cores continued to merge (Fig. 4b), and after a period of weakening, the supercell's mesocyclone began to restrengthen (Fig. 5). However, the stronger outbound winds from the squall line did not begin to interact with the mesocyclone until 2218 UTC (Fig. 4c). The tornado touched down at 2220 UTC in the southwest part of Jones County. The tornado was short-lived and the merged structure weakened considerably about 20-30 minutes after the demise of the tornado. The mesocyclone strength remained unchanged, but it did deepen notably during and after the tornado with the height increasing from 10 kft to 18 kft (Fig. 5).



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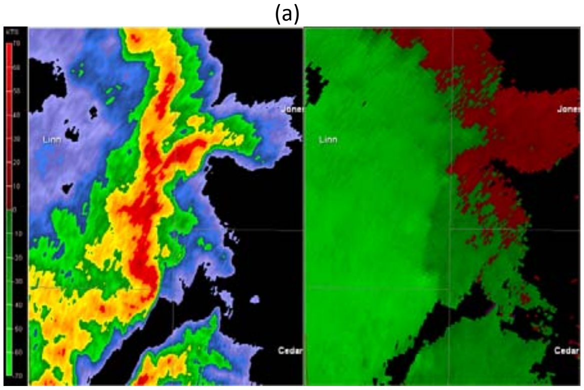

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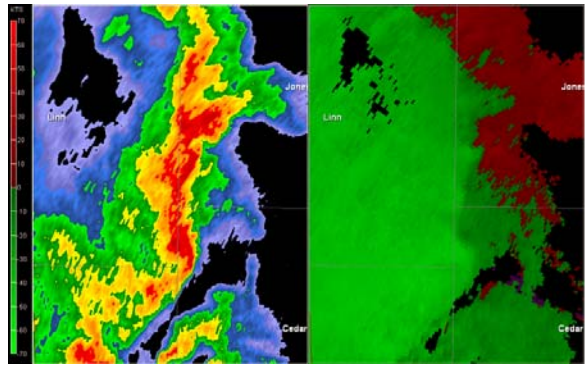


(c)

Figure 4. KDVN 0.5° reflectivity (left) and base velocity (right) images at (a) 2155 UTC, (b) 2213 UTC, and (c) 2218 UTC. Green indicates inbound velocity and red outbound.

From a 3D perspective looking at contoured values of the 55 dBZ isopleth (Fig 6a-b), as the merger occurs, the 55 dBZ and higher reflectivity core increased in volume between 2204 and 2213 UTC suggesting the updraft was strengthening. This agrees with the analysis of rotational velocity which showed a deepening and strengthening mesocyclone (Fig. 5).

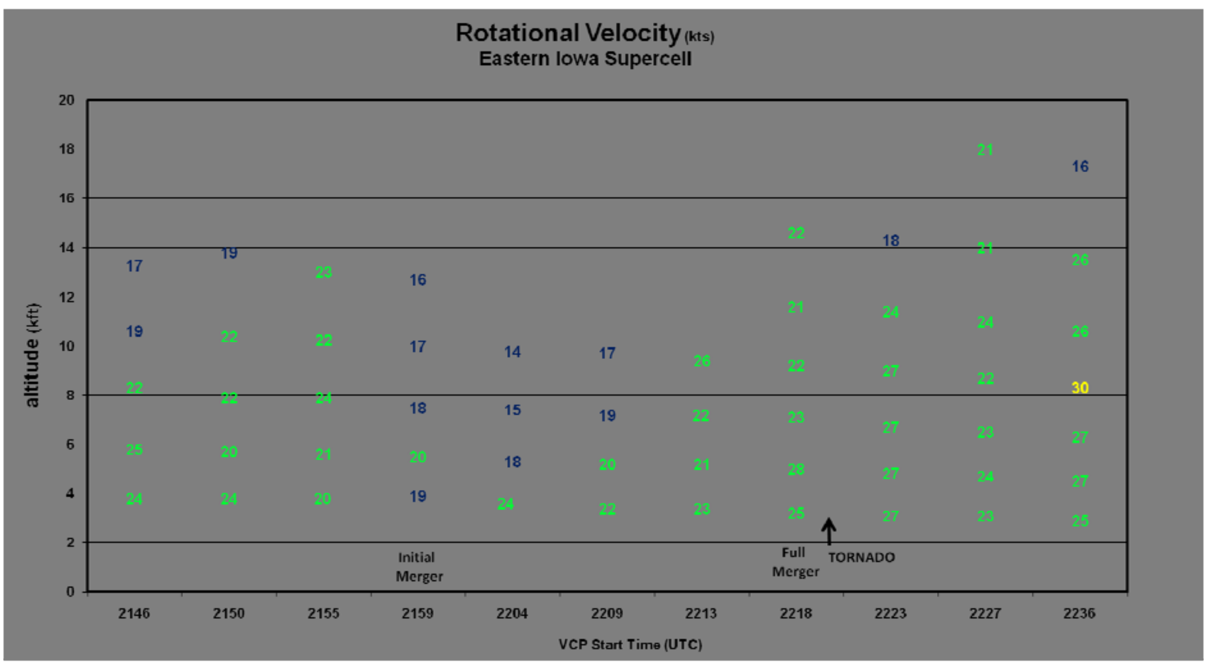
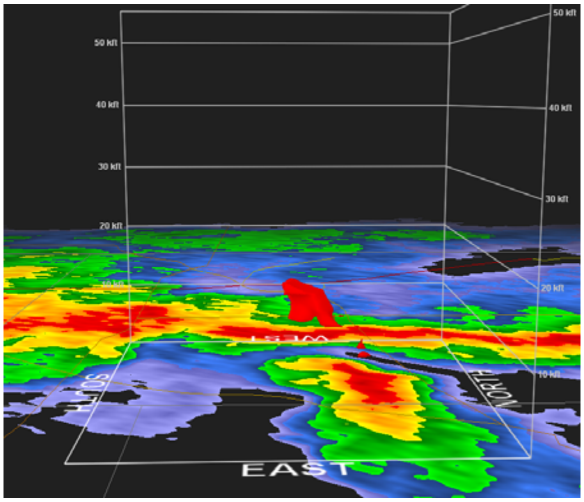
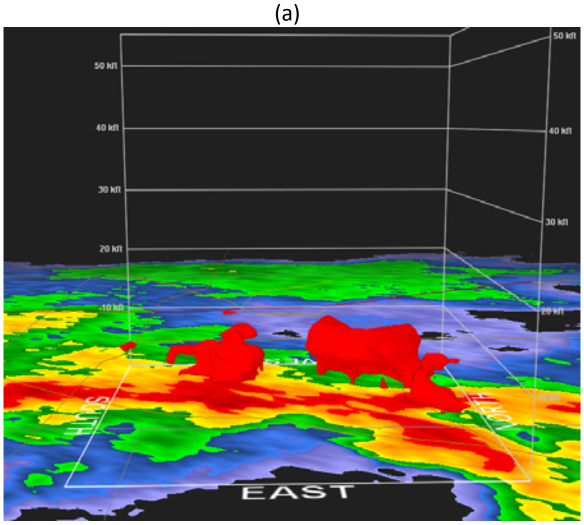


Figure 5. Time-height diagram of rotational velocity values from the eastern Iowa supercell's mesocyclone. Shear values (kts) are noted by warmer colors indicating stronger shears and cooler colors weaker shears.



(a)



(b)

Figure 6. Three-dimensional view of the squall line supercell storm merger at (a) 2204 UTC and (b) 2213 UTC. Reflectivity values > 55 dBZ are shaded red.

3.3 Northwest Illinois – 9 May 1995

This event is a case of squall line – supercell interaction leading to tornadogenesis documented by Wolf et al. (1996). Conditions were quite favorable for tornadoes on this day with 13 reported in a 3.5 hour period in eastern Iowa and northwest Illinois, four of which were rated F3 (NCDC 1996).

a) Pre-merger – 2215 -2306 UTC

At 2215 UTC, the KLOT WSR-88D located in Romeoville, Illinois, 100 nmi east of the study area, indicated a mixed-mode area of thunderstorms along the Mississippi River in extreme eastern Iowa and northwest Illinois. The cells oriented northwest to southeast in Fig. 7 were supercells located along a warm front, and the cells oriented more north to south were bow echoes located along the cold front. Differential motion resulted in numerous mergers that day, several of which were tornadic, and one of which is illustrated here. As the squall line neared the supercell in question (strongest appearing storm in the center of Fig. 7), its mesocyclone actually began to weaken between 2250 and 2306 UTC.

b) Merger – 2306-2327 UTC

Between 2317 and 2327 UTC, it appeared the original mesocyclone weakened, and then a new mesocyclone developed and intensified rapidly as the bow echo and supercell merged (Fig. 8). It was during this time frame at approximately 2317 UTC that a weak tornado was reported with this storm.

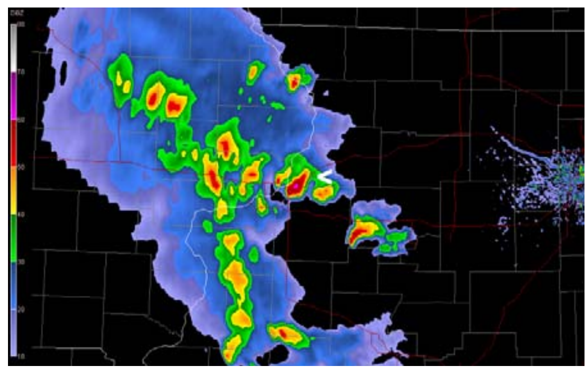


Figure 7. KLOT 0.5° reflectivity image at 2215 UTC.

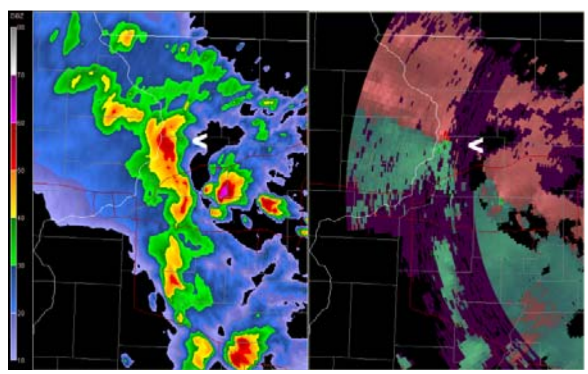


Figure 8. KLOT 0.5° reflectivity (left) and storm-relative velocity image (right) image at 2327 UTC. Green indicates inbound velocity and red outbound. The cell of interest is noted with a **<**.

This case indicates some shortcomings with 3D radar analysis which in part reflects limitations of the WSR-88D. At this range, the low-level portion of the storms are essentially not observed since the 0.5° beam height is between 10,000 and 12,000 ft. In addition, these were not tall storms with 18 dBZ echo tops only between 35 and 40 kft. Moreover, since this event occurred during the deployment and commissioning of the radar, VCP 21 was in use which provides fewer elevation angles (9) thus less vertical resolution than newer VCPs with higher resolution in space (e.g., VCPs 11 (11 angles) and 12 (12 angles)) and time (VCP 21 5 minutes vs. VCP 12 4.1 minutes). These shortcomings limited the utility of 3D imagery, thus none is shown for this case.

4. SUMMARY AND CONCLUSIONS

Storm mergers leading to tornadogenesis pose a special challenge to warning forecasters because mergers are ubiquitous, but tornadoes resulting from mergers happen in only a subset of occurrences. In many cases these tornadoes occur very rapidly during or after merger, and sometimes result in loss of life and significant property damage. The events shown here illustrate two of the many modes of merging storms, i.e., supercell – ordinary cell and squall line – supercell.

The use of three-dimensional radar imagery provides a more complete view of storm structure and interactions than what can be observed by viewing elevation angles individually. This may help improve understanding of the processes going on during merger, e.g., changes to updraft and downdraft strength.

However, the quality of 3D imagery, and in fact the analysis of merging storms, is hindered by WSR-88D sampling limitations. This is especially true for older VCPs with less vertical, horizontal, and temporal resolution than current VCPs; and is true for all VCPs for storms at a greater distance from the radar.

In addition, it takes some effort to develop color curves and manipulate images to gain a perspective that best helps elucidate what is going on. In research when time is available to develop and tweak color curves or manipulate viewing angles and lighting, that is not a problem. But operationally when forecasters are time constrained, this can be problematic, especially since these properties may vary from event to event, and even amongst storms on the radar at the same time.

Additional research on mergers is needed to improve understanding of the merger process in order to better assess when mergers are more likely to be tornadic than not. Studies should be expanded beyond radar-only assessments such as this one to include detailed information on the background environment, e.g., shear, instability, etc., and how that may impact merger outcomes. Null cases should be included to help deduce important aspects by understanding failure modes. Field studies using research-quality radars may wish to focus on squall line – supercell or squall line – ordinary cell mergers, as these types seem to be more predictable than other merger modes such as supercell – supercell. Finally, numerical modeling efforts could help improve understanding of the physical processes and circumstances involved in tornadogenesis success or failure through controlled experiments manipulating how storms interact and the environmental conditions in which they occur. This would provide great help in focusing observational studies.

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