P1.14 DAMAGE ASSESSMENT AND RADAR ANALYSIS OF THE 10-11 JULY 2011 DERECHO IN IOWA

Ray Wolf* and Donna Dubberke
NOAA/National Weather Service, Davenport, Iowa

Jeff Johnson, Kevin Deitsch and Kevin Skow
NOAA/National Weather Service, Des Moines, Iowa

1. INTRODUCTION

During the late afternoon and evening hours of 10 July 2011, a complex of thunderstorms developed in eastern Colorado and western Kansas and moved across Nebraska, while a second area of thunderstorms developed into a quasi-linear convective system (QLCS) in the Dakotas and moved southeast into Minnesota. The Nebraska complex and trailing storms from the QLCS in Minnesota eventually converged in Iowa during the early morning hours on 11 July, resulting in a complicated mass of thunderstorms with little apparent organization initially.

Approximately 1.5 hours after the first merger, a cluster of thunderstorms on the southern end of the mass evolved rapidly into a derecho-producing MCS in central Iowa. The MCS, appearing as a bow echo about 100 km (~60 mi) in length, produced a relatively short path of extreme wind damage in central and east-central Iowa, embedded within a wider and much longer area of lesser wind damage that stretched from central Iowa eastward through Chicago into the upper Ohio River valley (Fig. 1). Damage in the hardest hit areas was significant enough to warrant a Presidential disaster declaration for four Iowa counties.

WSR-88D radar indicated the merger of two mesovorticies north of the developing apex and along the leading edge of the convective system prior to the MCS's rapid strengthening and production of the most significant wind damage. Merger of these mesovorticies appeared to result in upscale growth into an intensifying line-end vortex in the manner proposed by Trapp and Weisman (2003) and observed by Atkins et al. (2004). Outflow from the QLCS may have played a role in mesovortex generation, and thus the rapid intensification of the line-end vortex as well. Subsequent development of the line-end vortex seemed to occur concurrently with the development of the rear-inflow jet; and as the line-end vortex intensified, so too did the rear-inflow jet as noted by Weisman (1993). Both occurred prior to the most extreme surface winds.

*Corresponding author address: Ray Wolf, NOAA/National Weather Service, 9050 Harrison St., Davenport, IA, 52806; e-mail: ray.wolf@noaa.gov.

The path of extreme damage was surveyed by National Weather Service (NWS) teams from the Des Moines and Davenport, Iowa offices. The resulting assessment of wind speeds produced by the storm is depicted in Fig. 2. Wind speed estimates up to 60 ms^{-1} (~130 mph) were based on damage to well-built structures and flattened high-power transmission lines (Figs. 3a-d). Significant damage to trees (snapped or uprooted) and local power lines (snapped or flattened) was pervasive. Damage of this degree is at the upper bound of what has been observed from straightline winds in Iowa, at least since 1995. To place this into historical perspective, Iowa's all-time official maximum wind speed record is 105 mph at Waterloo (9 July 1980, NWS observer measured), and unofficial readings of 115 mph at Ottumwa (28 June 1960, FAA observer estimate) and 123 mph in Washington (29 June 1998, automated school net station) have also been observed (Harry Hillaker, Iowa State Climatologist, personal communication).

Similar events with either HP supercell or bow echo convective modes producing extreme surface winds have been studied in the past. These include the 10 August 1992 derecho in Missouri (Przybylinski et al. 1993), the 27 May 2001 derecho in Oklahoma (Miller et al. 2002), the 29 June 1998 derecho in Iowa and Illinois (Atkins et al. 2004, bow echo phase; Miller and Johns 2000, HP supercell phase), Miller and Johns

(2000), and others. It is clear these events pose an especially significant threat to life due to their extreme nature, and the possibility that some people will underestimate the risk posed by non-tornadic severe convective winds (Godfrey 2010). This study will document the 11 July 2012 case toward a better understanding of extreme straightline wind events.

2. SYNOPTIC AND MESOSCALE BACKGROUND

Upper-air data and analyses from 0000 UTC 11 July 2011 (Figs. 4a-b) showed Iowa at the southern edge of strong 250- and 500-mb flow centered along the U.S.–Canadian border. No clear shortwave trough was apparent in the Northern Plains based on height fields; however, weak cold-air advection was indicated in that region at 500 mb.

In the lower troposphere, thermal-moisture advection resulting from a strong gradient in modest southerly flow was apparent at 850 mb (Fig. 4c) and 925 mb (not shown). Both the surface pressure (Fig. 4d) and lower tropospheric height gradient, however, implied a low-level jet would develop that evening. The combination of cold-air advection at 500-mb and lower-tropospheric warm-air advection pointed to increasing destabilization during the overnight hours. Soundings from Omaha, Nebraska (OAX) and Davenport, Iowa (DVN) already indicated an environment with extreme values of mean-layer CAPE, moderate-high 0-6-km bulk shear, and veering of the low-level winds (Fig 5a-b). RUC-based analyses at 0600 UTC (Fig. 6a-b) confirmed extreme mean-layer CAPE of 4000-5000 J kg^{-1}, a weak capping inversion, and an instability gradient suggestive of a boundary in north-central Iowa. Effective shear was moderate with values of 30-35 kts.

The environment observed in this event is that described by the Johns and Hirt (1987) and Johns (1993) warm season pattern, and also fits the composite for a rapidly developing MCS as documented by Coniglio et al. (2010). These cases have a stronger low-level jet closer to the storms, much larger CAPE, DCAPE and potential instability, plus weaker mid-level vertical shear and weaker dynamic forcing than their slowly developing counterparts.

3. RADAR AND DAMAGE ANALYSIS

At 0800 UTC 11 July 2011, an HP supercell with a moderately strong and broad mid-level mesocyclone had been producing severe winds (~30-40 ms^{-1}, 60-80 mph) in central Iowa, west and north of Des Moines. However as the storm continued to move east-northeast, it encountered an environment with increasing instability, a weakening cap, and outflow generated by thunderstorms to the north. In addition, at 0802 UTC, GOES-13 brightness temperature difference (BTD), the difference between 6.5 μm water vapor and 11 μm thermal IR data, indicated an intrusion of dry air into the mid-levels of the MCS (Fig. 7, in blue). Pryor (2011) showed that dry air intrusions observed in the BTD product can be associated with severe-wind producing downbursts. At 0832 UTC, WSR-88D data from Des Moines, Iowa (KDMX) indicated the storm intersected the first of two convective outflow boundaries (Fig. 8). Also, the reflectivity image indicated weak convective cells developing just to the north of the boundary. Appearance of weak convective cells such as these can be a good proxy indicator of parcel lift to the LFC due to a nearby boundary when either surface observations or radar data are inconclusive in locating the boundary.

Subsequent to the initial boundary interaction and observation of an incipient rear-inflow jet, a pair of mesovorticies developed along the leading edge of the MCS (Fig. 9). The mesovorticies were shallow in nature (< 3.7 km, < 12 kft) and located on the developing northern apex of the convective system. Both ground and aerial surveys conducted after the storm did not find any definitive evidence of tornadic damage with these mesovorticies. Shortly thereafter at 0900 UTC, the mesovorticies merged resulting in a broader and vertically deepening cyclonic circulation (Fig. 10 and 11a). A second convective outflow boundary moving in from the northwest merged with the system at or just prior to this time (not shown). It too may have been a factor in the development of the line-end vortex. The deepening of the circulation implies vertical stretching of tilted horizontal vorticity that would serve to maintain and possibly strengthen the line-end vortex, and therefore enhance the strength of the rear-inflow jet (Weisman 1993).

Around 0950 UTC, the circulation had reached its maximum intensity, as did the damage (Figs. 11a-b and 12a-b). Both KDMX and the Davenport, Iowa WSR-88D (KDVN) indicated the circulation had strengthened and deepened further to a height of approximately 11 km (35 kft). The horizontal size of the circulation (11-22 km, ~6-10 nm) was too large to be classified as a mesocyclone (Burgess 1976), but was similar in size to the line-end or book-end vortices modeled by Weisman (1993) and observed by Atkins et al. (2004) and others.

A comparison of the rotational shear diagrams for KDMX and KDVN, as well as the radar depictions in Figure 12a-b, illustrates the limitations and challenges faced when observing storms far from the radar. KDMX indicated a stronger circulation and more completely resolved both the lower and upper levels of the storm than did the KDVN radar.

4. CONCLUSIONS

This case documents an HP supercell to bow echo transition that is occasionally a *significant* severe weather producer in the Midwest. Once the transition completed, the storm progressed through a systematic and potentially anticipatable evolution. The storm complex interacted with convective outflow from thunderstorms to the north. A rear-inflow jet developed followed by the appearance of two mesovorticies on the leading edge of the storm's outflow. These two mesovorticies eventually merged, and the resultant circulation developed upscale into a line-end vortex. The circulation intensified as did the rear-inflow jet just prior to the most extreme wind damage.

The case also documents the importance of using multiple radars in the storm interrogation process when available. KDMX was closer to the MCS and provided higher vertical and horizontal resolution compared to KDVN. While similar general trends were observed by KDVN, they were much more clearly defined by KDMX. Finally, knowledge of the evolving storm environment, HP-bow echo transition paradigm, importance of boundary interactions, and role of mesovorticies in line-end vortex development, and utility of the GOES BTD product would all help to anticipate severe weather, perhaps even more than a "routine" severe weather event. Nonetheless, the ability to anticipate an event of this extreme intensity prior to its appearance at maturity on radar remains challenging.

5. ACKNOWLEDGEMENTS

Surface mesonet plots and some radar imagery were provided by the Iowa Environmental Mesonet. WSR-88D archive II data were viewed using GR2Analyst. The Storm Prediction Center provided synoptic and mesoscale data and analyses. Satellite data were provided by Ken Pryor, NESDIS, and viewed using the NOAA Weather and Climate Toolkit. Thanks to each for facilitating this project, and to Jeff Manion of the NWS Central Region for his review and comments.

6. REFERENCES

Atkins, N. T., J. M. Arnott, R. W. Przybylinski, R. A. Wolf, and B. D. Ketcham, 2004: Vortex structure and evolution within bow echoes. Part I: Single-Doppler and damage analysis of the 29 June 1998 derecho. Mon. Wea. Rev., 132:2224-2242.

Burgess, D.W., 1976: Single Doppler radar vortex recognition: Part 1 - Mesocyclone signatures. Preprints, 17th Conf. Radar Meteor., Amer. Meteor. Soc., 97-103.

Coniglio. M. C., J. Y. Hwang, and D. J. Stensrud, 2010: Environmental factors in the upscale growth and longevity of MCSs derived from Rapid Update Cycle analyses. Mon. Wea. Rev., 138:3514-3539.

Godfrey, C. M., P. L. Wolf, M. K. Goldsbury, J. A. Caudill, and D. P. Wedig, 2011: An evaluation of convective warning utilization by the general public. Preprints, Conf. on Wea. Warnings and Comm., Oklahoma City, OK, Amer. Meteor. Soc.

Johns, R. H., 1993: Meteorological conditions associated with bow echo development in convective storms. Wea. Forecasting, 8:294-299.

Miller, D. J., D. L. Andra, Jr., J. S. Evans, and R. H. Johns, 2002: Observations of the 27 May 2001 high-end derecho event in Oklahoma. Preprints, 21st Conf. on Severe Local Storms, San Antonio, TX, Amer. Meteor. Soc., 13-16.

Miller, D. J., and R. H. Johns, 2000: A detailed look at extreme wind damage in derecho events. Preprints, 20th Conf. on Severe Local Storms, Orlando, FL, Amer. Meteor. Soc., 52-55.

Johns, R. H., and W. D. Hirt, 1987: Derechos: Widespread convectively induced windstorms. Wea. Forecasting, 7:32-49.

Pryor, K. L., 2011: Microburst nowcasting applications of GOES. NOAA Tech. Rep. NESDIS 140, 44 pp.

Przybylinski, R. W., G. K. Schmocker, and T. J. Shea, 1993: Doppler radar observations of a bowing convective line segment associated with a long track severe windstorm. Preprints, 17th Conf. on Severe Local Storms, St. Louis, MO, Amer. Meteor. Soc. 582-587.

Trapp, R. J., and M. L. Weisman, 2003: Low-level mesovorticies within squall lines and bow echoes. Part II: Their genesis and implications. Mon. Wea. Rev., 113:2804-2823.

Weisman, M. L., 1993: The genesis of severe, long-lived bow echoes. J. Atmos. Sci., 50:645-670.

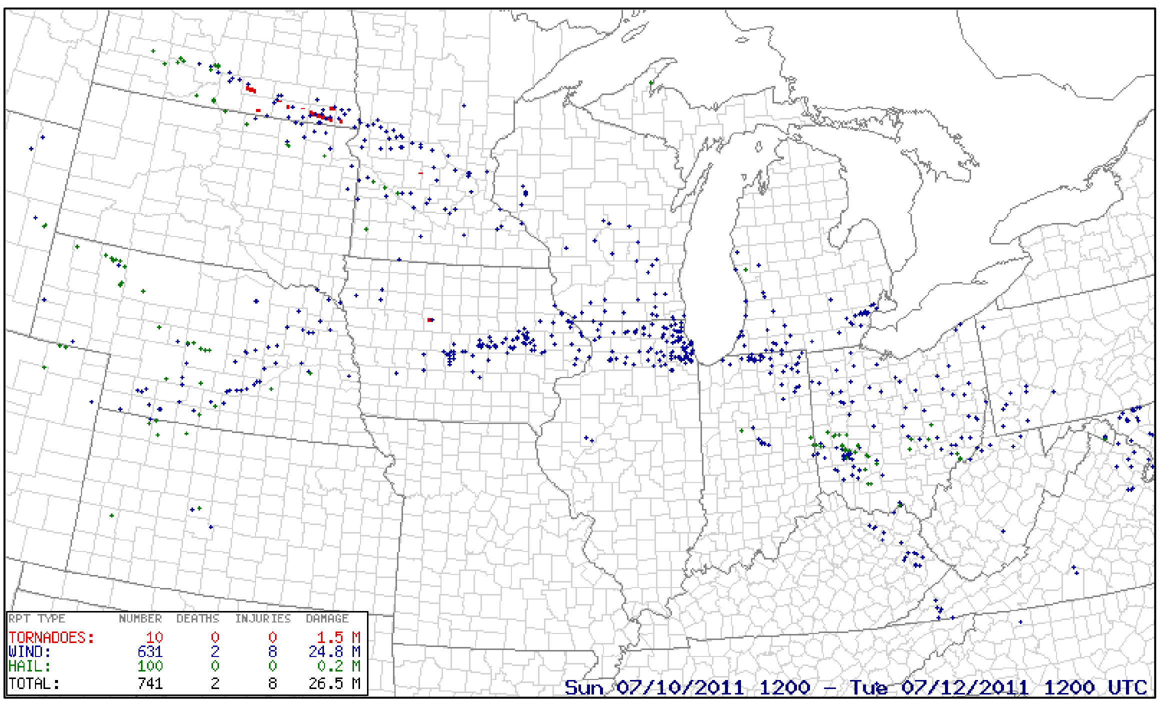


Figure 1. Severe weather reports from the two initial convective systems (Nebraska and Minnesota-Wisconsin) and eventual derecho (central Iowa eastward to Chicago and into the Ohio River valley). See legend in the lower left. *Courtesy NWS Storm Prediction Center.*

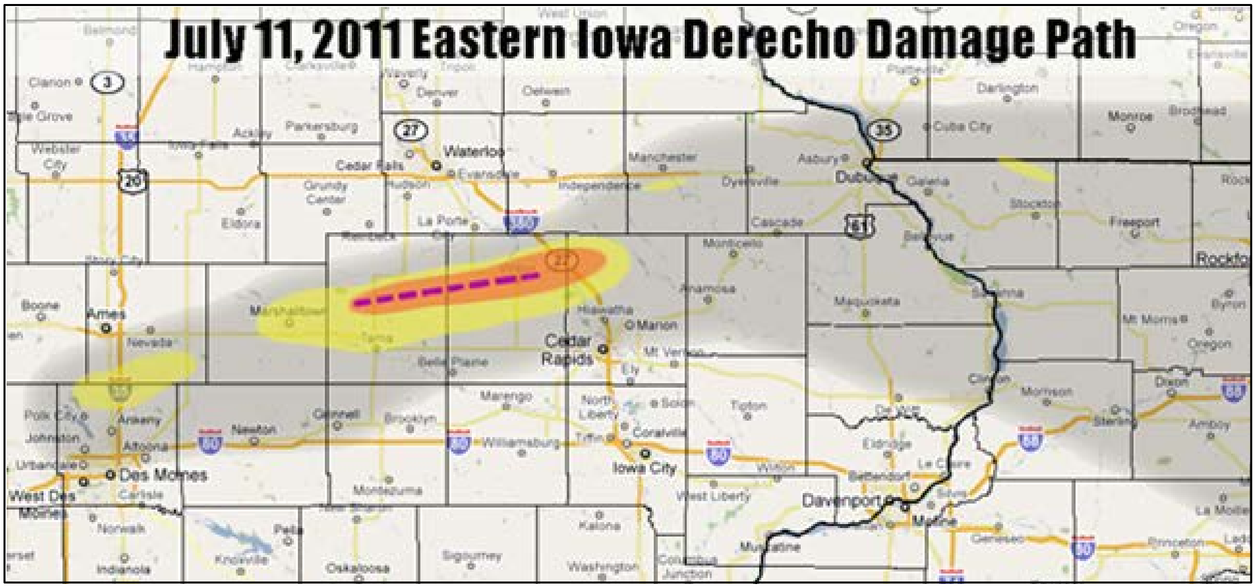


Figure 2. Subset of the area of wind damage produced by the 11 July 2011 derecho in eastern Iowa, extreme southern Wisconsin and northern Illinois, based on reports and surveys from local NWS offices. Severe-criteria wind estimates begin with gray shading – 26-31 ms^{-1} (58-70 mph), yellow – 31-45 ms^{-1} (70-100 mph), red – 45 ms^{-1} + (100 mph +). The dashed line indicates a damage path with winds estimated between 49 and 58 ms^{-1} (110 and 130 mph).

(a)

(b)

(c)

(d)

Figure 3a-d. From upper left to lower right, home in Vinton, Iowa (a), Iowa Braille School in Vinton (b), high tension power lines in rural Benton County (c), and the public library in Garrison, Iowa (d). All locations are in Benton County.

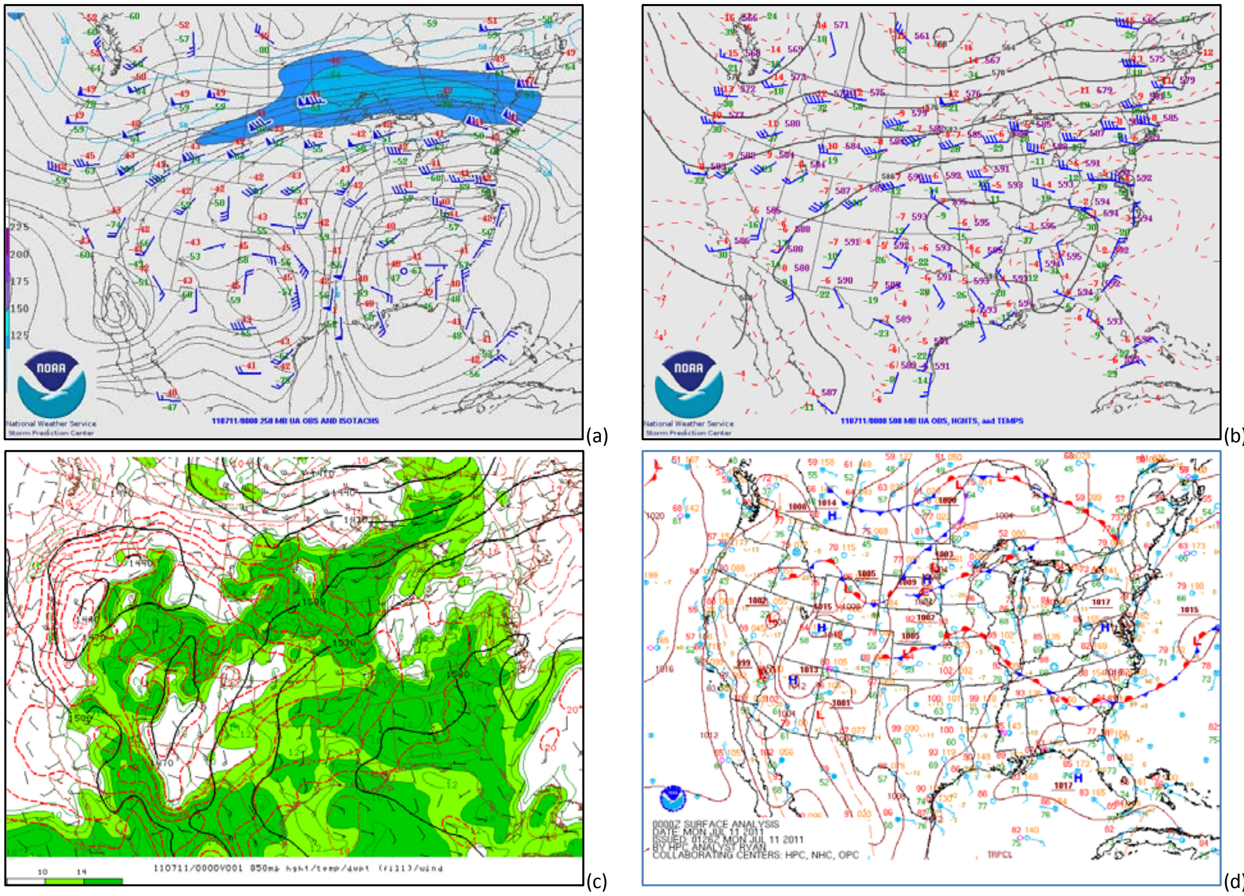


Figure 4a-d. 0000 UTC 11 July 2011 upper air and surface analyses. 250 mb (a), 500 mb (b), 850 mb (c) and surface (d). See text for details. *Courtesy NWS Storm and Hydrometeorological Prediction Centers.*

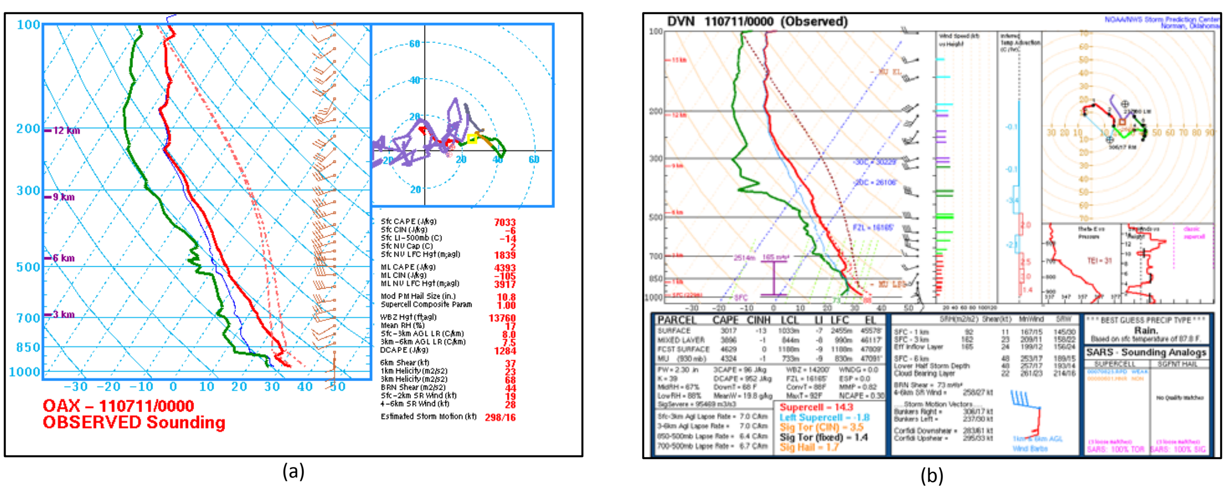
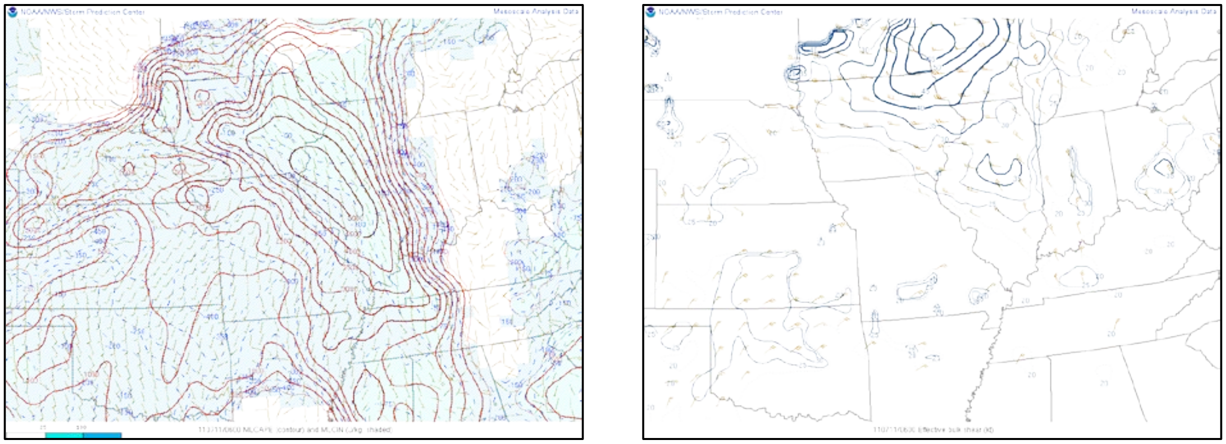


Figure 5a-b. 0000 UTC 11 July 2011 Omaha, NE (OAX) (a) and Davenport, IA (DVN) (b) soundings. See text for details. *Courtesy NWS Storm Prediction Center.*



(a) (b)

Figure 6a-b. 0000 UTC 11 July 2011 mean-layer CAPE and CIN (a) and effective bulk shear (b). *Courtesy NWS Storm Prediction Center.*

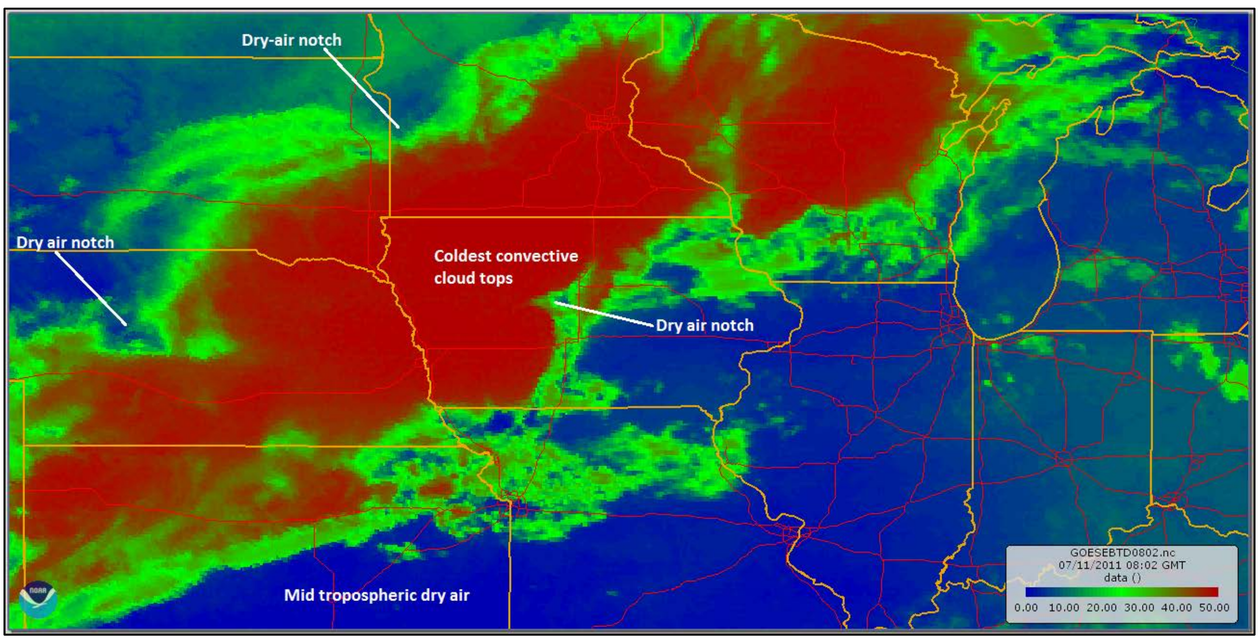


Figure 7. 0802 UTC GOES 13 brightness temperature difference. Cold, convective cloud tops are in red; mid-level dry air is in blue. Note the dry intrusion indicated in central Iowa. *Courtesy of NOAA NESDIS.*

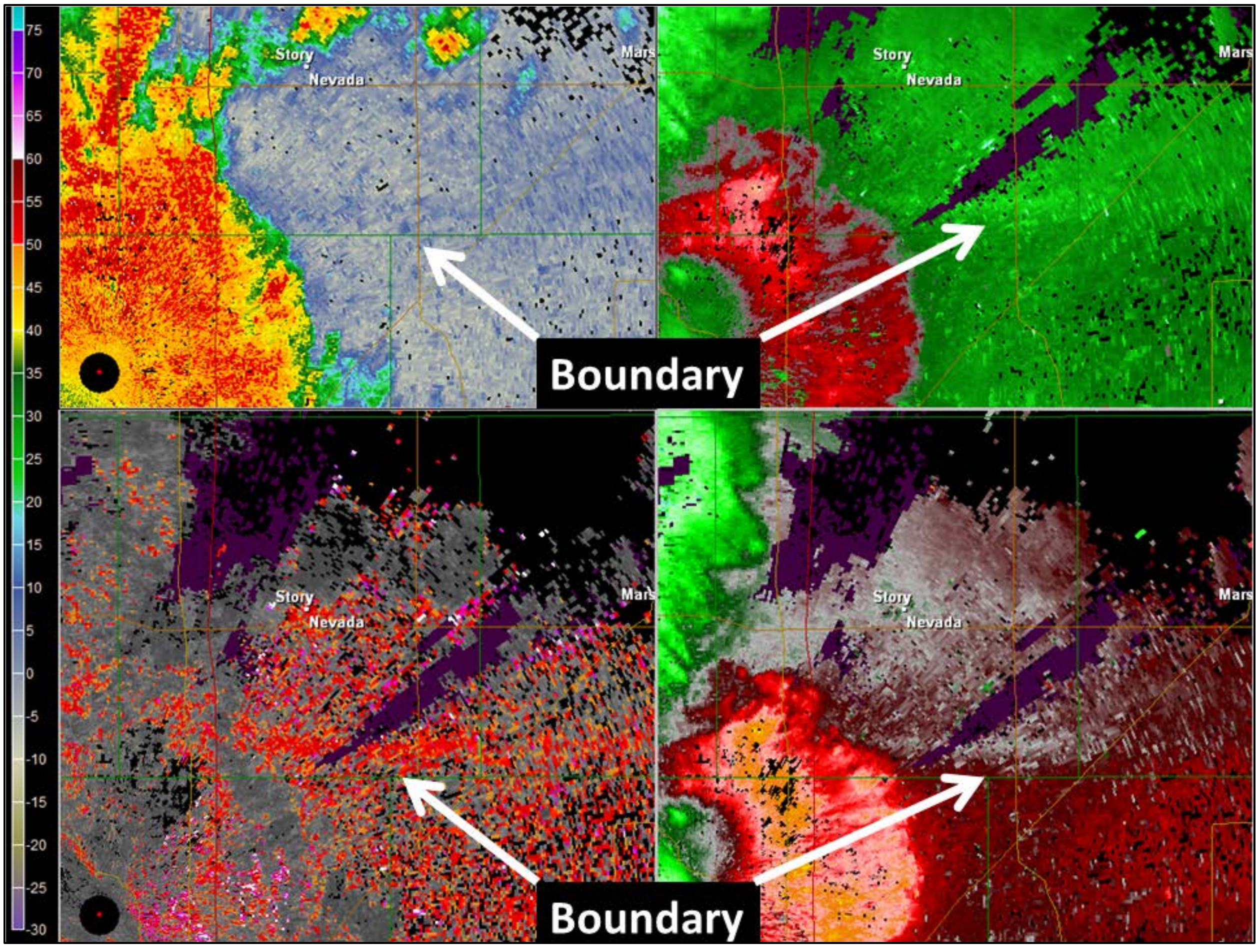


Figure 8. 0832 UTC KDMX 0.5° imagery of (clockwise from upper left) reflectivity, storm-relative velocity, base velocity and spectrum width. The radar is located in the lower left of the figure.

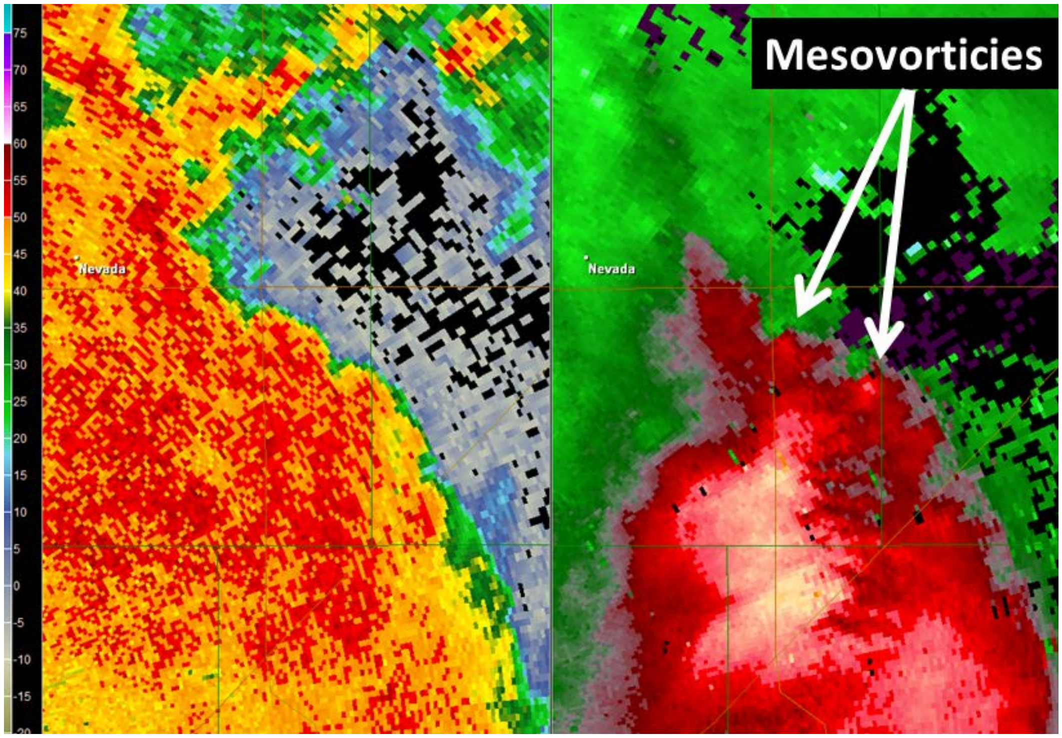


Figure 9. 0851 UTC KDMX 0.5° reflectivity and storm-relative velocity. Note the development of two mesovorticies on the leading edge of the storm in the storm-relative velocity image. The radar is located to the lower left in the figure.

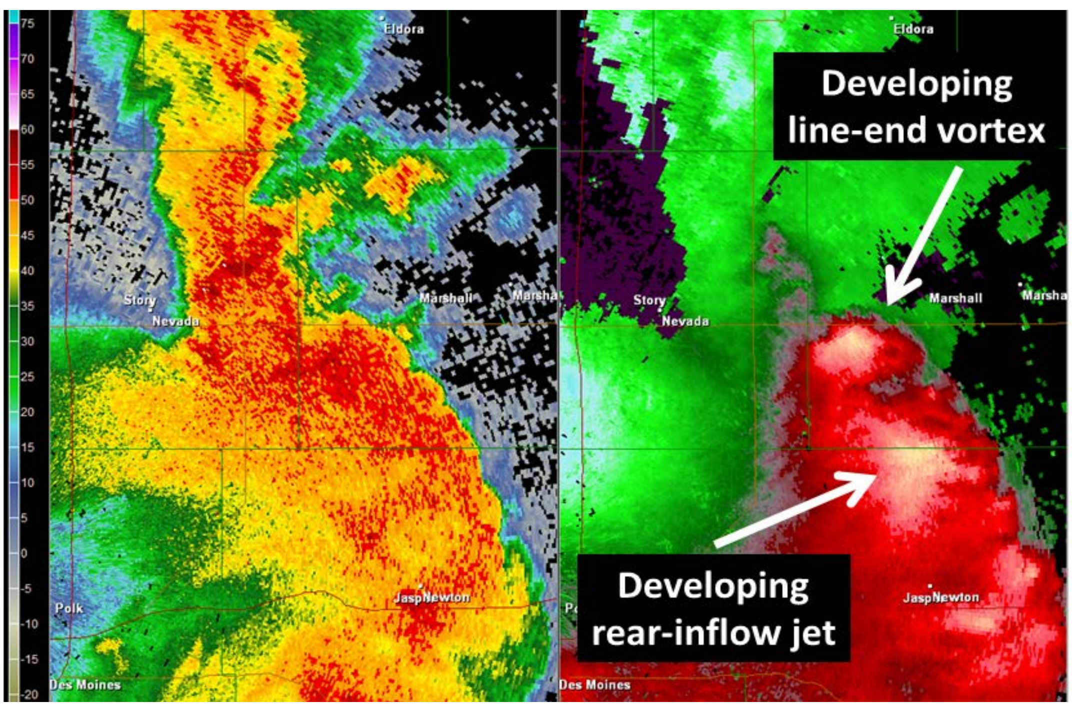
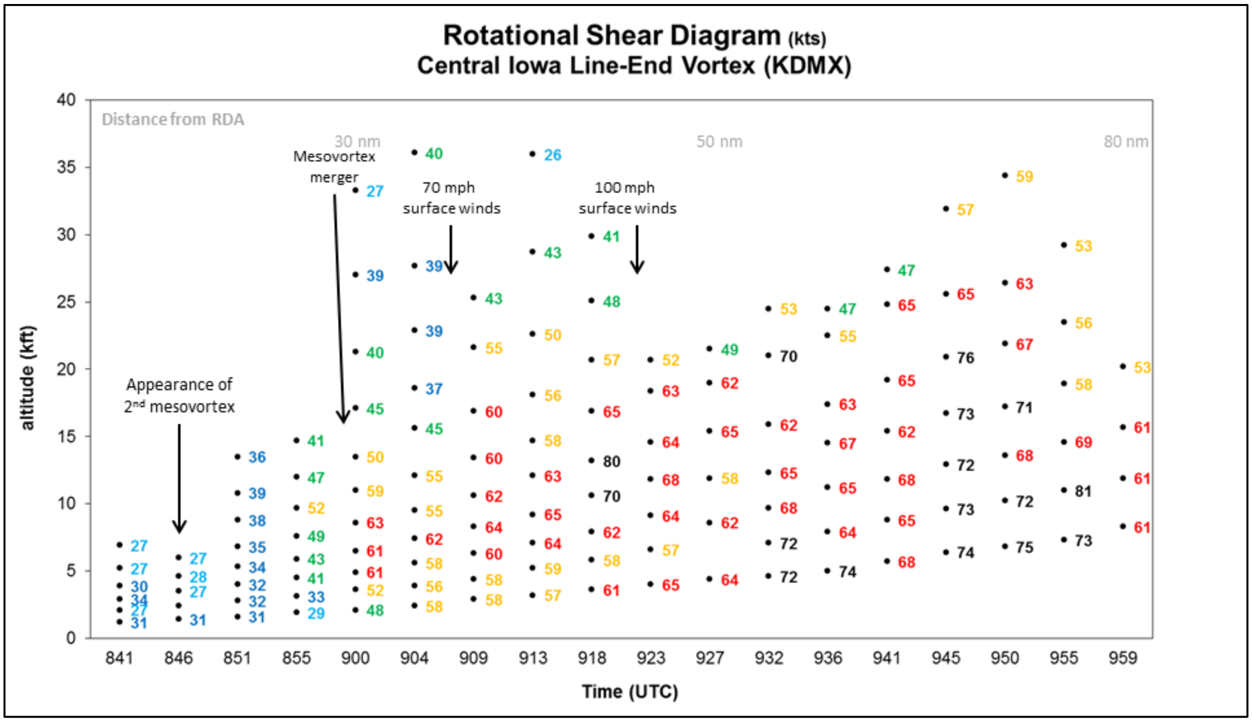
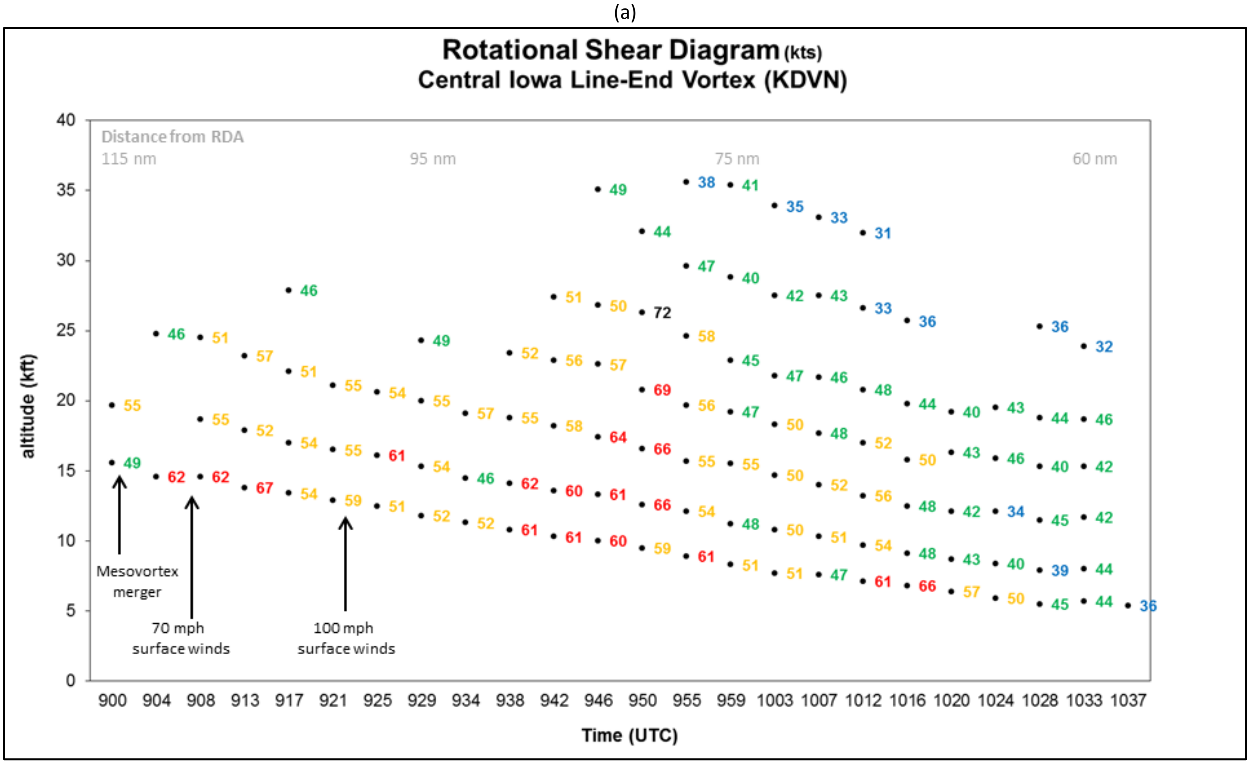


Figure 10. 0900 UTC KDMX 0.5° reflectivity and storm-relative velocity images just after the merger of the two mesovorticies and beginnings of the line-end vortex. The radar is located to the lower left in the figure.

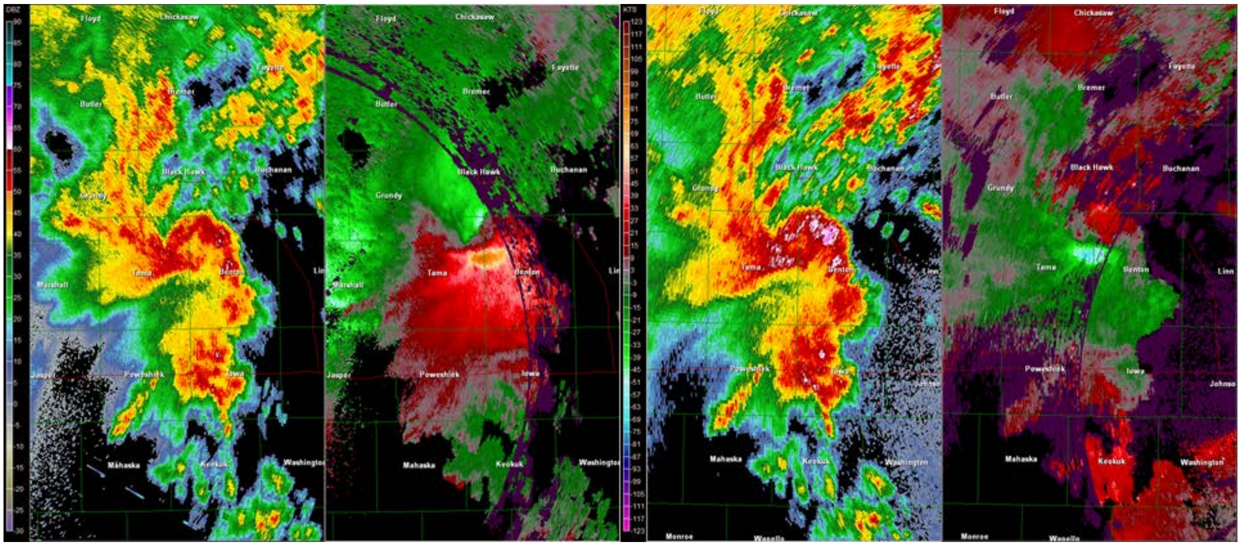


(a)



(b)

Figure 11a-b. Rotational shear diagram from KDMX (a) and KDVN (b) showing the evolution of the line-end vortex from the perspective of two radars. Warmer colors indicate higher rotational velocities and cooler colors indicate lower rotational velocities. Key aspects of the MCS's evolution are annotated on each diagram at the time of occurrence.



(a) (b)

Figure 12a-b. 0950 UTC KDMX (a) and KDVN (b) 0.5° reflectivity and storm-relative velocity near the time of the highest surface winds. KDMX is located to the lower left and KDVN is located to the lower right in the figure.