

The Impact of an Enhanced Damage Analysis on Determining the Damaging Wind Mechanism within a Quasi-Linear Convective System

JASON T. MARTINELLI
Creighton University, Omaha, Nebraska

JOSHUA BOUSTEAD, BARBARA MAYES, and VAN DE WALD
National Weather Service, Omaha, Nebraska

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ABSTRACT

During the evening hours of 20 August 2007, a quasi-linear convective system (QLCS) swept through the Omaha metropolitan area. Over the course of the week following the event, several undergraduate students and a faculty member from the Creighton University Department of Atmospheric Sciences conducted a rudimentary damage analysis. Equipped with a global positioning system (GPS)-enabled digital camera (Ricoh 500SE) and a hand-held Garmin GPS unit, the Creighton team documented the damage that occurred in and around the Omaha area. The geo-referenced damage data were then related to the Level II radar data from the Weather Surveillance Radar 1988-Doppler (WSR-88D) located at the National Weather Service Forecast Office (NWSFO) in Valley, Nebraska (KOAX) in an attempt to determine the portions of the convective system that produced the damage observed at the surface. Results showed the most significant surface damage occurred on the southern periphery of intense low-level circulations that developed along the leading edge of the QLCS north of the apex of the bow. Additionally, the results highlighted the inadequacy of the standard reporting system when used to examine marginal and/or non-tornadic events for which a local NWSFO does not conduct a formal damage survey.

1. Introduction

During the evening hours of 20 August 2007, a strong bowing quasi-linear convective system (QLCS) swept through the Omaha, Nebraska area resulting in sporadic reports of damaging winds. Given the non-tornadic nature of the event and the limited number of damage reports

Corresponding author address: Dr. Jason Martinelli, Creighton University Department of Atmospheric Sciences, 2500 California Plaza, Omaha, NE 68178
E-mail: Jay@Creighton.edu

obtained by the local National Weather Service Forecast Office (NWSFO) in Valley, Nebraska (KOAX), a formal damage assessment was not performed. However, using a GPS-enabled Ricoh 500SE digital camera and a handheld Garmin GPS unit, several members of the Creighton University Department of Atmospheric Sciences (CU-ATS) conducted a rudimentary damage survey in the days following the event. The importance of conducting a post-event damage assessment in order to understand the relationship between observable radar features and damage at the surface has been well documented in the literature (Fujita 1971 and 1978, Fujita and Wakimoto 1981, Atkins et al. 2005). Recently, Trapp et al. (2006) expounded to suggest that in an ideal world, a post event damage assessment should be conducted on all damage producing convective systems. It is understood that this is not possible given the known temporal and monetary expense of such an endeavor; however, the authors suggest that partnering with a neighboring academic institution would increase the frequency of post event damage assessments of some of the more marginal events.

This survey showed that the resultant wind damage was significantly underreported to the local weather service office. Furthermore, once the damage survey was complete, the geo-referenced data were examined in conjunction with the Level II radar data obtained by the Weather Surveillance Radar 1988-Doppler (WSR-88D) located at KOAX. Using this combined dataset, the Creighton team determined that the most significant damage was collocated with the tracks of two embedded mesovortices located along the leading edge of the system and not with the apex of the bow as is traditionally expected (Fujita 1978) Section 2 provides a brief overview of the pre-convective environment. Section 3 details the radar reflectivity and vortex structure associated with the damaging QLCS, Section 4 describes the results of the damage analysis, and Section 5 contains the summary and conclusions.

2. Pre-convective environment

The synoptic environment across the mid Missouri River Valley was favorable for convective development on 20 August 2007 (Fig. 1). At 0000 UTC 21 August, a shortwave trough was moving through eastern South Dakota and Nebraska associated with a thermal trough at 500 hPa and contributed to forcing for large-scale ascent across the region. Mid-level flow increased to 10 to 15 m s⁻¹ with the shortwave and contributed to 15 m s⁻¹ of 0 to 6 km bulk shear. Owing in part to the late seasonal occurrence of the event, significant low level moisture was in place across the region (not shown), enhancing the degree of mixed-layer (ML) convective available potential energy (CAPE) across the Missouri Valley, with ML convective inhibition greater than -25 J kg⁻¹ from southeast Nebraska into eastern Kansas. The combination of shear and instability favored organized convection, including the possibility of supercells (Rasmussen and Blanchard 1998). In addition to the favorable environment for supercells, strong convective downdrafts were also expected. Surface to 650 mb theta-e differences of 20 to 25 K were maximized over eastern Nebraska and Kansas (Atkins and Wakimoto 1991). The potential for strong convective downdrafts was also observed in the downdraft CAPE of 1700 J kg⁻¹ (not shown).

Initial surfaced-based thunderstorm development occurred along a surface trough from central Nebraska into central Kansas prior to 2100 UTC along the western edge of the MLCAPE axis and in a region of minimal MLCIN (Fig. 2). Through a number of cell mergers over south central Nebraska, the thunderstorms developed upscale into a forward propagating QLCS, which moved east-northeast and affected the Omaha, NE metropolitan area near 0000 UTC 21 August (Fig. 3). As the thunderstorms moved east-northeast into the axis of highest theta-e difference, reports of thunderstorm wind damage began (NCDC 2007). A radar analysis of the QLCS

mesovortices will follow in Section 3.

3. Radar Analysis

The Level II radar data from KOAX between 2346 UTC on 20 August and 0050 UTC on 21 August were examined in conjunction with the damage survey data in an attempt to identify the damaging wind mechanisms within this particular QLCS. Figure 4 shows an animated loop of the 0.5 degree base reflectivity and storm relative velocity for the period of interest. At 2346, the leading edge of the system was located approximately 40 km west northwest of the Omaha metropolitan area and moving east at $15\text{--}18\text{ m s}^{-1}$ (30-35 kt). At this time, there was a storm-scale circulation (C1) detected in Saunders County near the intersection of the east-west orientated warm frontal boundary and the northwest- southeast oriented combined cold front and outflow boundary. Initially detected between 2-6 km above ground level (AGL), C1 rapidly intensified in the lowest levels. Between 2354 and 0003 UTC, the rotational velocity of C1 exceeded 22.5 m s^{-1} (45 kt) between 1 and 2 km AGL (Fig. 5). Following a slight weakening in rotation, C1 intensified in the lowest levels between 0011 and 0020, with its rotational velocity exceeding 22.5 m s^{-1} (45 kt) between the lowest radar level and 2 km AGL (see Fig. 5). C1 rapidly weakened and became undetectable after 0020 in Saunders County just northwest of KOAX.

The surface under the path of C1 was surveyed extensively by the CU-ATS team with only non-tornadic damage (equivalent to EF0) to trees and crops documented. When comparing the locations of the damage to the radar-observed storm structure, it is clear the damage occurred on the southern periphery of C1 during the period in which C1 was most intense in its lowest levels (Fig 6).

Between 2345 and 0028, the QLCS rapidly intensified and solidified south of the warm frontal boundary across western Douglas County and began to exhibit signs of bowing. At this time, there were two additional storm-scale circulations detectable within the vicinity of KOAX. The second storm-scale circulation (C2) was first detected at 0024 in northern Sarpy County between 0-2 km AGL (Fig. 7). Initially, C2 had a maximum rotational velocity of approximately 15 m s^{-1} (30 kt) near 1 km AGL (Fig. 8). After a brief weakening period ending at 0032, C2 intensified and expanded upward. At this time, its maximum rotational velocities exceeded 15 m s^{-1} (30 kt) from near the surface to near 5 km AGL, with an embedded maximum of 22.5 m s^{-1} (44 kt) near 2.5 km AGL. It was at this time that significant wind damage commenced over eastern Douglas County and into western Pottawattamie County. The rapid deepening and intensification just prior to damage at the surface has been observed in other cases as well (Atkins et al. 2005 and Martinelli et al. 2007). Between 0045 and 0054, the rotational velocity of C2 exceeded 17.5 m s^{-1} (35 kt) below 1 km AGL. Through a review of media reports as well as witness accounts obtained during the post-event damage analysis, it is likely the damage continued to occur until approximately 0050. A survey of the surface under the path of C2 showed a nearly continuous 30 km long swath of damage equivalent to EF0 and low-end EF1 damage extending from northern Omaha into rural areas of Pottawattamie County (see Fig. 6).

The plan view storm-relative velocity data at 0041 UTC (Fig. 9) shows C2 and C3 clearly evident in the data. A strong area of outbound velocities across Sarpy County is also observed in Fig. 9. This rear inflow jet (RIJ) occurred behind the apex of the bowing segment and was likely enhanced by the presence of cyclonic and anticyclonic bookend vortices separated by approximately 50 km. Weisman (1993) found that bookend vortices in close proximity to one another could enhance rear-inflow by as much as 50% in numerical simulations. Much of this

area was traversed in an attempt to identify instances of damage. None were found.

A cross section taken along a radial oriented normal to the leading edge of the QLCS in the vicinity of C2 is also shown in Fig. 9. Two distinct flow branches typically associated with a strong bowing QLCS are evident. The front to rear (FTR) flow that rises abruptly near the gust front and over the strong reflectivity gradient along the leading edge before turning rearward into the stratiform region is apparent, as well as the rear to front flow (RTF) associated with a strong elevated RIJ that impinges to near the leading edge of the system. Similar to results shown in Atkins et al. (2005) for tornadic QLCS circulations C2 increased in depth and intensity and began producing damage at the time this area of rear inflow become most intense.

A third storm scale circulation (C3) was initially detected approximately 10 km northeast of KOAX at 0028 (not shown). Similar to C2, C3 originated within the lowest 2 km AGL along the leading edge of the QLCS. However, due to data quality issues, a full examination of the vortex characteristics of C3 was not conducted. A relatively simple inspection of C3 between 0032 and 0041 UTC showed that C3 maintained its strongest rotational velocities below 3 km AGL and was most intense during this time. Subsequent damage analysis showed C3 was spatially and temporally correlated to an intermittent swath of EF0 and low-end EF1 wind damage to crops and trees across southern Washington County (see Fig. 6).

4. Damage Analyses

Figure 10 shows the locations of the local storm reports (LSRs) obtained by the staff at KOAX. *Storm Data*, available via the National Climatic Data Center (NCDC) indicates one wind report in Douglas County and three wind reports in Pottawattamie County, with each of the four documented reports around the Omaha area associated with zero dollars in property damage. From this sporadic distribution of reports, it would be difficult to use this dataset for any detailed

evaluative purpose. It is particularly interesting to note that no reports of wind damage were obtained from Washington County for this event. Only when reading the *Storm Data* narrative can one begin to appreciate the extent of the damage (see NCDC 2007).

“A bow echo raced across the Omaha metropolitan area bringing strong winds which downed numerous large tree limbs and uprooted a few trees. This caused scattered damage across town, especially in the central and eastern parts of the city where felled trees caused damage to houses and vehicles and downed power lines. An estimated 20,000 customers lost power. A wind gust of 68 mph was measured by ASOS at Omaha Eppley at 746 pm CDT and a 60 mph gust was measured at 755 pm. Winds of 60 mph or greater were observed over most of the city.”

The scope of the event as described in *Storm Data*, relative to the LSRs, further supports the findings of Trapp et al. (2006) that severe wind reports associated with cases from the Bow Echo and Mesoscale Convective Vortex Experiment (BAMEX; Davis et al. 2004) served as a poor characterization of the scope and magnitude of the actual surveyed damage. Reports of severe weather received during severe weather events are often supplemented by additional information received well after the events before being added to the *Storm Data* repository. During the Omaha area media broadcasts immediately following the event, it became apparent there was significantly more wind damage than was reported to the staff at KOAX in near real time. In particular, there were numerous accounts of damage to large trees as well as homes and businesses in the northern part of the Omaha metropolitan area.

In order to document the observed wind damage, the CU-ATS team used a Ricoh 500SE GPS-enabled digital camera. The accuracy of the digital camera was tested against several other GPS devices and found to be accurate in all cases to within ± 3 meters. Each image taken with the camera was geo-coded with the latitude and longitude to the nearest .001 sec and time stamped. Using media reports of damage, LSRs, and the Level II radar data as a starting point, several undergraduate students from the CU-ATS traversed the region likely to be impacted by

the QLCS in search of damage, including specific areas such as under the rear inflow jet and those areas under the paths of the embedded mesovortices. During the course of assessment, several hundred instances of damage to trees, agriculture, and structures were documented across eastern Nebraska and western Iowa. Example images are found in Fig. 11.

Using the coordinates recorded by the Ricoh 500SE, a more accurate spatial representation of the damage associated with this event was determined. Figure 12 shows three coherent swaths of damaging winds, including one located across southern Washington County, despite the lack of reports.

5. Summary and conclusions

During the evening hours of 20 August 2007, a QLCS that traversed the Omaha Metropolitan area was associated with few official wind reports in near real time. Given the non-tornadic nature and lack of reports, the staff at KOAX did not conduct a damage survey. However, there were many media reports of trees down and damage to homes and structures in the Omaha area. Several members of the CU-ATS used GPS enabled devices to more accurately document the spatial extent of the damage. Using media reports, radar data, and storm reports, the survey team traversed much of eastern Nebraska and western Iowa photographically documenting and geocoding instances of damage. The Level II radar data from the WSR-88D in KOAX were then examined in detail. The results of the radar analysis showed there were several storm-scale vortices that existed within the QLCS between 2346 and 0050. C1 was first detected at 2346 in Saunders County. Originally detected between 2 and 6 km AGL, C1 weakened briefly in the low to mid-levels before re-intensifying near the surface. The post-event damage assessment documented several instances of damage were under the path of C1;

specifically on its southern periphery.

C2 was first detected at 0024 in the lowest 2 km AGL and remained relatively weak for the next two volume scans. Between 0037 and 0041, C2 deepened to a height of 5 km AGL and intensified. Between 0045 and 0054 UTC, C2 maintained greater than 15 m s^{-1} (30 kt) rotational velocity less than 1 km AGL. Similar to results shown in Atkins et al. (2005) for tornadic QLCS circulations, C2 increased in depth and intensity and began producing damage at the time this area of rear inflow became most intense. Although C3 could not be examined completely due to data quality errors, an examination of its structure between 0032-0048 UTC showed that it maintained its strongest shear in the lowest 3 km AGL and was associated with considerable straight-line wind damage in southern Washington County.

The Level II radar data were then reconciled with the documented damage data in order to identify the damaging wind mechanisms for this particular case. The data showed that nearly all of the observed instances of damage were associated with enhanced ground-relative winds attributable to the storm-scale vortices and not the RIJ region behind the apex of the bow, even though the ground-relative winds exceeded 30 m s^{-1} (60 kt) at 600 m AGL. This is consistent with the damage associated with severe bow echoes observed during BAMEX (Wheatley et al. 2006). Furthermore, if researchers relied solely on the accuracy of the LSR and *Storm Data*, these conclusions would not have been reached. Specifically, if one had examined this particular case in the absence of the additional data, they might have concluded that these circulations were not associated with *any* instances of damage. This further stresses the point made in Trapp et al. (2006) that users of *Storm Data* need to be aware of its limitations for use in research studies where highly detailed accounts are necessary.

The authors believe that data collected as part of a simple post-event damage assessment

are invaluable in improving knowledge of storm structures, thereby inherently improving the warning process. This has become even more pertinent as super-resolution radar data makes the detection of such small scale features more likely (Mayes et al. 2009). Knowing full well the time and budgetary constraints of the National Weather Service, data collection could be accomplished through a partnership with a neighboring academic institution, where one exists, as well as with local emergency managers.

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REFERENCES

- Atkins, N.T., C.S. Bouchard, R.W. Przybylinski, R.J. Trapp, and G. Schmocker, 2005:
Damaging surface wind mechanisms within the 10 June 2003 Saint Louis bow echo
during BAMEX. *Mon. Wea. Rev.*, 133, 2275–2296.
- Atkins, N. T. and Wakimoto R. M., 1991: Wet microburst activity over the southeastern United
States: Implications and forecast. *Wea. Forecasting*, 6, 470-482.
- Davis, C., N. Atkins, D. Bartels, L. Bosart, M. Coniglio, G. Bryan, W. Cotton, D. Dowell, B.
Jewett, R. Johns, D. Jorgensen, J. Knievel, K. Knupp, W.-C. Lee, G. McFarquhar, J.
Moore, R. Przybylinski, R. Rauber, B. Smull, J. Trapp, S. Trier, R. Wakimoto, M.

- Weisman, and C. Ziegler, 2004: The Bow Echo and MCV Experiment (BAMEX): Observations and opportunities. *Bull. Amer. Meteor. Soc.*, **85**, 1075–1093.
- Fujita, T. T., 1971: Proposed mechanism of suction spots accompanied by tornadoes. Preprints, *Seventh Conf. on Severe Local Storms*, Kansas City, MO, Amer. Meteor. Soc., 208–213.
- Fujita, T. T., 1978: Manual of downburst identification for project NIMROD. Satellite and Mesometeorology Res. Pap. No. 156, University of Chicago, Dept. of Geophysical Sciences, pp. 104.
- Fujita, T. T. and R. M. Wakimoto, 1981: Five scales of airflow associated with a series of downbursts of 16 July 1980. *Mon. Wea. Rev.*, **109**, 1438–1456.
- Martinelli, J.T., R.W. Pasken, R. W. Przybylinski, and Y-J Lin, 2007: An investigation of storm morphology and vortex evolution within a Midwestern quasi-linear convective system using conventional and Doppler radar data. *National Weather Digest*, 31, 153-164.
- Mayes, B. E., J.T. Martinelli, and D. Nietfeld, 2009: A detailed analysis of the nocturnal QLCS tornadoes that moved though Omaha, Nebraska on 8 June 2008, *23rd Conference on Weather and Forecasting*, Omaha, NE, Amer. Met. Soc.
- NCDC, 2007: *Storm Data*. Vol. 49, No. 8, 530 pp. [Available from National Climatic Data Center, 151 Patton Ave., Asheville, NC 28801-5001.]
- Rasmussen, E. N, and D. O. Blanchard, 1998: A baseline climatology of sounding-derived supercell and tornado forecasting parameters. *Wea. Forecasting*, **13**, 1148-1164.
- Trapp, R.J., D.M. Wheatley, N.T. Atkins, R.W. Przybylinski, and R. Wolf, 2006: Buyer beware: some words of caution on the use of severe wind reports in post event assessment and research. *Wea. Forecasting*, 21, 408–415.
- Weisman, M.L., 1993: The genesis of severe, long-lived bow echoes. *J. Atmos. Sci.*, 50, 645–

Wheatley, D.M., R.J. Trapp, and N.T. Atkins, 2006: Radar and damage analysis of severe bow echoes observed during BAMEX. *Mon. Wea. Rev.*, 134, 791–806.

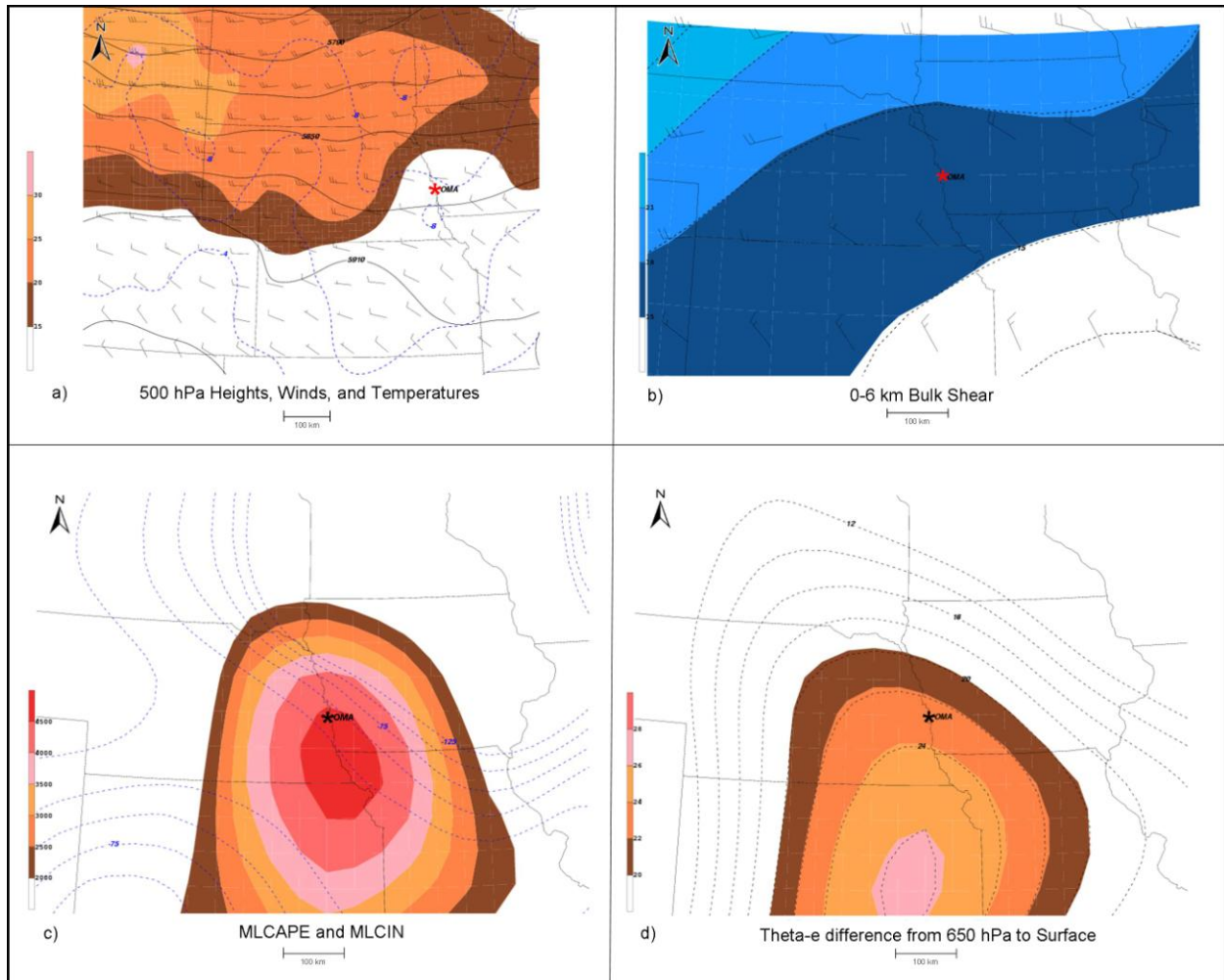


Figure 1. Four panel chart depicting the environment at 0000 UTC 21 August 2007. a) 500 hPa heights (dm, solid black contours), isotachs (m s^{-1} , shaded), winds (full barb represents 10 m s^{-1}), and temperatures (dashed blue contours), b) sea level pressure (hPa, yellow solid), 0-6 km Bulk Shear (shaded and barbs; a full barb represents 10 m s^{-1}), c) MLCAPE (J kg^{-1} , shaded) and MLCIN (J kg^{-1} , dashed blue contours), and d) surface-650 hPa thete-e difference (K).

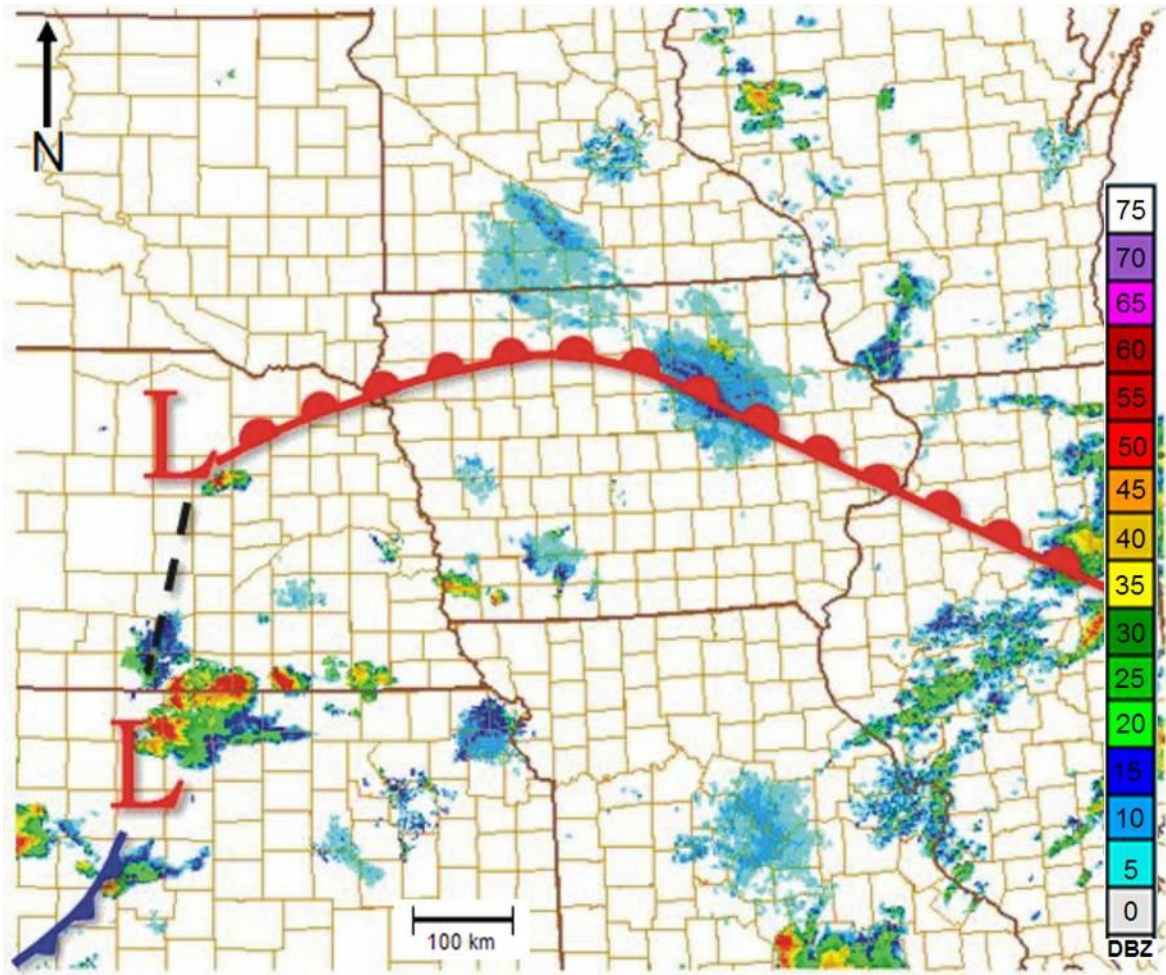


Figure 2. 0.5 deg regional radar reflectivity (dBZ) valid 2100 UTC 20 August 2007. The locations of surface features are indicated using traditional representation.

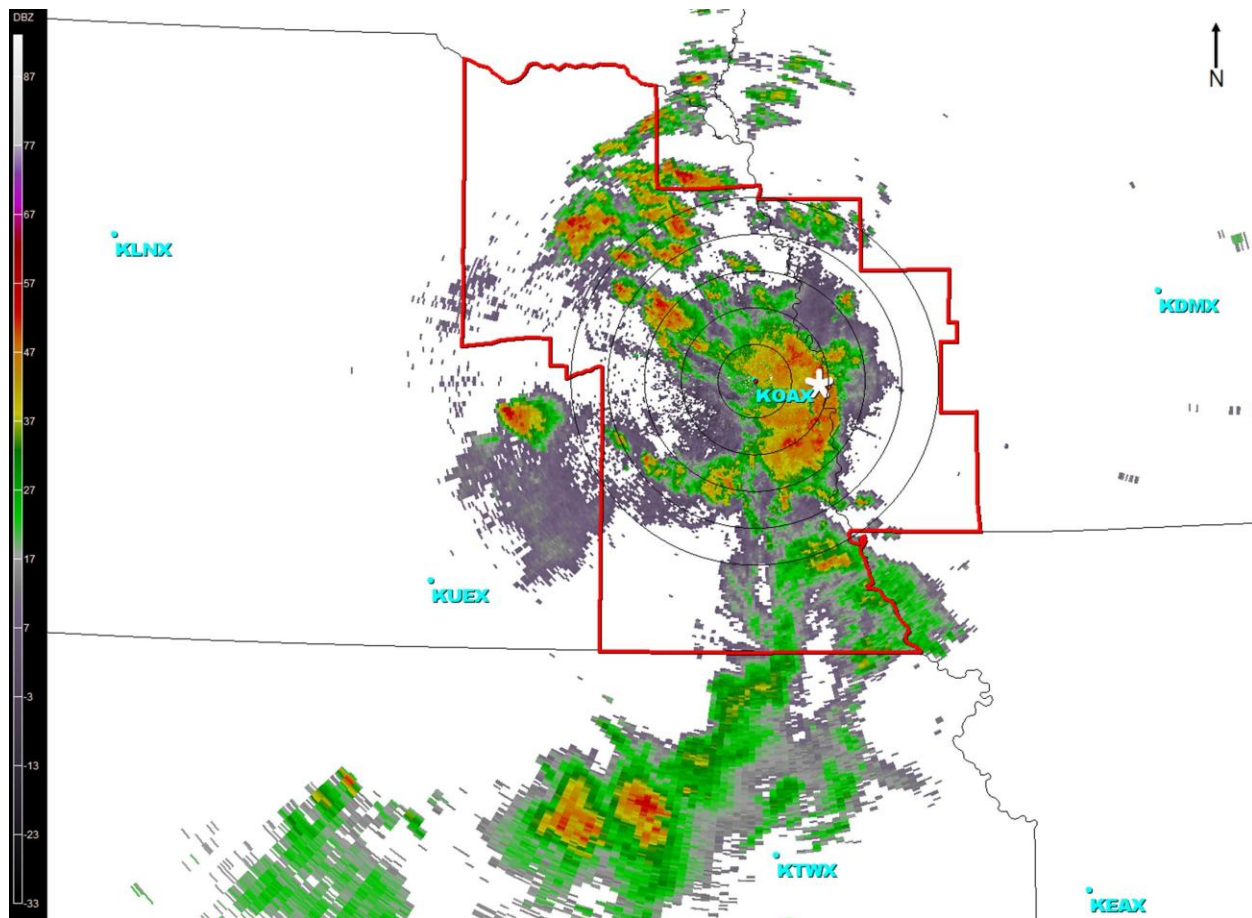


Figure 3. 0.5° reflectivity valid at 0045 UTC 21 August 2007. Range rings are spaced at 20 km intervals and the KOAX county warning area is outlined in red. Omaha, NE is indicated with an asterisk. Click to open an animation from 2027 UTC 20 August and 0137 UTC 21 August 2007.

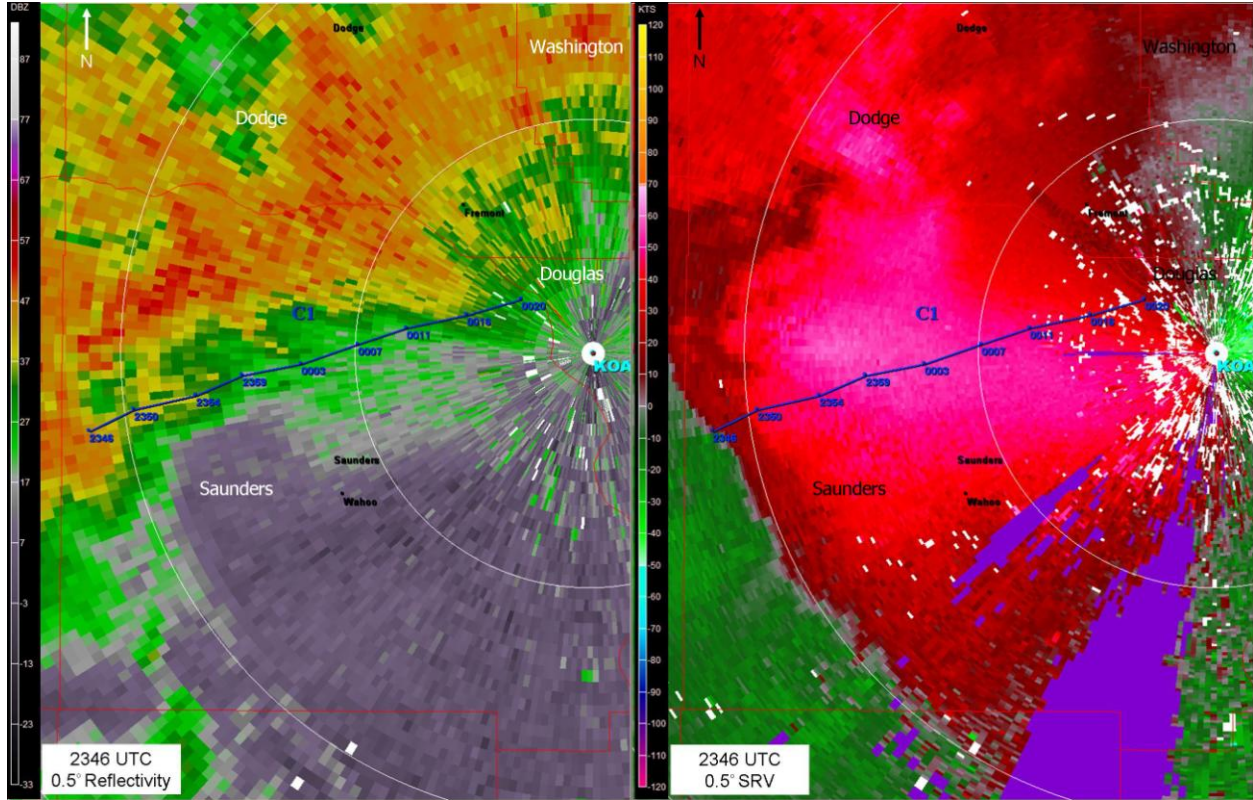


Figure 4. 0.5° reflectivity (left, dBZ) and storm-relative velocity (right, kt) products valid 2346 UTC 20 August 2007. Click for an animation from 2346-0050 UTC. Storm motion calculated as 250° at 21 m s⁻¹ (40 kt). The blue line indicates the subjectively analyzed surface track of the embedded storm-scale circulation (C1). Range rings are spaced at 20 km intervals.

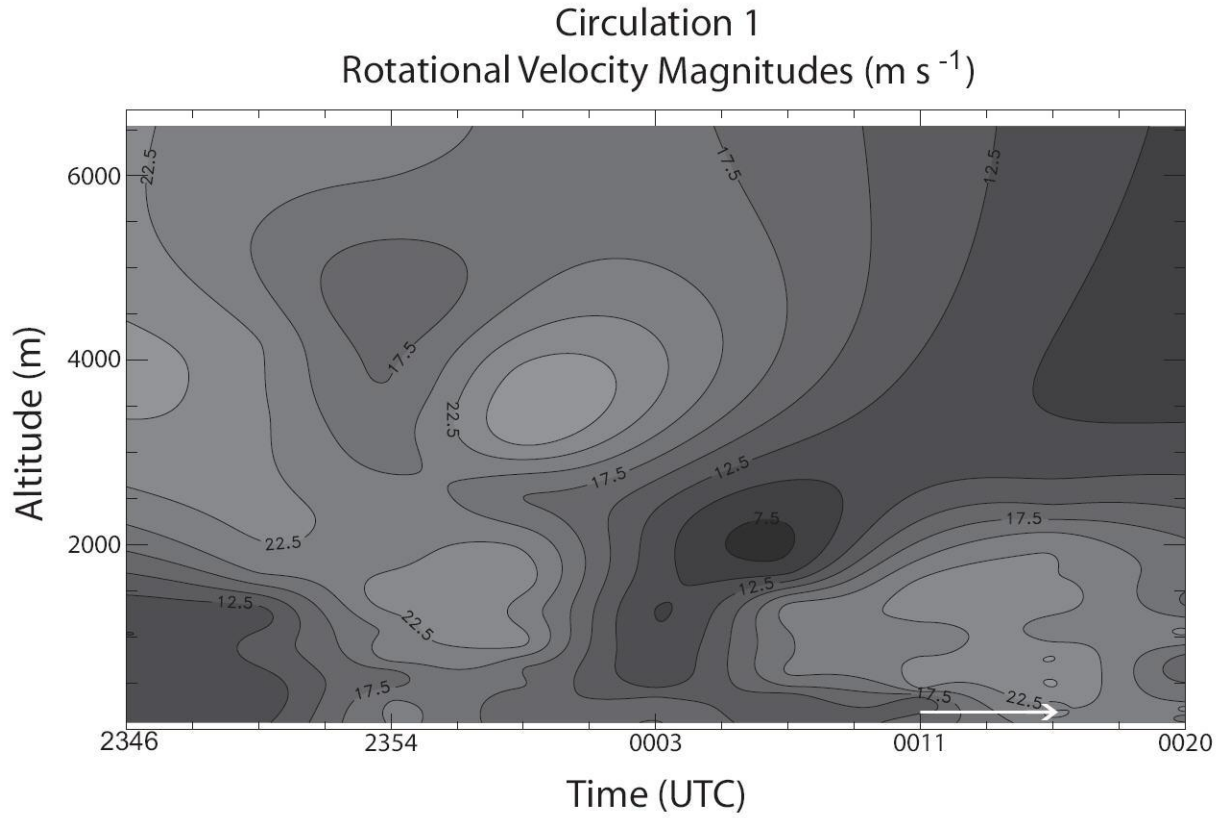


Figure 5. A time-height series of rotational velocity associated with C1. The white arrow represents the approximate temporal range when damage was occurring. Contours are spaced every 2.5 m s^{-1} .

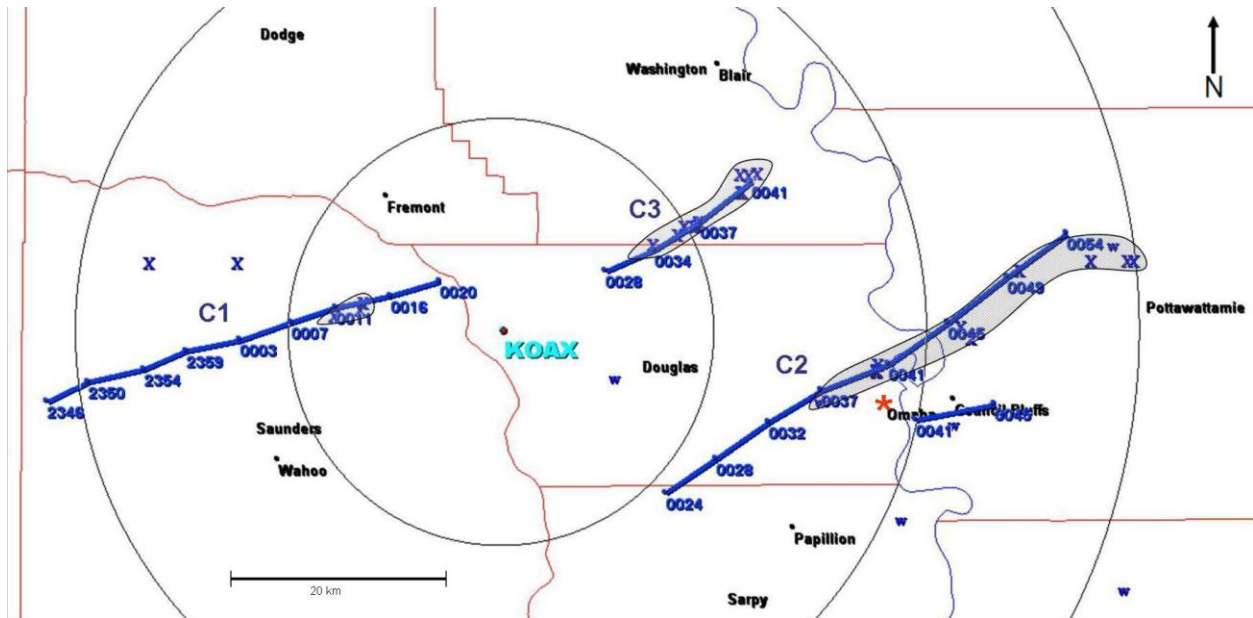


Figure 6. Map of Omaha, NE Metropolitan and surrounding area. The location of KOAX is indicated. The blue “W”s represent locations of severe wind reports. Range rings are spaced at 20 km intervals and Omaha is indicated with an asterisk. The subjectively analyzed tracks of three embedded storm-scale mesovortices are indicated (blue lines) with positions labeled for each radar volume scan. The hatched area represents areas of documented wind damage. “X”s indicate specific locations of documented wind damage.

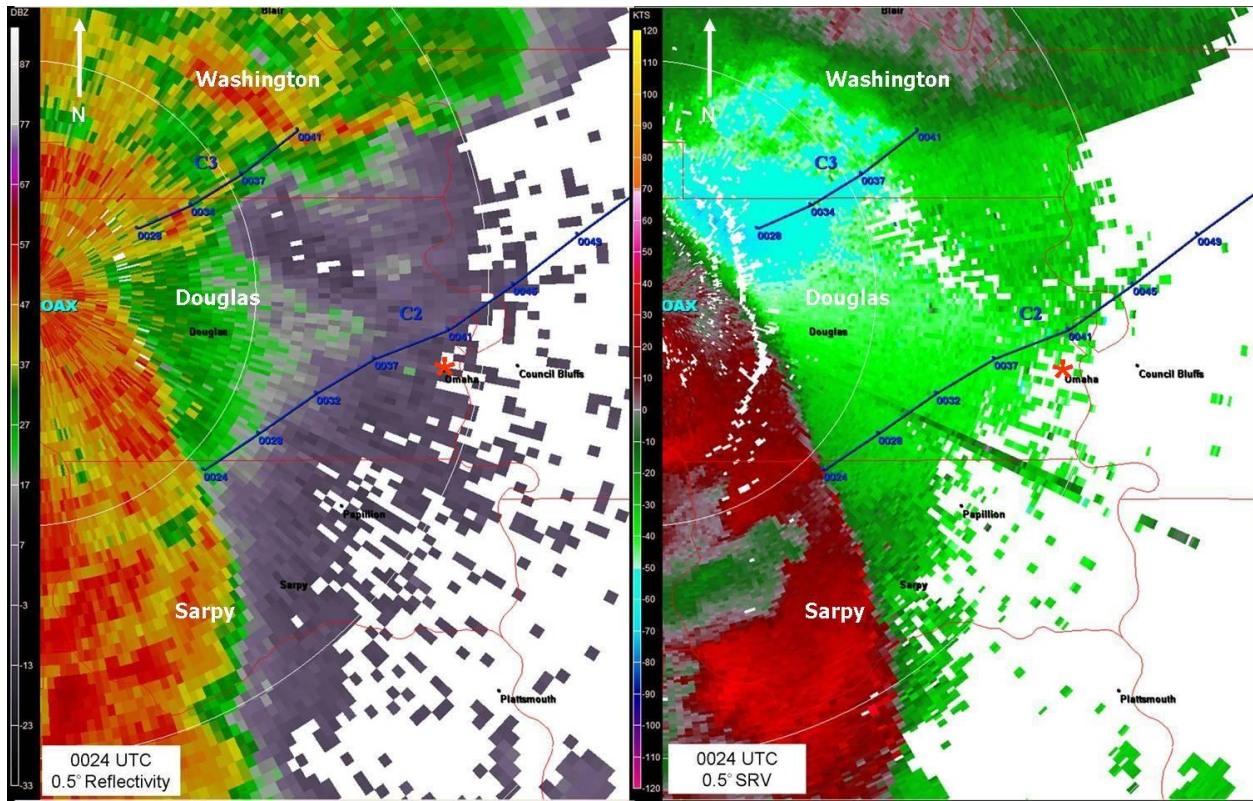


Figure 7. 0.5° reflectivity (left, dBz) and storm-relative velocity (right, kt) products valid 0024 UTC 20 August 2007. Storm motion calculated as 250° at 21 m s^{-1} (40 kt). The blue line indicates the subjectively analyzed surface track of the embedded storm-scale circulation (C2). Range rings are spaced at 20 km intervals and Omaha, NE is indicated by an asterisk.

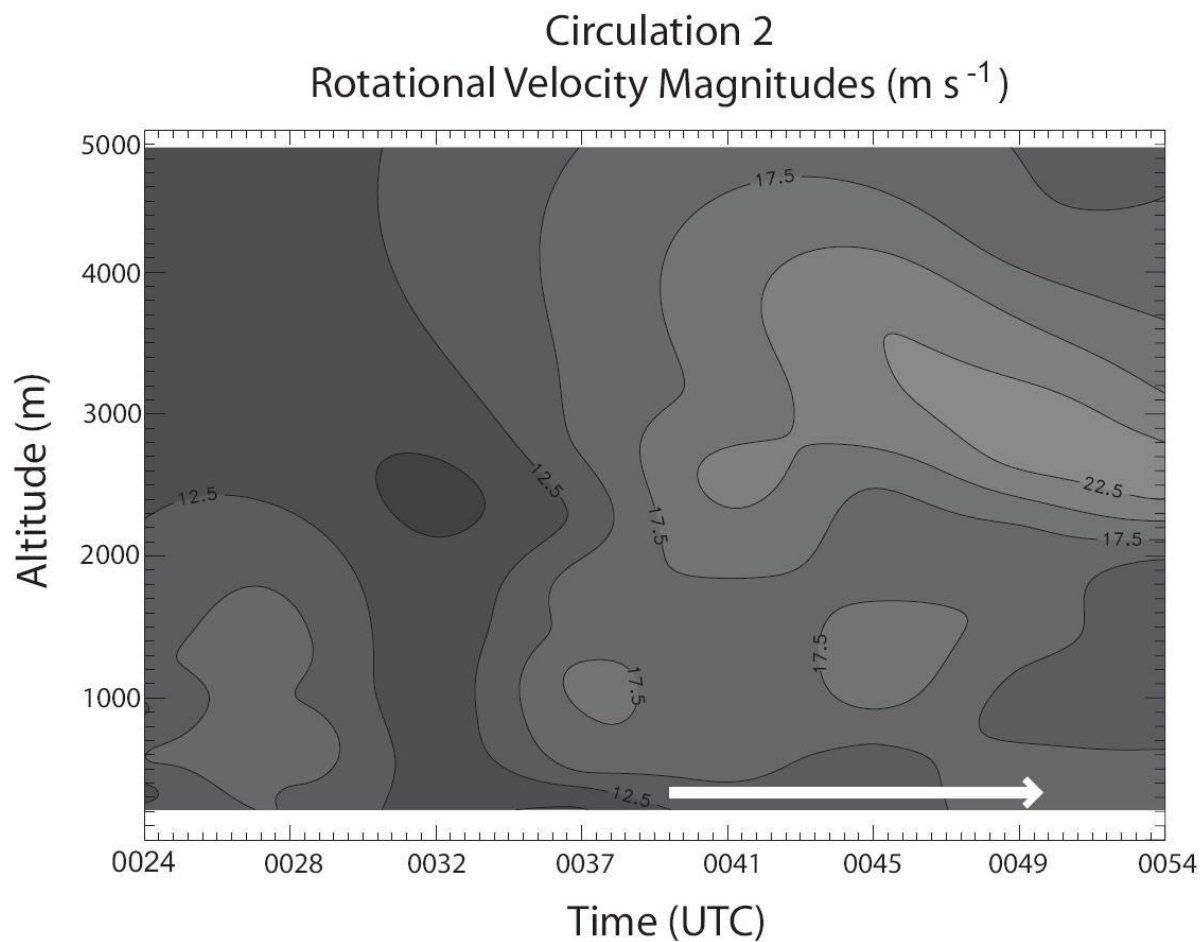


Figure 8. Time-height series of rotational velocity associated with C2. The white arrow represents the approximate temporal range when damage was occurring. Contours are spaced every 2.5 m s^{-1} .

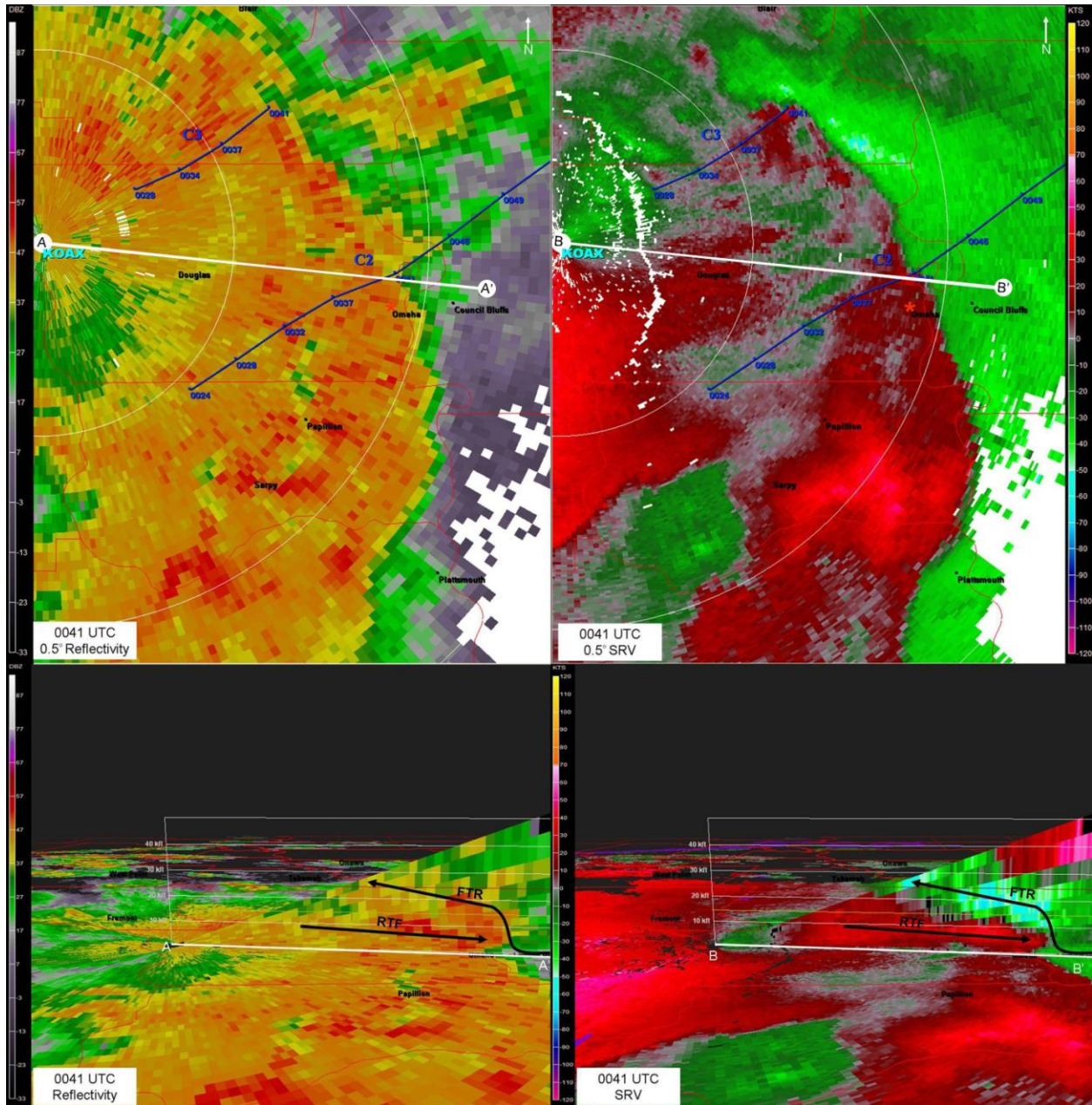


Figure 9. 0.5° reflectivity (upper left, dBZ) and storm-relative velocity (upper right, kt) products valid 2346 UTC 20 August 2007. Observed storm motion calculated as 250° at 21 m s^{-1} (40 kt). The white line in the upper two images denotes the location of the cross-section in the lower two images. The black arrows in the cross-sections illustrate the two primary flow branches typically found in a mature bowing QLCS. Range rings are spaced at 20 km intervals and Omaha, NE is indicated by an asterisk.

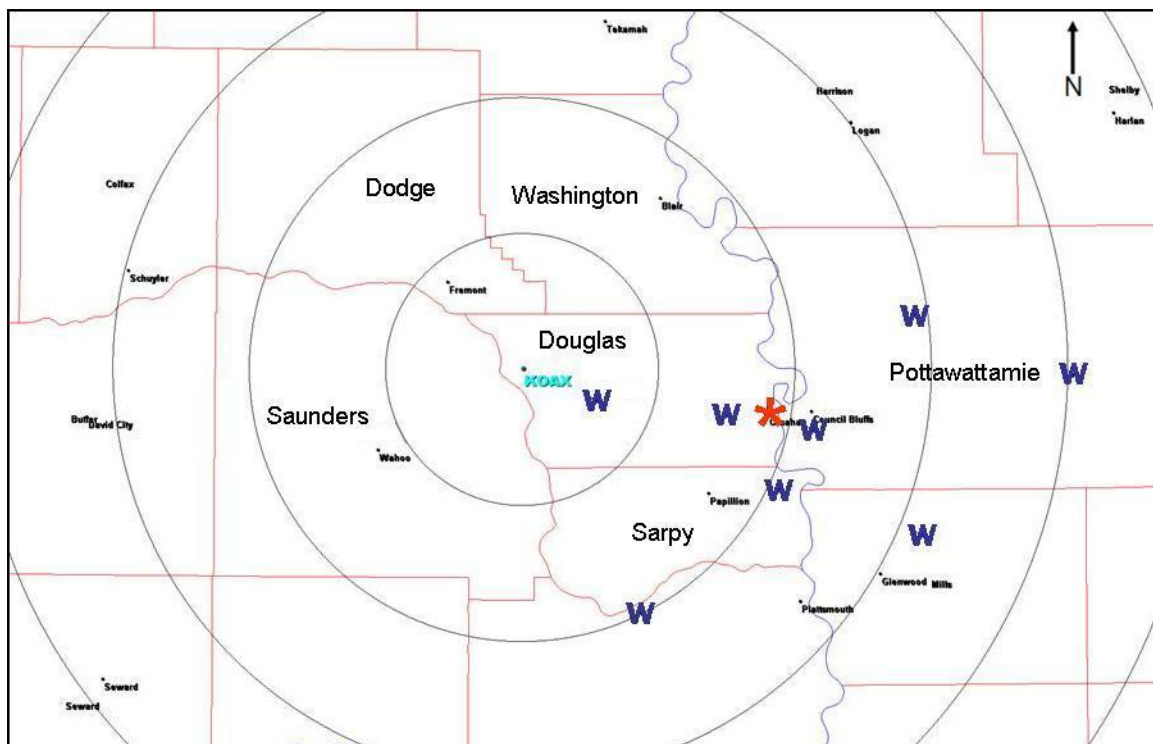


Figure 10. Map of the Omaha, NE metropolitan and surrounding area. The location of KOAX is indicated. The blue “W”s represent locations of severe wind reports. Range rings are spaced at 20 km intervals and Omaha, NE is indicated by an asterisk.



Figure 11. Example of geo-coded images documenting event damage taken with the Ricoh 500SE (shown in upper left portion of this figure).

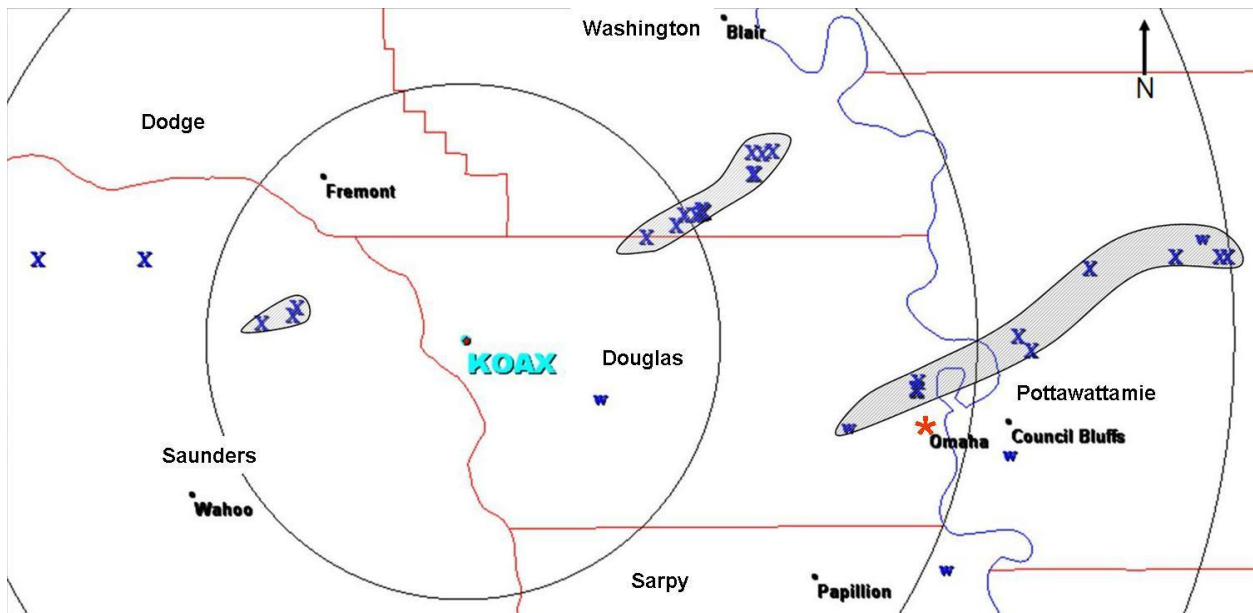


Figure 12. As in Fig. 10, except “X”s are added to indicate some of the specific locations of observed damage. The grey stippled region indicates a continuous swath of damage as determined by the survey team.