P4.9 The impact of an enhanced damage analysis on determining the damaging wind mechanism within the 20 August 2007 bow echo across eastern Nebraska and southwestern Iowa

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Introduction

During the evening hours of 20 August 2007, a strong bowing quasi-linear convective system (QLCS) pushed through the Omaha area resulting in sporadic reports of damaging winds. Given the non-tornadic nature of the event and the limited number of damage reports obtained by the local national weather service office, a formal damage assessment was not performed. However, using a GPS-enabled Ricoh 500 SE digital camera and a handheld Garmin GPS unit provided by a Research Initiatives Grant from the Creighton University Graduate School, several members of the Department of Atmospheric Sciences conducted a rudimentary damage survey in the days following the event. 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 WSR-88D located at the national weather service office in Valley, NE (KOAX). Using this combined dataset we were able to determine that the most significant damage was co-located with the tracks of two embedded meso-vortices located along the leading edge of the system and not with the apex of the bow as is traditionally expected.

Pre-Convective Environment

The 1200 UTC 20 August 2007 upper air, pre-storm environment across the central plains was characterized by relatively weak, nearly zonal flow aloft, a typical pattern for mid-summer across the region. A strong shortwave noted moving through the northern Rockies at 1200 UTC moved into the northern plains by 0000 UTC 21 August, resulting in a subtle, albeit weak, thermal trough extending into eastern Nebraska and eastern Kansas. A substantial increase in deep-level moisture occurred from 1200 to 0000 UTC, resulting in 700mb dew points increasing to +4 to +6 °C across east central and southeast Nebraska by the onset of the event. While larger scale forcing for ascent remained neutral to weakly positive, diurnal and mesoscale forcing were likely the main contributors to this severe weather event.

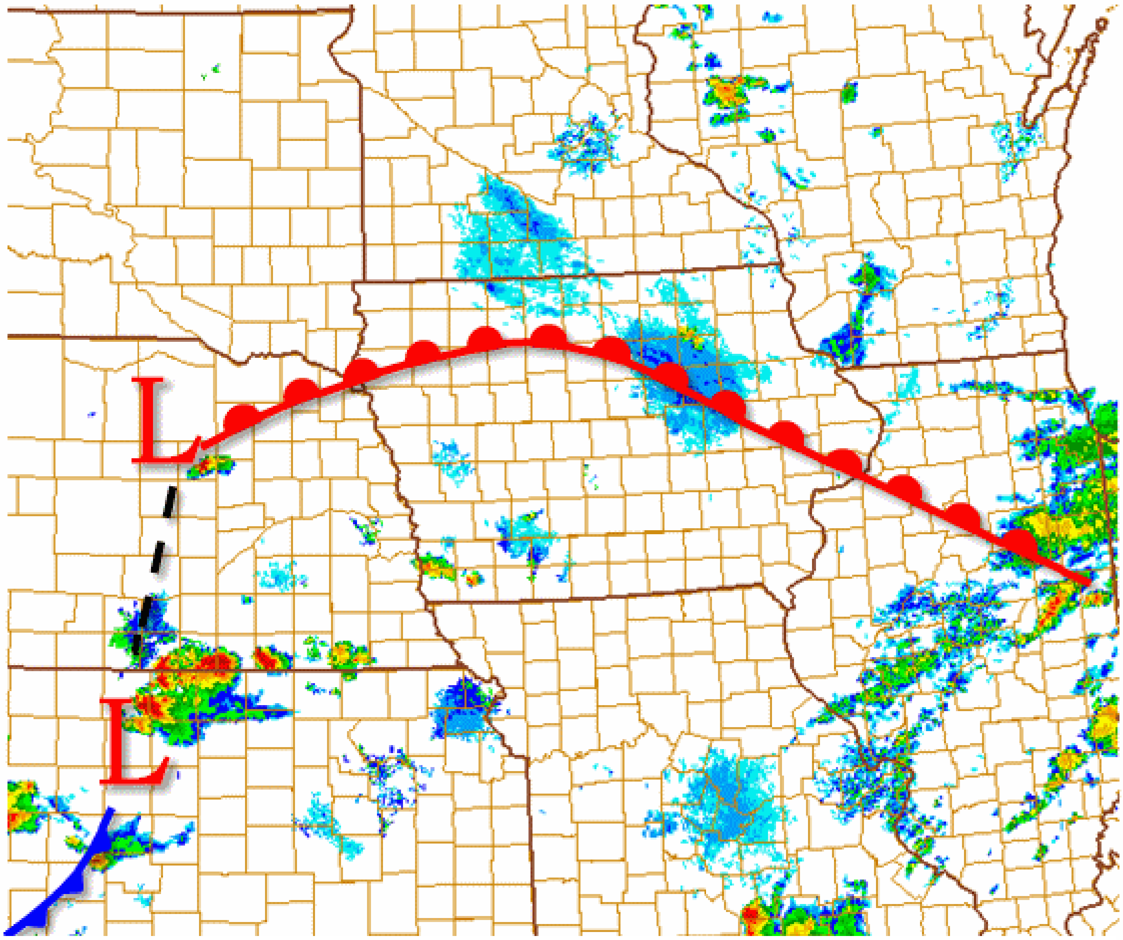

Fig. 1: Regional radar display valid at 2100 UTC 20 August 2007. The subjectively determined locations of pertinent surface features are indicated using traditional representation.

At the surface, a quasi-stationary frontal boundary existed from central Nebraska into southern Minnesota at 1200 UTC with a cluster of ongoing severe convection moving through portions of South Dakota and extreme northern Nebraska. An area of low pressure along the front (as a result of the approaching upper level wave) had developed across central Nebraska by 2100 UTC, with severe storms initiating in a corridor from north central Nebraska to near the Kansas and Nebraska border along and ahead of the trough axis. The quasi-stationary boundary attached to the low pressure center had drifted south into northern Iowa (Fig. 1). Temperatures in the pre-storm environment across eastern Nebraska and western Iowa had risen into middle 80s to lower 90s Fahrenheit with surface dew points in the upper 70s to lower 80s at 2100 UTC. This combination resulted in extreme instability across the region with MUCAPES as high as 6000-8000 J/kg (Fig. 2a), lifted indices as low as -13 (Fig. 2b), and with downdraft CAPES approaching 1700 J/kg. Mid-level 700-500mb lapse rates ranged around +8 °C/km (Fig. 2c), well within the steep to very-steep category, which would allow for rapid updraft development as the elevated mixed layer weakened with the approaching thermal trough aloft. The cluster of developing severe storms just east of the surface low center at 2100 UTC (Fig. 2d) would continue to strengthen into the significant severe episode across portions of eastern Nebraska and western Iowa as it moved across the region through 0300 UTC 21 August.

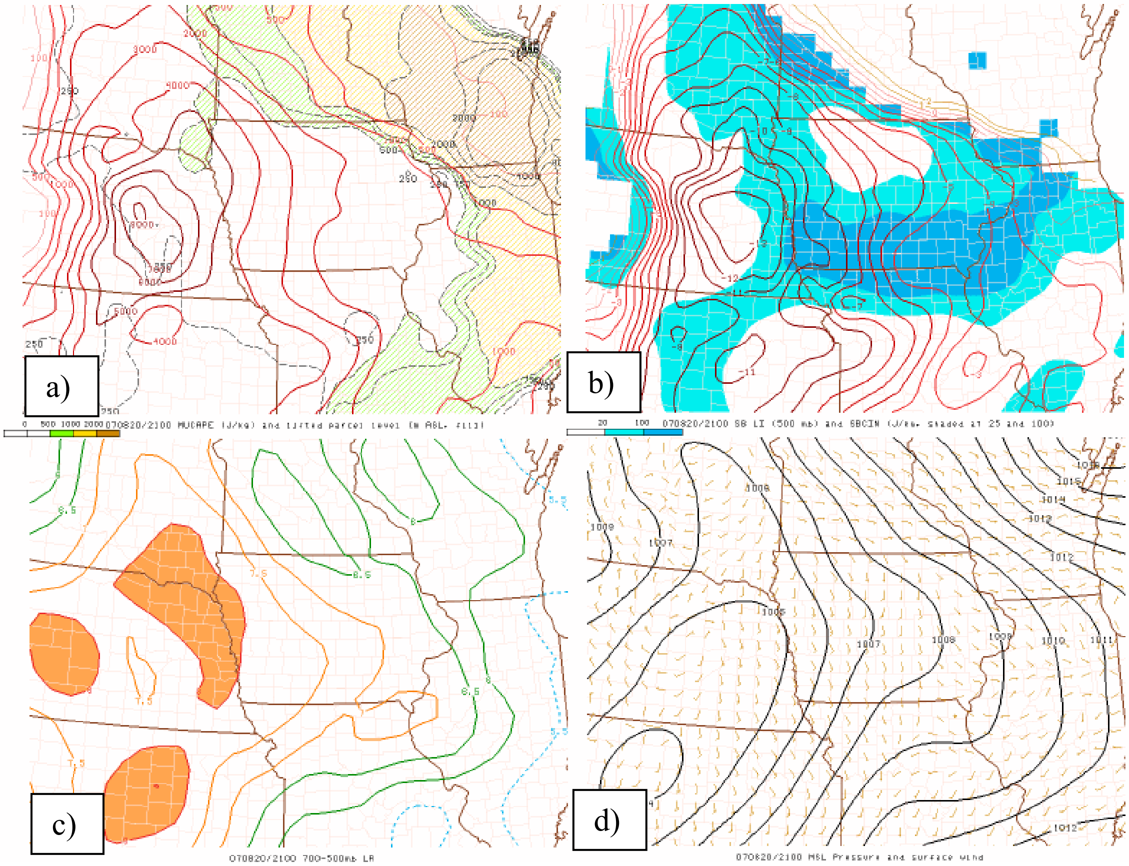

Fig. 2: RUC 1 h forecasts valid at 2100 UTC 20 August 2007. a) MUCAPE and LPL, b) Surface-based LI and surface-based CIN, c) 700-500 mb lapse rate, and d) MSLP and surface wind.

Despite marginal forcing aloft, wind shear for this event was quite strong. During the event, effective 0-6 km bulk shear ranged from 40 to 50 kts (Fig. 3a), well within the range for supercellular structure. Due to backed surface flow across east central Nebraska east of the low center, low-level shear also was quite strong. 0-3 km low-level shear ranged from 20 to 25 kts (Fig. 3b) and effective 0-3 km storm-relative helicity ranged from 300-400 m2/s2 (Fig. 3c). Not surprising, various SPC mesoanalysis composite indices were extremely high. The supercell composite index approached 44 (Fig. 3d), the effective significant tornado parameter approached 7, the significant hail parameter exceeded 3, the derecho composite was around 14, while the 0-1km EHI approached 7. While one should not focus on absolute values of composite parameters, respective bulls-eyes of each parameter were noted within the area of interest which is likely more important.

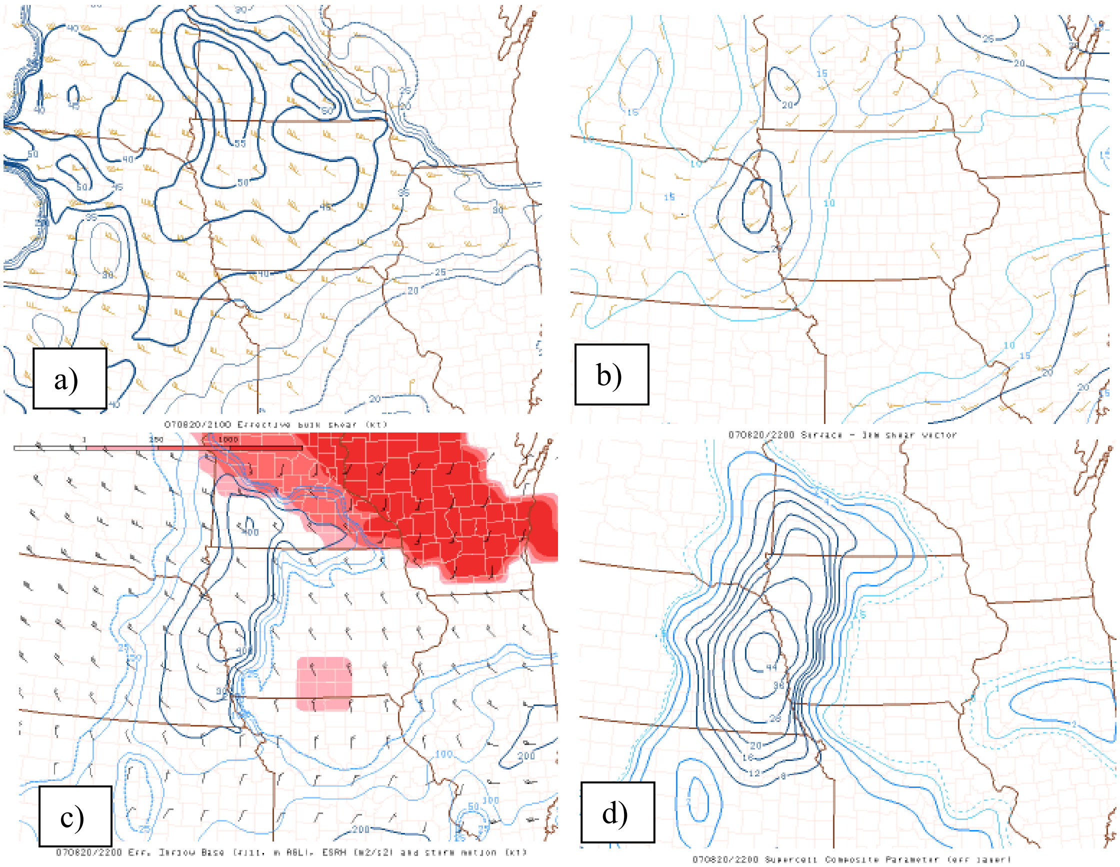

Fig. 3: RUC 1 h forecasts valid at 2100 UTC 20 August 2007. a) Effective bulk shear, b) Surface- 3 km shear vector, c) Inflow base and effective storm-relative helicity, and d) supercell composite parameter.

Due to the dynamic nature of the system with abundant clues for significant severe weather expected, including large hail and damaging winds, and even a threat for isolated tornadoes, the region remained in a slight risk of severe weather as indicated by the SPC Day 1 Convective outlook, through various subsequent product updates (Fig. 4a). Tornado probabilities were around 5% (Fig. 4b), while both wind and hail probabilities were around 30% (Fig. 4c and 4d, respectively). With such strong convective parameters in place, when combined with the extremely high values of CAPE and ample low to mid level moisture, along with significant low-level thermodynamic and shear indices, one could argue the need for an upgrade to a moderate risk by the SPC across at least a portion of the mid Missouri River valley. However, the resultant weaker forcing aloft across the central plains, with the stronger upper level dynamics across the northern plains, may have been the only limiting factor.

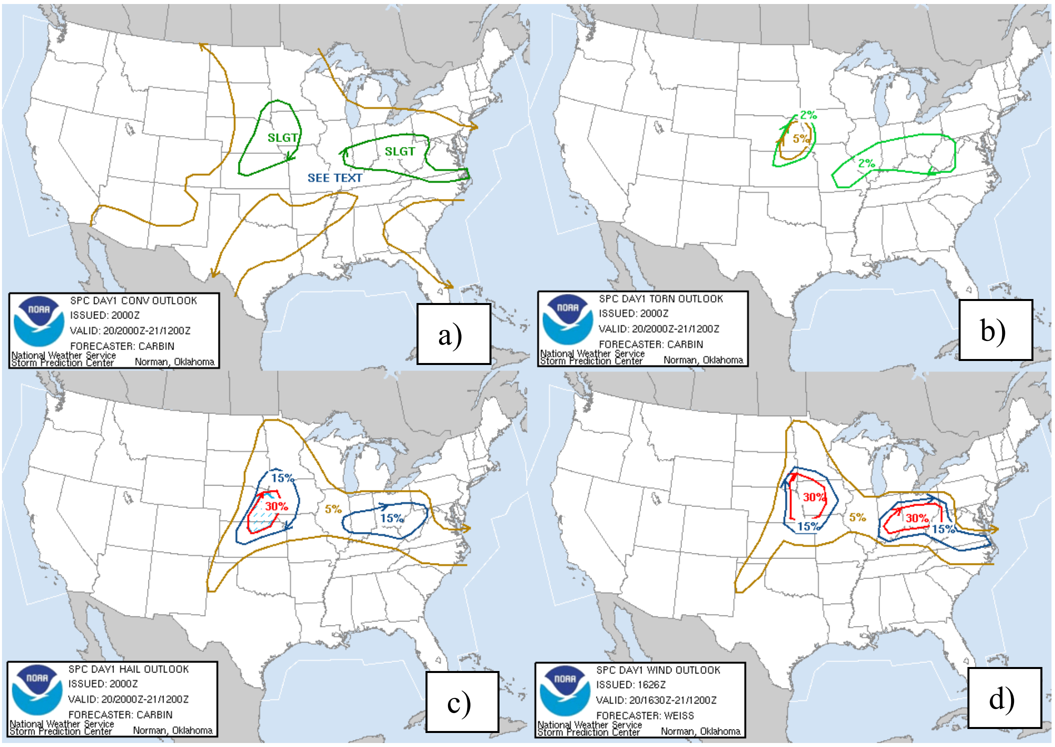

Fig. 4: SPC Day 1 Convective outlook valid 20/2000 UTC – 21/1200UTC. a) Categorical threat, b) tornado threat, c) hail threat, d) damaging wind threat.

Over the next several hours, the severe storms that had initiated in the corridor along and ahead of the trough axis grew upscale into an intense QLCS that bowed outward as it swept through the Omaha metropolitan area (Fig 5).

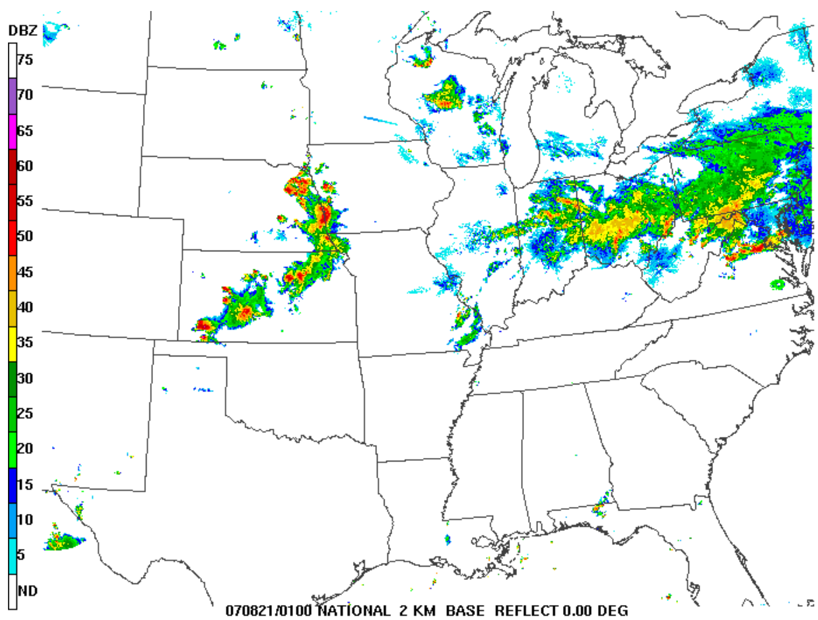

Fig. 5: Regional radar display valid at 0100 UTC 21 August 2007.

During the media broadcasts immediately following the event, it became apparent that there was significantly more wind damage than was reported to the staff at OAX. 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.

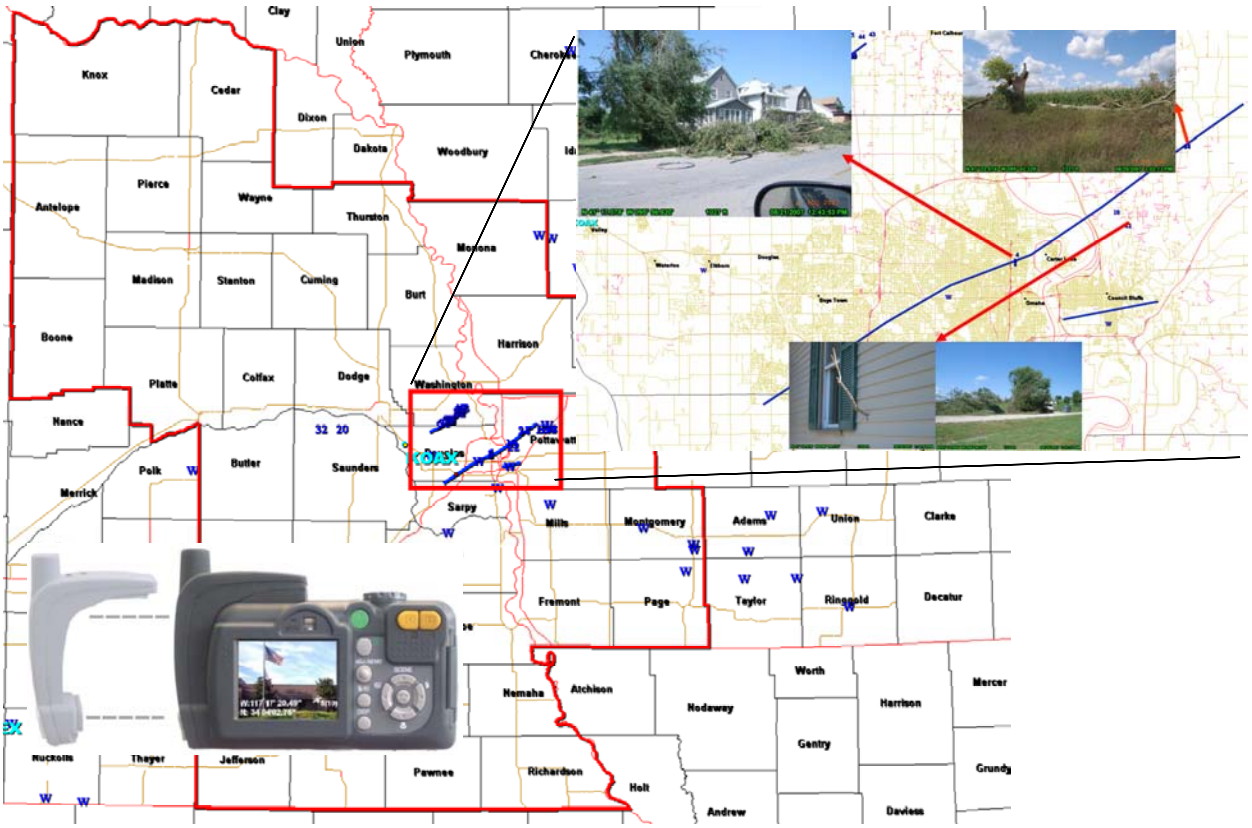

Fig. 6: Images documenting damage with encoding taken by the Ricoh 500SE (shown in lower left).

Data Collection

In order to document the intensity and location of the observed wind damage, we 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 geocoded with the latitude and longitude to the nearest .001 seconds and time stamped. Using media reports of damage and the Level II radar data as a starting point, several undergraduate students in the Department of Atmospheric Sciences at Creighton University searched for damage in the region likely to be impacted by the rear inflow jet as well as those areas under the paths of the embedded mesovortices. During the course of assessment, approximately 100 images of damage to trees, agriculture, and/or structures were taken across the eastern NE and western IA area. Example images can be found in Fig. 6.

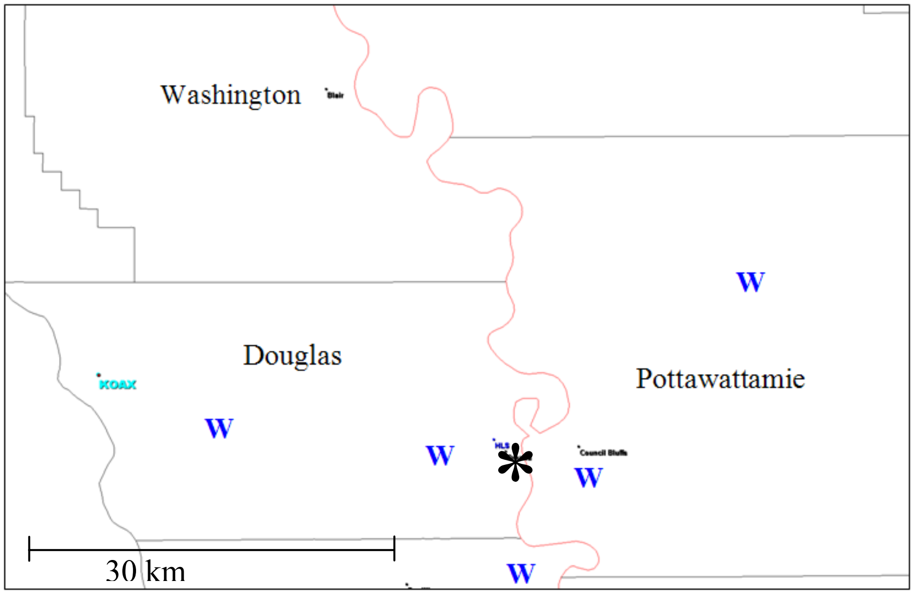

Fig. 7: Map of the area surrounding the Omaha Metropolitan area. The approximate location of Omaha is indicated with an asterisk. The blue "W"s represent wind reports obtained by the staff at KOAX

Figure 7 shows the locations of the damage reports obtained by the staff at OAX. From this seemingly random distribution of five reports, it would be nearly impossible to use this dataset for any evaluative purpose. It is particularly interesting to note that there were no official reports of wind damage from Washington County for this event. Using the coordinates recorded by the Ricoh camera, the following figure was constructed reflecting a more accurate spatial extent of the damage. Figure 8 clearly shows that there was a coherent and extensive swath of damaging winds in southern Washington County, despite the lack of reports.

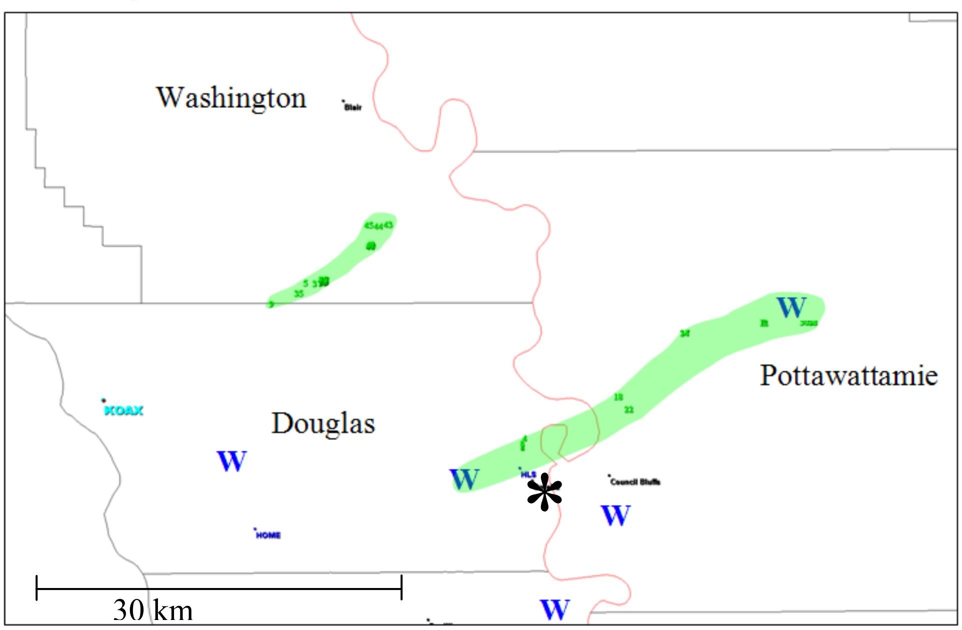

Fig. 8: As in Fig. 7 except now the locations of selected damage occurrences are plotted (green numbers) and an estimated damage swath is indicated by green shading.

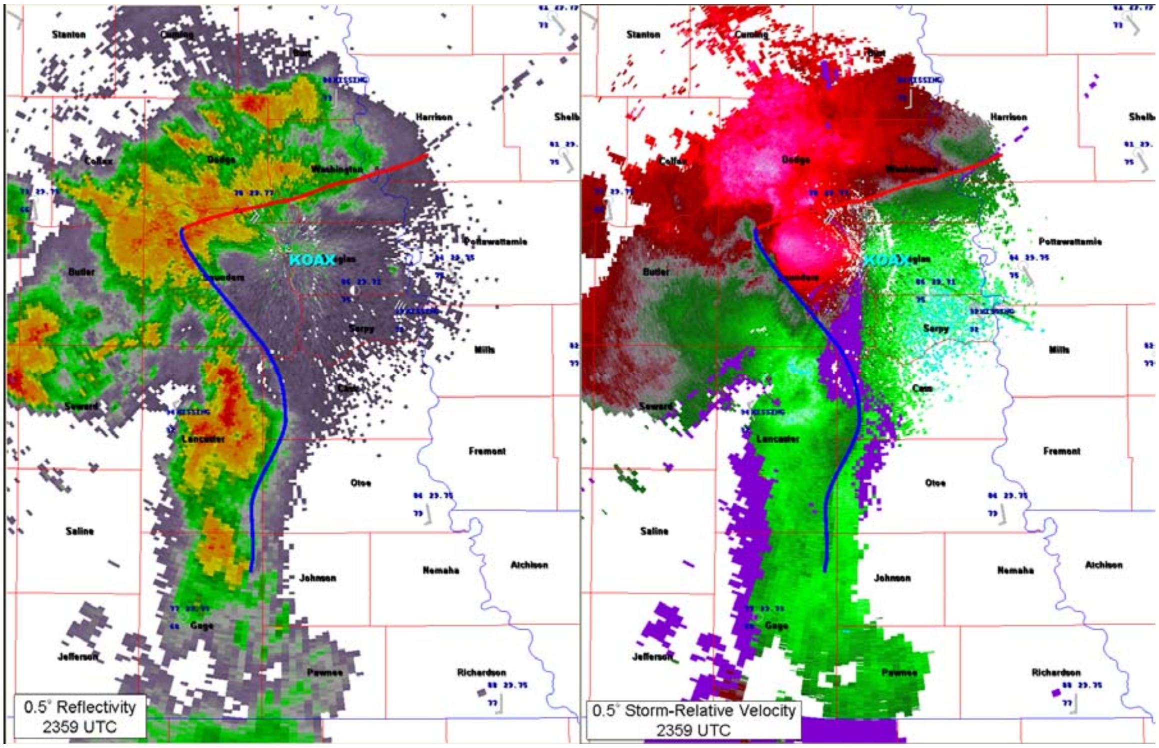

Fig. 9: The 0.5 ° reflectivity and storm-relative velocity data valid at 2359 UTC 20 August 2007. The blue solid line represents the location of the cold frontal / outflow boundary feature and the red line indicates the location of the warm frontal type feature.

Radar Analysis

The level II radar data from KOAX were examined in conjunction with the damage survey data in an attempt to identify the damaging wind mechanisms within this particular QLCS.

At 2359 UTC, the leading edge of the system was located approximately 30 nm west northwest of the Omaha Metropolitan area and moving west at 30-35 kt (Fig. 9). At this time there was already one storm-scale circulation present located near the intersection of the east-west orientated warm frontal boundary and the northwest-southeast oriented cold front / outflow boundary. At about this time, there were several reports of isolated damage from the cell located in Lancaster County. Over the next 40 minutes, the system rapidly intensifies south of the warm frontal boundary and produces numerous instances of damage across Washington and Douglas Counties in eastern Nebraska and Pottawattamie County in western Iowa.

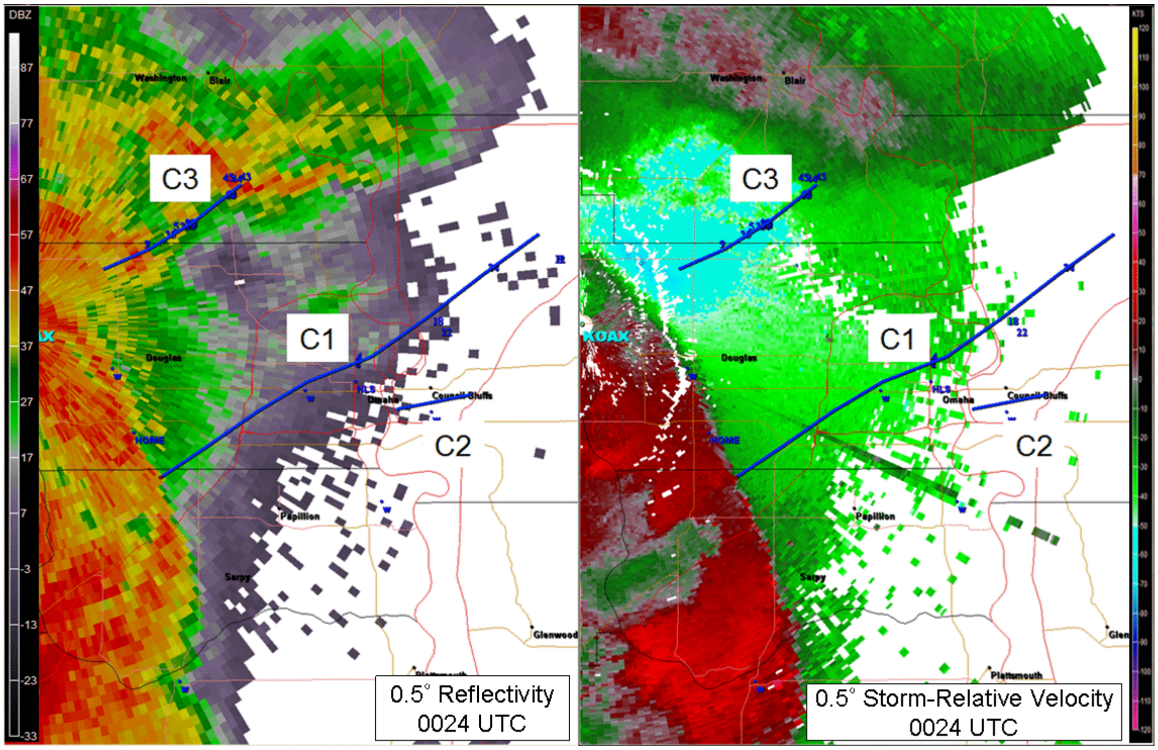

Fig. 10: The 0.5 ° reflectivity and storm-relative velocity data valid at 0024 UTC 21 August 2007. The blue solid lines represent the subjectively analyzed paths of the storm-scale circulations along the leading edge of the QLCS. The observed wind damage reports are plotted in blue "w"s and the augmented reports are plotted in blue numbers.

By 0024 UTC (Fig. 10), the QLCS had filled in across western Douglas County and had begun the bowing process. At this time, there were two circulations detected within the Omaha CWA. C1, first detected during this volume scan, contained its maximum rotational velocities (20-30 kt) in the lowest 2 km AGL. C3 had also originated within the lowest 2 km AGL approximately 40 minutes prior to C1. However, due to data quality issues as a result of the direction of C3's motion and its proximity to the radar, a full examination of C3's vortex characteristics has not been performed. A relatively simple inspection of C3 between 0032 and 0058 UTC showed that C3 maintained its strongest rotational velocities below 3 km AGL was spatially and temporally correlated to significant wind damage across southern Washington County. Similar to other observations of QLCS vortices, C1 was generally small in diameter (1-3 nm) and confined to the lowest portion of the atmosphere. Over the next several volume scans, C1 remained relatively weak but coherent below approximately 2 km AGL (Fig 11). Between 0037 and 0041, C1 intensified and expanded upward. At this time, its maximum rotational velocities exceeded 40 kt from near the surface to near 5 km AGL, with an embedded maximum of 50 kt near 2.5 km AGL. It was at this time, that significant wind damage began being observed over eastern Douglas County and into western Pottawattamie County. The rapid deepening and intensification just prior to damage at the surface has been seen in other cases as well (Atkins et al. 2005, Martinelli et al. 2007, and others) . Between 0045 and 0054 UTC, C1's rotational velocity exceeded

45 kt < 1 km AGL. Through a review of media reports as well as witness accounts obtained during the post-event damage analysis, it is likely that the damage continued to occur until approximately 0050 UTC.

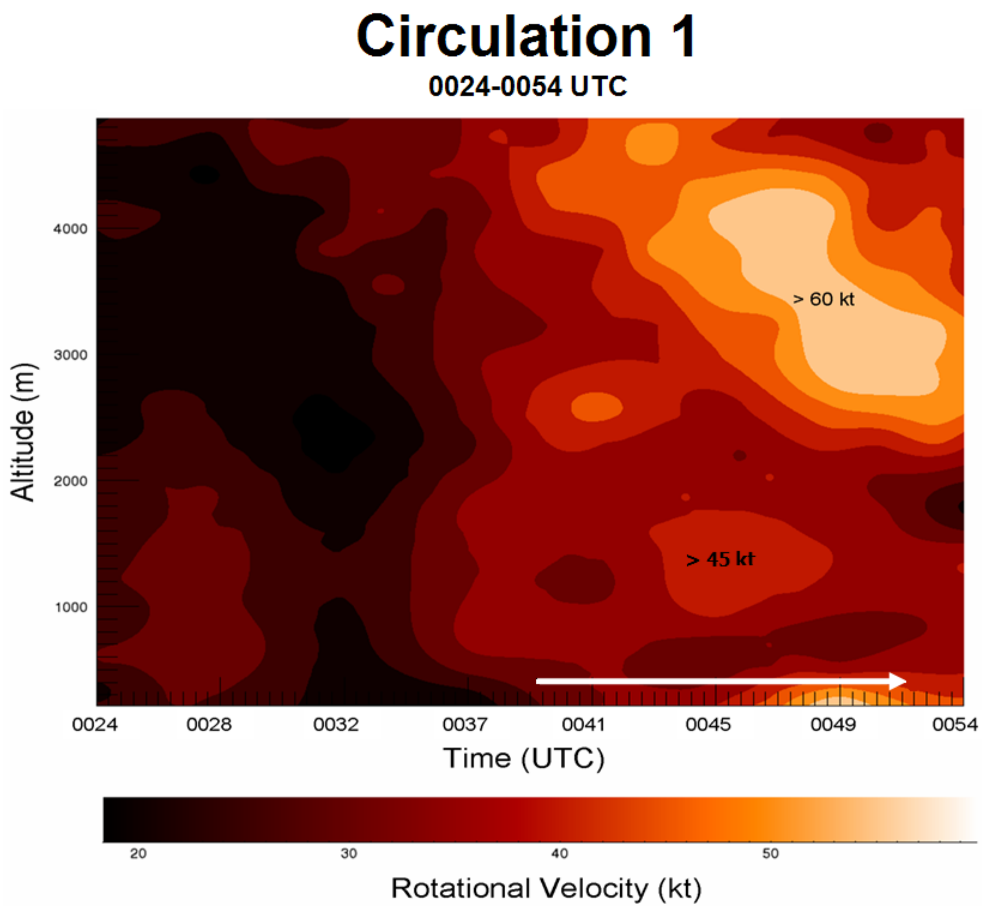

Fig. 11: A time-height trace of the rotational velocity associated with C1. The white arrow represents the approximate temporal range when damage was occurring.

The plan view storm-relative velocity data at 0041 UTC (Fig. 12) again shows C1 and C3 clearly evident in the data. Additionally, C2 was first detected here at the 0.8° elevation angle (not shown) and extended between 1.5 and 3 km AGL. C3 quickly dissipated—becoming indistinguishable after 0050 UTC. During this period, there was one wind report that occurred in the spatial and temporal proximity to the southern periphery of C3. It could not be corroborated with witness accounts and our survey turned up no evidence of damage. Also observed in the plan view data is a strong area of outbound velocities across Sarpy County. This enhanced area of rear inflow (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 30 nm. 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.

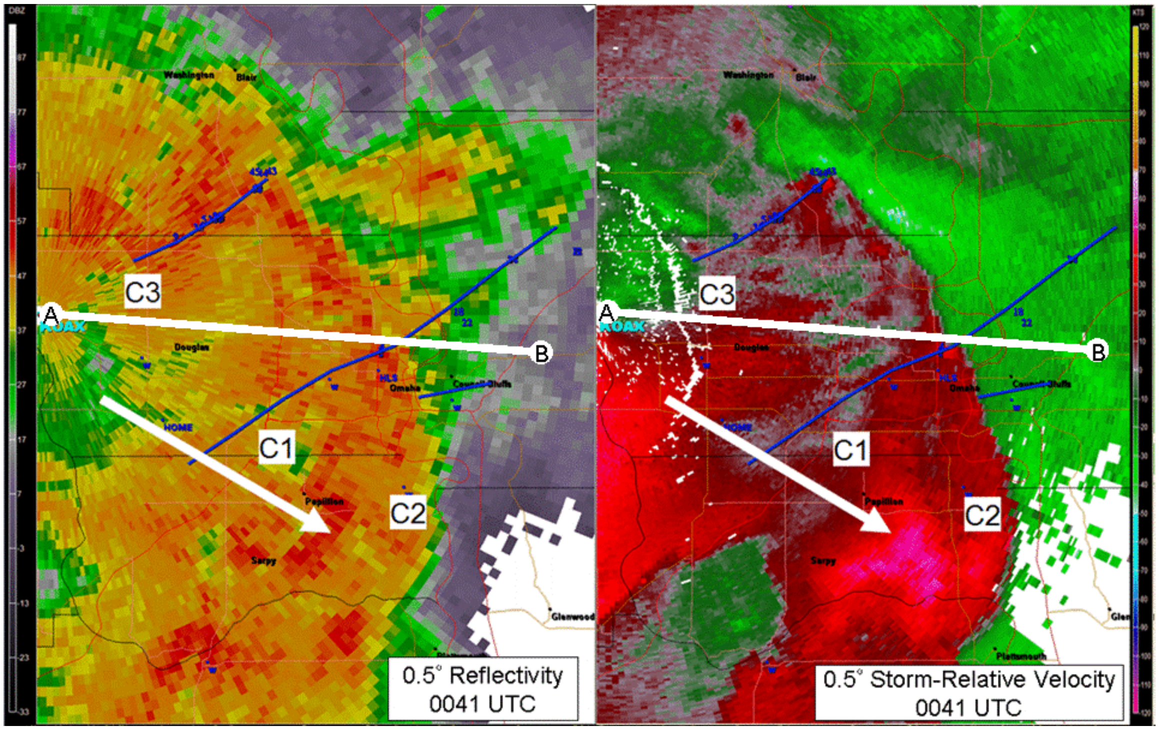

Fig. 12: As in Fig. 10 except valid at 0041 UTC. Additionally, the approximate location of the most intense rear inflow is indicated by the white arrow. The line labeled A to B represents the location of the cross-section shown in Fig 13.

A cross section taken along a radial oriented normal to the leading edge of the QLCS in the vicinity of C1 is shown in Fig. 13. The 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, as well as the rear to front flow 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, C1 developed just to the north of the location of the most intense rear inflow. In addition, C1 increased in depth and intensity and began producing damage at the time the RIJ become most intense. This is also similar in findings to those of Atkins et al. (2005).

Figure 14 shows the subjectively determined tracks of the storm-scale vortices between 0024 and 0054 UTC. Also indicated in Fig. 14 is the estimated areal extent of the damage. It is evinced from this figure that much of the damage in this case was associated with the two most intense and long-lived embedded mesovortices and not with the descending rear inflow jet as typically shown. This is similar to the results obtained through extensive post-event damage analysis as part of the Bow Echo and Mesoscale Convective Vortex (BAMEX) Experiment (Wheatley et al. 2006). Furthermore, if total reliance was placed on the accuracy of the collected storm data, these conclusions would have been impossible to deduce, and 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.

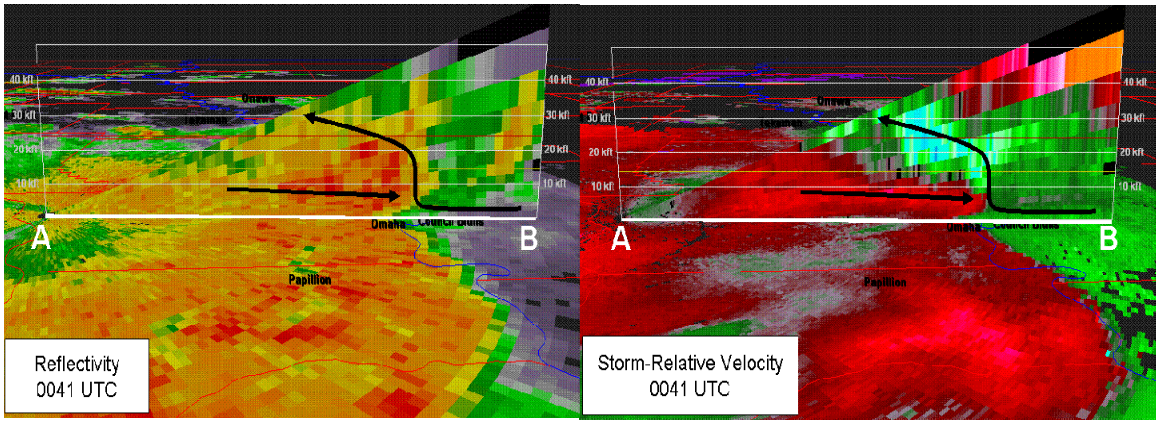

Fig. 13: (Top) As in Fig. 10 except valid at 0041 UTC. Additionally, the locations of the cross-sections (bottom) are shown with the thick white line.

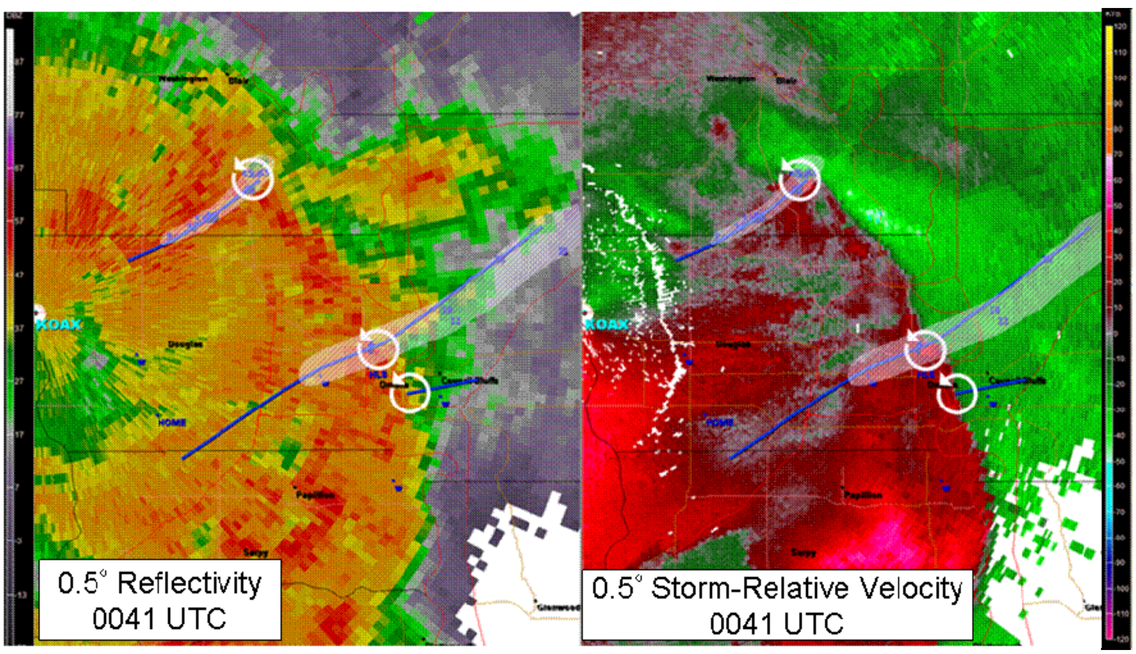

Fig. 14: As in Fig. 10. Additionally, the approximate spatial extent of the documented damage is shaded. The locations of the circulations at this time are indicated using the circular arrows.

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. Given the non-tornadic nature and lack of reports, the staff at OAX 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. Using a GPS enabled digital camera and another handheld GPS device, several undergraduate students from the Department of Atmospheric Sciences at Creighton University attempted to more-accurately document the intensity and spatial extent of the damage. Using media reports, radar data, and storm reports, the students traversed much of eastern Nebraska and western Iowa photographically documenting 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 that there were three storm-scale vortices detected within the QLCS during the 0000-0100 UTC time period. The southern most circulation, C2, was a short-lived circulation initially detected between 1.5 and 3 km AGL. Although there was one wind report in the spatial and temporal vicinity of the southern periphery of C3, this could not be corroborated with witness accounts nor could any instances of damage be found by the survey team. The northern most circulation, C3, could not be examined completely due to data quality errors. However, a brief look at C3's structure between 0032 and 0048 UTC showed that it maintained its strongest shears in the lowest 3 km AGL and was associated with considerable damage in southern Washington County. C1 was examined in detail. C1 was first detected at 0024 UTC in the lowest 2 km AGL and remained relatively weak for the next two volume scans. Between 0037 and 0041, C1 rapidly deepened to a height of 5 km AGL and intensified. Between 0045 and 0054 UTC, C1 maintained greater than 45 kt rotational velocity at < 1 km AGL. Similar to observations of tornadic QLCS circulations presented in Atkins et al. (2005), C1 developed north of the strong RIJ and intensified when the RIJ reached its peak intensity.

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 concluded that nearly all of the observed instances of damage were associated with enhanced ground-relative winds associated with the storm-scale vortices. This is consistent with the damage associated with severe bow echoes observed during BAMEX (Trapp et al. 2006). Additionally, there were no instances of damage observed to be associated with the RIJ region behind the apex of the bow, even though the ground-relative magnitudes exceeded 60 kt at 600 m AGL. If this case had been examined in absence of the supplementary data, research would have erroneously concluded that the storm-scale vortices were not associated with *any* significant damage. This further stresses the point made in Wheatley et al. (2006) that you need to be very aware of the limitations of using *Storm Data* for research studies where highly detailed accounts are necessary.

The authors believe that data collected as part of a simple post-event damage assessment can be invaluable in improving knowledge of storm-structures, thereby inherently improving the warning process. This will become even more pertinent as the newly deployed "super-resolution" data makes the detection of such small scale features more likely. Knowing full well the time and budgetary constraints of the National Oceanic and Atmospheric Association, this could be accomplished through a formal or informal partnership with a neighboring academic institution.

References

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