6.6 OBSERVATIONS FROM THE 23 AUGUST 2007 CHICAGO DERECHO

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1. Introduction

During the afternoon of 23 August 2007, a quasi-linear convective system (QLCS) with embedded bowing line segments moved across the Lower Great Lakes and produced a nearly continuous swath of wind damage extending from northwest Illinois eastward into southeast Lower Michigan. There were multiple reports of wind gusts in excess of 35 ms^{-1}, wind damage of up to EF-1 intensity, as well as two brief tornadoes along the path of this convective system across northern Illinois. The number, intensity, and time span of the reports were such that this QLCS can be classified as a derecho (Johns and Hirt 1987). This derecho-producing convective system (DCS) moved across densely populated areas of northeast Illinois during the mid-afternoon, injuring approximately four dozen people, some severely, and resulted in two confirmed fatalities. Other casualties were reported in the region, though outside of the immediate Chicago Metropolitan area. In addition to the human casualties, this storm caused an estimated five million dollars in property damage, including the destruction of several buildings, just in northeast Illinois alone.

As the DCS matured and moved across northern Illinois, several mesovortices formed along its leading edge. The mesovortices varied considerably in strength, depth, and duration. This posed a substantial challenge in correctly identifying and warning for such features. Numerical simulations (Trapp and Weisman 2003) and multiple observational case studies (Atkins et al. 2004, Atkins et al. 2005, Przybylinski et al. 2006) have shown that mesovortices along the leading edge of QLCSs tend to produce paths of intense and concentrated wind damage and sometimes tornadoes.

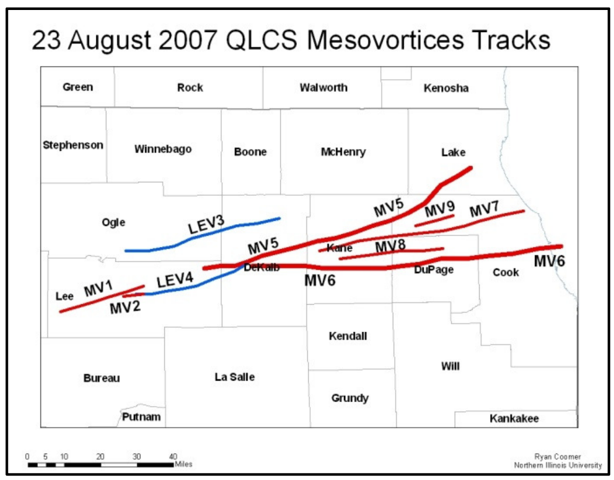

Fig. 1. Map of tracks of the vortices associated with the northern bowing segment. Red lines are the tracks of the mesovortices, while the blue lines depict the tracks of the line end vortices.

Although numerous vortices formed along the leading edge of the convective line during the life cycle of the DCS (Fig. 1), this study focuses on the most intense mesovortices that moved through northeast Illinois. These mesovortices tracked across the densely populated and highly urbanized Chicago Metropolitan area, producing widespread wind damage (Fig. 2) and a disproportionately large number of casualties. This study will focus on the synoptic and mesoscale environment that supported these strong mesovortices, as well as their depth, intensity, and longevity as they moved across northeast Illinois.

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Finally, radar imagery of the mesovortices will be reviewed, including Doppler radar data from the National Weather Service WSR-88Ds, and from the FAA terminal Doppler radar at O'Hare Airport.

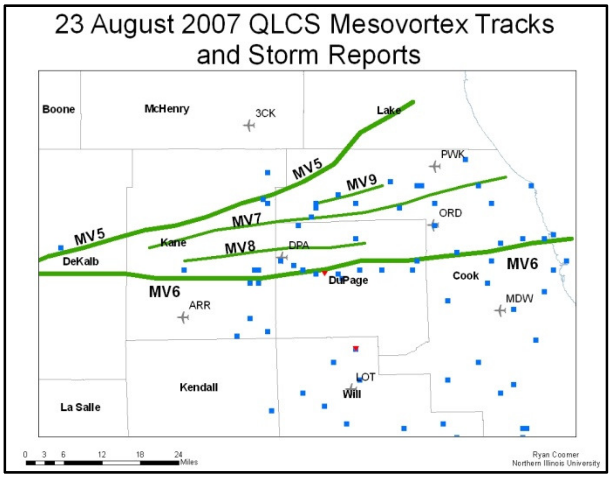

Fig. 2. Map of wind damage (blue squares) and tornado reports (red triangles) with tracks of the various mesovortices overlaid.

2. Synoptic and Mesoscale Environment

The DCS that swept across the Lower Great Lakes originated from a mesoscale convective system (MCS) that had developed over the central High Plains the previous night. By 1200 UTC on 23 August 2007, water vapor imagery and profiler data showed the presence of a mid-level shortwave trough axis translating eastward into Iowa (Fig. 3). Elevated, non-severe thunderstorms associated with this feature persisted past sunrise and through the morning hours as the remnant MCS moved eastward across Iowa.

Ahead of the MCS, visible satellite imagery showed a southward moving outflow boundary emanating from an earlier thunderstorm complex over Wisconsin (Fig. 4). This east-west oriented outflow boundary appeared to stall out over far northern Illinois by 1700 UTC. An enhanced cumulus field developed south of the boundary, with slightly less robust cumulus development to the north. Surface observations revealed very little temperature or dewpoint discontinuity across the boundary, though winds to the south of the boundary were stronger resulting in enhanced

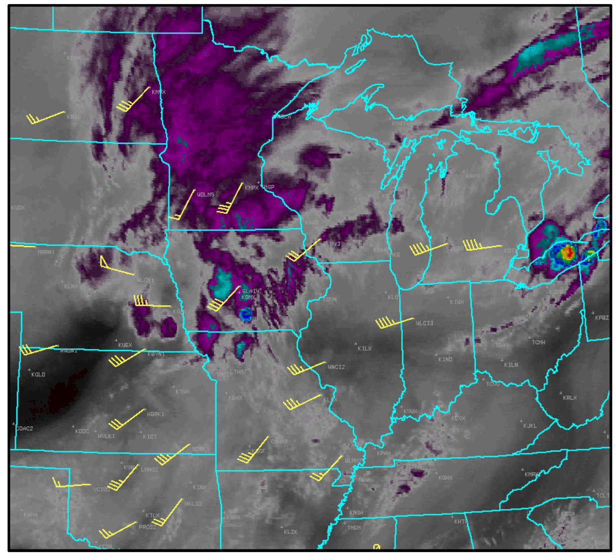

Fig. 3. GOES-East water vapor imagery at 1200 UTC with 500 hPa winds from regional profilers and NWS WSR-88D VWP's in yellow.

convergence along the remnant outflow. Other than the developing cumulus field, visible satellite imagery showed very little cloudiness over the northern half of Illinois. Strong heating of the boundary layer coupled with dewpoints between 21 and 23°C resulted in a high θ_e airmass. The 1800 UTC sounding taken at Lincoln, IL (Fig. 5), shows the presence of relatively steep mid-level lapse rates (700-500 hPa), around 7°C

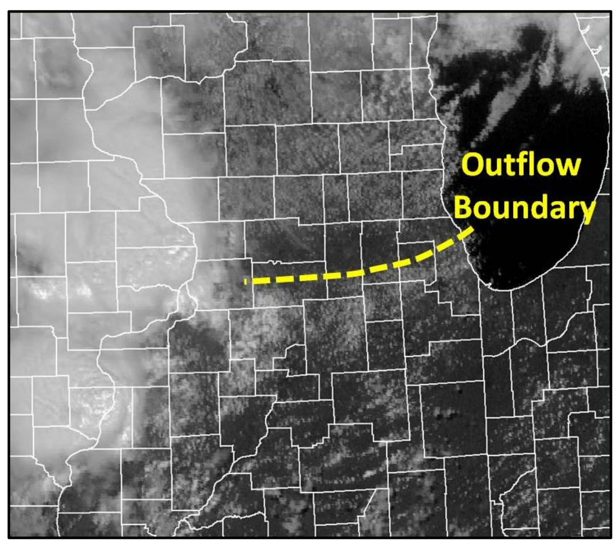

Fig. 4. Visible satellite imagery at 1745 UTC centered on northern Illinois, with the dotted yellow line indicating the location of the convective outflow boundary.

km^{-1}. Combined with the high θ_e air mass in the boundary layer, this led to mean layer convective potential energy (MLCAPE) values above 2000 J kg^{-1} across northern Illinois with very little convective inhibition.

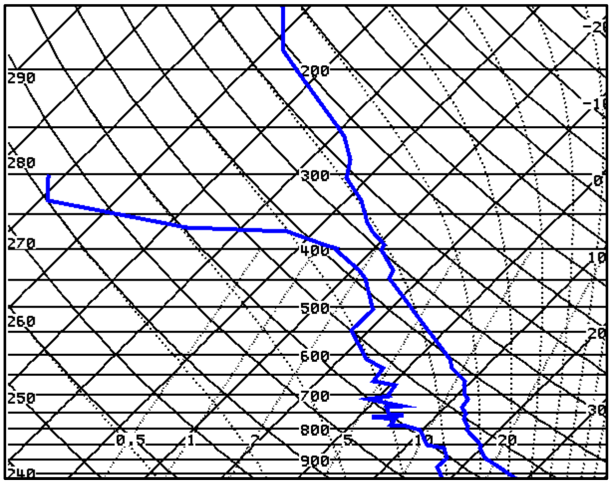

Fig. 5. Sounding from Lincoln, IL (KILX) taken at 1800 UTC.

In addition to the presence of moderate to strong instability, the environment was strongly sheared for late August. A special upper air observation at Davenport, IA (KDVN) sampled 25 ms^{-1} winds around 5 km AGL, with largely unidirectional west-southwesterly winds from 1-5 km. The wind profile, with the shear vector oriented parallel to the mean wind, was conducive for a derecho-producing MCS to form, should a developing cold pool align itself perpendicularly to the shear vector (Cohen et al. 2007, Corfidi 2003). The regional wind profiler at Winchester, IL (Fig. 6) as well as ACARS data (Fig. 7) sampled winds of at least 22.5 ms^{-1} around 5 km, resulting in 0-5 km shear values of around 20 ms^{-1} in advance of the intensifying convection. These

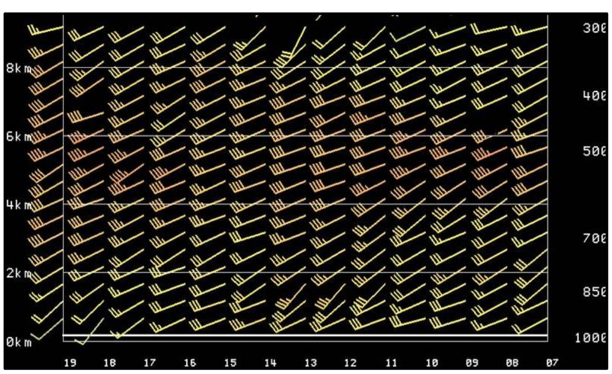

Fig. 6. Winchester wind profiler from 0700 UTC to 1900 UTC on 23 August.

shear values are within the range that Weisman and Trapp (2003) found to be conducive for the development of longer-lived, deeper mesovortices in numerical simulations. These mesovortices stand a much greater chance of producing extensive swaths of extreme wind damage.

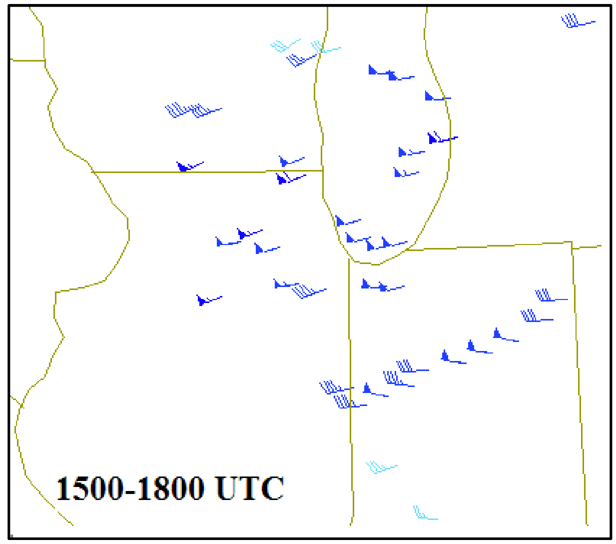

Fig. 7. Winds at 5 km from 1500 UTC to 1800 UTC as sampled by ACARS soundings.

3. Radar Evolution

By 1700 UTC on 23 August 2007, the initially elevated convection over Iowa and far northern Missouri began to intensify, with satellite imagery indicating cloud top temperatures cooling from around -60°C to colder than -70°C. Cloud to ground lightning activity increased considerably as the convection approached the Mississippi River, with radar imagery showing a notable increase in both the maximum heights of 50 dBZ echoes and the echo tops of the storms.

Initially, there were two separate areas of elevated convection that rapidly intensified around 1700 UTC (Fig. 8). The first area was over east central Iowa and far northwest Illinois where an apparent multicell cluster of thunderstorms strengthened and began to accelerate eastward, eventually developing a cold pool and evolving into a bowing line segment as it moved into northeast Illinois. The second area was over west central Illinois where a high precipitation supercell formed, acquiring a deep and relatively strong mesocyclone. By around 1745 UTC, WSR-88D imagery from Lincoln, IL suggested that the rear flank downdraft with this supercell grew in intensity and began to accelerate northeastward, with the supercell quickly transitioning to a bowing line segment.

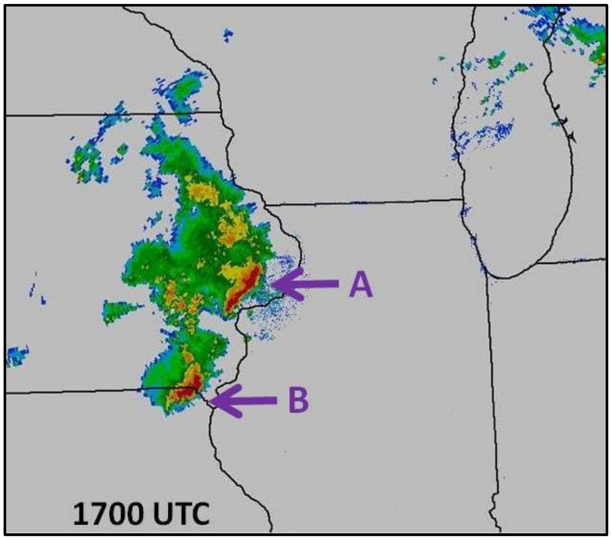

Fig. 8. Regional WSR-88D Mosaic at 1700 UTC, showing two intensifying areas of convection over eastern Iowa.

3.1 Multicell Transition

Several multicell thunderstorms congealed into one larger thunderstorm cluster and began to accelerate eastward across northern Illinois (line segment A, hereafter). The transition from early stages of organization to mature bow was longer than the southern line segment, with the development of a mature cold pool taking some time to occur. A pair of line end vortices developed early in the life cycle of this portion of the developing DCS. The line end vortices appeared to play a role in the development and intensification of some of the vortices that formed in association with this line segment. Careful examination of KLOT WSR-88D data revealed that multiple mesovortices did form within this portion of the developing DCS. Several of these mesovortices were deep and persistent, producing long and nearly continuous swaths of wind damage, some quite substantial, as they moved across the Chicago Metropolitan area.

3.2 Supercell Transition

The more southern of the two initial line segments (line segment B, hereafter) originated from a supercell thunderstorm, an evolution that Klimowski et al. (2004) found to occur in about 15% of bow echo cases. There was a broad circulation, a remnant of the original mesocyclone, which appeared to evolve into the cyclonic line end vortex. This feature persisted as the line segment bowed northeastward moving at 22.5 ms^{-1} across north central Illinois between 1845 UTC and 2000 UTC. As line segment B moved into northeast Illinois by 2000 UTC, some mesovortices developed along the leading edge of this portion of the DCS. The mesovortices with line segment B tended to be shorter lived, shallower, and less intense than those with line segment A. Radar data showed that line segments A and B began to merge by 2045 UTC (Fig. 9) as they moved across northeast Illinois.

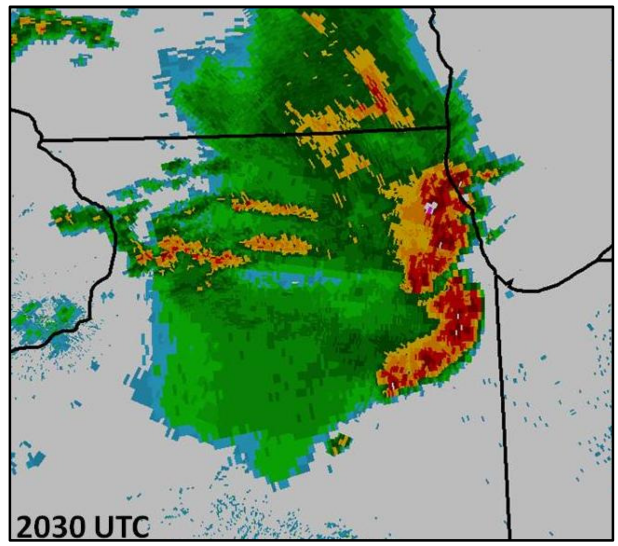

Fig. 9. Regional WSR-88D mosaic at 2030 UTC showing line segments A and B about to merge over northeast IL.

It is difficult to determine conclusively why the vortices associated with line segment B tended to exhibit weaker rotational velocities and were more transient in nature when compared to those of line segment A. However, some environmental characteristics varied between the two segments. First, the observed storm motion for line segment B was approximately 250° at 22.5 ms^{-1}, while line segment A was moving at 265° at about 20 ms^{-1}. Based on the wind profiles observed at 1800 UTC at KILX, these storm motions resulted in a noteworthy difference in storm relative shear values between the two segments. The slower and more rightward motion of line segment A resulted 0-5 km storm relative helicity values of 150-175 $m^2\ s^{-2}$, while the faster and more northeasterly motion of line segment B only resulted in SRH values of 75-100 $m^2\ s^{-2}$. Typically, environmental bulk shear has shown more utility in predicting the development of mesovortices than storm relative helicity. Supercells tend to exhibit deviant storm motion more often, making storm relative helicity more a representative parameter to measure shear's effect on storm morphology (Weisman and Trapp 2003). However, in this case, the differing storm motions among the two line segments likely had implications on the amount of storm relative shear each experienced, which may well have played a role in line segment A being a more efficient producer of stronger, longer lived mesovortices.

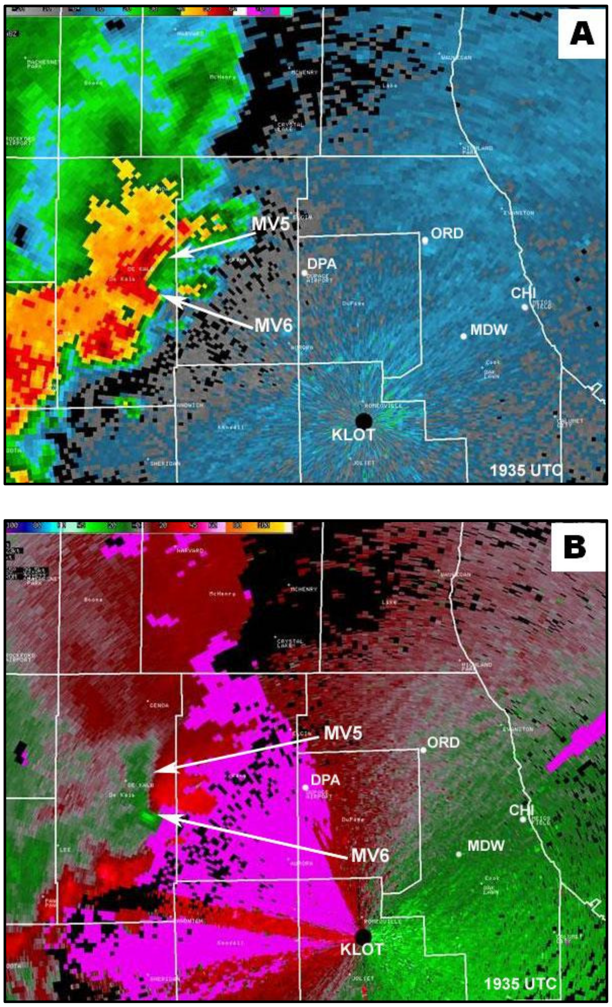

Fig. 10. WSR-88D imagery from KLOT (Romeoville, IL) at 1935 UTC showing (a) reflectivity and (b) storm relative motion.

Another possible factor in the tendency for stronger, more persistent mesovortices within line segment A is the possible interaction with the remnant east-west outflow boundary from earlier convection (Fig. 4). Wheatley and Trapp (2008) have found that the enhanced convergence along pre-existing surface boundaries intersecting a QLCS can result in vortex intensification. The strongest and most persistent mesovortices formed within line segment A were in close proximity to where the remnant outflow boundary stalled and was last discernible in radar and satellite imagery.

4. Vortices

4.1 Mesovortices 5 and 6

Two of the five mesovortices (MV5 and MV6 as seen in Fig. 10) had relatively long life times, forming along the leading edge of the northern bowing segment between 1910 and 1925 UTC (Fig. 10). MV5 initially formed below 3 km and exhibited weak rotation with rotational velocity (Vr) magnitudes between 8 and 11 ms^{-1} (1910 UTC) and a core diameter of 2.5 km (not shown). This

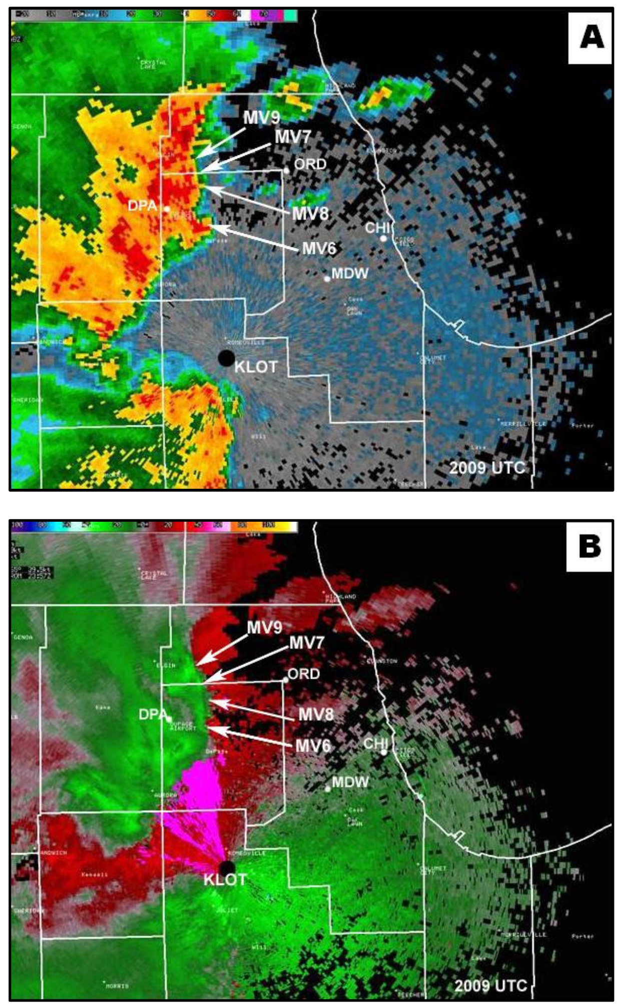

Fig. 11. WSR-88D imagery from KLOT (Romeoville, IL) at 2009 UTC showing (a) reflectivity and (b) storm relative motion.

vortex intensified and deepened rapidly to a height of 6 km during the next 20 minutes, similar to observations recorded by Atkins et al. (2005) and

Przybylinski et al. (2000). However, the lower part of the vortex (below 2 km) became nearly non-existent after 1920 UTC which is uncharacteristic from previous investigations. It is difficult to say why this vortex took on this structure.

After 1930 UTC, MV5 appeared to take on the characteristics of a second northern line-end vortex with the strongest magnitudes of Vr (15 – 16 ms^{-1}) between 3 and 5 km AGL and an average core diameter of 4 to 4.5 km. After 1954 UTC, small east-west oriented convective cells formed over northern Cook County, east of the northern part of line segment A in the vicinity of the old surface boundary (Fig. 11a). It is difficult to say if this boundary had any role with MV5, however, MV5 did have a lifespan of over seventy minutes. Atkins et al. (2005) showed that longer-lived mesovortices associated with the June 10, 2003 St. Louis bow echo event spawned more tornadoes when compared to the shorter-lived vortices. In this case, MV5 did not spawn a tornado during its long lifespan and the damaging winds during these later periods occurred south of the path of this vortex. This vortex weakened after 2019 UTC as it moved across northwest Cook County and into southern Lake County.

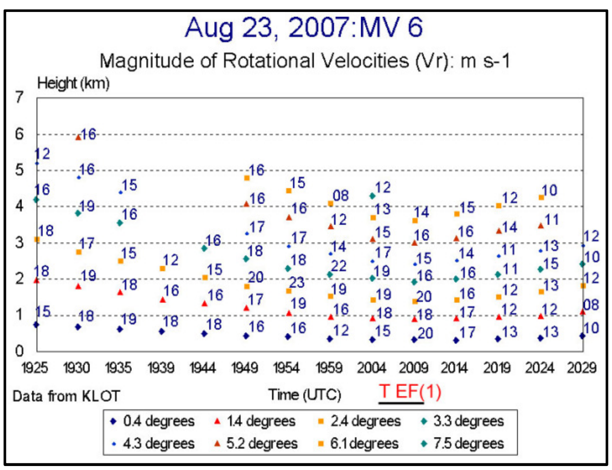

Fig. 12. Time-height diagram of Vr for MV6.

MV6 formed along the southern part of the line segment at 1925 UTC, fifteen minutes after MV5. This vortex formed and rapidly deepened just before 1925 UTC, and reached a height greater than 5 km with the strongest rotation (18 ms^{-1}) identified between 2 and 3.5 km. The 1935 UTC reflectivity and storm-relative velocity images (Fig. 10) show the location of both MV5 and MV6. A reflectivity hook observed along the leading edge of the line segment coincides with the location of MV6. The Vr trace shown in Fig. 12 revealed that this vortex further deepened to a height of 6 km at 1930 UTC with the strongest Vr values (18 to 19 ms^{-1}) remaining below 2 km. The rapid trend of stronger Vr values building downward toward the surface suggested an increasing threat of enhanced damaging winds and even possible tornadogenesis. The height of MV6 dropped significantly to below 3 km by 1939 UTC, however, Vr values of 16 ms^{-1} and greater were still confined to below 1.7 km through 1944 UTC during the period of decreasing vortex depth. Values of 16 ms-1 and greater continued to indicate the potential for damaging surface winds.

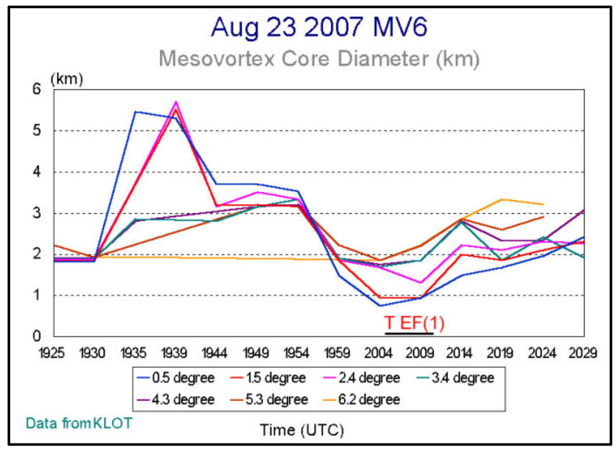

Fig. 13. Time-height diagram of the diameter of the couplet for MV6.

The Vr magnitudes increased a second time between 1944 and 1949 UTC within the 1.5 to 3 km layer of MV6 with the strongest values (19 – 23 ms^{-1}) centered around 2 km. These strong values within this layer continued through 2009 UTC. Concurrently, the depth of MV6 increased a second time to the height of 6 km at 1949 UTC. These trends in mesovortex height and increasing rotation in the vicinity of 2 km have been shown to be a good indicator for tornadogenesis (Atkins et al. 2005 and Przybylinski et al. 2000). Further reinforcing the above features, the mesovortex core diameter dropped from 3 km to less than 1 km within the lowest two elevation slices from 1954 to 2004 UTC (Fig. 13), while the Vr magnitude increased to greater than 20 ms^{-1} at the 0.5° at 2009 UTC. All of these proved to be good predictors of an EF-1 tornado that occurred over western DuPage County at 2008 UTC resulting in tree and home damage. Figure 11 shows the reflectivity and storm-relative Doppler velocity data for 2009 UTC from KLOT, very near the time of the tornado occurrence. The most noticeable feature is the reflectivity hook coincident with MV6, appearing a second time during its lifetime.

From 2019 UTC until 2039 UTC, when MV6 emerged out over Lake Michigan, the vortex generally appeared to be in a weakening phase. During this time period the depth of MV6 decreased from greater than 5 km to less than 3 km, while the core diameter increased as well. While both of these would typically indicate a weakening MV6 and a decreasing threat of damaging winds: Doppler velocity data from the FAA terminal Doppler radar at O'Hare showed that an intense rotational couplet developed at 2037 UTC (Fig. 14). At its peak intensity, the terminal Doppler detected gate-to-gate shear values of 41 ms^{-1} around 200 m above ground. Data from KLOT WSR-88D also showed a corresponding spike in Vr values at 2034 UTC as the circulation was approaching the lakefront. A subsequent storm survey revealed that this re-intensification of the rotation did correspond with an increase in both the magnitude and extent of wind damage associated with MV6 as it neared Lake Michigan.

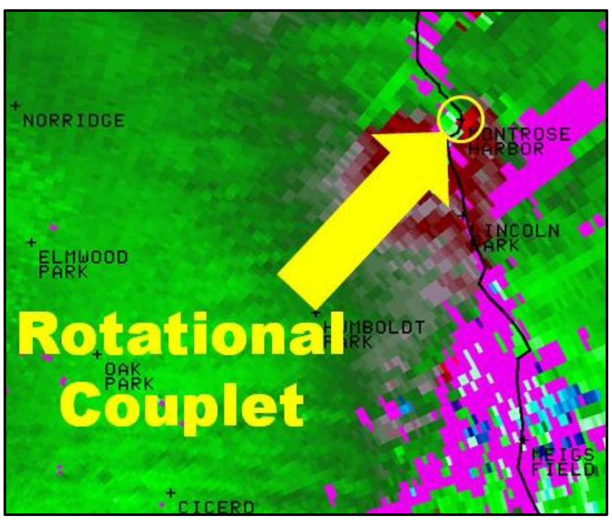

Fig. 14. FAA O'Hare terminal Doppler storm relative motion image at 2037 UTC.

4.2 Vortices 7, 8 and 9

As MV5 transitioned to a mid-level feature (rotation was generally confined to 2km and above) tracking across Kane and northern Cook counties, several smaller, shorter lived vortices (MV7, 8 and 9) developed to its south after 1944 UTC. These MVs were located along the leading edge of the convective line segment between MV5 and MV6, where strong low-level reflectivity gradients existed suggesting an area of strong updrafts (Fig. 11a). The orientation of these vortices along the leading edge of this convective segment is similar to numerical simulations of misocyclone development along the leading edge of thunderstorm "outflow-like" density current (Lee and Wilhelmson 1997). They have suggested that the leading edge of the current encounters low-level southerly flow resulting in the development of shearing instabilities, and from these shearing instabilities small vortices can form.

Of these three vortices, MV7 became the strongest having the greatest depth (near 5 km) and strong rotation confined to the 1.8 to 2.5 km layer (Fig. 15). The Vr values never exceeded 18 ms^{-1} within this layer, while low-level rotation (below 2 km) ranged from 12 to 17 ms^{-1} (Fig. 15). These vortex characteristics differ from MV6 traits, where Vr magnitudes exceeded 20 ms^{-1} in the vicinity of 2 km, vortex height varied significantly, and low-level rotation reached 20 ms^{-1}. The core diameters of these vortices (MV7, MV8, and MV9) all generally remained 2 km or less, but each briefly exhibited strong rotational velocities in excess of 15 ms^{-1} below 1 km. Despite their generally shorter lifespans, each of these vortices produced swaths of damaging winds across northern DuPage and northern Cook Counties.

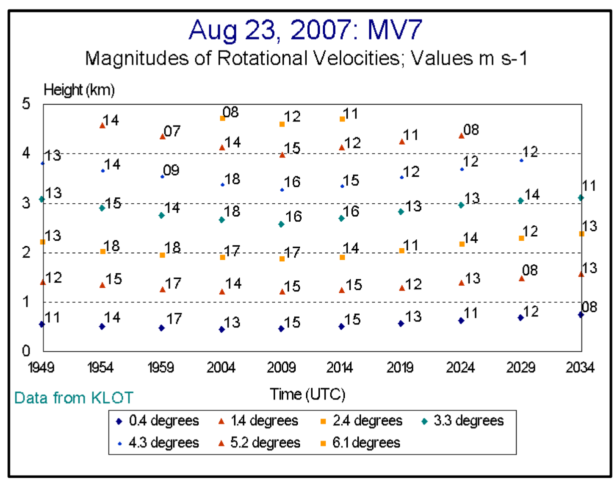

Fig. 15. Time-height diagram of the rotational velocities (Vr) for MV7.

5. Summary

The derecho-producing convective system (DCS) that moved across northern Illinois during the afternoon of 23 August 2007 contained numerous mesovortices that generated swaths of intense straight-line wind damage and two weak tornadoes. The DCS of 23 August 2007 produced millions of dollars in damage and caused dozens of injuries and two fatalities across the Chicago Metropolitan area. Although numerous leading-line mesovortices formed as the DCS moved across northern Illinois, three mesovortices were responsible for the most intense wind damage.

Initially there was a northern and a southern complex of thunderstorms that later congealed into one QLCS. The northern segment was found to contain longer-lasting, deeper, and stronger mesovortices when compared to the southern segment. The authors speculate that this was because its storm motion resulted in a better low-level and 0-5km shear value, and because a pre-existing outflow boundary may have provided enhanced low level convergence to support the stronger, longer-lasting mesovortices.

The longest-lasting mesovortex was MV5, and this mesovortex was unique in that it grew upscale to become the northern line-end vortex, though at one point it contained a low-level rotational velocity value of 14 ms^{-1}. The strongest and deepest mesovortex, MV6, contained a maximum low-level rotational velocity of 20 ms^{-1}, which occurred just before the mesovortex produced an EF-1 tornado. And although MV7 was shorter-lived than MV5 and MV6, it still produced rotational velocities of over 15 ms^{-1}. Even though all three of these mesovortices exhibited different depths, strengths, and durations, each was associated with a swath of intense wind damage across northern Illinois.

This case also illustrates just how quickly mesovortices can develop, intensify and become tornadic. While the National Weather Service WSR-88D radar offers updated radar data every 4.1 minutes in its fastest updating volume coverage pattern (VCP), warning forecasters during the 23 August 2007 event also had access to data from FAA terminal Doppler radars. These FAA radars provided updated volume scans at the lowest elevation every minute. This higher temporal resolution data enabled warning forecasters to identify and warn for tornadic mesovorticies more quickly than they could have with WSR-88D data alone. A faster updating VCP for the National Weather Service WSR-88Ds likely would improve warning forecasters' ability to warn for QLCS type tornadoes.

The next step in this research will be continuing to quantify all of the mesovortices that occurred, and overlaying their paths with the resultant wind damage swaths that occurred. In relating the amount and strength of the resultant damage to the parent mesovortex, forecasters may be able to identify the more intense mesovortices in real-time before straight-line wind damage or tornadoes occur.

6. References

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