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The 19 July 2006 Midwest Derecho: A Meteorological Perspective and Lessons Learned

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I. Introduction

The 2006 summer convective season was one of the more prolific periods of severe weather over the Mid-Mississippi River Valley region. Historically, mid July through the end of August over this region is a period comprised of isolated "pulse-severe type" convection rather than organized convection. In contrast the period of April through June the number of severe weather events are at their peak (Britt, 2008). During the later half of July 2006 two major wind storm events, occurred over the Greater St. Louis Metropolitan area and surrounding counties. The first windstorm event occurred on 19 July 2006 and caused wind damage to several buildings, and destructive tree and power line damage resulting in one fatality and thirty injuries. By late evening of 19 July, 2006, over 500,000 customers over the area were left without power. The 19 July 2006 windstorm was followed by a second windstorm on Friday morning, 21 July 2006 and caused additional tree and powerline damage (Sieveking and Przybylinski 2008 elsewhere in this volume). An additional 250,000 customers were left without power due to the high winds and weak non-supercell tornadoes. At this same time impressive heat scorched the area with temperatures reaching the mid to upper 90s and dewpoints in the mid to upper 70s.

Nolen (1959) and Hamilton (1970) first documented the relationship between bow-shape convective systems (referred to as a line echo wave pattern and straight-line damaging surface winds and tornadoes. Fujita (1978) documented the kinematic structure and time evolution of a radar echo he referred to as a bow echo. He showed that bow echoes were frequently associated with straight-line wind damage or downbursts at the surface. Severe bow echoes can result in significant property damage and loss of life over an extended region (e.g. Fujita and Wakimoto 1981, Johns and Hirt 1987, and Przybylinski 1995). Fujita's conceptual model suggests that the strongest wind damage occurred during the bow echo stage. However, recent observations and numerical simulation studies have shown that during the early stages of bowing, damaging winds and even weak tornadoes may result from subsystem-scale vorticies which form along the leading edge and generally at and north of the bow apex. These vortices can rise to heights of 4 or 5 km while their strongest rotation often remains at low-levels (below 3 km) (Atkins et al. 2004, Atkins et al. 2005, Funk et al. 1999, Przybylinski et al. 2000). System-scale vortices known as "book-end vortices" may also form at the ends of the bow echo and be responsible for the production of damaging winds along the northern (southern) periphery of the large vortex (Atkins et al. 2004); Weisman (1993). In a minority of derecho cases, system and sub-system scale vortices may be absent in organized convective systems while they only produce damaging straight-line winds. These systems can evolve in highly unstable – weak shear environments and can exist for extended periods and can fit the classification of a derecho (Przybylinski et al 1993).

In this study, we will examine environmental conditions and storm evolution with Weather Surveillance Radar 1988 Doppler (WSR-88D)

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from WFO (Weather Forecast Office) Lincoln, IL (KILX) and WFO St. Louis MO (KLSX). The first part will cover the broad synoptic-scale environment over the Upper and Middle-Mississippi Valley region from 1200 UTC (here after all times in UTC) 19 July through early afternoon. The second section will cover the storm evolution over southern Minnesota and northern Iowa. This will be followed by a more detailed overview of the mesoscale environment across southern Iowa, Illinois and Missouri during the mid and late afternoon. This final part of this paper will include detailed radar analysis from KILX and KLSX covering central Illinois through east-central Missouri. Additionally, we will attempt to show why there was an absent of mesovortex evolution with this case compared to other cases documented over this region. Reflectivity and Doppler velocity imagery will be compared to damage survey analysis conducted over the Greater St. Louis metropolitan area (STL). We will also make comparisons of the storm reflectivity structure of the 19 July 2006 case to the 10 August 1992 damaging wind event.

II. Synoptic-scale Analysis

Centered over the southern Rockies and south-central Plains a broad mid to upper level ridge gradually built eastward across the middle Mississippi Valley on 19 July 2006 (Fig. 1). Coincident with the upper ridge, a warm elevated mixed layer extended eastward from the high plains into the Midwest, with 7.0-7.5 °C/km 700-500 mb lapse rates as far east as the middle Mississippi Valley and Great Lakes region. General consensus forecasts and the majority of numerical model guidance suggested that this capping would largely inhibit organized thunderstorm development across the middle Mississippi Valley on 19 July 2006. To the north of the upper ridge, a progressive belt of mid to upper level westerlies was present across the northern tier of the United States. An upper trough and associated jet streak (60-70 kt at 500 mb) developed east-southeastward across the Northern Plains/Upper Midwest and central Canadian province. A leading low amplitude shortwave trough and warm air advection regime supported early day strong to severe thunderstorm development across portions of the Dakotas and Minnesota. At 1200, 19 July 2006 a Mesoscale Convective System (MCS), with a history of severe hail and isolated damaging winds, was ongoing over parts of southwest Minnesota (Fig. 2). A very moist low level airmass was in place across much of the middle Mississippi Valley, with 850 mb dewpoints around 11-14 °C (Fig. 3). A weak cold front had moved south-southeastward across the region on the previous day, gradually stalling in a general west to east fashion across the southern portions of Missouri, Illinois, and Indiana during the evening and nighttime hours of 18 July into early 19 July. This front demarcated a warm and moist airmass to the south of the front.

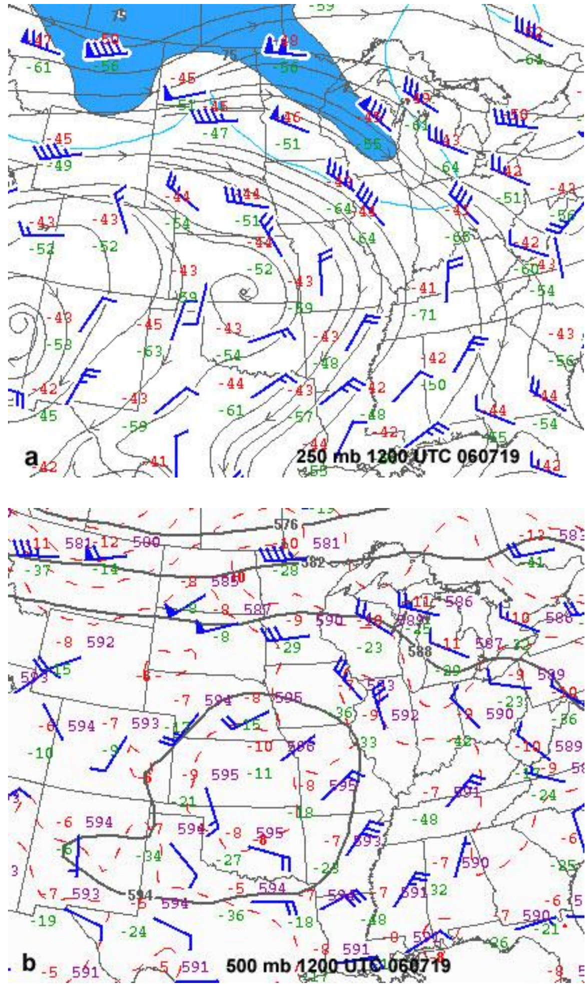


Fig. 1: (a) 250 –hPa analysis and (b) 500 –hPa analysis for 1200 UTC 19 July 2006. Isolines of height every 6 dm are solid lines. Isotherms are every 5° C are dashed red.

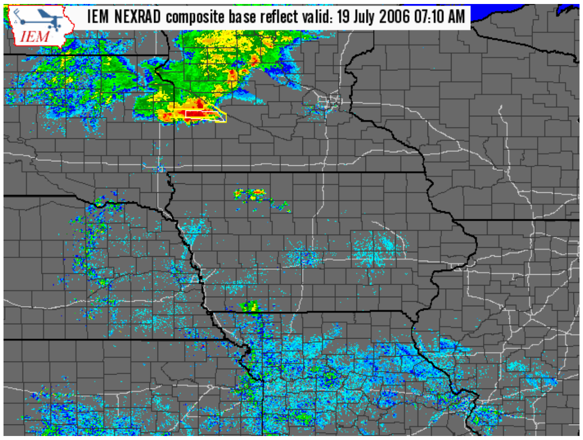


Figure 2: Radar composite at 1210 UTC from Iowa Sate Univeristy Department of Agronomy.

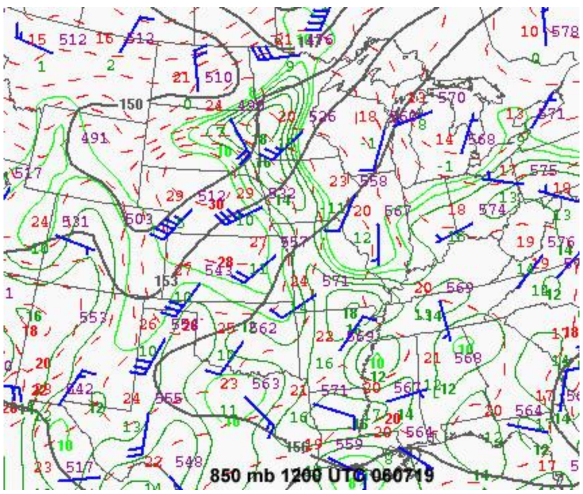


Figure. 3. Same as figure 1 except for 850 –hPa.

(70s °F surface dewpoints) and a drier airmass to the north (50s to lower 60s °F surface dewpoints) across the upper Mississippi Valley and Great Lakes region. This boundary gradually returned north-northeastward during the day on 19 July as a warm front (Fig. 4).

III. Storm Evolution

Figure 5 shows the total storm path of the 19 July 2006 derecho from central Minnesota through central Illinois and then southwest into south-central Missouri. After 1430 a large bow echo produced swaths of damaging winds over parts of south-central through southeast Minnesota. Concurrently a new cluster of storms formed over north-central Iowa at this time and moved east-southeastward over northeast and east-central sections of the state.

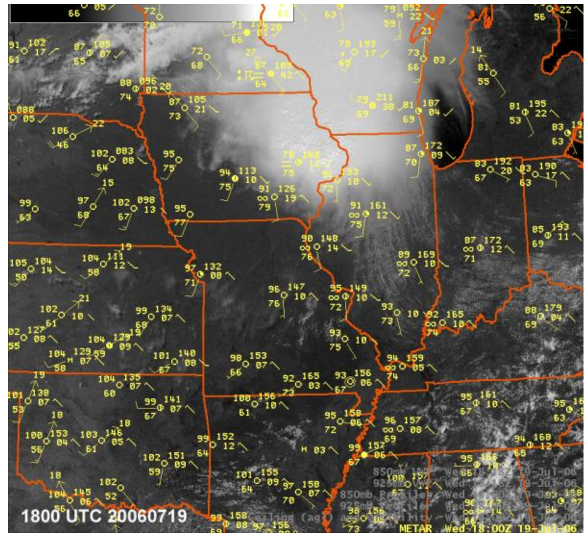


Figure 4. Visible satellite imagery with surface plot overlaid for 1800 UTC 19 July 2006.

This convective cluster appeared to inhibit the transport of very warm and moist flow into the bow echo system as it significantly weakened over west-central Wisconsin (Fig. 6). The Iowa MCS further intensified after 1600 over eastern sections of the state producing areas of damaging winds southeastward into parts of northwest Illinois. The Iowa MCS became the predominant MCS as it moved towards central Illinois by mid afternoon.

IV. Mesoscale environment over the Mid-Mississippi Valley Region (2000 – 2100 UTC)

With the forward propagating severe MCS/bow echo crossing west-central Illinois by mid afternoon (2000-2100), strong instability was in

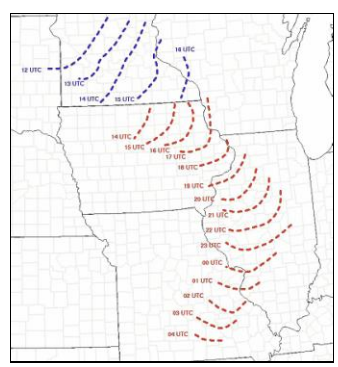


Figure. 5. MCS storm track across the upper and middle Mississippi Valley regions 19 July 2006.

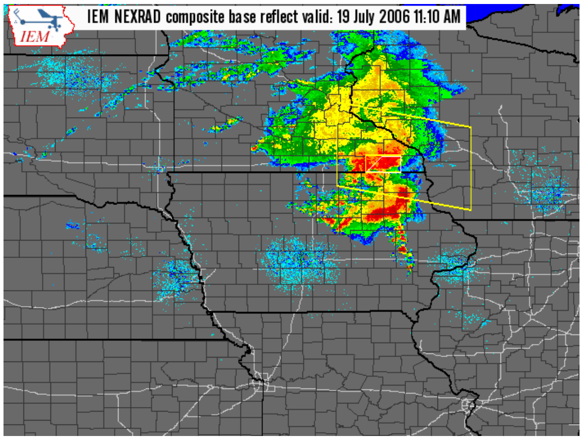


Figure 6. Same as figure 3 except for 1610 UTC.

place across eastern Missouri and west central/southwest Illinois. Surface temperatures warming well into the 90s °F, and SPC's RUC-based objective mesoanalysis (Bothwell et al. 2002) data reflected 2500-6000 J kg^{-1} of 100 mb mixed layer (ML)CAPE across eastern Missouri and west central/southwest Illinois (Fig. 7). With the eastward building upper ridge, mid tropospheric winds gradually weakened during the day, as illustrated by Winchester, IL (WNC – west central IL) profiler data (Fig. 8). Accordingly deep layer vertical shear was rather modest across the region with around 10 – 22 m s^{-1} of 0-6 km bulk shear (Fig. 9).

RUC soundings (Benjamin et al. 2004) are used to further illustrate the representative environment in close proximity to the severe MCS as it crossed west central/southwest Illinois and eastern Missouri during the later afternoon/early evening hours of 19 July 2006. Using the NSHARP sounding analysis program (Hart et al. 1999), a 2100 RUC 00-hr sounding for Springfield, IL (SPI) reflected very strong instability with 5392 J kg^{-1} of 100 mb Mixed Layer (ML)CAPE, 6065 J kg^{-1} of Most Unstable (MU)CAPE, a Lifted Index (LI) of -12°C, in addition to steep mid level lapse rates (700-500 mb) of 7.3°C/km (Fig. 10a). Deep layer (0-6 km and 0-8 km) was weak around 11 m s^{-1}, and 0-3 km bulk shear of 8 m s^{-1}. Additionally the RUC 2200 delta theta-e value between the surface and 600 -hPa over STL was 32 °K. Atkins and Wakimoto (1991) have shown that the minimum threshold for wet microburst days is greater than 20°K.

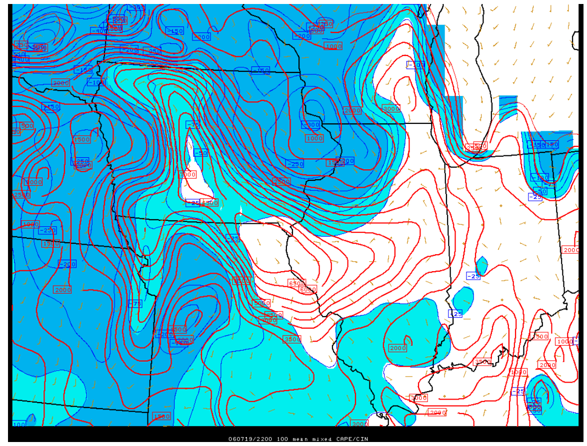


Figure. 7. SPC Mesoscale analysis valid 2200 UTC 19 July 2006. MLCAPE (red contours) and CINH (blue shading).

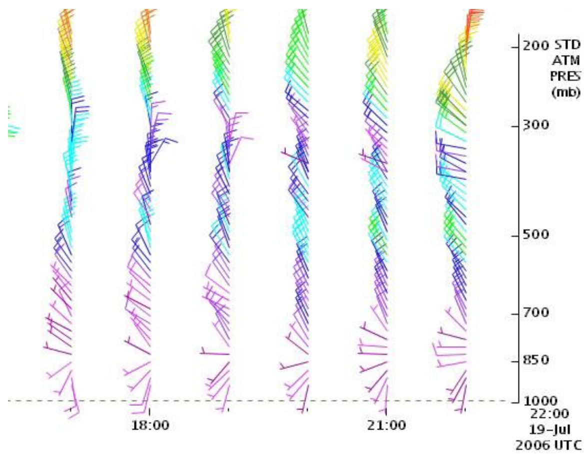


Figure. 8. Profiler data from Winchester Illinois from 1700 – 2200 UTC 19 July, 2006.

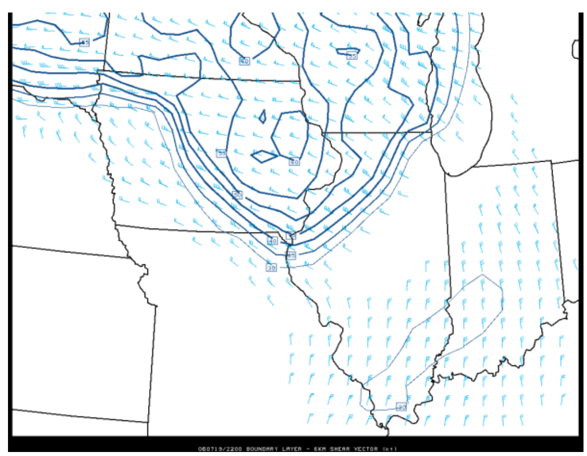


Figure. 9. Same as figure 7 except for Deep Layer (0-6 km) Bulk Shear (kt).

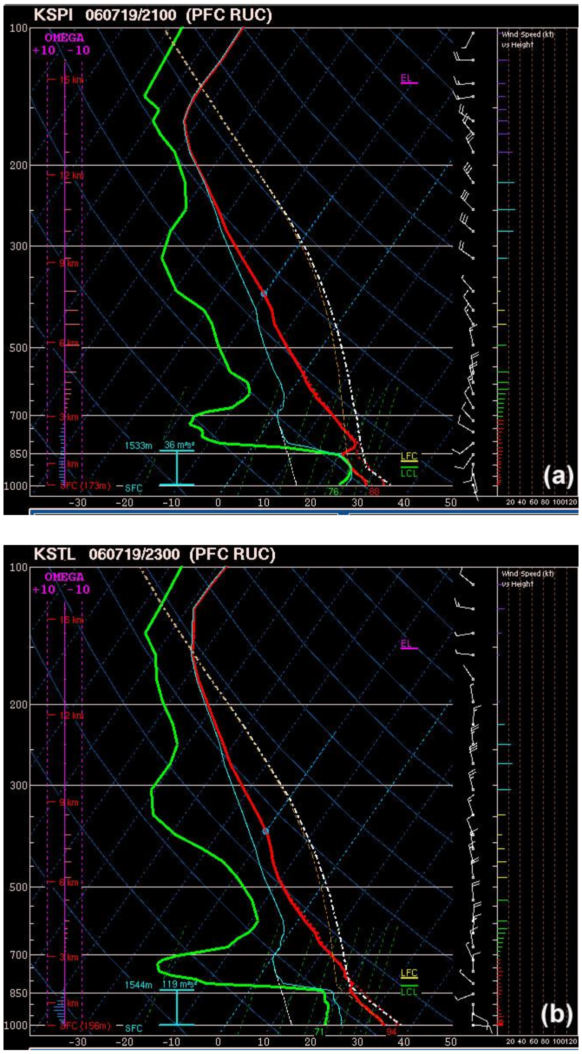


Figure 10. (a) 00-hr RUC sounding for Springfield IL (SPI) valid for 2100 UTC 19 July 2006. (b) 00-hr RUC sounding for St. Louis (STL) valid for 2300 UTC 19 July 2006.

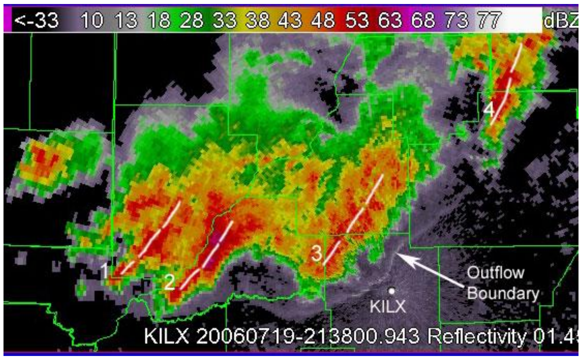
By 2300 RUC 00-hr sounding for STL indicated somewhat weaker, yet still very unstable, addition to steep mid level lapse rates (700-500 mb) of 7.3°C/km (Fig. 10a). Deep layer (0-6 km and 0-8 km) was weak around 11 m s^{-1}, and 0-3 km bulk shear of 8 m s^{-1}. ML CAPE of 2882 J/kg, MUCAPE of 2954 J/kg, and a LI -9°C with a 7.4°C/km 700-500 mb lapse rate (Fig. 10b). Deep layer shear (0-6 km and 0-8 km) continued to remain weak with values of 12 m s^{-1} / 11 m s^{-1} (respectively) and 0-3 km bulk shear of 6 m $s^{-1.}$

In all, five Severe Thunderstorm Watches were issued by the Storm Prediction Center (SPC) in collaboration with local National Weather Service Offices (WFOs) on 19 July 2006. The final watch of the day for the region, Severe Thunderstorm Watch was issued at 545 pm CDT (2245) for portions of southwest Illinois and east central Missouri, including the St. Louis Metropolitan area, until 1100 pm CDT (0400).

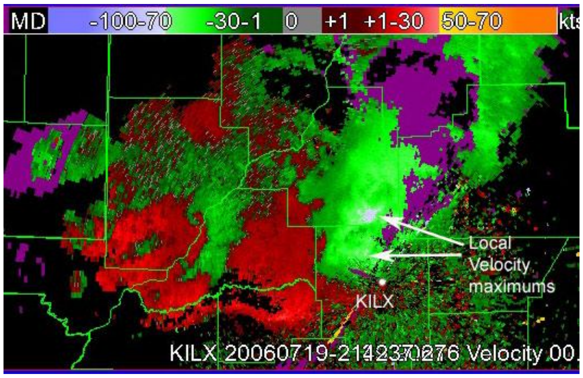
IV. Radar analysis across Central Illinois from KILX

Analyses of the reflectivity and Doppler velocity images over central Illinois and the STL area were obtained from single Doppler data collected at KILX and KLSX respectively. Damaging wind and hail reports came from Storm Data at National Climatic Data Center (NCDC). Detailed damage assessments over parts of the STL area were conducted the personnel from .WFO LSX.

As the severe storm system moved southward across Central Illinois the overall convective complex at 2138 showed four linear convective segments (1-4) oriented north-northeast to south-southwest within the larger convective .complex (Fig. 11). One isolated storm was located 20 km west of the larger complex. Strong low-level reflectivity gradients were documented along the southern and southeast flanks of each segment suggesting the probable region of inflow into each segment. Each of the four segments also revealed multicellular type evolution where new convective towers formed along the southern flank of each segment resembling the MCS archetype of “Parallel Stratiform” (Parker 2000) in a smaller scale. This type of reflectivity structure differs from other forward propagating damaging wind MCS events where solid convective lines and bow echoes are common across the middle Mississippi Valley region. Previous cases studied have shown that convective lines and bow echoes which produce swaths of damaging winds and tornadoes do occur when bulk shear magnitudes reach 15 to 20 m s^{-1} within the 0-3 and the 0-6 km layers (Atkins and Przybylinski 2000, Atkins et al. 2004, Atkins et al. 2005, Przybylinski 1995 and Przybylinski et al. 2000.



a.



b.

Figure 11. WSR-88D radar imagery from Lincoln, Illinois (KILX) at 2138 UTC showing (a) reflectivity (b) base velocity

Base reflectivity data from KILX also revealed a fine line representing the leading outflow extending as much as 5 to 8 km downshear from the segments. It is interesting to note that mesovortex identification and development was absent along the forward and southeastern flanks of each convective segment. Owing to this fact, profiler _data at 2100 from Winchester Illinois at this time illustrated weak low-level shear (0-3 km) of 5 m s^{-1} and modest deep layer shear (0-6 km) of 12 m s^{-1} RUC sounding data at SPI further confirmed this finding with 0-3 km shear of 8 m s^{-1} and 0-6 km shear of 11 m s^{-1}. Atkins and Przybylinski 2000, Atkins et al. 2005 and Przybylinski et al. 2000 showed that mesovortices often develop in moderate to strong low-level shear environments. Weisman and Trapp (2003) also documented that bulk shear has more utility in predicting the development of mesovortices than storm-relative helicity.

In viewing subsequent reflectivity and Doppler velocity images from KILX the convective segments were quite persistent as the system moved south across central Illinois. Single Doppler velocity data at 0.5 degree elevation slice from KILX at 2142 revealed two local inbound velocity maximums exceeding 35 m s^{-1} with convective segment #3 (Fig. 14b). The larger of the two maximums were located over southern Tazewell County near the center of convective segment #3 while the first maximum was located 3 to 5 km north-northwest of KILX. Viewing angle considerations may have played a role in not capturing the full breath of the local velocity maximums. The location of each and other nearby wind maximums further solidified the existence of multicell evolution within this segment. Damage reports from WFO KILX via (NCDC) showed that estimated wind speeds over this area ranged from 26 to 28 m s^{-1}.

After 2145 (not shown), convective segments 1 and 2 merged into a larger convective cluster 15 to 20 km west of KILX while segments 3 and 4 remain isolated. Isolated small convective cells were developing along the western flank of the larger convective cluster. This overall reflectivity structure persisted through 2220 as the system moved across the Springfield, Illinois (KSPI) area. Base velocity data from KILX at this time continued to show three distinct local velocity maximums of 25 – 30 m s^{-1} (not shown) each associated with the highly reflective cores along the axis of segment 3. A fourth outbound velocity maximum was identified with weaker convective cores along the eastern of segment #3. Much of the damage reports during this period occurred with segment #3 across Sagamon County Illinois including the city of Springfield. Magnitudes of the estimated wind speeds from storm damage reports over this area ranged from 26 to 28 m s^{-1} similar to reports north of KILX.

V. Radar analysis over parts of Southwest Illinois and East Central Missouri including the Greater St. Louis Metropolitan Area.

Between 2320 and 2332, segment #3 continued to expand is size and showed the characteristics of a developing small bowing line segment across Macoupin County, Illinois 110 km north-northeast of STL (Fig. 12a). Isolated new convective towers immediately formed along the downshear side of this segment and

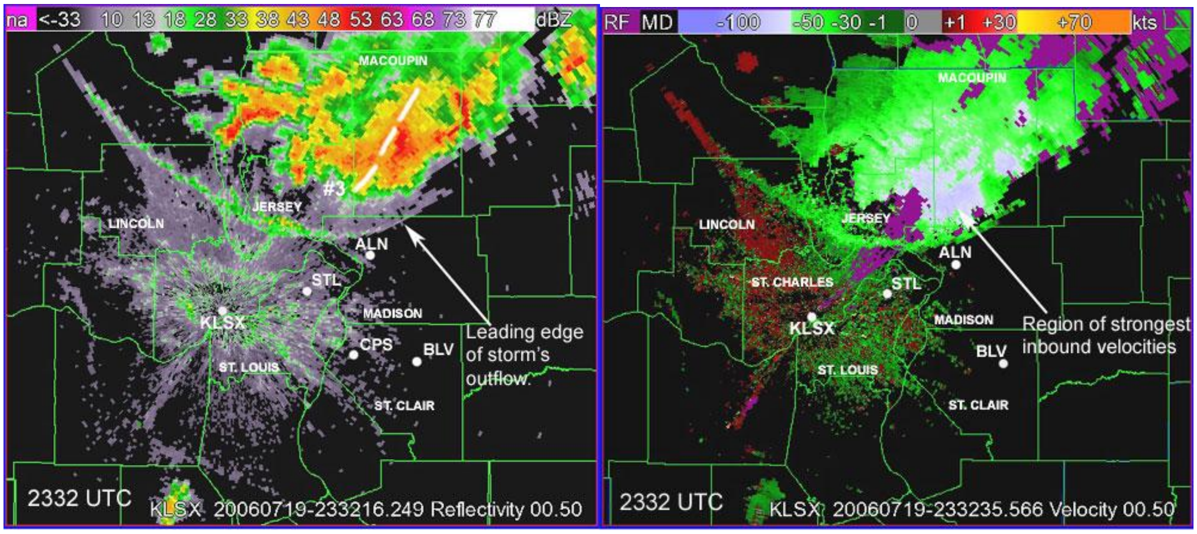


Figure.12. Plan view reflectivity (left) and Doppler velocity (right) from KLSX at 2332 UTC 19 July 2006.

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gradually merged with the larger convective segment again showing the multicell convective mode. This line segment was briefly observed til 2345 UTC. Base velocity from KLSX showed a relatively large area of inbound velocities with magnitudes reaching 35 m s^{-1} over much of southwest and west- central parts Macoupin into eastern Jersey counties in southwest Illinois (Fig. 12b). The strongest winds appeared to be along the leading edge of the line segment into the region of newly isolated convective towers associated with segment #3. Damage assessment findings showed that the tree damage increased in intensity and coverage over parts of southwest Macoupin and east-central Jersey Counties in conjunction with the higher inbound velocity magnitudes noted on the KLSX WSR-88D. Two local weather stations over southwest Macoupin county reported brief gusts to 40 and 38 m s^{-1} at 2335 respectively. Hail the size of 1.75 and 2.54 cm was common over this area, damaging leaves on corn and soy bean plants.

Further west towards the Mississippi and Illinois Rivers, the first of two segments were smaller in size compared to observations documented over central Illinois. Isolated pulse-type convective towers and smaller segments were oriented north-northeast to south-southwest. The number of damage reports over this area was less compared to the eastern segment and wind gusts from the isolated convective cores reached 25 to 30 m s^{-1}.

At 0000, the leading edge of the gust front extended 20 to 50 km downshear from the stronger convective towers from southern Macoupin County Illinois through downtown St. Louis across southwest St. Charles County and then northwest into western Lincoln County Missouri (Fig 13). Segment #3 briefly became a quasi-linear segment oriented southwest to northeast showing again multicell evolution with the stronger convective towers developing along the downshear side and merging with the larger mass of higher reflectivity. Bulk Shear values from 2300 UTC RUC sounding at St. Louis continued to show magnitudes of weak shear; 7 m s^{-1} (0-3 km) and 12 m s^{-1} (0-6 km) suggesting pulse to multicellular mode convection. The area of highest inbounds velocities (40 m s^{-1}) stretched from the region of developing towers through the area of mature storms. Segment #3 was moving towards the west of downtown St. Louis. The topography north and northeast of downtown St. Louis may have played a role in the intensity of wind damage in the downtown and surrounding areas in the city. The Mississippi River and areas extending 10 km east of the river northeast of the downtown area are comprised of a large flood plain region. Thus it is possible that the strong surface gusts

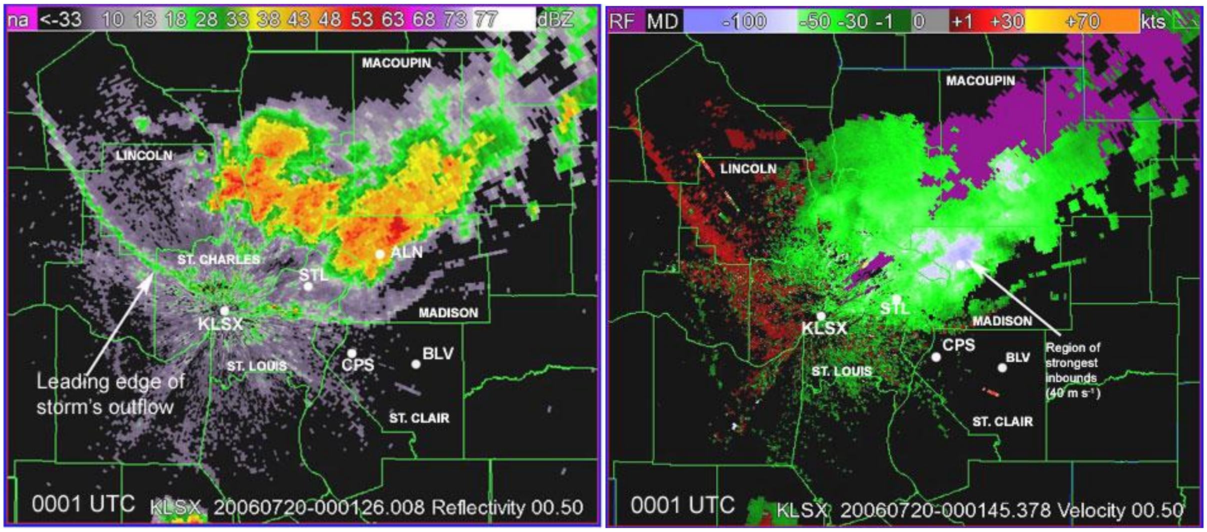

Figure.13. Plan view reflectivity (left) and velocity (right) from KLSX at 0001 UTC 20 July 2006.

encountering less friction over the river and the flood plain region northeast of downtown St. Louis may have heightened the intensity of damage from the northern city limits through downtown and areas west and south of the immediate downtown area. After the passage of the initial gust front and secondary surges with the stronger convective core, several large tractor trailers were overturned along the Interstate 270 bridge over the Mississippi River. Damage assessment findings showed that the greatest tree and structural damage was found near the south side of downtown through Tower Grove Park (5 km southwest of downtown St. Louis) where numerous large trees were uprooted or snapped. This was the worst tree damage in the park since its existence.

Except for the Automatic Surface Observing System (ASOS) at Cahokia Parks Airport (CPS) (6.5 km km south-southeast of downtown St. Louis) there were no other wind sensors over the flood plain region or along the Mississippi River to obtain real-time wind speed data. Table 1 shows a listing of ASOS, few local Emergency Managers and trained spotter sites which shows the peak wind speeds and time of occurrence. The highest wind values from the two storm spotters over southwest and southern Macoupin County at 2335 and 2340 were associated with convective segment #3. The ASOS instrumentation at Lambert International Airport in St. Louis lost power after the surge of high winds associated with the leading gust front. No other wind information from this site was available after the passage of the gust front.

Time (UTC)	**Highest Gusts (ms^{-1})**	**County**	**Source**
2335	40	Macoupin County IL	Trained Spotter
2340	39	Macoupin County IL	Trained Spotter
2353	32	Madison County IL	Alton Airport (AWOS)
2355	31 Associated with Gust Front	St.Louis County MO	St. Louis Lambert Field (ASOS)
0019	30	St.Clair County IL	Cahokia Parks Airport (ASOS)

Table 1 shows measured peak winds ($m\ s^{-1}$) either during the passage of the gust front or when a cell or cluster of storms passed over the station site.

Narrow convective segments (#1 and #2) earlier seen over parts of southwest Illinois at 2332 and west of Segment #3 expanded in size by 0001 over parts of southern Jersey through

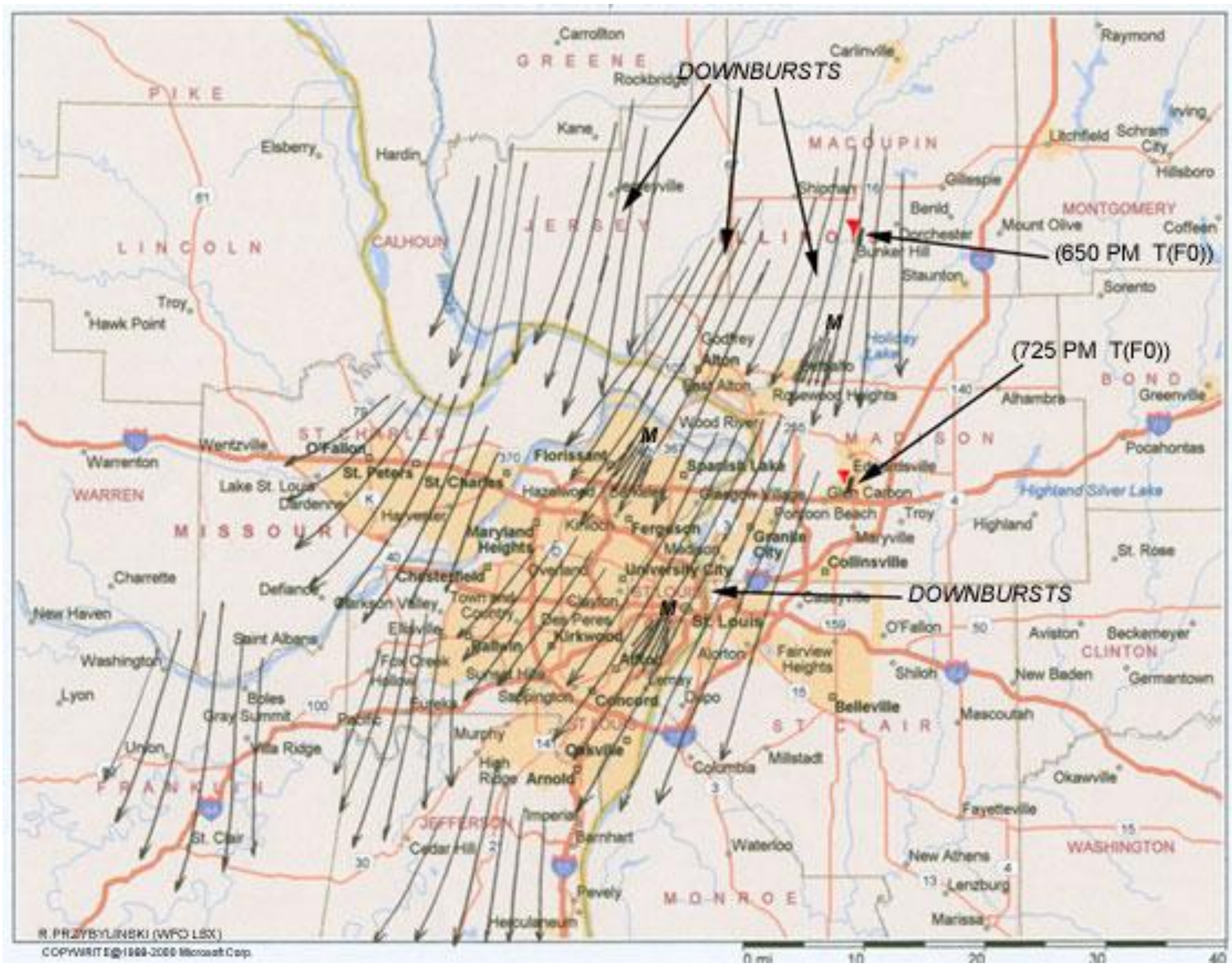

Figure 14: 19 July 2006 NWS damage assessment over parts of southwest Illinois and east-central Missouri.

central Calhoun Counties in southwest Illinois. New isolated convective towers along the southern flank merged with other mature cells resulting in a larger cluster of storms compared to othe 2332 reflectivity image. The leading gust front along the western flank of the convective system accelerated southwest between 2332 and 0001 and extended 50 km downshear from the leading convective towers over Calhoun and Jersey counties. Only isolated severe reports were received over Jersey and Calhoun counties as the larger cluster moved south-southwest into northern St. Charles County. The lack of reports over these areas may have been the result of the numerous phones calls received from spotters, law enforcement, and the public across St. Louis City and St. Louis County Missouri and western parts of Madison County Illinois associated with segment #3. From 0001 to 0114 numerous reports of wind damage occurred over the eastern half of St. Charles County through St. Louis City and many parts of St. Louis County. Figure 14 shows a mapping of the downbursts and microbursts over these areas. The greatest concentration of damage appeared with convective segment #3 as this cluster moved through the city of St. Louis. Numerous trees laid to the south and southwest. Numerous homes, vehicles and power lines were damaged by fallen trees and large limbs. Since the predominate direction for bowing convective systems and strong to severe winds over eastern Missouri is from 290°, tree root systems do develop in response to the sway of the wind. Thus trees over this region are heavily anchored from the west and northwest (Emmett 2006). Since the predominant wind direction from the 19 July 2006 convective system was from 010° to 030° the tree root systems are not well anchored and established from this direction resulting in many more fallen trees with this event.

At 0114, a quasi-linear convective system (QLCS) was briefly observed 50 to 70 km south and southwest of St. Louis (not shown). The MCS slowly turned and moved in a south-southwesterly direction in response to the building upper-level ridge over Illinois. A nearly continuous area of damaging winds extended from the south and southwest sections of STL through south-central Missouri and then into southeast sections of the state before weakening after 0400 UTC.

The 19 July 2006 MCS resembled the 10 August 1992 MCS which formed southwest of STL and moved south and southwest into west-central Arkansas (Przybylinski et al. 1993). This system also showed an isolated pulse to multicellular convective system producing extensive tree and limb damage from parts of east-central through south-central Missouri and into sections of west-central Arkansas. The upper-level ridge was not as pronounced on this date compared to the 19 July 2006 event. However both MCSs evolved in a weak shear – highly unstable environment and failed to show any organized convective line or bowing structures. Of the forty-two cases studied over the Middle Mississippi Valley region, these are the only two cases where the MCS moved in a south-southwest direction.

IV. Summary

An overview of the 19 July 2006 derecho was presented. The early convective system formed in a moderate to highly unstable environment with modest shear. From this MCS a bow echo evolved over southern Minnesota and moved east before weakening over west-central Wisconsin. A second cluster of strong thunderstorms formed over north-central Iowa by mid-morning and moved along the eastern and southeast periphery of a pronounced upper-level ridge. The movement of the 19 July 2006 is atypical over this region since the mean direction of spring and early summer MCSs is from 290°. The MCS moved into a highly unstable – weak shear environment from central Illinois through east-central Missouri as the upper level ridge was moving eastward across northern and central Illinois. The overall convective system took on the characteristic of MCS Archetype “Parallel Stratiform” in a smaller scale where several convective segments showing multicellular characteristics and were oriented from north-northeast to south-southwest. New convective towers formed on the downshear flank of each segment and merged with the larger echo mass. Extensive wind damage from this MCS occurred over much of the St. Louis region leaving residents over a large area without power for several days. The highest degree of damage occurred across the immediate St. Louis downtown area and areas to the south and southwest. Many homes, vehicles were damaged while power lines were down for several days. All of this occurred under oppressive heat and high humidities.

V. Acknowledgements

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