6.5 Analysis of the 21 July 2006 Greater St. Louis and Southwest Illinois Bow Echo Event

James E. Sieveking* and Ron W. Przybylinski

NOAA National Weather Service
St. Louis, MO

Introduction

On 21 July 2006, a bow echo crossed the St. Louis metropolitan area producing 30 ms^{-1} wind gusts, causing additional destruction to a city that was still reeling from historic tree and power line damage that had occurred less than two days prior from a separate severe weather event (Przybylinski et al. 2008). This exacerbated an ongoing power outage; causing the total number of customers without electricity to rise over 750,000 in the National Weather Service (NWS) St. Louis (LSX) county warning area (CWA) (Figure 1). This was the largest and most widespread power outage ever to occur in St. Louis. An astounding labor force of 5,200 contractors and employees from 13 states were called upon to restore power to the region. Many families waited up to ten days for their power to be restored, which led not only to inconvenience, but human suffering. At least 536 gastrointestinal illness cases were reported in the City of St. Louis alone due to the consumption of spoiled food.

As the bow echo crossed the Mississippi River into southwest Illinois, three mesovortices were observed north of the bow's apex. Storm surveys conducted by the NWS revealed five non-supercell tornadoes and five microbursts occurred within the larger downburst footprint of the bow echo. Severe wind speeds as high as 40 ms^{-1} were estimated within the microburst regions, while tornadoes were classified as F0 or F1 on the Fujita Scale.

The Storm Prediction Center (SPC) mesoscale analysis and rapid update cycle (RUC) model data from 12:00 UTC strongly supported the development of a quasi-linear convective system (QLCS) and foreshadowed the heightened potential for tornadogenesis across southwest Illinois.

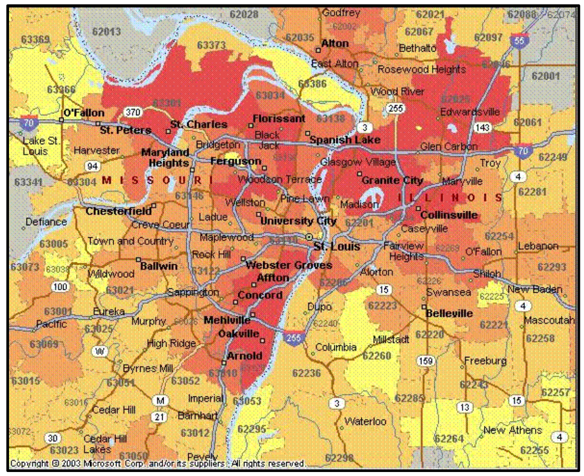

Figure 1. The AmerenUE power outage map from 21 July 2006, zoomed into the St. Louis metropolitan area, depicts where the strongest winds and worst damage (red) had occurred.

Utilizing the Warning Decision Support System (WDSS), velocity cross sections suggest that the bow echo's development and associated severe wind gusts were closely related to the evolution of the mesoscale rear inflow jet. St. Louis WSR-88D (KLSX) radar analysis along with storm surveys, identified a close correlation between tornadogenesis and radar observed mesovortices across southwest Illinois.

Tornadogenesis from mesovortices embedded within a QLCS is a warning decision challenge that faces NWS forecasters. Unlike a supercells' hook echo, there are no highly-correlated reflectivity radar signatures to identify QLCS tornadoes (Godfrey et al. 2004). The most current research suggests that the lead-time between initial detection of low-level rotation on radar to tornado formation can be as short as five minutes, or roughly one volume scan. Time height cross section analysis of rotational velocity (Vr) from the most dominant mesovortex documented in this case will complement the current research and give further merit to the development of faster scan strategies for the WSR-88D.

* Corresponding author address: James E. Sieveking NOAA National Weather Service, St. Charles, MO 63304; email: jim.sieveking@noaa.gov

Storm Environment

Numerous studies have proven that severe linear convective systems, such as bow echoes, form in environments that are characterized by large convective instability and moderate to strong low-level shear (Johns and Hirt 1987; Weisman 1993; Evans and Doswell 2001). It has also been documented that QLCSs are more likely to produce tornadoes in environments that are similar to those observed for supercell tornadoes, characterized by high values of low-level shear and instability (Godfrey et.al 2004). Studies by Rasmussen and others have shown the importance of low LCL values and sufficient 0-3km CAPE for supercell tornadogenesis.

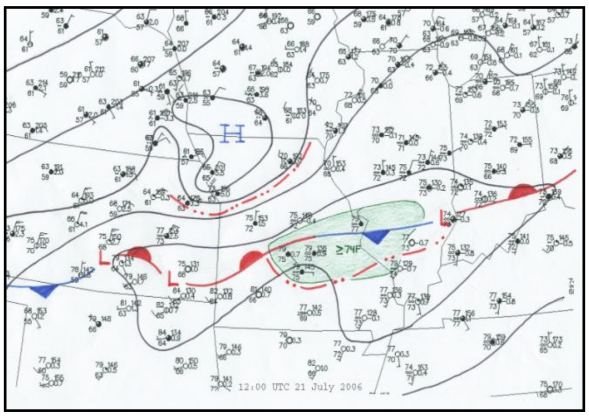

Figure 2. 12:00 UTC 21 July 2006 surface analysis

The synoptic environment on the morning of 21 July 2006 was more typical of late spring, rather than mid-July across the middle Mississippi River Valley. A nocturnal mesoscale convective system (MCS) had formed north of a stationary frontal boundary that was positioned from southeast Kansas through east central Missouri and into southwest Illinois (Figure 2). At 12:00 UTC the MCS's outflow boundary was steadily marching southeast toward central Missouri.

Aloft, a positively tilted shortwave was poised to lift through the area, providing unseasonably high deep layer shear and the necessary lift to initiate the convection. The magnitude of 0-6km and 0-3km bulk shear at 09:00 UTC from Lathrop, Missouri profiler was 20 and 17 ms^{-1} respectively. Weisman et al 2003 concluded that the development of mesovortices can be

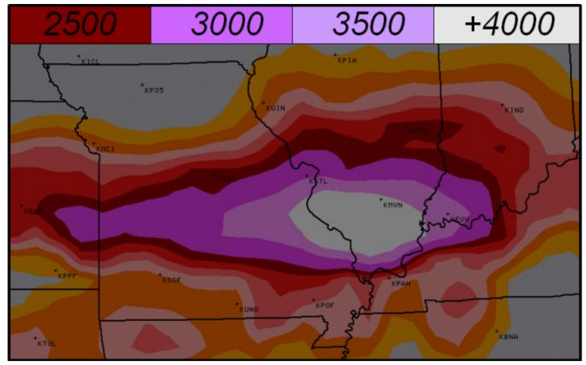

Figure 3. 12:00 UTC 21 July 2006 RUC MLCAPE (Jkg^{-1})

anticipated when the ambient environment is characterized by strong, low-level vertical wind shear.

Due to the extensive cirrus shield from the decaying MCS and low level stratus that had formed overnight, surface temperatures at 12:00 UTC were near 80ºF. Pooling dewpoints in the middle and upper 70s along the frontal boundary contributed to a large area of instability. 12:00 UTC RUC model data depicted MLCAPE's in excess of 3000 Jkg^{-1} along and south of Interstate 70 in east central Missouri and southwest Illinois (Figure 3). Small dewpoint depressions on the order of only a few degrees were observed in the vicinity of the front, with LCL heights around 600 meters. By 16:00 UTC, low level CAPE (0-3km) values were above 50 Jkg^{-1} across southwest Illinois (Figure 4), owing to the potential of rapid vertical stretching along the leading edge of the bow echo and likelihood of tornadogenesis (Rasmussen 2003).

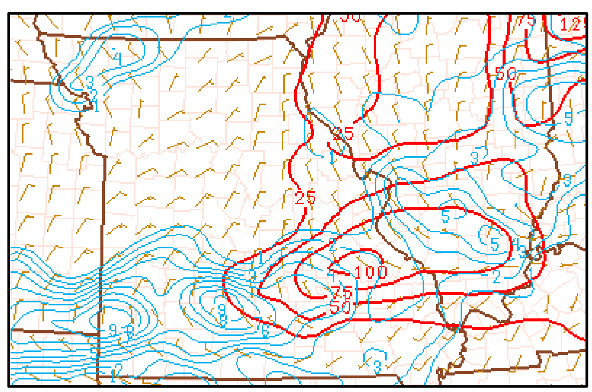

Figure 4. 16:00 UTC 21 July 2006 SPC mesoscale analysis of 0-3km CAPE (Jkg^{-1}) (red) and surface vorticity (cyan).

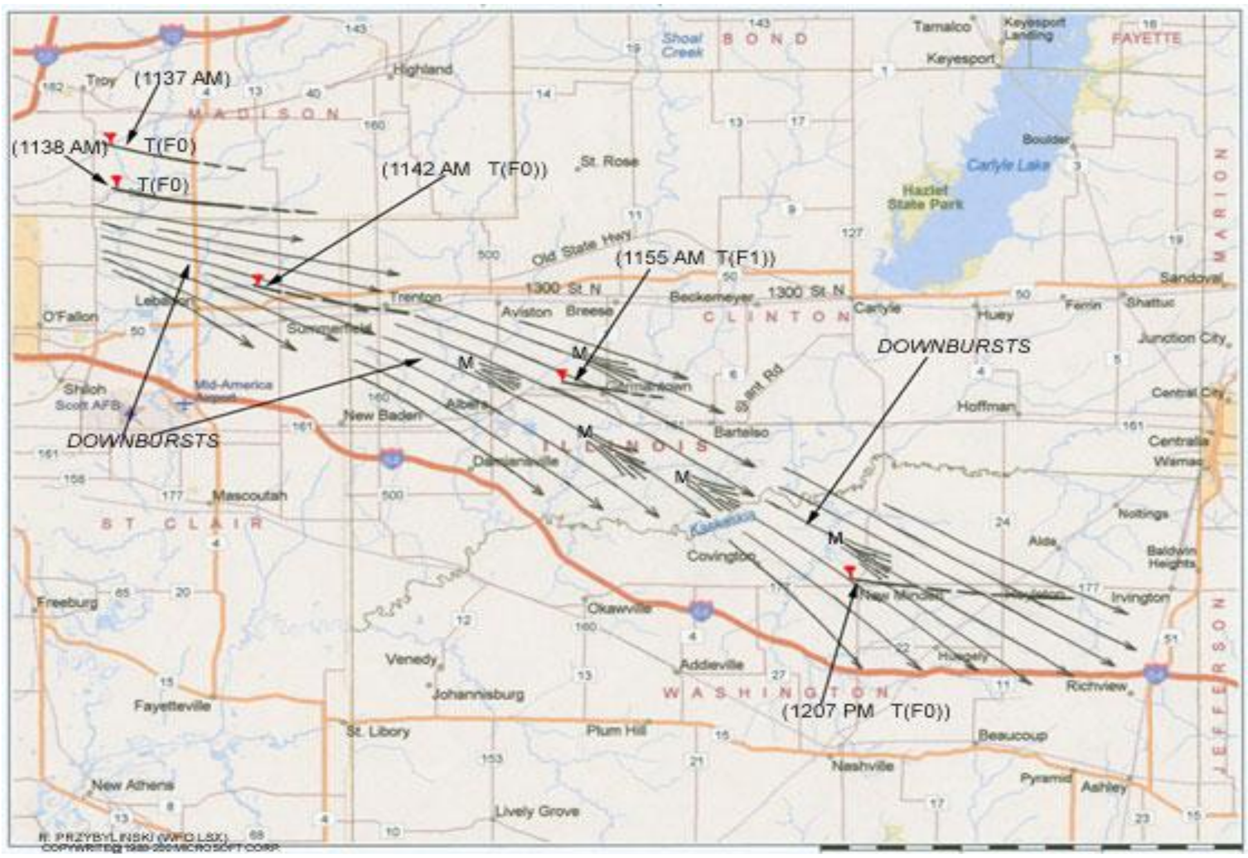

Figure 5. 21 July 2006 NWS damage survey of southwest Illinois. The large downburst foot print from the bow echo is depicted with embedded microbursts (M) and weak non-supercell tornadoes (red triangles).

Radar Analysis

Convective Initiation

Convection initiated in central Missouri along the outflow boundary emanating from the decaying nocturnal MCS over northwest Missouri. The linear cluster of thunderstorms were initially elevated due to the weak capping inversion that existed over the area, but as they traversed further east, they became rooted within the unstable boundary layer. The thunderstorms quickly became severe and produced nickel size hail and minor tree damage in the city of Columbia, Missouri.

Bow Echo Formation

The broken line of thunderstorms continued east along the frontal boundary into the far western stretches of the St. Louis metropolitan area, producing sporadic reports of wind damage and marginally severe hail. A rapid intensification occurred with the northern portion of the convective line shortly after a merger with a cluster of isolated cells over western Lincoln County, Missouri. The linear reflectivity structure then began to bow out as it accelerated east-southeast toward the northern St. Louis metropolitan area. Studies by Finley et al. 2001 have shown the importance of the low-level cold pool intensification after storm – convective line mergers in the formation and strengthening of the convective line segment and bow echo formation. Utilizing WDSS, radar cross sections of velocity (not shown) clearly identified the descending rear inflow jet. Spotter reports of severe wind gusts and damage across eastern St. Charles County and northern St. Louis County were highly correlated with the radar's depiction of the RIJ descending through the boundary layer toward the surface.

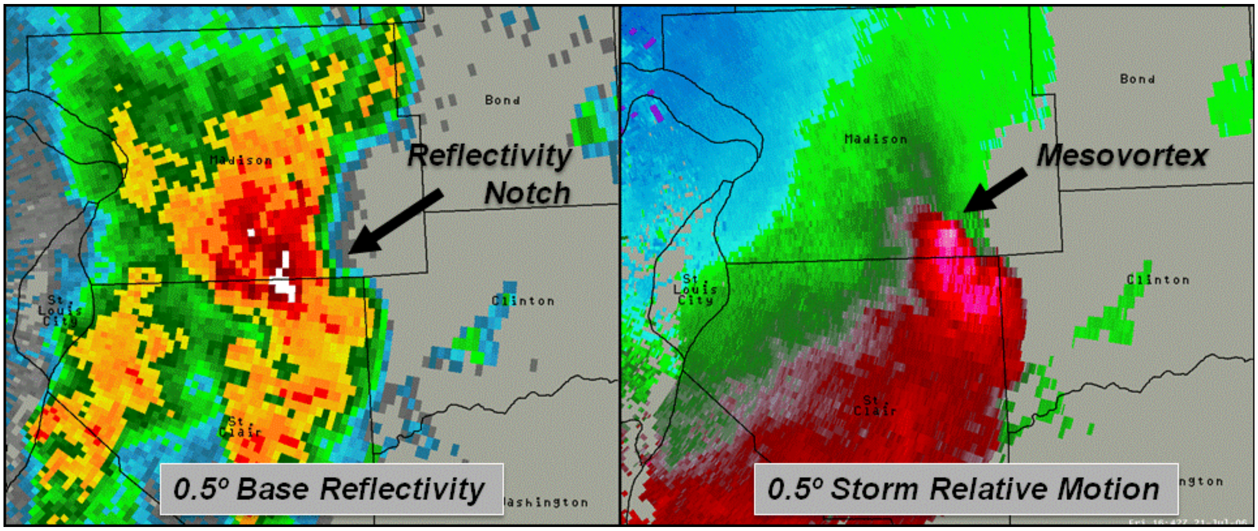

Figure 6. KLSX 0.5º base reflectivity and storm-relative velocity at 16:42 UTC 21 July 2006.

Mesovortices and Tornadogenesis

The reflectivity structure of the bow echo was classic as it crossed the Mississippi River into southwest Illinois, with an accelerating spearhead echo marking the apex and strongest damaging winds. Widespread wind damage occurred along the entire path of the bow's apex across southwest Illinois from downbursts and locally stronger microbursts. In addition, five tornado tracks were identified by the NWS through post-storm damage surveys (Figure 5).

Two mesovorticies formed near the northern end of the bowing structure as the system moved from southern Madison County through Washington County, Illinois. Only the first and most persistent of the two mesovortices will be examined.

The first mesovortex formed approximately 5 km northeast of Collinsville, Illinois at 16:27 UTC (Figure 7). The vortex was identified at approximately 1.8 km above ground level (AGL). During the next two volume scans the vortex deepened to 3.5 km (Figure 8), while the strongest rotation was confined to the lowest 2.5 km with magnitudes of rotational velocities (Vr) of 26 ms^{-1} (Figure 6).

Two tornadoes formed nearly simultaneously at 16:37 UTC and 16:38 UTC over southern Madison County. Each tornado produced continuous tree and structural damage, rated F(0) on the Fujita Scale. They were short lived tornadoes, one lasting nine minutes, and the other only six minutes. During the time that both tornadoes were occurring, the diameter of the mesovortex tightened to 2.6 km and 2.2 km respectively on the 0.5º and 1.5º radar scans (Figure 8).

From 16:47 to 16:56 UTC the depth of the mesovortex rose to 4.5 km while the strongest rotation remained below 1.5 km, with Vr values of 19 ms^{-1}. Atkins et al 2005 showed that the strongest rotation with the two tornadic vortices during the 10 June 2003 bow echo event was also confined below 1.5 km.

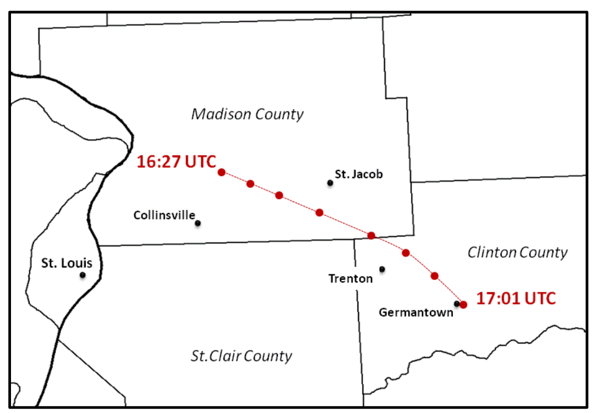

Figure 7. Map of the mesovortex track. Each red dot represents the center of the circulation every volume scan during the 34 minute lifespan.

The mesovortex spawned a third and final tornado northwest of Germantown, in central Clinton County at 16:55 UTC. The tornado had a very short lifespan of approximately 3 minutes, but produced F1 damage when it destroyed a large utility building. The strength of the low-level rotation continued to be strong with Vr values of 18 ms^{-1} during the time of tornado occurrence. Another slight decrease in the diameter of the mesovortex was observed prior to the third tornado touchdown (Figure 8).

The mesovortex existed for 34 minutes, producing three short-lived tornadoes across the rural countryside of southwest Illinois. Nonetheless, monetary damage from this single mesovortex still amounted to nearly $250,000.

Despite the initial rotation observed on the 1.5º radar scan at 16:37 UTC, the lead time from mesovortex identification in the lowest radar scan (0.5º) to the first tornado occurrence was only 5 minutes, or roughly one volume scan (Figure 8).

Summary

Historic damage to the infrastructure of the power grid across the St. Louis metropolitan area left more than three-quarters of a million citizens without power for up to ten days following a tandem of severe weather events during the middle of July 2006.

The bow echo of 21 July 2006, the second severe event to hit the area in less than 48 hours, produced severe weather from central Missouri to southwest Illinois. The greatest damage occurred during the mature stage of the bow echo from St. Charles County, Missouri to Washington County, Illinois. The descending RIJ observed on radar correlated well with damage reports from severe wind gusts. It is hypothesized that forecasters should anticipate an increase in coverage and intensity of severe wind gusts when this feature is observed.

A dominant non-descending mesovortex formed north of the bow's apex and produced three short-lived tornadoes as it traveled 27 miles across southwest Illinois. As documented by Atkins et al 2005, the mesovortex formed concurrently with the descent of the RIJ. Furthermore, the longevity of the circulation in this case study supports Atkins and others hypothesis that damaging mesovortices tend to have a longer lifespan.

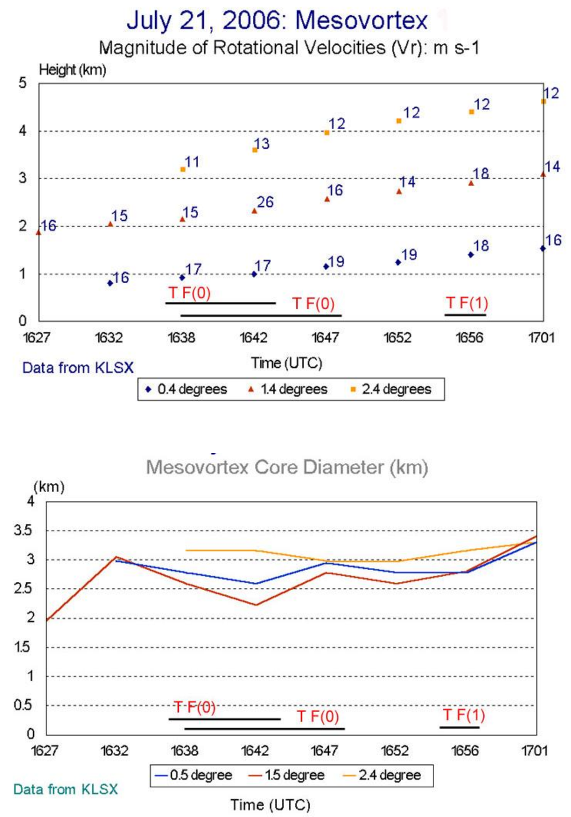

Figure 8. Time-height trace of rotational velocities (ms^{-1}) (top) and time-core diameter (km) trace (bottom) for the mesovortex.

Unfortunately, the post-event correlation that Atkins has documented provides little comfort or insight to the warning forecaster that must decide if a circulation will become tornadic. Given the lead-time between initial mesovortex detection and tornadogenesis in this case was around five minutes, the warning forecaster must accurately assess the pre-storm environment before mesovortex formation. It is hypothesized that if the pre-storm environment is conducive for tornadogenesis (i.e. high values of low-level bulk shear and CAPE), that a warning forecaster should seriously consider issuing a tornado warning for mesovortices that are persistent for more than one volume scan.

QLCS mesovortices can produce short-lived tornadoes with very little lead-time. They have produced up to EF3 damage as well as caused injuries and fatalities. The authors suggest that faster NWS WSR-88D scan strategies be developed to provide better identification and tracking of QLCS mesovortices.

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