



## 2. Storm Environment

### a. Upper Air Analysis

The upper air analysis from the afternoon of 6 May 2003 depicted a deep trough of low pressure at 500 mb across the Rocky Mountains and the greater intermountain west (not shown). Differential positive vorticity advection was approaching the forecast area from the west, as a strong shortwave had rotated around the base of the mid level trough and had ejected into the central plains. Accompanying the shortwave was a  $30 \text{ m s}^{-1}$  jet streak that was embedded in the west-southwesterly flow at mid levels and overlaid the southern half of Missouri and Illinois. This created deep layer shear values around  $25 \text{ m s}^{-1}$  south of Interstate 70. At 850 mb a veering  $15 \text{ m s}^{-1}$  low level jet had progressed eastward into the forecast area from Kansas and Oklahoma.

### b. Surface Analysis

At the surface (2300 UTC), a low pressure center was located across eastern Kansas, with an attached northward advancing warm front located 20 miles south of Interstate 70 (Fig. 2) in east-central Missouri. A definitive discontinuity in temperature, dewpoint, and wind direction existed across the warm frontal boundary. The air mass to the south of the front was characterized as a maritime tropical air mass, with temperatures rising into the lower 80s ( $^{\circ}\text{F}$ ) and dewpoints above  $70(^{\circ}\text{F})$  being advected northward ahead of the approaching surface low. Winds were primarily uniform from the south-southwest in the warm sector, except across extreme eastern Missouri and southwest Illinois. Locally, winds had backed to the southeast in response to outflow from earlier convection that had occurred across southwest Illinois. North of the boundary, easterly winds advected cooler and drier air into northern Missouri and central Illinois. Temperatures struggled to reach the upper 60s ( $^{\circ}\text{F}$ ) and dewpoints were in the middle 50s ( $^{\circ}\text{F}$ ) under a dense cirrus overcast sky.

### c. Convective Indices, Storm Mode, and Tornadoogenesis

Rawinsonde sounding data at 1800 UTC (hereafter all times in UTC) from Springfield, MO (KSGF) indicated that a large degree of instability existed in the warm sector (Fig.3). The lifted index (LI) was calculated to be  $-9.8$ , convective available potential energy (CAPE) was  $3615 \text{ J Kg}^{-1}$ , and convective inhibition (CIN) was  $50 \text{ J Kg}^{-1}$ . This

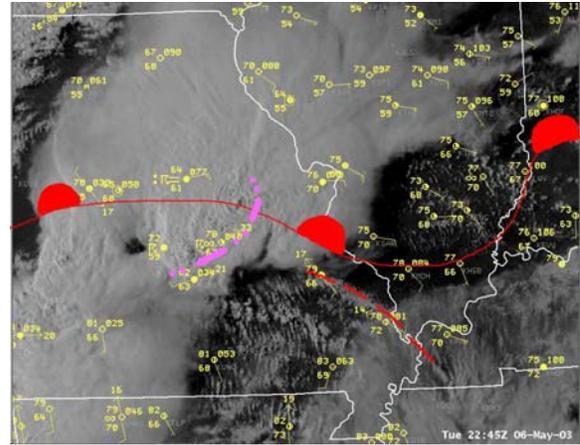


Figure 2. GOES visible satellite imagery and surface data plots.

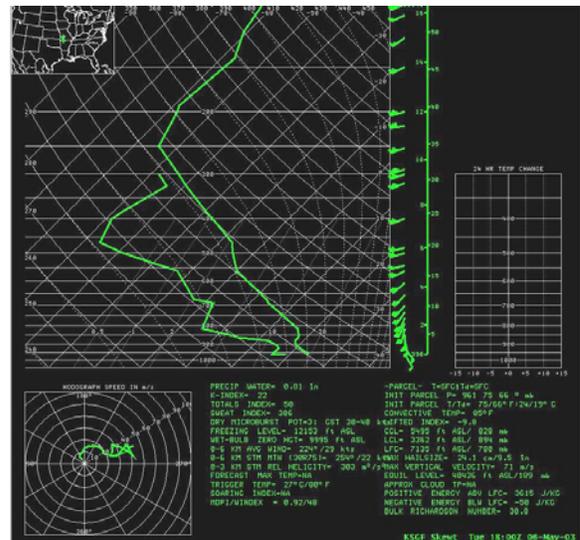


Figure 3. Skew-T Log-P sounding from Springfield Missouri (KSGF) at 1800 UTC, 06 May 2003.

degree of instability coupled with sufficient 0-6 km deep layer shear ( $25 \text{ m s}^{-1}$ ) and 0-3 km storm relative helicity values over  $300 \text{ m}^2 \text{ s}^{-2}$  indicated that the storm mode that afternoon and evening would likely be supercells, with a strong potential for tornadogenesis (Davies-Jones et al 1990). The potential for tornadogenesis was enhanced locally across eastern Missouri and southwest Illinois through the increased low level helicity associated with the retreating outflow boundary and surface warm front. The rapid update cycle (RUC) model output portrayed a similar pattern of indices across the warm sector. Helicity values were forecast to approach  $500 \text{ m}^2 \text{ s}^{-2}$  south of Interstate 70 across central and east-central Missouri in tandem with

the warm front. A secondary maximum (greater than  $300 \text{ m}^2 \text{ s}^{-2}$ ) was to exist south of St. Louis along the Mississippi River, toward the bootheel of Missouri, where the retreating outflow boundary was present.

### 3. Radar Analysis and Storm Structure

Discrete supercells developed as expected along a southwest to northeast orientated line across west-central Missouri during the early afternoon. The line of supercells pressed east from Pleasant Hill (EAX) and Springfield (SGF) county warning areas (CWA) into the LSX CWA by 2130. Four distinct stages of storm evolution occurred during the following four hours as the convective system crossed LSX's CWA. This section will focus on the four stages of storm evolution that occurred: discrete supercell (2247), quasi-linear convective system development (2327), formation of the bow echo and strong mesovortex (2353), an embedded HP supercell within the bow echo (0110)(Fig.4).

#### a. Discrete Supercells

A broken line of convection was located across central Missouri from Laclede County (southwest) to Gasconade County (northeast) at 2247 (Fig. 5). Three distinct supercells were of particular concern in the CWA of the Saint Louis Weather Forecast Office (WFO LSX). The northernmost storm was the strongest and most organized of the three, and was traveling along the west-east orientated warm frontal boundary. This storm exhibited High Precipitation (HP) characteristics, with multiple low-level inflow notches, capped by high reflectivities aloft along the southeastern flank of the storm. This area signified the storm's organized updraft region. The strongest low-level reflectivity gradients and adjacent highest reflectivity cores exhibiting magnitudes of 70 dBZ were observed at this location. One distinct mesocyclone was identified within the HP supercell (Mesovortex 1) and was characterized as being very deep and strong. This supercell shared many characteristics to the historic Missouri-Illinois HP hailstorm of 10 April 2001 that

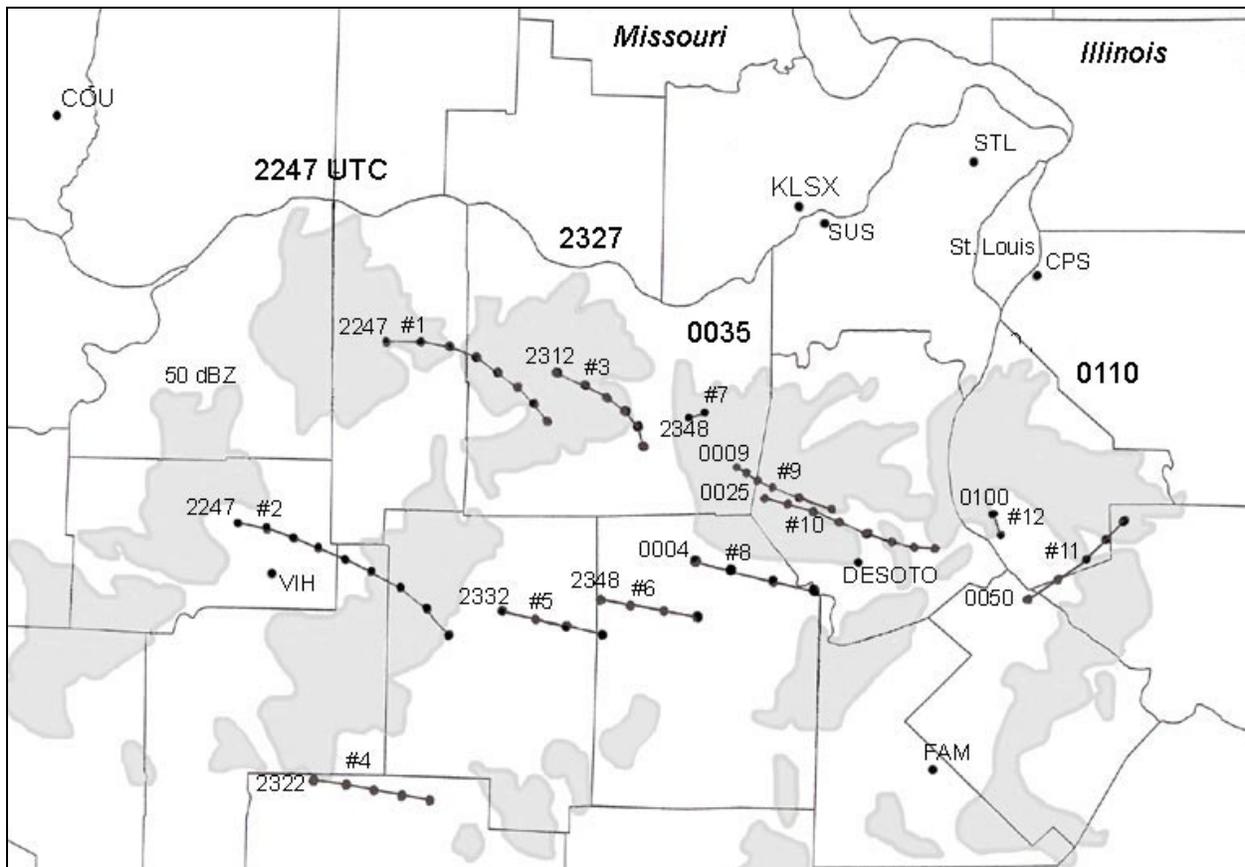


Figure 4. Radar composite of the 06 May 2003 Severe Storm System from KLSX radar. Solid contours are tracks of mesovortices. Times are in UTC.

Glass and Britt studied in 2002. The second storm immediately southwest of the HP storm exhibited classic supercell characteristics. A well defined pendant echo was evident along the southern right rear flank of the storm. Reflectivity values as high as 65 dBZ were noted in the vicinity of the pendant echo. A well defined mesocyclone identified within the region of the pendant echo was also characterized as being very deep and strong (Mesovortex 2). The third and final supercell wasn't as organized as the other two storms. The highest reflectivities were found on the western flank of the storm and a poorly defined pendant

echo was evident on the southeast flank. Unfortunately, range folded velocity data limited the interrogation of this storm, and therefore no distinct mesocyclone could be identified at 2247 for the southernmost storm.

#### *b. Quasi-linear Convective System Development*

The line of discrete supercells progressed eastward through 2327, and entered Franklin and Crawford counties. The HP storm exhibited excellent storm structure throughout the period. A spiraling pendant, or hook, on the southeastern flank of the storm was evident at 2327, along with a large core of 65 dBZ or greater in the center of the storm. Cyclic mesocyclone production was observed within the HP storm, similar to the 10 April 2001 hailstorm (Glass and Britt, 2002). Figure 6 shows the first mesovortex, C1, once the primary circulation, matured and was moving southwest toward the rear of the storm. The new mesocyclone (C2) formed to the southeast of C1 over a deep layer along the forward flank and ahead of the low-level gust front/reflectivity appendage. The other two supercells maintained their classic structures up until 2327. Shortly after 2327, the storms encountered convective towers within their inflow regions and significant storm interactions occurred. The supercells ultimately merged into a quasi-linear mode of convection and began to move eastward, slightly faster than the HP storm.

#### *c. Formation of the Bow Echo and Strong Mesovortex*

The demise of the northern HP storm occurred after 2353 (not shown), when new convective towers rapidly formed immediately down shear of the HP storm – northern convective line, cutting off the storm's inflow region. These towers gradually merged with the northern part of the larger convective line, suggesting an increased potential for intensification of the convective line's cold pool. After 0004, the convective line segment rapidly accelerated eastward across northern Washington and southern Jefferson Counties and the overall convective complex evolved into a classic bow echo structure (Fig. 7). 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. Mesovortex #2, became the second and last of two strong circulations with the northern HP storm before dissipating at 2343. Several other mesovortices rapidly formed after 2332

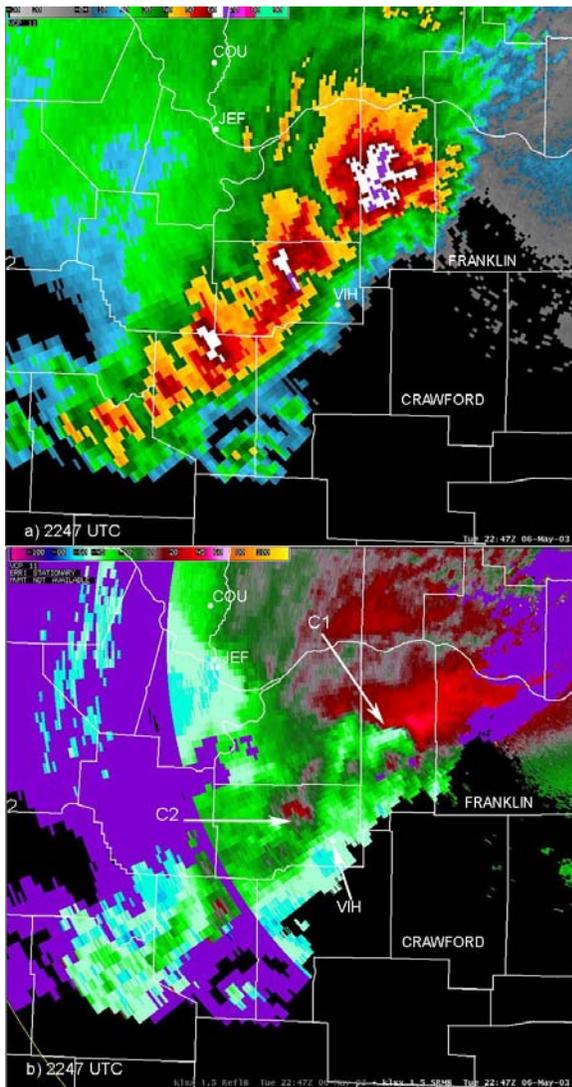


Figure 5. WSR-88D plan-view reflectivity (a) and storm-relative velocity (b) from KLSX radar at 2247 UTC, 06 May 2003. Mesovortices #1 and #2 are highlighted as C1 and C2 respectively.

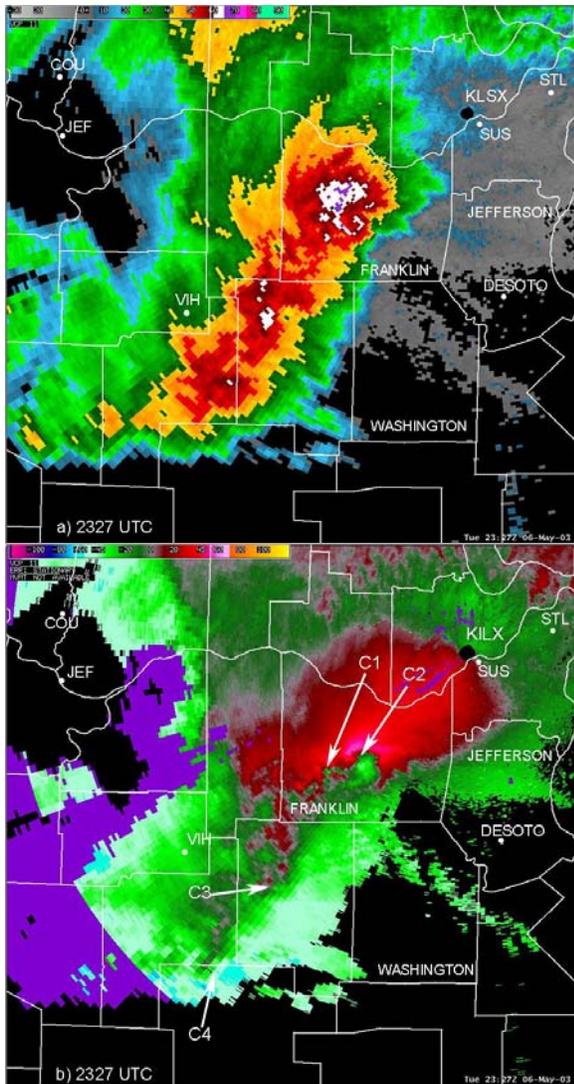


Figure 6. Same as Figure 5 except for 2327 UTC 06 May 2003.

along the central portion of the convective line south of the HP storm, and prior to the formation of strong convective towers downshear of the convective line. Embedded within the line, mesovortices #5 and #6 rapidly intensified into strong circulations and were responsible for considerable tree damage over parts of northeast Crawford and northwest Washington counties. These vortices moved in a direction nearly parallel to the convective line segment. Mesovortices 9 and 10 formed after 0004 along the eastern flank of the developing comma-head and bow echo (Fig. 7). Both mesovortices rapidly formed into very deep and strong circulations, but exhibited large core diameters. Finley et al. 2001 showed through numerical simulations that a strengthening cold pool can have a significant impact on the evolution

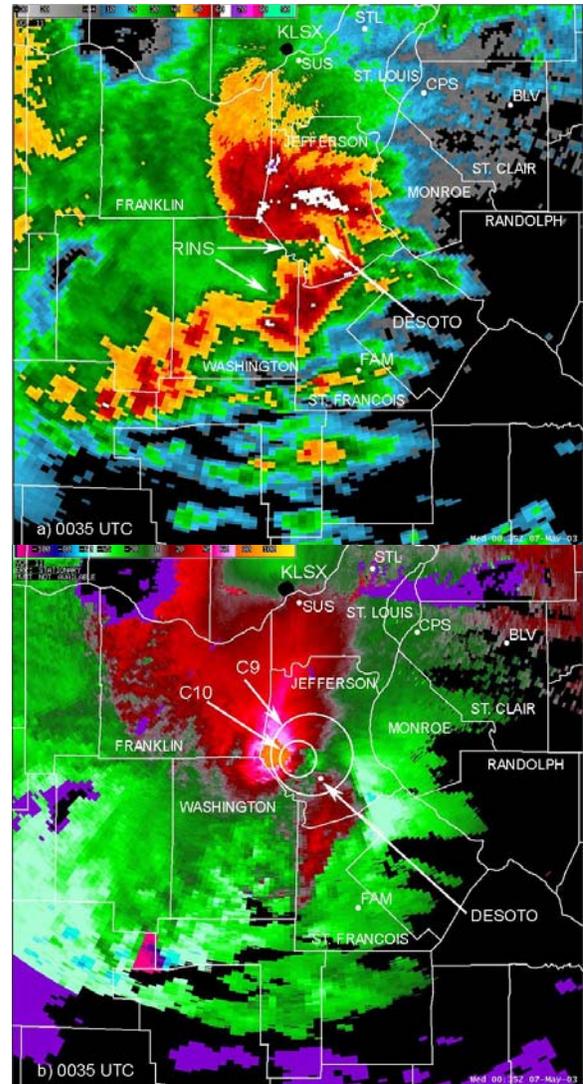


Figure 7. Same as Figure 5 except for 0035 UTC 07 May 2003.

of the vorticity field and subsequent mesovortex development. As the gust front accelerates, the vertical vorticity field nearly doubles along the gust front, due to increased tilting and convergence. This induced rotation on a larger scale. Further, details on the structure and evolution of these mesovortices is presented in Section 4.

#### d. Embedded HP Supercell within Bow Echo

After 0050, the system had evolved into the 'comma-echo' stage of bow echo evolution (Fujita 1978) with a prominent rotating comma-head at the northern end. At 0100 a distinct rear inflow notch (RIN) was observed along the trailing flank of the bow south of the comma-head, while a storm exhibiting HP supercell reflectivity

characteristics rapidly evolved near the apex of the bow as it entered far southwest Illinois. The “S” shaped reflectivity pattern included a well defined low-level inflow notch, capped by reflectivities greater than 50 dBZ aloft and a RIN along the trailing flank (Fig. 8). Striking was the presence of a very deep and strong mesocyclone which rapidly formed near the center of the “S” shaped pattern after 0100. The strongest rotational velocities ( $> 25 \text{ m s}^{-1}$ ) were noted between 3.0 and 7.0 km, while the core diameter was 4 km. An area of extensive wind damage (F0 through lower end F1) approximately 4 km wide and 8 km long was well correlated with the path of the strong mesocyclone over southern Monroe County Illinois. One tornado, (F1) having a damage path of 5.5 km, occurred within the central part of the larger damage swath. Numerous farm buildings, other structures and trees were damaged by the straight line wind and tornado. At 0120, a second tornado (F1 damage) briefly touched down 5.0 km southeast of the community of Redbud in western Randolph County. Additional tree damage occurred 0.5 km south of this tornado track. The HP storm weakened and became part of the larger bow echo system after 0120. Wind and tornadic damage ceased with this system after 0130.

#### 4. Structure of Mesovortices 9 and 10

Owing to the close proximity of the KLSX WSR-88D radar to the bow echo and advantageous viewing angles, the structure and evolution of mesovortices 9 and 10 were analyzed in detail (Fig. 9). Mesovortex 9 formed at 0009 UTC after the demise of the HP storm, near the northern end of the accelerated bowing convective line, and before the first wave of intense damaging winds across southern Jefferson County including the community of Desoto. The Vr trace shown in Figure 10 reveals a very deep and strong mesovortex with the strongest rotation identified between 3 and 5 km. However, during the very early stages, mesovortex 9 also exhibited a large core diameter (20 km), suggesting bookend vortex characteristics as defined by Weisman (1993). The cyclonic mesovortex intensified during the subsequent two volume scans (0014 and 0019), where it then continuously grew upscale. The stronger rotational velocities also descended with time beginning at 0014 and below 1 km AGL. The lowering of the mesovortex and increasing magnitudes of Vr in the lower part of the vortex after 0009 appeared to correlate well with the accelerated bowing segment and first wave of intense damage across the community of Desoto

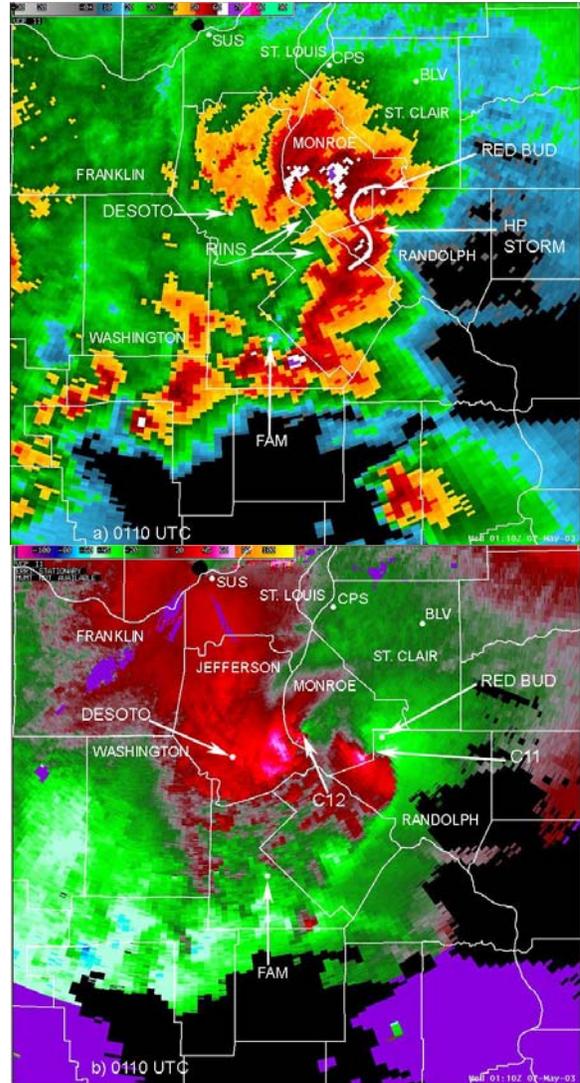


Figure 8. Same as Figure 5 except for 0110 UTC 07 May 2003.

and parts of southern Jefferson County. The overall reflectivity pattern at 0035 showed a classic bow-shaped reflectivity pattern with a well defined ‘RIN’ along the upshear flank of the bow and a classic comma-head near the northern part of the storm. The strongest degree of wind damage occurred from just north of the apex of the bow across the northern half of the RIN. Much of the tree and structural damage showed a divergent pattern, with the primary axis of intense damage laying east to east-southeast from 12 km west of Desoto through the community to 5 km east-southeast of town. Witnesses and an assessment of damage in the community and surrounding areas suggested that the first wave of severe winds ( $> 30 \text{ m s}^{-1}$ ) exceeded a period of fifteen minutes, with gusts up to  $50 \text{ m s}^{-1}$ . Figure

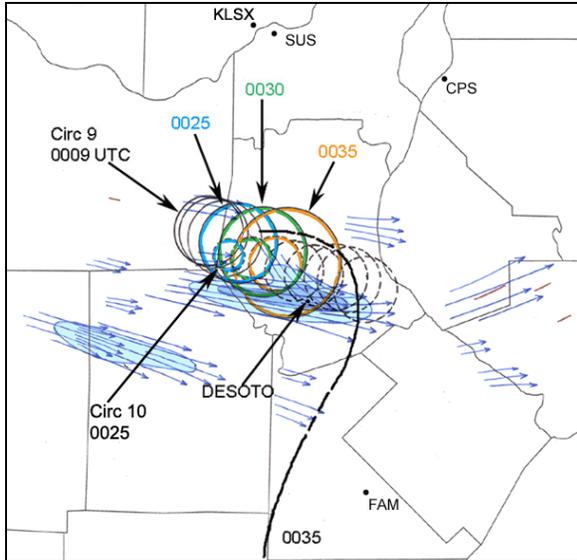


Figure 9. Composite of the evolution of Mesovortices 9 and 10 with damage swaths overlaid. Shaded areas of light(dark) blue represents estimated winds of 30(40+)  $m s^{-1}$  respectively. Red lines represent tornado tracks. Time is in UTC.

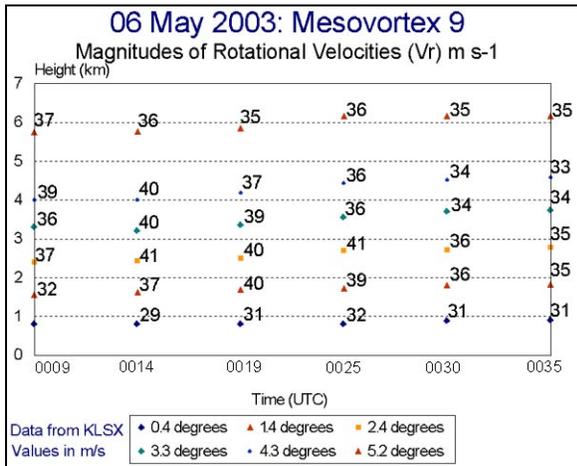


Figure 10. Time-height trace of rotational velocities for Mesovortex 9. Magnitudes of Vr are in  $m s^{-1}$ .

10 clearly shows the strongest wind gusts and greatest amount of damage occurred during, and just after the period of vortex lowering and highest magnitudes of Vr below 3 km AGL between 0014 and 0030. The lowering of mesovortex 9 and increased magnitudes of Vr is similar to observations noted by Atkins et al. (2004) and Przybylinski and Schmocker 1992 where a strong correlation was established between a lowering and intensification of a bookend vortex and the strength of the observed surface wind damage.

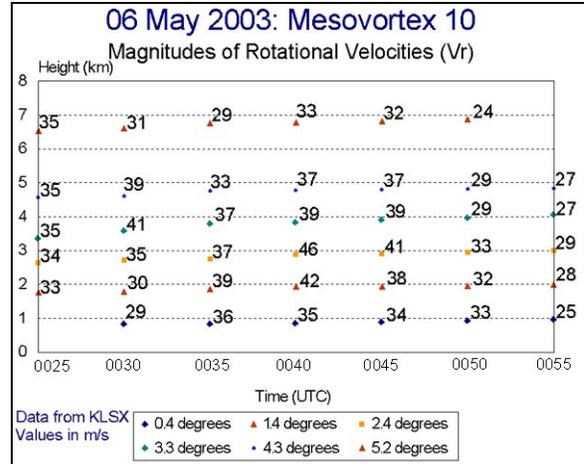


Figure 11. Same as Figure 10 except for Mesovortex 10.

The Vr trace shown in figure 10 suggests that monitoring the book-end vortex vertical extent and the lowering of the highest Vr magnitudes may be useful for identifying areas prone to high surface wind gusts for a period of time. Mesovortex 10 rapidly formed within the larger mesovortex C9 at 0025 over west-central Jefferson County (Fig. 9). Both C9 and C10 co-existed for a period of fifteen minutes. Similar to C9 this mesovortex was initially very deep with the strongest Vr identified between 3 and 7 km. The core diameter however was considerably smaller compared to C9's with an average overall diameter of 6 km compared to C9's diameter of 20 km. C10 initially showed an unbalanced vortex couplet below 3 km, with much stronger outbound velocities compared to the inbound component. Mesovortex 10 gradually became a balanced vortex ten minutes later (0035). Similar to C9, Vr magnitudes of mesovortex 10 lowered in altitude and intensified after 0025, with the highest magnitudes of Vr noted between 2 and 3.5 km at 0040. The second wave of damaging winds occurred around 0045 across DeSoto and correlated well with the strongest Vr preceding mesovortex passage over the town. The greatest degree of damaging winds occurred along the south and southwest periphery of this circulation, as the vortex traversed southeastward. Witnesses and damage assessment indicated the period of intense winds was brief (less than 5 minutes) compared to the first wave of damaging winds. This severe wind gust left large trees laying southeastward across the community. Similar to C9, mesovortex 10 grew upscale with time, but had a longer lifetime compared to C9. Mesovortex 10 weakened after

0050 and became cyclonic divergent in character.

## 5. Warning Decision Making

Forecasters at WFO LSX identified the potential for severe weather two days in advance and mentioned the possibility of thunderstorms over the southern half of the CWA on 6 May in the hazardous weather outlook. The product was updated at 1730 6 May 2003 to highlight the "possible outbreak of severe weather that afternoon and evening...with isolated tornadoes, damaging winds, and large hail up to the size of baseballs." The first tornado warning for Jefferson County was issued at 2336, based on the strong velocity signature of the HP supercell. Forecasters were concerned about the potential of tornadoes given the strong mesovortex, but "large hail and destructive straight line wind" wording was also included in the text of the warning given the HP structure. The tornado warning was extended at 0015 7 May 2003 as the HP storm slowed its eastward progression and began to collapse. It became apparent to warning forecasters around 0015 that severe winds were likely to occur across Jefferson County after identifying the strengthening bow echo radar signature and strong mesovortex near the northern end of the bow. A severe weather statement was issued at 0029 relaying the potential of "80 mph winds or greater" to affect Jefferson County with the town of Desoto highlighted as one of the cities in the direct path of the bow echo. Residents of the town of DeSoto were given nearly an hour of lead time (54 minutes) to take shelter as the storm began at 0030.

## 6. Summary

The 6 May 2003 damaging wind event was recorded as one of the most damaging severe weather events across the state of Missouri during period of 5–10 May 2003. Discrete classic and HP supercells gradually evolved into a classic bow echo structure across parts of east-central Missouri and far southwest Illinois. Once the HP supercell encountered strong convective towers in the inflow region, the storm collapsed, and the cold pool strengthened through precipitation loading and evaporative cooling. Two strong mesovortices (C9 and C10) appeared to play critical roles in the production of damaging winds for approximately thirty minutes. Eyewitness reports indicated that two distinct periods of severe wind occurred in Desoto Missouri, with the first period of severe wind lasting approximately fifteen minutes. Wind gusts estimates reaching  $50 \text{ m s}^{-1}$  were reported

with the first wave of damaging winds, while estimated gusts of  $35 \text{ m s}^{-1}$  were reported with the second shorter period of damaging winds. Mesovortex C9 and the rapid eastward movement of the bow echo appeared to be linked to the first wave of damaging winds, while C10 was responsible for the second period of wind damage. Both episodes of damaging winds resulted in significant structural and tree damage to the town of Desoto. Detailed radar analysis of C9 and C10 showed that the strongest Vr magnitudes initially existed at mid-levels (3–5 km) of the vortex. During the subsequent fifteen minutes, the traced revealed that the strongest Vr values lowered with time (below 3 km) as the mesovortex grew upscale.

The results in this study suggest that monitoring the rapid growth of tall convective towers downwind from an HP storm, formation of a developing solid line segment south of the HP storm and mesovortices near the apex and northern end of the bow are critical in the detection and severe weather warning process. Monitoring the structural evolution of the line-end mesovortices may be possible to determine the potential strength and period of strongest wind damage. This information would likely lead to improved warnings for damaging winds and tornadoes

## 7. Acknowledgements

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