A Detailed Analysis of a Long-Tracked Supercell

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1) Introduction

Starting early in the day on 12 March 2006, and continuing into the early morning hours of 13 March, a significant tornado outbreak occurred across the Midwest with tornadoes confirmed in Oklahoma, Missouri, Arkansas, and Illinois. Multiple waves of severe convection occurred with the first tornado reported at 1512 UTC in Jackson County, Missouri near Kansas City, and the last reported at 0800 UTC in Laclede County, Missouri. In between, Storm Prediction Center (SPC) local storm reports included 140 tornadoes, numerous occurrences of baseball size hail, and a measured wind gust of 107 kt. Figure 1 shows the local storm reports from SPC. The vast majority of these reports were associated with waves of discrete supercell thunderstorms. This paper will detail a small portion of a long-lived storm that initiated over southeastern Oklahoma, became supercellular a short time later, and subsequently exhibited cyclic mesocyclogenesis across Missouri, Illinois, and Indiana. This storm demonstrated several distinct periods during which multiple tornadoes were reported separated by others with little or no severe activity.

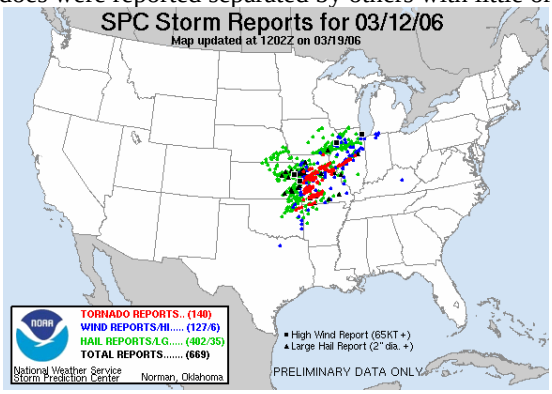

Fig.1. Preliminary local storm reports from the 12 March 2006 event. Image Courtesy of SPC.

2) Synoptic Overview

As with many past significant outbreak days, the 12 March 2006 event occurred within a "synoptically evident" pattern (Doswell 1993). The 250-mb chart from 1200 UTC 12 March 2006 (Fig. 2) showed a deep trough in place over the western half of the United States, while a ridge covered the eastern half of the country. A 100 kt jet stream extended from Baja California to eastern Canada. Intermittent jet streaks were analyzed from central New Mexico through north central Kansas into southern Nebraska. A large area of diffluence was positioned over the central and southern Plains, expanding into the southern Great Lakes region.

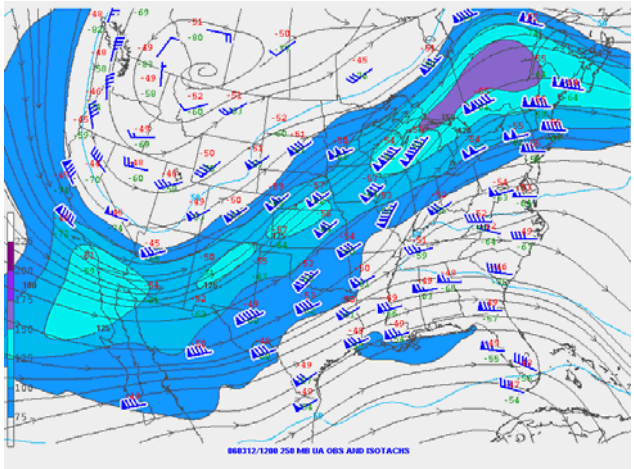

Fig. 2. 250-mb chart valid at 12 UTC 12 March 2006. Upper air station data and wind barbs are plotted using standard convention. Black lines are streamlines and the shading represents objectively analyzed wind magnitudes greater than 75 kt.

At 500-mb, there was a similar reflection the large trough that stretched from the eastern Pacific to the Rockies. An imbedded shortwave was present over Colorado and New Mexico. Weak ridging covered the east coast of the United States, extending into eastern Canada. A 60-80 kt southwesterly jet stretched from the base of the trough in southern Arizona to northern Michigan. Additionally, hand analyses identify a shortwave over Arizona and southwest Utah in proximity to the 115 kt jet core in the base of the trough over southern Arizona. This short-wave likely played a significant role by providing weak large-scale ascent over the outbreak area.

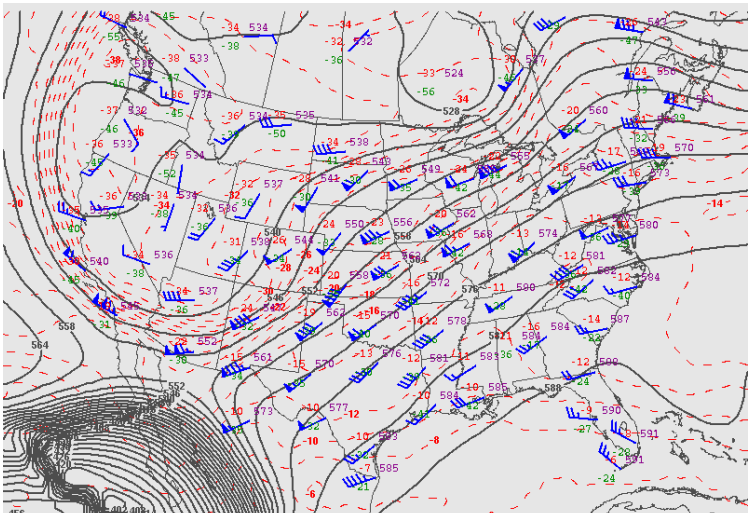

Fig. 3. 500-mb chart valid at 12 UTC 12 March 2006. Upper air station data and wind barbs are plotted using standard convention. Geopotential heights and temperatures are plotted using solid black lines and dashed red lines, respectively.

At 850-mb, an area of lower heights was situated over Utah and Colorado (Fig. 4). Ahead of this low, a 30-40 kt southwesterly low-level jet was transporting warm moist air from the southern Plains towards the Ohio River Valley. Dew points in this area were greater than 8°C. At the same time, an axis of 12°-14° C dew points stretched from central Arkansas to extreme southeastern Kansas. In addition, a large area of warm-air advection covered the central Plains, particularly Oklahoma, Kansas, Missouri, and Nebraska.

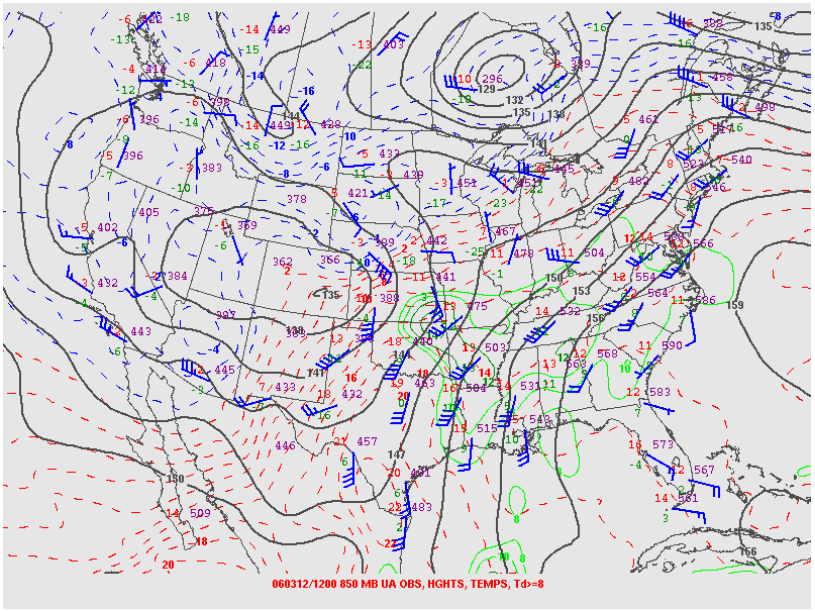

Fig. 4. 850-mb chart valid at 12 UTC 12 March 2006. Upper air station data and wind barbs are plotted using standard convention. Geopotential heights and temperatures are plotted using solid black lines and dashed red lines, respectively. Solid green lines represent dew points greater than or equal to 8° Celsius.

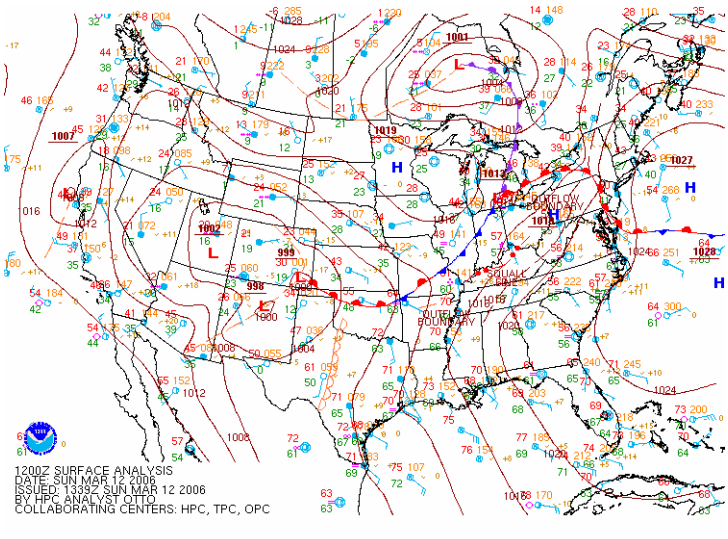

Fig. 5. Hydrological Prediction Center surface chart valid at 12 UTC 12 March 2006. Surface station data, fronts and wind barbs are plotted using standard convention. Isobars are plotted using solid black lines.

At the surface, a frontal boundary extended southwesterly from the synoptic-scale low pressure center located in southern Canada through the great lakes becoming a weak stationary boundary across southern Illinois (Fig 5). This boundary connected with a warm front extending from a low center developing on the leeward side of the Rockies. The portion of the boundary that extends across southern Missouri and into Illinois and Indiana would lift northward throughout the day and evening, serving as a focus for the severe convection. Additionally, a dry line was emerging from western Oklahoma into west-central Texas. Temperatures in the warm sector, ahead of the dry line, were in the low 70s F, while dew points were in the mid 60s F.

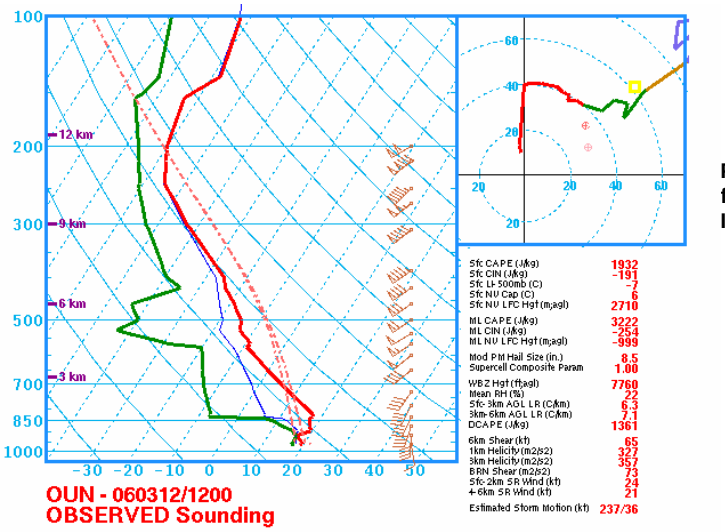

Fig. 6. 12 UTC 12 March 2006 sounding from Norman, Oklahoma (KOUN). Image courtesy of SPC.

The 1200 UTC sounding from Norman, Oklahoma (KOUN) was chosen as a representative sample of the preconvective environment. At this time, KOUN was located south of the boundary, within the preconvective warm sector, and several hundred kilometers from convective initiation and tornadic development. It showed 3222 J kg^{-1} of mixed-layer convective available potential energy (MLCAPE) with -191 J kg^{-1} of mixed-layer convective inhibition (MLCIN; Fig. 6). A very shallow layer of moist air was in place from near the surface to about 900 mb. An elevated mixed layer was present between approximately 825 mb and 575 mb associated with lapse rates near 7°C km^{-1}. The sounding was very dry above 850 mb. The wind profile indicated winds veering and increasing speed with height. The 0-6 km shear was 65 kt and the 0-1 km storm relative helicity (SRH) was 327 $m^2 s^{-2}$. The parameters were clearly in place to indicate the strong potential for rotating supercell development. Additionally, the "sickle shape" of the hodograph that has been shown by Miller (2006) to accompany significant outbreak tornado days was also present on 12 March 2006.

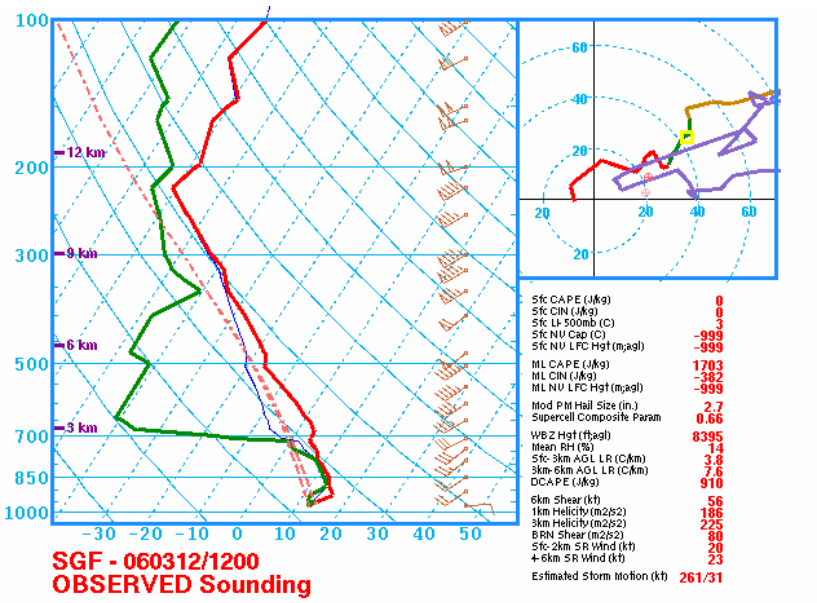

Fig. 7. 12 UTC 12 March 2006 sounding from Springfield, Missouri (KSGF). Image courtesy of SPC.

The Springfield, Missouri (KSGF) 1200 UTC sounding occurred north of the boundary, as evidenced by the presence of a shallow frontal inversion and weak easterly winds near the surface (Fig. 7). There was an abundant amount of low-level moisture that extended from the surface to near 750mb. A large, deep, dry layer was in place above 700 mb. MLCAPE of 1703 J kg^{-1} and MLCIN of -382 J kg^{-1} were present. There was a slight veering of the wind near the surface, with a relatively unidirectional southwesterly flow above 900mb. Wind speeds were increasing significantly with height. The 0-6 km shear value was 56 kt, while the 0-1 km and 0-3 km SRH values were 186 and 225 m^2 s^{-2} respectively.

At 1200 UTC, the area of positive MLCAPE extended from central Texas through central Oklahoma, northeastward into the Ohio River Valley (not shown). Lifted condensation level (LCL) heights across this area were generally less than 1000 m AGL, with localized heights of around 600 m over central Missouri and central Indiana. The lifted index (LI) values throughout central Oklahoma and western Arkansas were -4° to -6°C. Deep-layer shear values were exceeded 50 kt north of a line that extended from Oklahoma, through Missouri into Illinois. In addition, 0-1 km SRH values exceeded 300 m^2 s^{-2} across all of north central Texas, Oklahoma, Arkansas, Kansas and parts of Nebraska. Another maximum of SRH values was positioned over northern Tennessee, Kentucky, and parts of Eastern Ohio. The high values of CAPE, along with low LCL heights, low LIs, strong shear, and high SRH indicated the threat for a large convective outbreak, capable of producing tornadic supercells. In addition, wet bulb zero heights from 9000-10000 ft AGL and low freezing levels indicated the threat for large hail.

Through the afternoon hours, the low over eastern Colorado continued to deepen (not shown) and move eastward into western Kansas. The warm front associated with the system strengthened and lifted northward, and was positioned from northern Kansas across southern Missouri and Illinois and into Indiana. A cold front developed to the southwest of the low, and was located over extreme western Kansas, southeastern Colorado, and central New Mexico. The dryline had progressed along the warm front and was now situated over eastern Kansas, central Oklahoma, and central Texas. Temperatures in the warm sector had increased to the upper 70s and lower 80s F, while dew points remained in the middle 60s. In addition, a large area of surface based convective available potential energy (SBCAPE) extended from eastern Texas, to Oklahoma, Arkansas, and Southern Missouri. The highest values of 2000-3000 J kg^{-1} were located near Springfield, Missouri. Daytime surface heating, the weak large scale ascent associated with the approaching short wave trough, and the passing of the warm front weakened the convective inhibition that had been present over northern Oklahoma, southern Missouri and eastern Kansas. LI values from -4° to -8°C were in place over eastern Oklahoma, southeastern Kansas, northern Arkansas and southern Missouri. LCL heights generally measured less than 1000 m. Values as low as 600-800 m AGL were observed over eastern Oklahoma, Kansas, Missouri and southern Illinois. Deep-layer shear values

exceeding 50 kt remained relatively unchanged over most of Oklahoma, Missouri, and Kansas, while values exceeding 90 kt could be found over central Nebraska, Kansas, and southwest Iowa. 0-1 km SRH values were in excess of 200 $m^2 s^{-2}$ over the southern plains. The highest values (greater than 500 $m^2 s^{-2}$) could be found in an area extending from northwestern Missouri to extreme southeastern Nebraska.

Given these factors, the most favorable area for convective development was in the warm sector, ahead of the advancing dry line. The CAPE, LCL, shear, and SRH values indicated the likelihood of severe convection development, capable of producing large hail and tornadoes. Convective initiation began as discrete supercells along the Kansas / Oklahoma border ahead of the dryline between 17 and 18 UTC. Over the next several hours, these cells intensified, becoming supercells that resulted in numerous reports of damaging winds and large hail. As the first wave of supercells moved across Missouri, additional convection regenerated along the intersection of the dry line and warm front near Kansas City, Missouri after 2200 UTC.

3) Radar Analysis

At 12 UTC, a cluster of elevated supercells was already ongoing over central Kansas, located well north of the fontal boundary. There was also a quasi-linear mesoscale convective system with trailing stratiform precipitation extending from southern Missouri along the Ohio River into western Pennsylvania, which had evolved and moved southeastward over the previous 6-10 hours (Fig. 8).

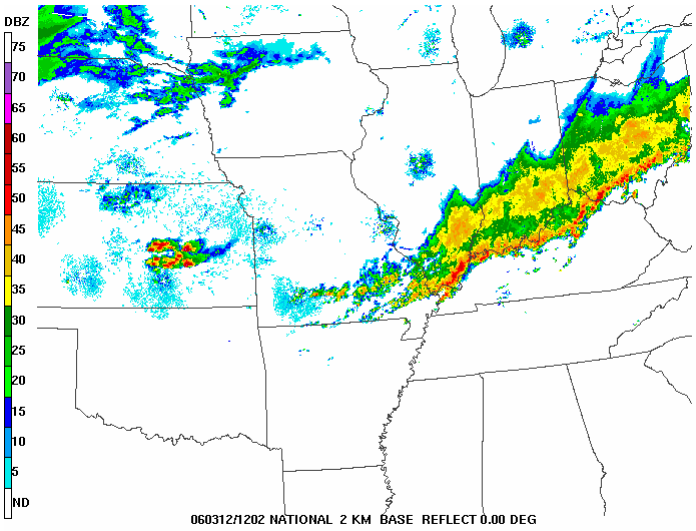

Fig. 8. Regional radar image depicting the ongoing convection at 1202 UTC 12 March 2006. Image is courtesy of SPC.

Over the next several hours, the existing cluster of elevated thunderstorms in Kansas moved toward the northeast and new convective cells continued to develop over south-central Kansas and north-central Oklahoma. The first echo associated with the long-lived supercell discussed in this paper occurred over Pawnee County, Oklahoma at 1735 UTC (Fig. 9).

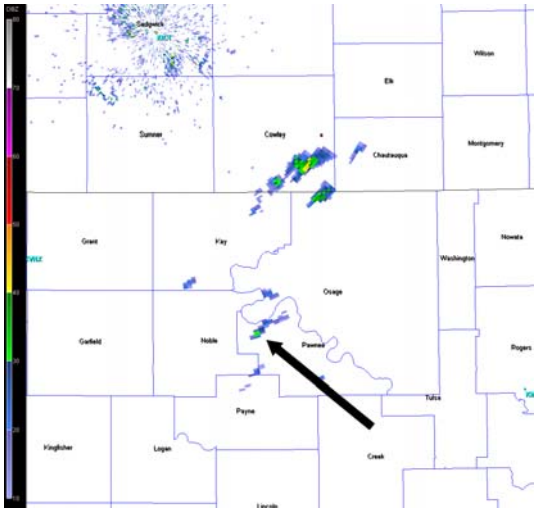

Fig. 9. 0.5 degree reflectivity plan view valid at 1735 UTC. The initiation of the cell that would become the long-lived supercell is highlighted with the black arrow.

Over the next thirty minutes, the cell intensified and displayed reflectivity structures typically associated with a supercell by 1805 UTC. Although there was weak rotation present during this period of intensification, the first detectable mesoscyclone was noted at 1805 UTC. The maximum rotation was detected at the 1.3° elevation angle (2 km AGL) at a range of 93 km from the KICT WSR-88D (Fig. 10). The circulation extended to a height of approximately 6 km AGL. Its strongest rotational velocities at this time were at 4.5 km AGL (39.5 kt). At this range, the circulation could be classified as a moderate mesocyclone (Andra 1997). Weak convergence was detected at the lowest elevation angle and strong divergence was detected above the circulation.

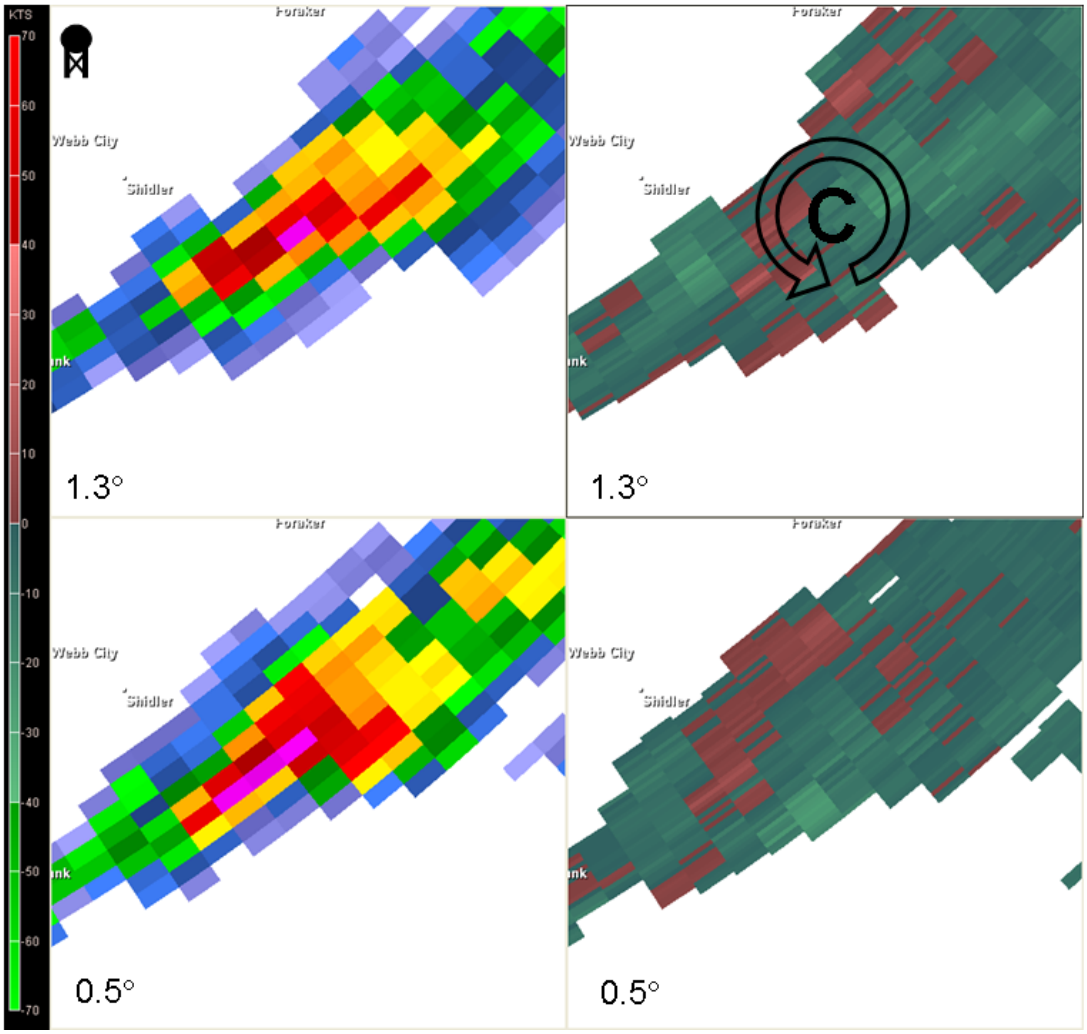

Fig. 10. 0.5 and 1.3 degree reflectivity and storm relative velocity plan views valid at 1805 UTC. The circular arrow represents the location of the cyclonic mesocyclone. The radar location is off to the northwest in all images.

From this point on, the storm remained intense and continued to track across Missouri and Illinois into northern Indiana before dissipating in Southern Michigan. From inception until demise, the storm had a track-length of over 1100 km and lasted more than 14 hours (Fig. 11).

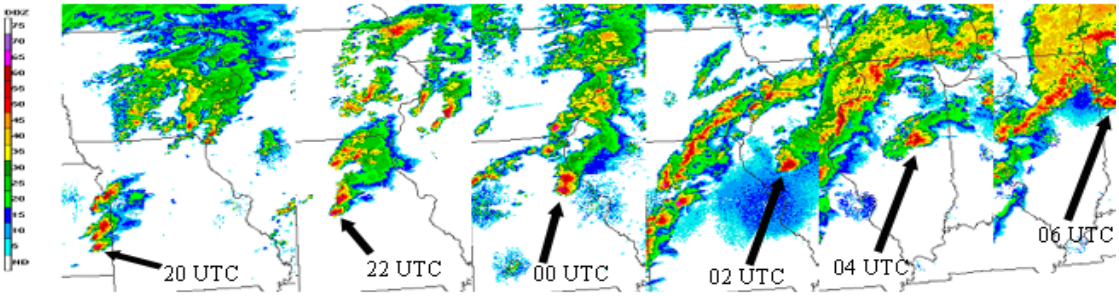

Fig. 11. Regional radar images depicting the propagation of the supercell from 20 UTC 12 March – 06 UTC 13 March 2006. In each image, the long-lived supercell is highlighted by the black arrow. Images are courtesy of SPC.

The cyclic supercell experienced several distinct tornadic phases throughout its lifecycle. Although more research is needed, it appears that tornadic periods followed instances of storm interactions.

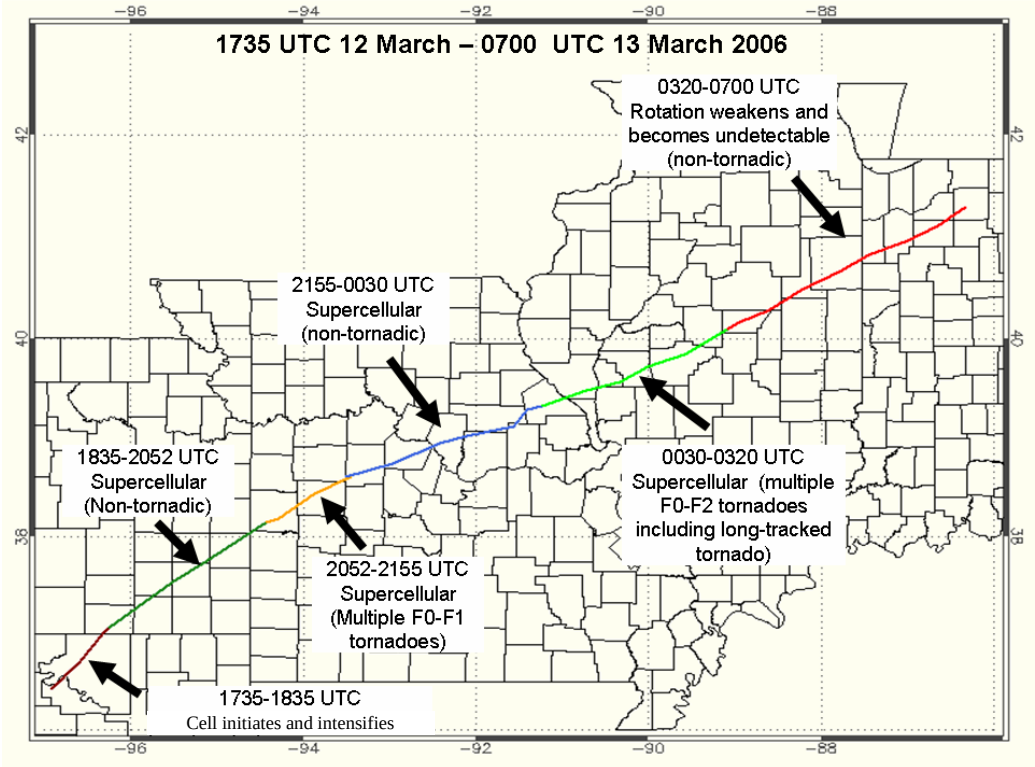

Fig. 12. The subjectively analyzed storm track is plotted from its inception until its dissipation. Each distinct phase is indicated with a different color line segment.

4) Circulation Characteristics

4.1) Broad overview

Figure 12 shows the track of the long-lived storm as determined by examining the level II radar data from the WSR-88Ds at Withita, Kansas (KICT), Springfield, Missouri (KSGF), Kansas City, Missouri (KEAX), Saint Charles, Missouri (KLSX), Springfield, Illinois (KILX), and Chicago, Illinois (KLOT). Multiple mesocyclone cores were observed through much of the supercell's lifetime. As noted previously, there were several distinct periods during which the storm was cyclically tornadic. The first occurred as the storm entered Missouri and is indicated on Fig. 12 with an orange line. The second tornadic period occurred as the main supercell merged with another storm over Pike, County, Missouri. This phase resulted in numerous short-lived tornadoes as well as a long-tracked tornado with a path length of 106 km. This second phase is indicated on Fig. 12 with the lime green line segment.

Given the vast quantity of data, a course time-series of rotational velocity magnitudes was constructed. This was done by examining *every other* radar volume scan starting at 1735 UTC until approximately 0700 UTC. Each of the selected volume scans was examined thoroughly for the presence of a mesocyclone. Additionally, during times when multiple circulations were detected, the intervening volume scans were examined as well in order to determine which mesocyclone was new and which was the preexisting circulation. The resulting dataset amounts to a course analysis of the dominant mesocyclone present during the storm's life span. Once the rotational velocities were subjectively determined, the data were analyzed and plotted using the International Data Language (IDL) software package. Figure 13 shows the resulting data plotted for the 2100 UTC 12 March to 0550 UTC 13 March 2006 period. This plot shows several distinct instances of mesocyclone intensification. The first occurred after 2100 UTC and was associated with a tornadoes reported across Henry, Pettis, and Benton Counties in Missouri. Another period of strengthening occurred near 2330 UTC and was associated with tornadoes reported in Cooper, County in Missouri. Just after 0100 UTC, mesocyclone rapidly intensified and deepened, coincident with the development of the long-tracked tornado that passed near Springfield, Illinois. After 0300 UTC, the magnitude of the rotation quickly decreased and no additional tornadoes were reported.

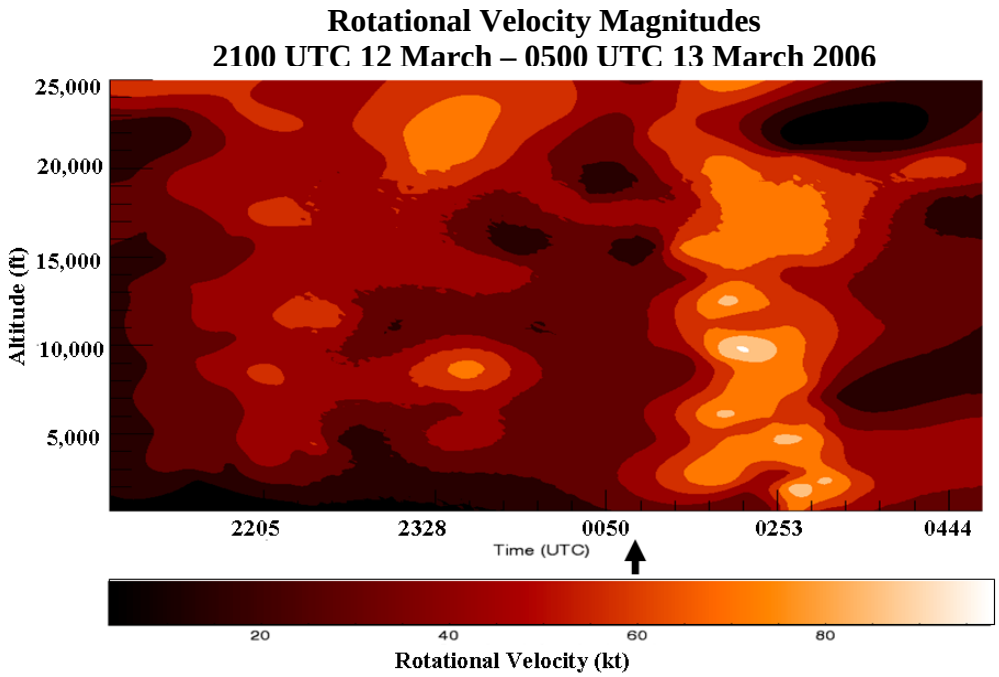

Fig. 13. Rotational velocity magnitudes for the dominant circulation between 2100 UTC 12 March until 0500 UTC 13 March 2006. The black arrow indicates the start of the long tracked (66 mi; 80 min) F2 tornado that developed along the Pike / Greene County border en route to Springfield, Illinois.

4.2) Pike County, Missouri

The following discussion will detail the supercell as it began to merge with another storm over Pike County, Missouri. During the beginning of the merger process, there were at least five detectable cyclonic circulations and three confirmed tornadoes associated with the merging cells over Pike County. Figure 14 shows the subjectively plotted circulation tracks across Pike County, Missouri.

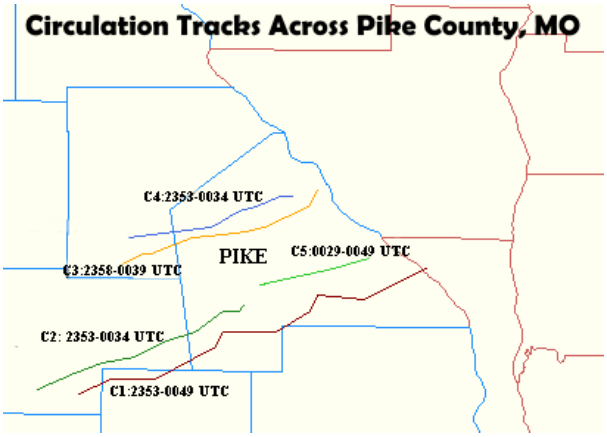

Fig. 14. Circulation tracks for the vortices associated with the merging supercells as they moved into and through Pike County, Missouri.

Figure 15 shows the supercells at 2353 UTC as they began the merger process and entered Pike County. The colored lines indicate the location and paths of the circulations plotted in Fig. 14. The short, white lines highlighted with the arrow represent the tornado paths as determined from the damage analysis conducted by the Saint Louis National Weather Service Forecast Office (KLSX).

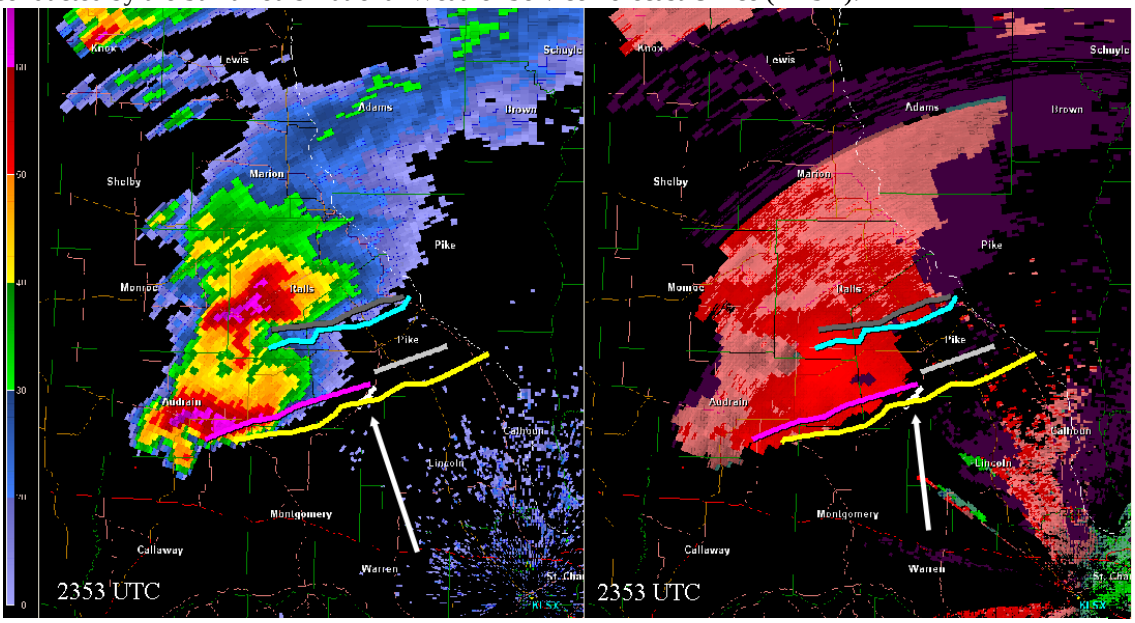

Fig. 15. 0.5° reflectivity and storm-relative velocity plan views valid at 2353 UTC. The colored lines represent the circulation tracks as plotted in Fig. 14. The arrow highlights the paths of the short-lived tornadoes (white lines) as determined by the staff at KLSX.

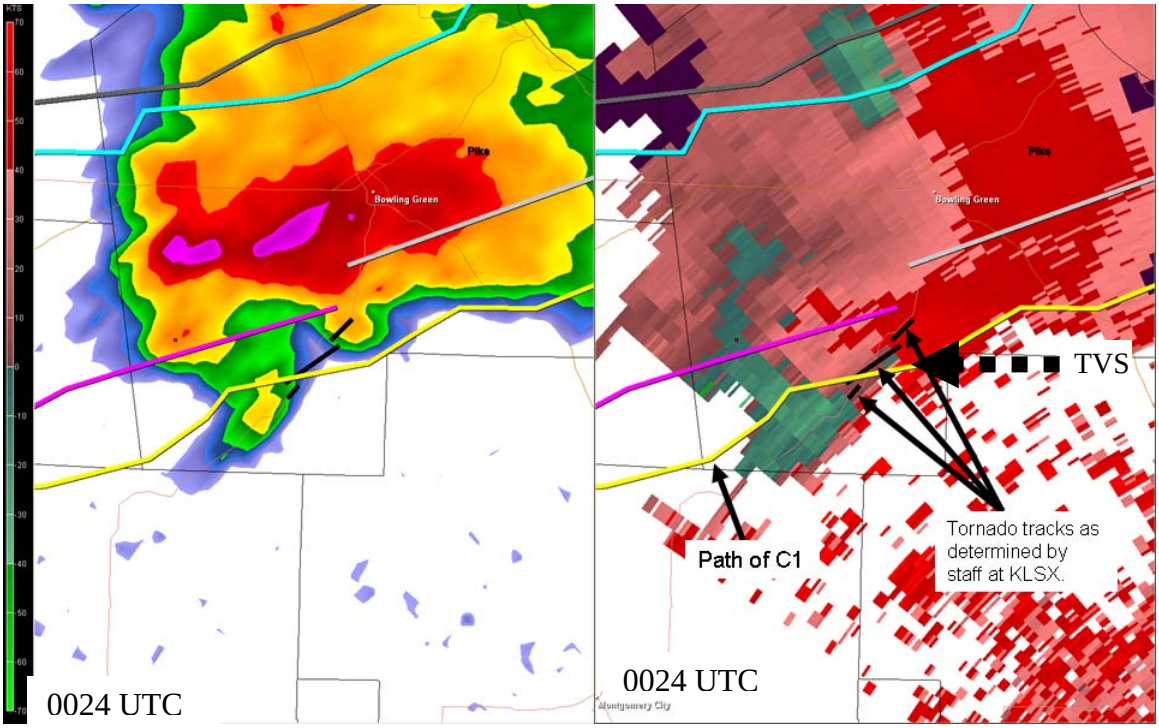

Fig. 16. 0.5° reflectivity and storm-relative velocity plan views valid at 0024 UTC. The colored lines represent the circulation tracks as plotted in Fig. 14. The grouping of three solid arrows highlights the paths of the short-lived tornadoes (black lines) as determined by the staff at KLSX. The thick dashed arrow highlights the embedded tornado vortex signature (TVS) signature.

Figures 15 and 16 show the supercells and tracks of their attendant circulations as they move into Pike County, Missouri and begin the merger process. Close inspection of radar data valid at 0024 UTC (Fig. 16; just after tornado touchdown) shows the presence of multiple mesocyclone circulations as well as a TVS signature (dashed arrow). The TVS signature appears to be associated with the larger scale vortex C1. Additionally, Fig.16 shows that the time and location of the observed tornadoes coincide closely with the location of C1, the southern-most mesocyclone associated with the long-lived supercell. It is the authors' speculation that tornadogenesis may have been triggered by the updraft of the southern storm interacting with the rear-flank downdraft of the northern storm.

Time-series plots of rotational velocity magnitudes for each of the dominant storm-scale circulations were examined in conjunction with the radar and post-event damage assessment data in order to diagnose any differences between the circulation(s) that resulted in tornadoes and those that did not. Figures 15 and 16 clearly show that C1 (yellow) and C2 (pink) were associated with the southern cell and C3 (light blue) and C4 (dark grey) were the dominant circulations associated with the northern cell. Figure 17 shows the V_r trace for C1 between 2353 and 0049 UTC. C1 was initially detected at 2353 UTC with its maximum rotation between 10 and 15 K feet AGL. Over the next 30 minutes, C1 increased in magnitude and depth reaching maxima in both at 0019 UTC, the time of tornado occurrence over Pike County, Missouri. After 0025 UTC, the mesocyclone's intensity rapidly decreased and tornado damage was no longer reported after approximately 0034 UTC. Similar to C1, C2 was also first detected at mid levels, with subsequent low-level rotation being detected a short time later (Fig. 18). In contrast to C1, however, the low-level rotation associated with C2 was not intense, and no tornado reports are noted along the path of C2. The V_r traces for C3 and C4 are shown in Figs. 19 and 20 respectively. In contrast to C1, the maximum rotation associated with C3 and C4 did not exhibit significant intensification at lower levels (<7 K ft AGL), rather the circulation remained strongest aloft, never developing an intense low-level mesocyclone. Therefore, analysis concludes that C1 was most likely responsible for the three tornadoes reported across central Pike County, Missouri.

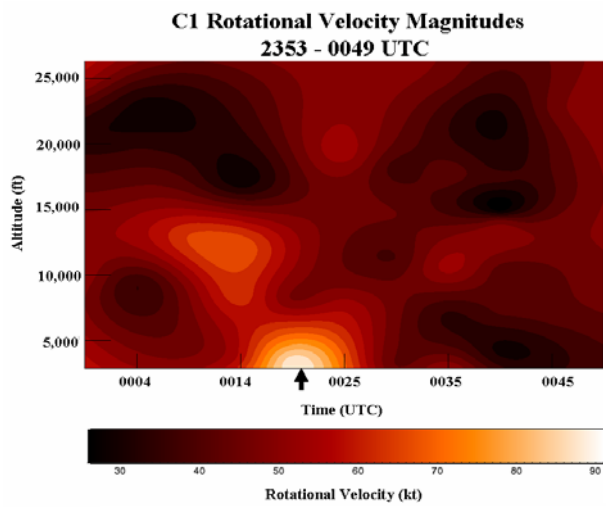

Figure 17: Subjectively analyzed rotational velocities for C1 (see Fig. 14) associated with the merging supercells as they moved into and through Pike County, Missouri.

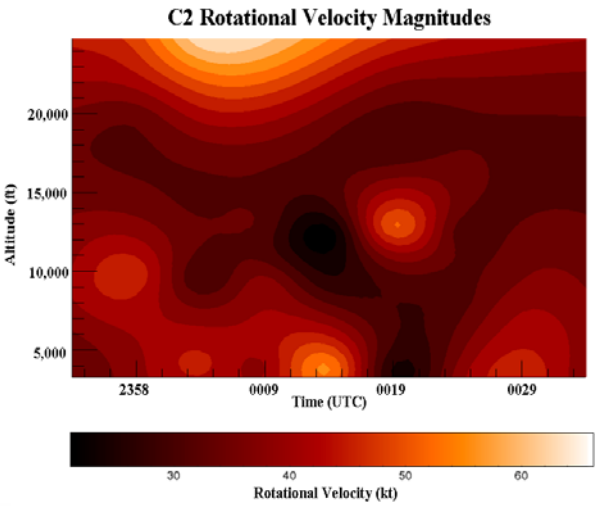

Figure 18: Objectively analyzed rotational velocities for C2 (see Fig. 14) associated with the merging supercells as they moved into and through Pike County, Missouri.

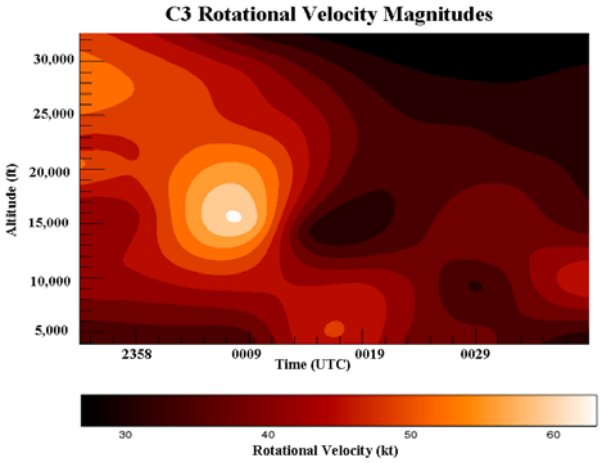

Figure 19: Subjectively analyzed rotational velocities for C3 (see Fig. 14) associated with the merging supercells as they moved into and through Pike County, Missouri.

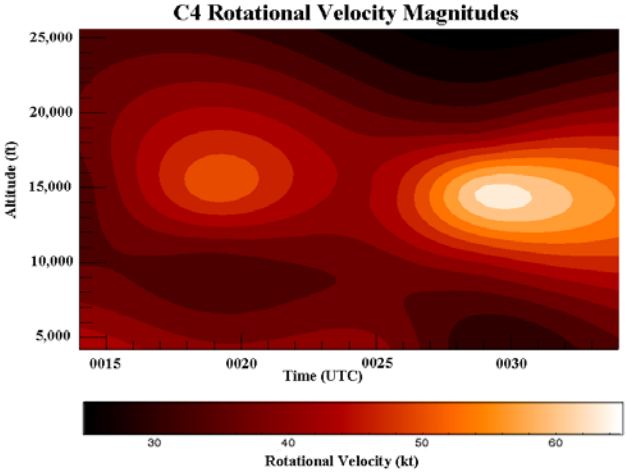

Figure 20: Objectively analyzed rotational velocities for C4 (see Fig. 14) associated with the merging supercells as they moved into and through Pike County, Missouri.

5) Summary

A synoptically evident severe weather outbreak occurred during the day of 12 March 2006 and extended into the overnight hours of 13 March 2006. Discrete supercells developed in a moderately unstable, strongly deep-sheared environment ahead of an advancing low pressure system and attendant dryline. Several of these supercells were long-lived (life time > 4h), with one in particular having a duration > 11 h and a path length > 1100 km. This long-tracked supercell experienced multiple distinct tornadic and non-tornadic phases during its life time. A rough analysis performed on every other volume scan reveals several periods during which the dominant mesocyclone intensified and deepened, each coinciding with tornado reports.

A detailed analysis of level II radar data was performed for the time period during which the supercell was moving through Pike County, Missouri. This particular period was chosen due to the proximity of the storms to the WSR-88D in Saint Charles, Missouri, as well as the existence of a comprehensive post-event damage analysis. In addition, this period was associated with the onset of the long-lived supercells most prolific tornadic phase, occurring as the long-lived supercell began the merging with another storm. During the onset of the merger process, there were multiple mesocyclones evident in the radar data. C1 and C2 were associated with the southern supercell, while C3 and C4 were associated with the northern cell. In addition, a TVS was evident associated with C1. V_r traces were conducted for the dominant circulations during the period when the two storms were beginning to merge as they entered and traversed Pike County, Missouri. Three of the circulations (C1, C2, and C3) all developed some rotation at low-levels, while C4 maintained its strongest rotation aloft. Of the three that produced some detectable low-level rotation, C1 showed rapid intensification at low-levels and appeared to be responsible for the three short-lived tornadoes over Pike County, Missouri. Future research will include a detailed analysis of the storm through its entire life span in an attempt to determine the role of storm interactions in the transition from non-tornadic to tornadic phases.

6) References

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