

THE JULY 13, 2004 TORNADO EVENT: ANALYSIS OF TORNADOGENESIS IN A HIGHLY UNSTABLE ENVIRONMENT.

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1. INTRODUCTION

On the afternoon of 13 July 2004, an F4 tornado rapidly developed, and completely destroyed a manufacturing plant with 140 people inside. Miraculously, no one was injured. A warning was issued, the people quickly took action, and many lives were saved. All 140 employees were able to take cover in one of their three storm shelters. A unique set of environmental circumstances that day allowed for rapid tornadogenesis. It is hypothesized that the relative location of the tornadic storm to a storm just previous, allowed for the ingestion of enhanced storm-scale horizontal vorticity that allowed it to produce a violent tornado.

The highly unstable atmosphere (Convective Available Potential Energy [CAPE] > 7000 J kg⁻¹) that day allowed for maximum vertical stretching of the enhanced vorticity. This aided the extremely rapid evolution speed with which a shower developed into a supercell with an F4 tornado (< 30 minutes). Intersecting boundaries, the high levels of instability, and the environmental and storm-scale storm relative helicity were critical players in producing the resultant tornado.

This study will examine the process of tornadogenesis that occurred that day and the overall evolution of convection. The purpose is to gain a better understanding of the storm-scale processes and dynamics involved.

2. BACKGROUND

The process of tornadogenesis has been studied extensively over recent years, most notably by the Verifications of the Origin of Rotation in Tornadoes Experiment (VORTEX) (Rasmussen et al. 1994). VORTEX-95 found that about 70% of F2 or greater tornadoes observed were associated with boundaries (Markowski et al. 1998a).

VORTEX-95 also suggested that tornadogenesis is not accomplished from a mixture of storm-generated and ambient horizontal vorticity alone. An additional source of vertical vorticity is necessary. Storms that move along a boundary rather than directly across may have a better chance of processing sufficiently unstable air and being maintained for a prolonged period, all the while ingesting enhanced horizontal vorticity (Markowski et al. 1998a).

Horizontal vorticity can be produced along baroclinic boundaries such as along an outflow boundary, especially along the cool side of the outflow boundary. Low-level horizontal vorticity along this boundary can easily be tilted or stretched when coming in contact with a strong updraft that occurs in an environment with ample CAPE and strong deep shear (Markowski et al. 1998a). Forced uplift along a front will generate a low-level mesocyclone along the rear-flank gust front and will rapidly exceed the vorticity of the mid level rotation (Wakimoto and Atkins 1996).

A recent study that analyzed over 5000 mesocyclones across the United States found that only around 25% of mesocyclones actually produce tornadoes (Trapp et al. 2005). According to Atkins et al. 1999, when a supercell interacts with an outflow boundary from nearby convection, it is more likely to produce a tornado. It is this theory that is most closely supportive of what we expect helped create the F4 tornado on 13 July 2004.

3. SYNOPTIC ENVIRONMENT

During the morning of 13 July 2004, there was a deepening synoptic trough over the upper Midwest. An associated surface low was over northern Ontario, with a cold front extending through the upper Midwest into the central Plains at 12 UTC. Strong instability was evident downstream from these features into the Midwest, including Illinois.

3.1 Upper Air

Analysis of the 250 hPa level at 12 UTC 13 July and the 00 UTC 14 July 2004 showed a 100kt jet across the North Dakota and Minnesota, diving south into Iowa and northern Illinois (Figures 1 and 2). This positioning was favorable for upward vertical motions associated with ageostrophic responses to jet maxima winds.

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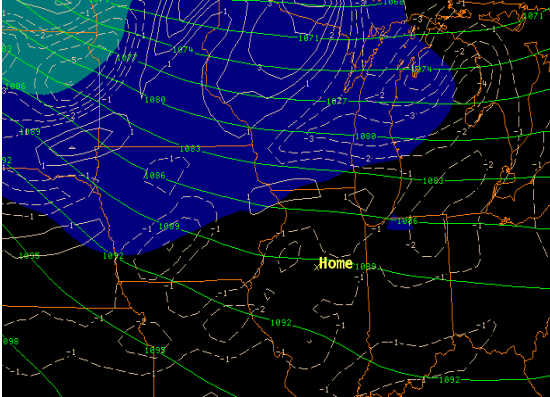


Figure 1. 12 UTC 13 Jul 2004 MesoEta 250 hPa Winds and Divergence. (Image >50, >80 kts). Yellow Home marks the location of the Parsons Plant.

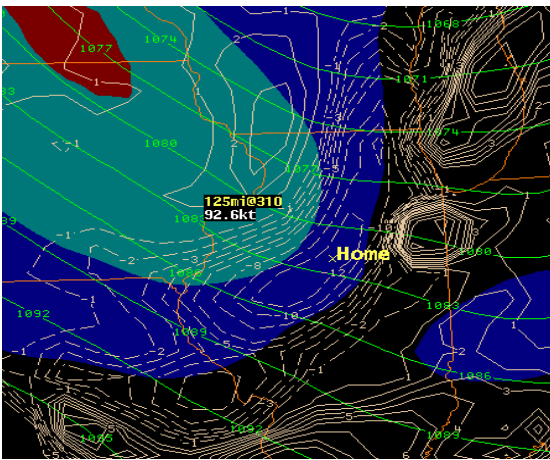


Figure 2. 12 UTC 13 Jul 2004 MesoEta 250 hPa Winds and Divergence. (Image >50, >80, >100 kts). Yellow Home marks the location of the Parsons Plant.

At 18 UTC, the 500 hPa temperature over northern Illinois, was -10.2°C , which is just colder than the -10°C threshold for indicating a large cold pool (Figure 3). The cold pool was also manifested in the extremely high CAPE readings from 18 UTC, which will be covered later.

The 700 hPa temperature from the ILX 18 UTC sounding was 10.4°C , which indicated little to no cap on thunderstorm development due to warm air aloft. Typically 12°C is used for indications of a capping inversion at 700 hPa (Figure 4) (Johns-Doswell 1992).

A Convective Inhibition (CIN) value of 50 J kg^{-1} or greater indicates that convection could be suppressed, but a value of 0 J kg^{-1} was found at ILX at 19 UTC. (Figure 5) The 700 hPa temperature and CIN value both show that available potential energy could be maximized for the creation and sustenance of convection once it developed in central Illinois.

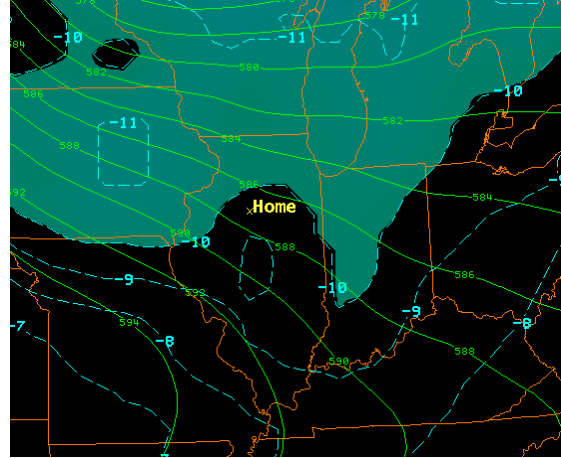


Figure 3. 18 UTC 13 Jul 2004 MesoEta 500 hPa Height and temp. (Temp Image $< -10^{\circ}\text{C}$). Yellow Home marks the location of the Parsons Plant.

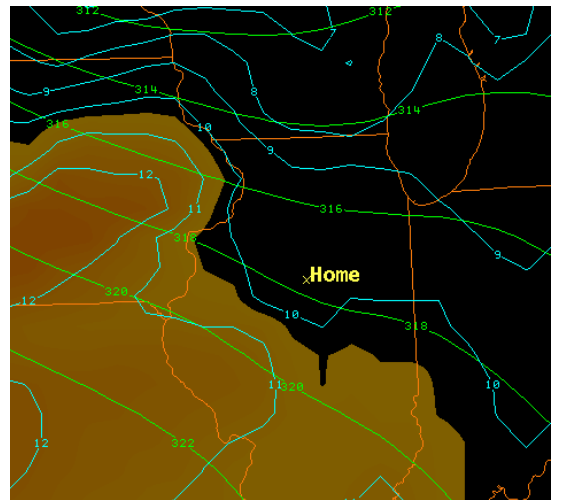


Figure 4. 18 UTC 13 Jul 2004 MesoEta 700 hPa Height and Temperature (Temp Image $> 10.3^{\circ}\text{C}$) Yellow Home marks the Parsons Plant.

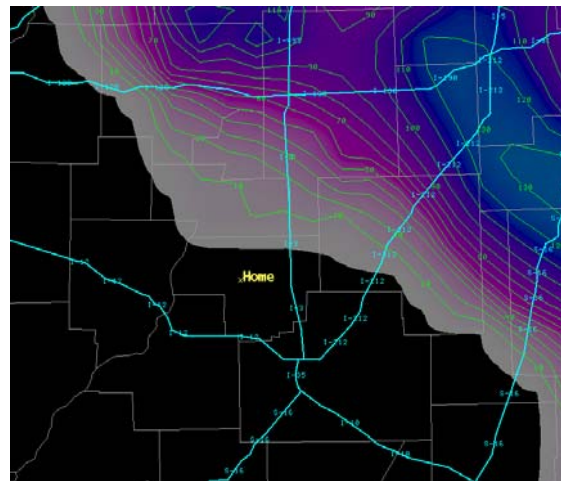


Figure 5. 19 UTC 13 July 2004 CIN. (Image starting at $>0 \text{ J kg}^{-1}$) Yellow Home marks the Parsons Plant.

3.2 Thermodynamics and Shear Profile

The environmental sounding from NWS Davenport, IA (DVN) at 12 UTC on 13 July 2004 (Figure 6) revealed strong instability above the nocturnal inversion at 950 hPa. The Lifted Index was -9°C with CAPE values of 3000 J kg^{-1} . Winds veered gradually with height reaching 40 knots by 4.5 km (15000 ft) MSL.

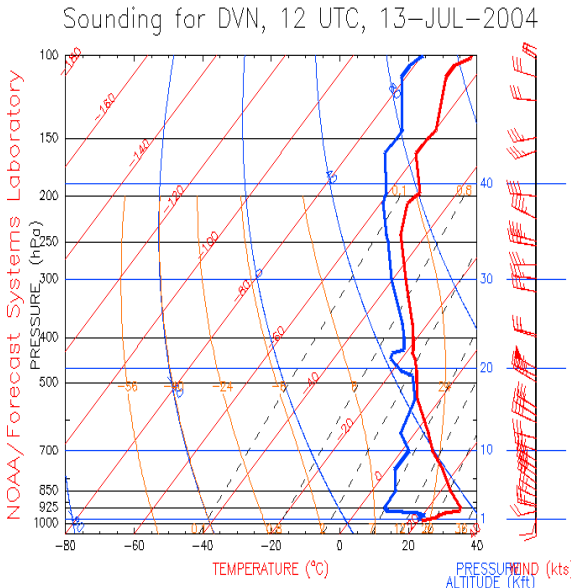


Figure 6. 1200 UTC 13 July 2004 DVN Sounding

The 12 UTC sounding from Lincoln IL (ILX) (Figure 7) indicated strong instability as well. The Lifted Index was -11°C with CAPE values of 4800 J kg^{-1} . The wind field was weaker than at DVN and unidirectional as the region had not yet come under the influence of the approaching upper trough and surface front.

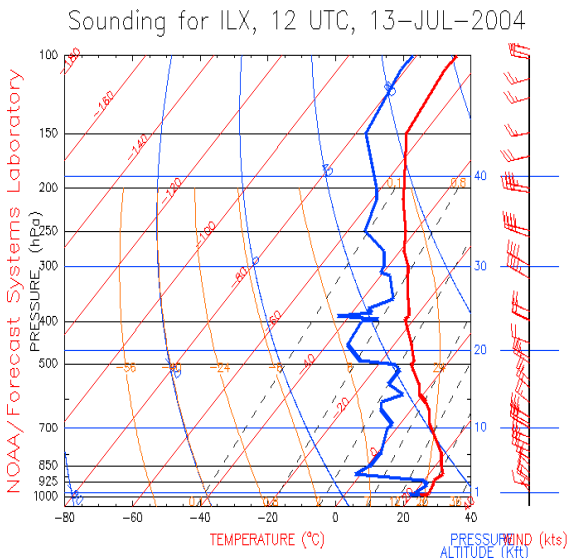


Figure 7. 1200 UTC 13 July 2004 ILX Sounding

Sounding for ILX, 18 UTC, 13-JUL-2004

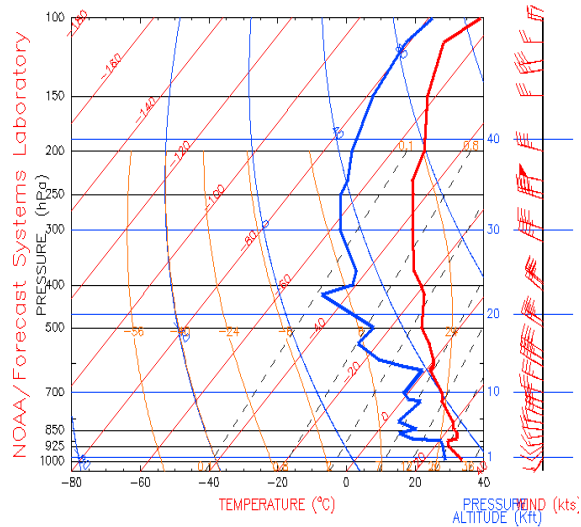


Figure 8. 1800 UTC 13 July 2004 ILX Sounding

By midday the upper trough had moved into the western Great Lakes, with the surface front extending from northern Ontario, through northwest Illinois, into the central Plains at 18 UTC. The pre frontal environment had become increasingly unstable as insolation and thermal advections eroded the nocturnal inversion and surface dew points climbed into the middle to upper 20s C (upper 70s and lower 80s F).

The Lincoln, IL (KILX) sounding at 1800 UTC 13 July 2004 (figure 8) indicated the Lifted Index had dropped to -14°C and the CAPE increased to nearly 7400 J kg^{-1} . The wind profile had become more favorable for severe convection as well with winds veering gradually with height and speeds reaching 40 knots by 4.5 km (15000 ft) MSL.

Clearly, any convection that day would quickly develop into strong storms given the available instability. However, the potential for tornadic storms was not as clear. The 1200 UTC KILX sounding showed 28 knots of 0-6 km bulk shear and $85\text{ m}^2\text{ s}^{-2}$ of 0-3 km Storm Relative Helicity (SRH). By 1800 UTC, the KILX sounding showed 35 knots of 0-6 km bulk shear and $120\text{ m}^2\text{ s}^{-2}$ of 0-3 km SRH. These values are supportive of supercell thunderstorm development, but are not especially supportive of tornadic storm development.

However, Kerr and Darkow 1996, indicated that high CAPE – low helicity environments are also conducive for F2 or greater tornadoes as are low CAPE – high helicity environments. Taking into consideration the research by Markowski 1998a, and Atkins 1999, it is plausible that most of the high CAPE-low helicity violent tornadoes were generated by the supercells traveling parallel to, and on the cool side of, a nearby outflow boundary.

Looking at the 19 UTC LAPS sounding (Figure 9) generated at the plant location, low level shear had increased, but SRH was still below levels typically needed for producing violent tornadoes. CAPE had increased to over 7000 J kg^{-1} , which matched closely what the 18 UTC ILX sounding indicated.

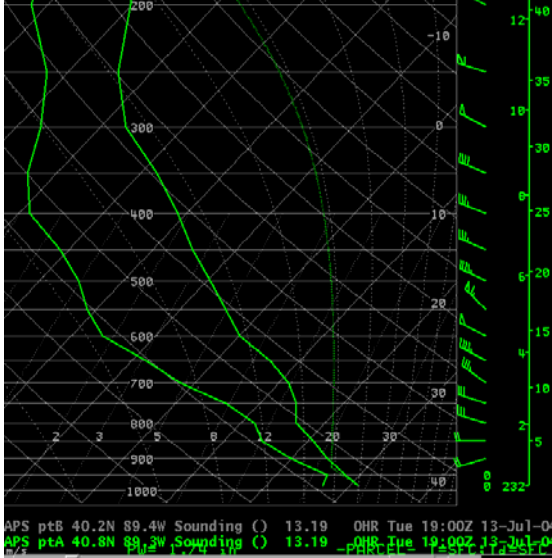


Figure 9. 19 UTC 13 July 2004 LAPS sounding at the Parsons Company

3.3 Surface

In central Illinois during the morning of 13 July 2004, a surface low was progressing across southern Canada with a cold front trailing southwestward across central Iowa. (Figure 10) Ahead of the cold front, warm and moist air was advecting northward on steady southwest flow. Surface temperatures by 15 UTC were already in the upper 20s to lower 30s C (middle to upper 80s), with dewpoints well into the 20s C (70s F).

By 19 UTC, the dewpoints had climbed into the upper 20s C (lower 80s F) in central Illinois (Figure 11). This was primarily in the vicinity of a northeast to southwest surface boundary as seen in the 1902 UTC visible satellite image (Figure 12).

Convective initiation seemed to be linked to the intersection of the outflow boundary from the supercell to the north, and the ambient boundary just west of the Plant. Storms developed farther north along the boundary, but timing and placement conditions came together with the pair of storms that worked together to generate the F4 tornado.

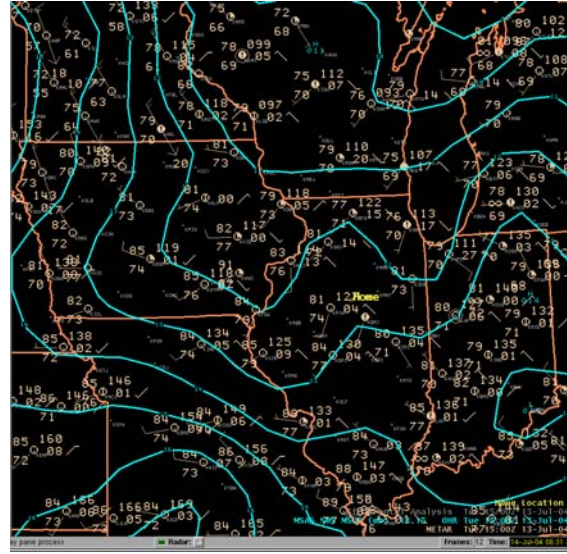


Figure 10. 15 UTC Surface plot with observations. Parsons Company indicated with the yellow X labeled 'Home'.

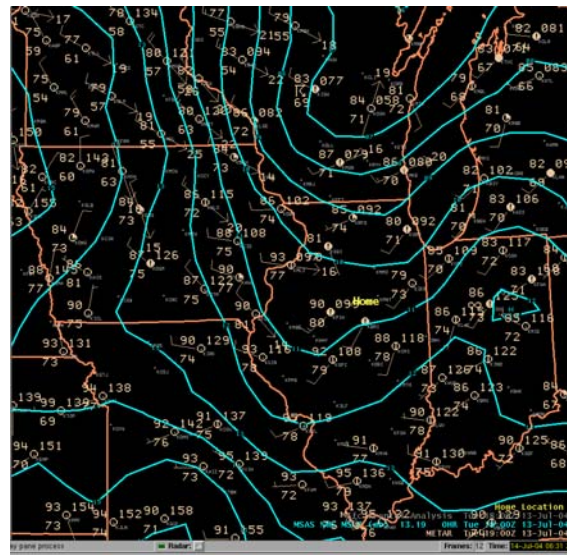


Figure 11. 19 UTC surface observation map. Parsons Company indicated with the yellow X labeled 'Home'.

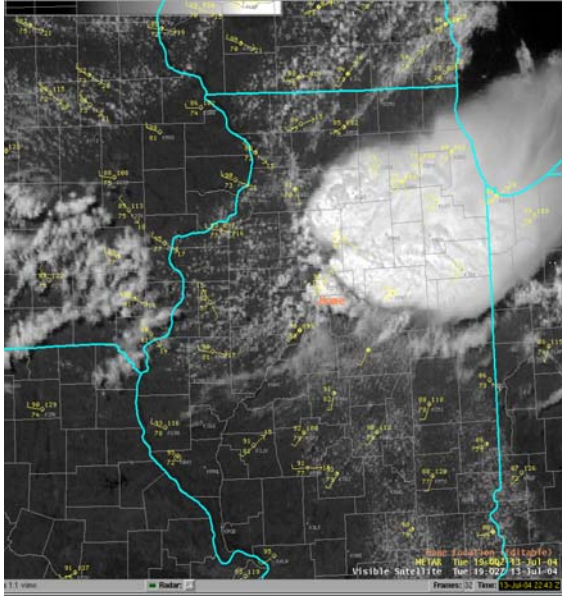


Figure 12. 1902 UTC visible satellite. Parsons plant marked with the orange 'Home' symbol.

4. TORNADOGENESIS

By 18 UTC 13 July 2004, an outflow boundary from the supercell that developed earlier that day in northwestern Illinois was pushing south toward the NWS Lincoln (ILX) County Warning Area (CWA). As the outflow boundary pushed south and intersected with the southwest to northeast ambient boundary, seen in figure 12, additional storms erupted and moved southeastward toward our CWA. Earlier that afternoon, the initial supercell in northwestern Illinois had produced 10 cm (4-inch) hail, and an F0 tornado. A strong persistent mesocyclone developed in that supercell, but the ambient SRH and storm generated vorticity appeared to not be enough to develop a strong tornado.

The location of convective initiation for the two storms was nearly in the same location, but about 15 minutes apart (Figures 13 and 14). Storm number 1 in Woodford County moved almost due east as it laid down an outflow boundary. The exact presence of the outflow boundary is barely visible in the 0.5 degree reflectivity images, but most likely was covered up by anvil precipitation from the first storm.

Storm number 2 quickly developed a mesocyclone that was indicated by radar with a mesocyclone alert at 1916 UTC (figure 15), as indicated with the thicker yellow circle.

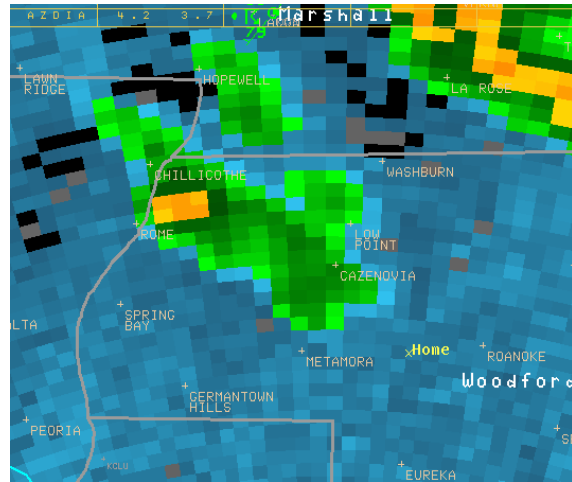


Figure 13. 1846 UTC KILX 0.5 degree reflectivity Parsons indicated with the yellow X labeled 'Home'.

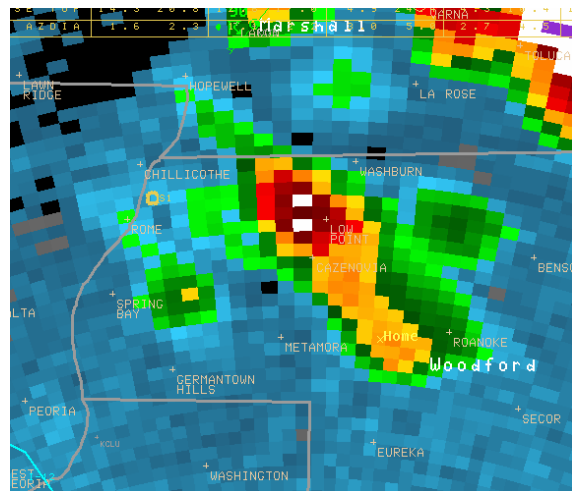


Figure 14. 1901 UTC KILX 0.5 degree reflectivity Parsons indicated with the yellow X labeled 'Home'.

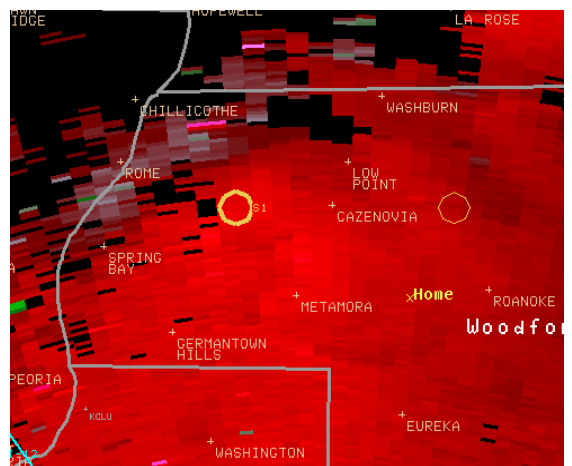


Figure 15. 1916 UTC KILX 0.5 degree SRM Parsons indicated with the yellow X labeled 'Home'.

By 1936 UTC, a Tornado Vortex Signature (TVS) alert was generated by the KILX WSR-88D radar (Figure 16), as indicated by the pink inverted triangle.

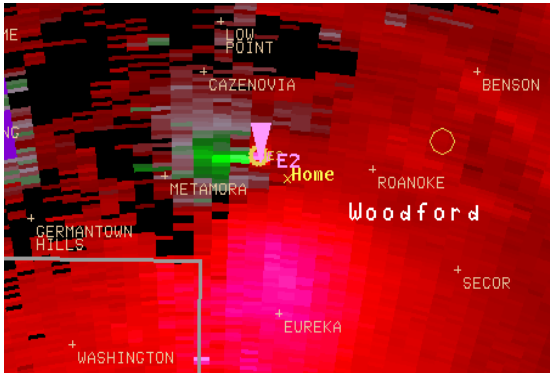


Figure 16. 1926 UTC KILX 0.5 degree SRM Parsons indicated with the yellow X labeled 'Home'.

A hook echo was visible in the reflectivity image at 1926 UTC, when the TVS signature alerted. (Figure 17)

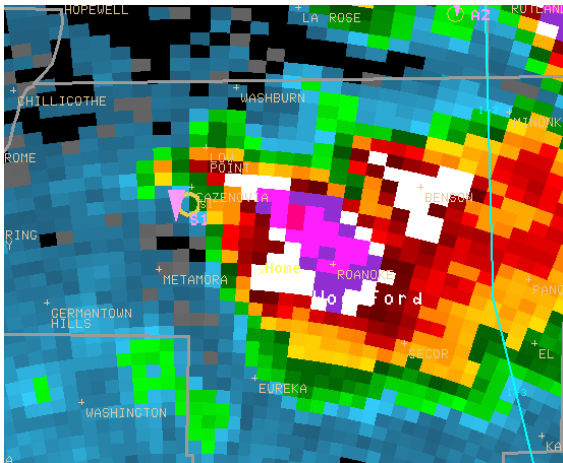


Figure 17. 1926 UTC KILX 0.5 degree reflectivity Parsons indicated with the yellow X labeled 'Home'.

By 1926 UTC, storm number 1 had entered into its dissipating stage, but survived long enough to produce an outflow boundary just south of storm number 2. The outflow boundary had advanced just far enough south for storm number 2 to travel parallel to the boundary on the cool side. Markowski et al 1998 indicated this was the ideal location to dramatically increase the possibility of tornadogenesis due to the presence of enhanced storm-scale vorticity. The additional vorticity was ingested into storm number 2 and rapidly stretched into the vertical due to CAPE values over 7000 J kg^{-1} .

By 1934 UTC, the storm produced an F0 tornado that progressed southeast toward the Parsons Plant. The tornado increased to F4 intensity by 1941 UTC, just as it hit the plant. The SRM and reflectivity images from this time show gate to gate shear and a strong hook echo with a TVS signature (Figures 18 and 19). The rotational velocity, or Vr-shear reading at 1941 UTC was 0.036 s^{-1} on the 0.5 degree SRM slice, with a velocity differential of 59.7 m s^{-1} (116 kts). Vr-shear readings of 0.20 s^{-1} on the lowest slice have been found to be sufficient for tornadogenesis.

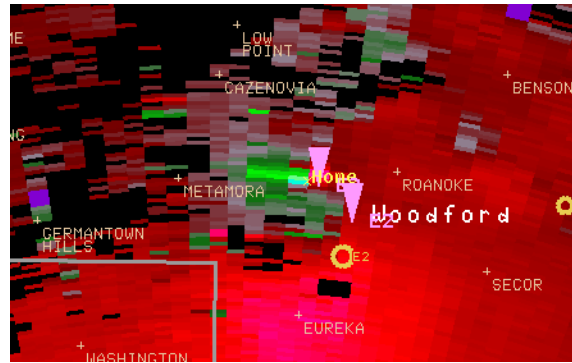


Figure 18. 1941 UTC KILX 0.5 degree reflectivity Parsons indicated with the yellow X labeled 'Home'.

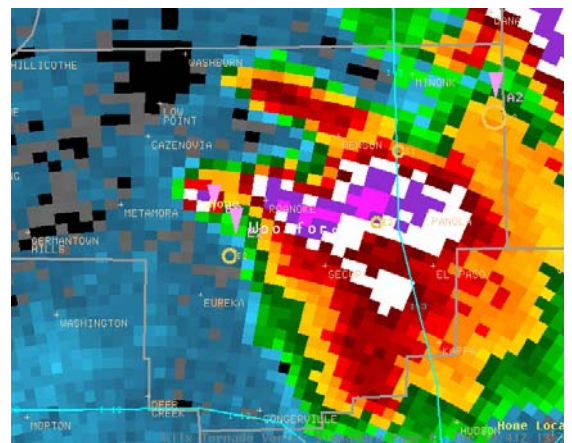


Figure 19. 1941 UTC KILX 0.5 degree SRM Parsons indicated with the yellow X labeled 'Home'.

The tornado dissipated rapidly once it reached just southeast of Roanoke. From the radar images, once the two storms merged, it appears that the outflow boundary mixed out, or the tornadic storm moved into an unfavorable position for tornadogenesis relative to the outflow boundary of storm number 1.

5. DETAILED SUMMARY OF THE TORNADO DAMAGE PATH

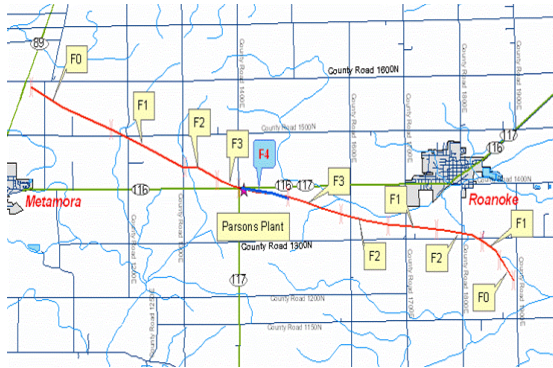


Figure 20 Tornado track and intensity summary

Figure 20 shows how the violent tornado tracked for 15.45 km (9.6 miles) across Woodford County, reaching F4 intensity along a 1.6 km (1-mile) stretch between Metamora and Roanoke.

The tornado touched down approximately 2.9 km (1.8 miles) north of Metamora, around 90 meters (a few hundred yards) southeast of the intersection of Illinois Route 89 and county road 1600N. The tornado was initially of F0 (64-115 km hr⁻¹, 40-72 mph) strength. It moved southeast, and strengthened to F2 intensity (182-253 km hr⁻¹, 113-157 mph) near the time it reached county road 1300E. It then began a temporary eastward movement for about 800 meters (a half mile), before curving southeast again. It crossed Route 116 just west of the Route 117 junction, and was at F3 strength (254-331 km hr⁻¹, 158-206 mph) at this point.

The tornado increased to F4 intensity (338-386 km hr⁻¹, 210-240 mph) as it crossed Route 117, demolishing the manufacturing plant at this intersection. Approximately 140 people were in the plant at the time, but all made it to storm shelters in time (approximately 3-5 minutes before the tornado arrived). Steel beams and metal siding from the plant were found approximately 1 km (3/4 mile) east in a farm field.

From the plant, the tornado continued east, just south of Routes 116/117, affecting 4 farmsteads approximately 0.8 to 1.6 km (1/2 to 1 mile) east of the plant. Two of the farmsteads closest to the plant, 0.8 to 1 km east (about 1/2 to 3/4 mile east) had the 2-story houses completely blown away, with only debris remaining in the basements and nearby property. The other two farmsteads had significant damage to the 2-story houses, with outbuildings demolished. The center of the tornado's track was

about 90 meters (100 yards) south of the farmsteads on the south side of the highway.

From the plant to the farmsteads, the storm was F4 intensity. The average width of the tornado during this time was 360 meters (400 yards), and was close to 400 meters (1/4 mile) wide at times.

At this point, the tornado began to travel in a more east-southeast direction, and caused significant damage to a barn near the intersection of county roads 1300N and 1700E. It caused significant damage at a farmstead at the southeast corner of 1300N and 1800E. The tornado crossed 1300N shortly afterward, and lifted around 2:55 pm about 4 km (2.5 miles) southeast of Roanoke, at county road 1900E.

The tornado was on the ground for approximately 21 minutes.

6. SUMMARY

Numerous storms developed that day in a highly unstable environment. CAPE values were over 7000 J kg⁻¹ and there was little to no cap to limit convective potential. Yet only one storm produced a violent tornado. This seems to be attributed to the insufficient amount of ambient SRH and the storm generated vorticity that the other storms experienced. During VORTEX-95, Markowski et al 1998b indicated that there is a high variability of SRH near outflow boundaries in a convective environment. Also, Atkins et al 1996 suggested that storms that interact with outflow boundaries have greatly increased potential of becoming tornadic. Many storms that day had long lived mesocyclones that developed from the ambient and storm generated vorticity, but did not develop violent tornadoes. It appears that there is enough evidence in this case to hypothesize that this tornadic storm interacted with the outflow boundary of storm number one at precisely the necessary location and direction of movement to generate a violent F4 tornado. Perhaps in the future, additional technology and monitoring devices might allow for sampling of the lower atmosphere at storm scale resolution, possibly detecting more of these boundaries and changes in SRH in real time.

7. ACKNOWLEDGMENT

The authors would like to acknowledge Llyle Barker, SOO, NWS Lincoln IL, for providing his review, comments, and valuable suggestions on the manuscript.

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