P9.9 THE SOUTHWEST OHIO MINISUPERCELL TORNADO OUTBREAK OF 11 JULY 2006. PART I: MESOSCALE AND RADAR ANALYSIS

Daniel P. Hawblitzel*
NOAA/National Weather Service, Wilmington, OH

1. INTRODUCTION

Tornadic minisupercells, while being a well-documented phenomenon, still pose a significant challenge to warning operations due to their small horizontal and vertical dimensions and relatively weak velocity signatures. Two of the more common synoptic settings for minisupercells include cold core 500-hPa lows in midlatitudes and landfalling tropical cyclones. Both environments are typically characterized by limited instability (CAPE often less than 1500 J/kg) and strong low-level wind shear. Guyer and Davies (2006) noted that tornado events within cold core settings were often associated with 500-hPa temperatures colder than -10°C, marginal boundary layer moisture (dewpoints in the 40s and 50s Fahrenheit), low equilibrium levels and a nearby well-defined surface low in close proximity to a surface boundary intersection. On the other hand, environments characteristic of tropical cyclone tornadoes may differ considerably from those of cold core systems. These cases usually involve a thin CAPE profile, midlevel lapse rates near moist adiabatic, deep moisture, low surface dewpoint depressions, low LFC and LCL heights, limited deep-layer shear, and levels of maximum buoyancy and wind near 700-hPa (e.g. McCaul 1991). In many cases, low-level winds may be stronger than those in middle and upper levels which creates a curved "horseshoe-shaped" hodograph.

Observations of minisupercells across a wide range of synoptic settings (e.g. Grant and Prentice 1996; Spratt et al. 1997) indicate that they generally share the same radar traits regardless of their environment. These characteristics include echo tops near 12-km or less, shallow rotation (often below 4.5 km) and rotational velocity (V_r) values ranging from 15-29 kt. In addition, radar signatures such as hook echoes and weak echo regions have been commonly observed in minisupercells, but these features may be much more subtle than those of a typical tornado-producing supercell. These weak signatures may pose a significant challenge to the warning process, especially if minisupercell development is not anticipated beforehand.

Such a case occurred on the evening of 11 July 2006, when an unexpected minisupercell outbreak occurred over southwest Ohio. Twelve confirmed tornadoes touched down within a 2.5-hour period across southwest Ohio that evening, confined entirely to the county warning area (CWA) of the National Weather Service office in Wilmington, Ohio (ILN). This was the most confirmed tornadoes to occur in ILN's CWA in a single day since the office began forecast and warning operations in 1994. This event was particularly challenging since model forecasts of low instability (MLCAPE ranging from 300 to 1200 J kg^{-1}) and limited deep-layer shear (0-6 km shear of 24 to 30 kt) led forecasters at the local office and the Storm Prediction Center (SPC) to believe that any thunderstorms which developed that evening would not be severe. As a result, SPC did not designate any probabilities of severe weather to the Ohio Valley, and the local office was minimally staffed. When storms developed into minisupercells, they did not initially appear severe to local forecasters, so no tornado warning was in effect when the first tornado of the evening struck a residential area southwest of Dayton, Ohio with F1 damage. Due to the storm's benign appearance on radar, it continued to go unwarned when it produced a second tornado near the Dayton Mall in the southern Dayton suburbs, again with F1 damage. By this point, ILN forecasters knew to significantly lower warning thresholds for the remainder of the event.

By the end of the evening, numerous tornadoes had impacted portions of the Dayton, Cincinnati and Columbus media markets. Though all of the tornadoes were weak (F0 or F1), some of these tornadoes affected populated areas with little or no advance warning. This garnered a great deal of attention from the media and general public. The complex and high-profile nature of this event led to many questions. How could such a significant event occur without anticipation by forecasters? Why were radar signatures so weak? Was it possible to know beforehand that storm signatures would be weaker than normal, and that warning thresholds would need to be lowered? This study attempts to answer these questions by analyzing the environment and radar signatures from that evening using a framework of previous minisupercell studies.

2. METHODOLOGY

This study utilizes the Weather Event Simulator and Advanced Weather Interactive Processing System (AWIPS) to review data from 11-12 July 2006. Data includes the 40-km Rapid Update Cycle (RUC), surface observations, rawinsonde observations, and Weather Surveillance Radar-1988 Doppler (WSR-88D) radar data from Wilmington, Ohio (KILN). Rotational velocity was calculated by halving the absolute value of the difference between the maximum inbound velocity and maximum outbound velocity values. Mesocyclone depth was estimated by determining the level of the highest scan with detectable rotation. Echo tops were estimated using the AWIPS Enhanced Echo Tops product. Upper air parameters from the 0000 UTC 12 July ILN sounding were calculated using SoundingPro, a program developed locally at ILN.

** Corresponding author address: Daniel P. Hawblitzel, NOAA/National Weather Service*
1901 South State Route 134, Wilmington, OH 45177-9708
email: daniel.hawblitzel@noaa.gov

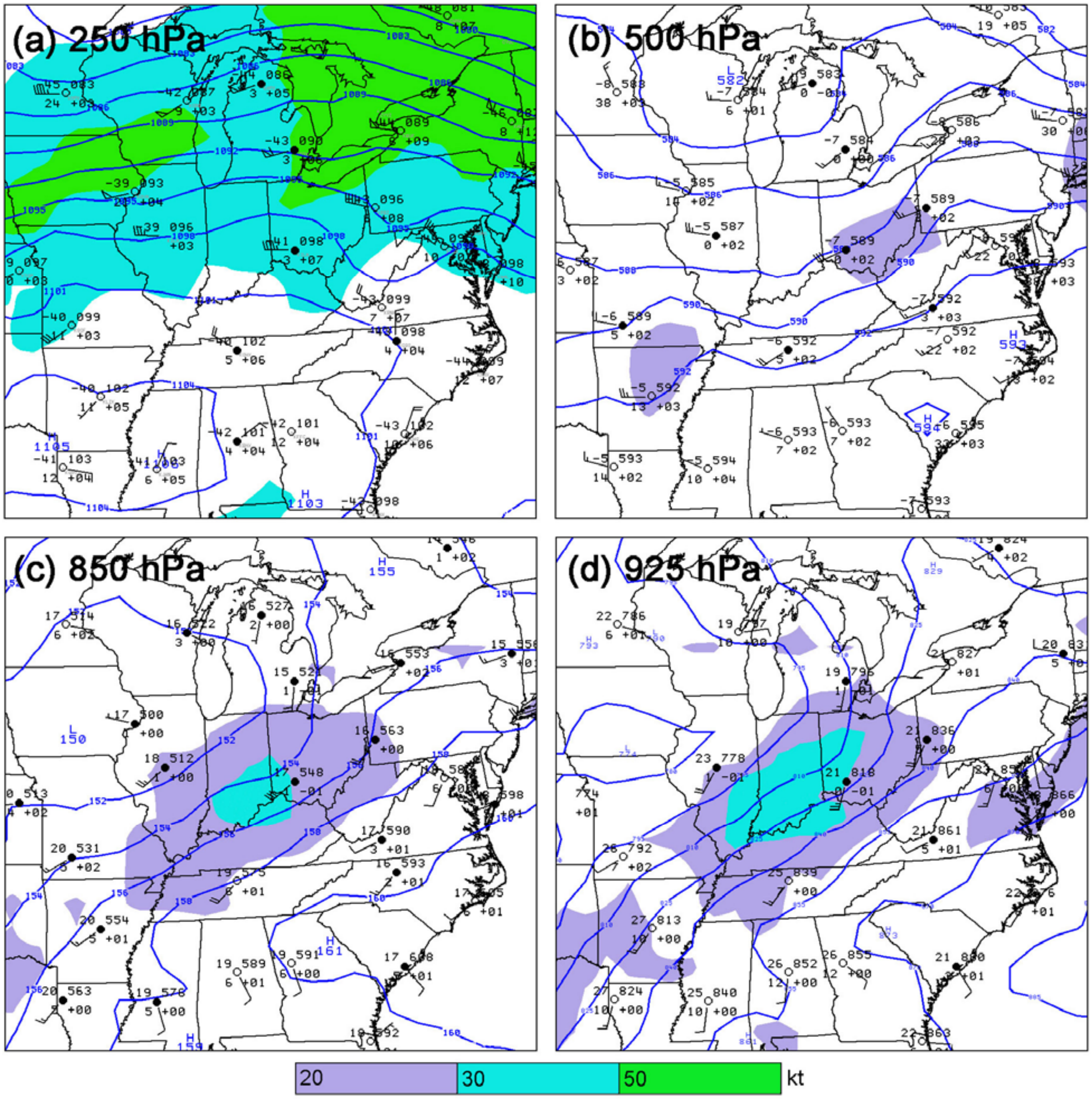


Figure 1. RAOB data and RUC analyses valid 0000 UTC on 12 July 2006 at: (a) 250 hPa, (b) 500 hPa, (c) 850 hPa and (d) 925 hPa. Blue contours denote isoheights and isotachs are shaded

3. SYNOPTIC/MESOSCALE ENVIRONMENT

On the evening of 11 July 2006, a large upper high extended across much of the southeastern United States with a weak ridge axis extending northward into southwest Ohio (Fig. 1a). A weak 50-kt jet across the Great Lakes was rounding the northern periphery of the ridge. This upper pattern led to weak upper flow across the Ohio Valley. A weak 500-hPa longwave trough was in place across the Great Lakes with an embedded weak shortwave trough axis extending from Michigan across central Ohio and into West Virginia, and a second weaker trough axis from southern Indiana into central Tennessee (Fig. 1b). Winds across the Ohio Valley at this level were weak (≤ 30 kt). A more significant closed low existed at 925 and 850 hPa over Iowa (Figs. 1c, d). A low-level jet developing ahead of the 850-hPa low was nosing into southwest Ohio with speeds up to 35 kt, with a larger area of 30-kt and higher winds at 925 hPa.

At the surface, a stationary boundary stretched from southern Iowa into southern Michigan at 0000 UTC 12 June (not shown). This placed southwest Ohio deep into the warm sector, where low-level moisture had been steadily increasing through the day with dewpoints in the lower 70s °F across the region. A weakening convective complex had tracked across Indiana and Ohio earlier that afternoon which kept a thick cloud

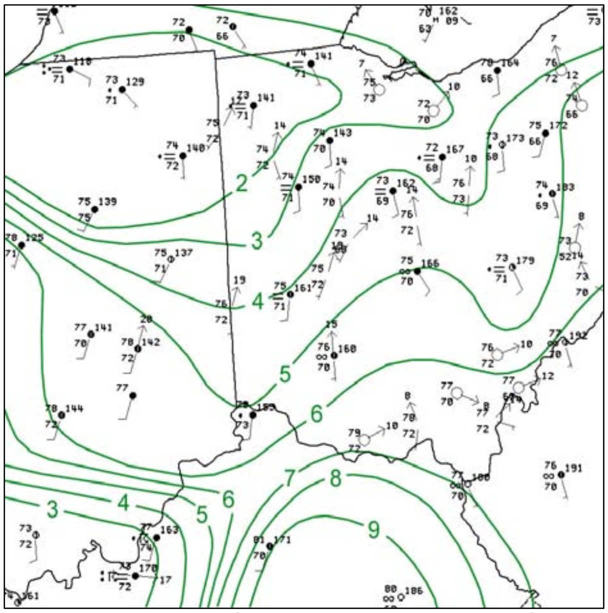


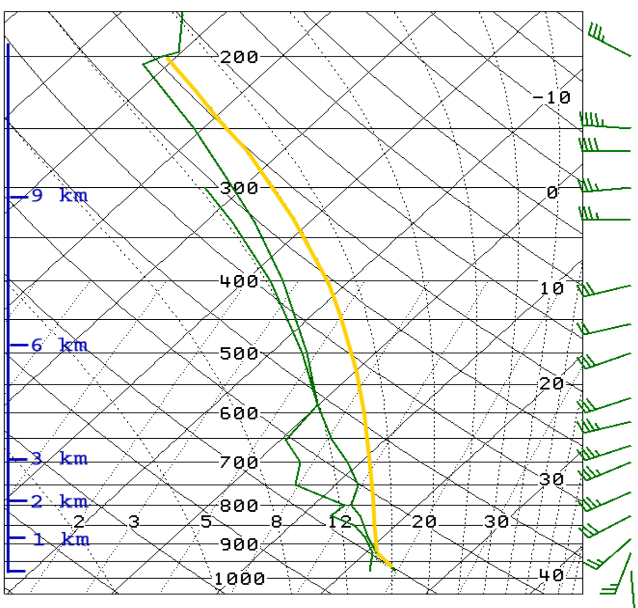
Figure 2. Regional surface observations at 2300 UTC on 11 July 2006. Temperature and dewpoint temperature plotted in °F. Green contours depict dewpoint depressions in °F.

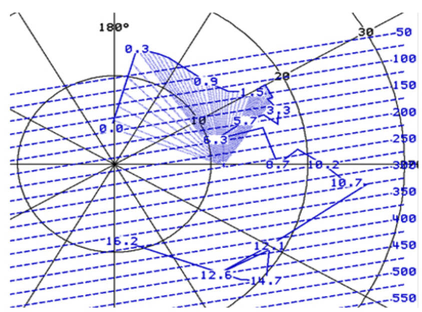
canopy in place, so surface temperatures reached only into the middle to upper 70s °F. Because of the humid, rain-cooled airmass, surface dewpoint depressions were very low, ranging only from 3–6°F (Fig. 2). No well-defined surface boundaries were evident in the vicinity of southwest Ohio.

A 0000 UTC upper air sounding was launched at ILN right at the onset of severe convection, and just an hour before tornadic storms moved into the Wilmington area (Fig. 3). Even though convection was ongoing nearby, it was 30 km upstream from Wilmington when the sounding was released at 2300 UTC, and did not reach the area until nearly an hour later. Thus, the sounding represented well the atmosphere that evening, confirmed by comparisons to nearby 0000 UTC soundings and the 1200 UTC ILN sounding which showed similar profiles (not shown). The ILN sounding indicated that mixed-layer instability was weak to moderate with ML CAPE of 1068 J kg^{-1}. Low-level CAPE was more favorable for severe thunderstorms with 0-3 km CAPE of 133 J kg^{-1}. Lapse rates were weak and even became less than moist adiabatic above 500 hPa, indicating a stable layer aloft. Winds throughout most of the troposphere were relatively weak and remained under 40 kt below 10 km. A relative wind maximum of 35 kt existed near 2.5 km. As a result of the weak midlevel winds, 0-6 km shear was an unimpressive 25 kt. Low-level shear values were comparatively stronger with 0-1 km bulk shear of 21 kt, 0-3 km helicity of 244 m^2 s^{-2} and 0-1 km helicity of 189 m^2 s^{-2}. The airmass was nearly saturated throughout most of the troposphere, but with a dry layer noted in the 600-700 hPa layer. Due to a very moist boundary layer, LCL and LFC heights were very low at 422 m and 571 m respectively.

4. RADAR DATA

The tornadic storms displayed signatures typical of minisupercells, with small precipitation cores, relatively low echo tops and relatively weak rotational velocity values. Six supercells developed that evening, five of which became tornadic. Characteristics of these six storms are given in Table 1. Two examples of reflectivity and storm-relative velocity images are shown in Figures 4 and 5. Maximum V_r values of these storms generally ranged from 20 to 30 kt, though one storm had V_r values as high as 33 kt. Rotational velocity values were almost always maximized near or shortly before





Sfc CAPE	1165 J/kg
ML CAPE	1068 J/kg
0-3 km CAPE	133 J/kg
6km Shear	25.4 kt
1km Shear	21.0 kt
0-3km Helicity	244 m^2/s^2
0-1km Helicity	189 m^2/s^2
LCL	422 m
LFC	571 m

Figure 3. ILN upper air sounding taken 0000 UTC on 12 July 2006. Whole (half) wind barb denotes 10 (5) kt.

Cell No.	Distance from radar (nm)	Time of first meso (UTC)	Time of first hook (UTC)	Max V_r (kt)	Time of Max V_r (UTC)	Max depth of meso (kft)	Width of meso at time of tor (nm)	Max echo tops (kft)	Time of max echo tops (UTC)	Time of tornado (UTC)
1	28–40	2126	2200	25.9	2147	11.6		44	2200	None
2	23–26	2300	2307	20.4	2328	10.4	1.2 0.7	39	2315	2320 2338
3	4–23	2304	2312	26.3	2345	10.1	0.9 0.3 0.7 0.9	*Too close to radar*	*Too close to radar*	2350 0029 0040 0056
4	32–46	2353	0027	22.4	0006	6.5	1.9 1.4	33	2345	0018 0044
5	22–32	2358	0002	33.4	0018	10.9	0.4	46	0010	0023
6	6–23	0050	0053	28.6	0100	10.6	0.9 1.1 1.1	*Too close to radar*	*Too close to radar*	0102 0136 0152

Table 1. Characteristics of the six minisupercells which developed over southwest Ohio on 11 July 2006. Listed in the table are the range of distances from the radar while a mesocyclone was detected, the time the mesocyclone was first detected on radar, the time the hook echo was first detected, the maximum rotational velocity (V_r), time of maximum V_r, maximum depth of the mesocyclone, width of the mesocyclone , maximum echo tops, time of the maximum echo tops and time of tornado touchdown.

the time of tornado touchdown. Mesocyclones were small, generally with diameters less than 2 nm, and most less than 1 nm. Vertical depths of the mesocyclones were shallow (≤ 11 kft), with one tornadic storm showing rotation only up to 6.5 kft. Maximum echo tops ranged from 33–46 kft and were maximized at or before the time of tornado touchdown in every case. In addition, a hook echo was detected in every supercell, and preceded every tornado except one. One particular feature of interest was an enhanced region of westward- to northwestward-directed velocity above the mesocyclones (not shown). A similar feature was detected by Schneider and Sharp (2007) in tornadic supercells in landfalling tropical systems over North Carolina. They referred to this feature as a velocity enhancement signature (VES), and noted that such a feature preceded 14 out of 15 tornadoes in that study. Similarly, every tornado in this study was preceded by a VES. The potential significance of this feature to tornadogenesis is discussed in much further detail in part two of this study.

It should be noted that since the mesocyclones were small in diameter and had rotational velocity values generally less than 30 kt, they did not stand out when using the standard velocity color curve in AWIPS. Figure 6 shows the mesocyclones of two tornadic storms that evening, comparing the standard AWIPS velocity color curve (which was in use at ILN at the time) to a curve which enhances weak velocities. The mesocyclones are much more apparent in the latter case.

5. DISCUSSION

One of the more noticeable characteristics of the 0000 UTC 12 July 2006 ILN sounding was the strong low-level shear, with 0-1 km shear and helicity values which were well supportive of tornadoes. This strong shear was due to the low-level jet which was advancing northeast into the Ohio Valley, undercutting the ridge aloft where winds were weaker. This resulted in a vertical wind profile that peaked near 2.5 km with slightly decreasing winds above this level. This wind profile was similar to the horseshoe-shaped hodograph which has been found to be characteristic of tornado events in many landfalling tropical systems. The significant number of tornadoes that have occurred in this and other such cases shows that weak deep-layer shear may not necessarily inhibit tornadic storms when shear and buoyancy are concentrated in the lower troposphere.

The thermal profile of the ILN sounding showed deceptively low buoyancy for mid-summer, but like the shear, showed important similarities to an average tornadic tropical cyclone environment. The low instability and thin CAPE profiles were due to weak midlevel lapse rates, with a conditionally unstable layer below 500-hPa and a stable layer above this level, remarkably similar to the composite sounding of ten hurricane-tornado proximity soundings presented in McCaul (1991). Additionally, moisture was very high throughout the troposphere with a nearly saturated sounding and a very moist boundary layer, which led to particularly low LFC and LCL heights. These were likely significant factors in determining the type and severity of thunderstorms that evening. The low base of the free convective layer allowed for a concentration of instability in the lower troposphere, with 0-3 km CAPE values which were more indicative of severe potential than the value of CAPE alone. Studies such as McCaul and Weisman (1996, 2001) indicate that in cases of small CAPE, compression of shear and buoyancy into the lower troposphere as in the case of 11 July 2006 can still result in shallow but intense supercells. In addition, McCaul and Cohen (2002) showed that minisupercells are more favored when LFC heights are low due to

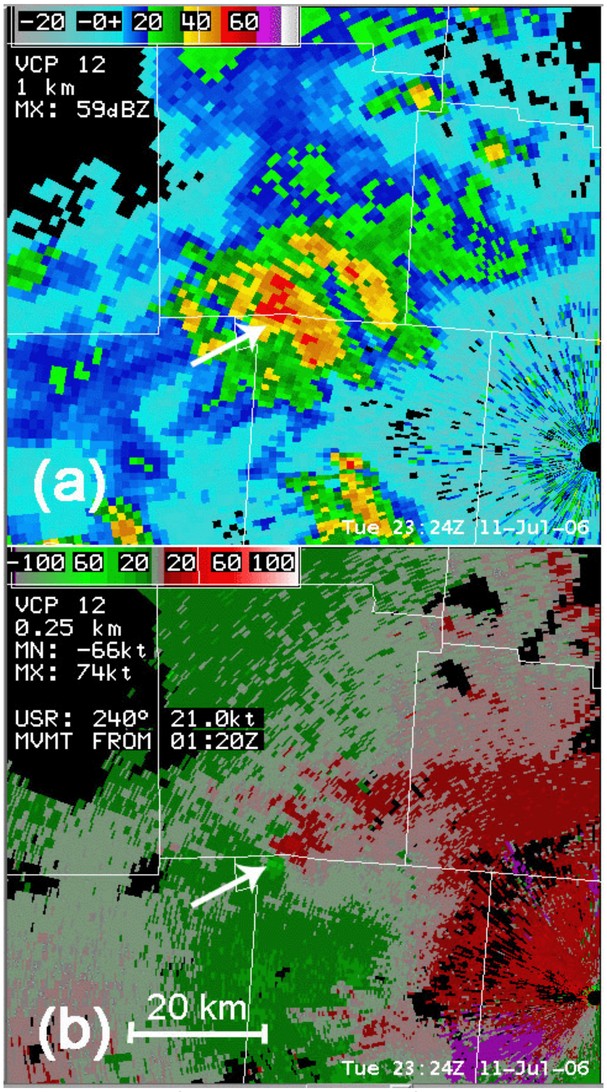


Figure 4. KILN WSR-88D data at 2324 UTC on 11 July 2006: (a) 0.5° reflectivity image and (b) 2.4° storm relative velocity at the time a tornado touched down near Carlisle, Ohio (denoted by the white arrow). The radar is sampling the cell at about 2000 ft (600 m) in (a) and 6800 ft (2000 m) in (b). The KILN radar is located in the lower right of the image. Color scale units are dBZ in (a) and knots in (b).

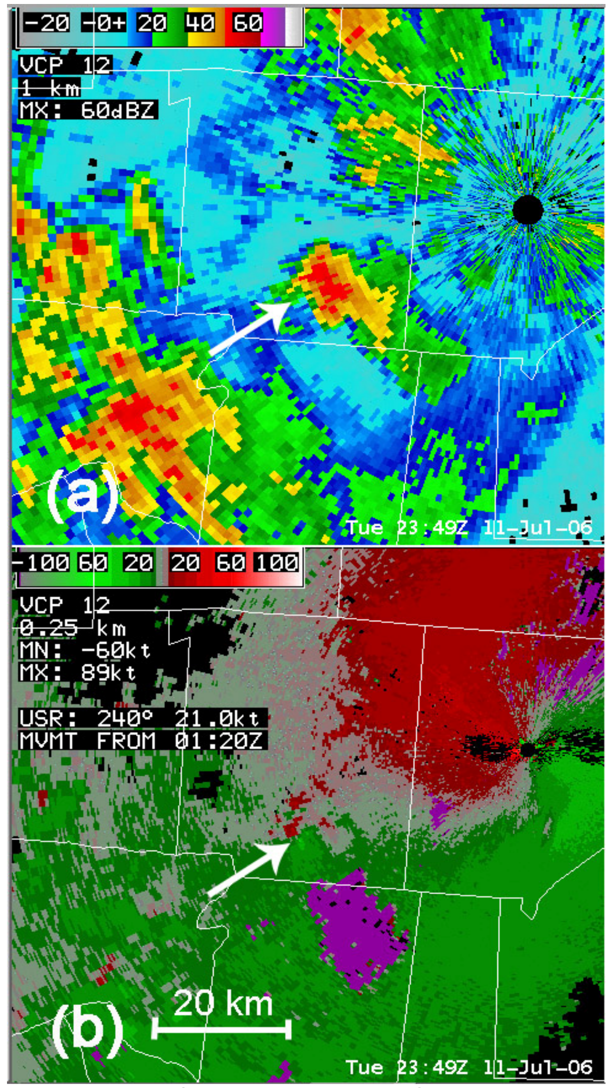


Figure 5. KILN WSR-88D data at 2349 UTC on 11 July 2006: (a) 0.5° reflectivity image and (b) 1.8° storm relative velocity at the time a tornado touched down near Maineville, Ohio (denoted by the white arrow). The radar is sampling the cell at about 1400 ft (400 m) in (a) and 3800 ft (1200 m) in (b). The KILN radar is located on the right hand side of the image. Color scale units are dBZ in (a) and knots in (b).

increased entrainment of low theta-e air into the updraft above the mixing layer. Thus the very low LCL heights in the case of 11 July 2006, owing to surface dewpoint depressions of 5°F or less, may have been critical in determining minisupercells as the preferred convective mode that evening.

The radar reflectivity and velocity signatures of this case showed distinct similarities to minisupercell storms in both numerical and observational studies of tornadic tropical systems. These similarities include small hook echoes, low echo tops and weak mesocyclones that were narrow and shallow. Similar to other minisupercell cases, rotational velocity values were mostly 30 kt or less, with mesocyclones not extending above 12 kft. In such cases storm signatures may be particularly sensitive to radar sampling issues. Shallow mesocyclones may be undetected due to beam overshooting, especially at further distances from the radar. Small-diameter mesocyclones may not be sampled adequately so velocity values will appear deceptively weak, especially further from the radar where radar resolution is lower. Additionally, due to small mesocyclone diameters, rotational values (vorticity) may not be as weak as pure values of velocity suggest. Finally, the color curve in use at ILN that evening showed velocity in 10-knot increments. This significantly hindered detection of rotation since most rotational velocity values were less than 30 kt. A color curve which interpolates colors to enhance weak velocity signatures allowed the mesocyclones to be much more apparent to the radar operator.

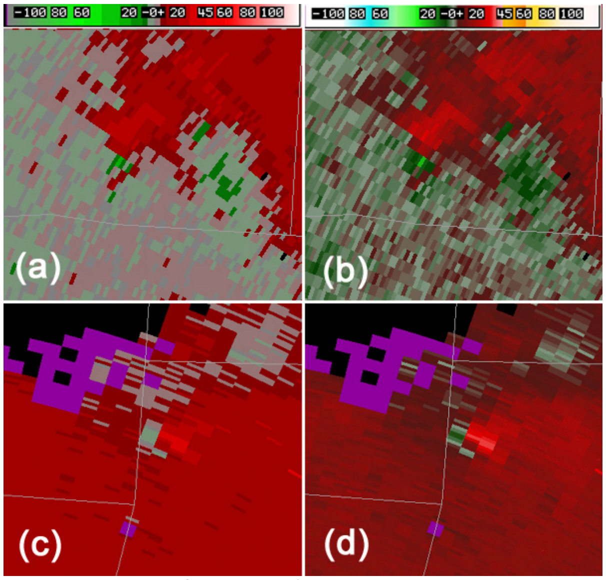


Figure 6. KILN WSR-88D 0.9° storm-relative velocity at (a, b) 2336 UTC on 11 July 2006 as a tornado struck a shopping mall near Dayton, Ohio, and (c, d) at 0035 UTC on 12 July 2006 as a tornado touched down northwest of Columbus, Ohio. The SRM images are shown using: (a, c) the default AWIPS velocity color curve and (b, d) a color curve which enhances lower velocity values. The color curve in (a, c) was in use at ILN at the time. The KILN radar is located to the southeast of the image in (a, b) and to the southwest of the image in (b, d). Color scale units are in knots.

6. CONCLUSIONS

While tornadic minisupercells are not uncommon in the Midwestern United States, forecasters for that part of the country may tend to associate them with cool season events or closed cold-core upper lows. Even in the case of minisupercells occurring within the remnants of a tropical system, forecasters may be inclined to associate the possibility of tornadoes and minisupercells to the mere presence of a tropical system, and may not fully understand which specific ingredients are supportive for shallow tornadic storms. In the case of 11 July 2006, pattern recognition alone would not have alerted forecasters to the tornadic minisupercell potential since no closed upper low or tropical cyclones existed anywhere in the vicinity. Environmental conditions, however, were very similar to the latter setting. Knowing these environmental similarities, particularly the very low LCL heights and the compression of shear and buoyancy into the lower troposphere, may have made it possible to anticipate tornadic minisupercells that evening. This knowledge may have prevented forecasters from being deceived by the weak deep-layer shear and low values of total CAPE.

The high-profile nature of this case underscores the need for forecasters to be able to anticipate minisupercells and know their characteristic radar traits. Simple pattern recognition will not catch every minisupercell environment, so it is important that forecasters understand which specific ingredients favor this type of storm. In addition, it may be beneficial for offices to establish guidelines for warning thresholds in minisupercell situations, and create custom velocity color curves that enhance lower velocities to help radar operators spot weak rotation. Though minisupercell situations may be challenging to forecast and warn for, having a thorough understanding of minisupercell characteristics and their environments will likely lead to improved warning performance.

7. ACKNOWLEDGEMENTS

The author would like to express appreciation to local management at WFO Wilmington, OH (ILN) for their support for this research and paper. A special thanks is owed to John DiStefano, SOO at ILN, for his assistance and allowing me the time to complete this study. The author also wishes to thank Stephen Hrebenach, senior forecaster at ILN, for his assistance and comments, and Dave Radell of Eastern Region Scientific Services Division for his thorough review of this manuscript.

8. REFERENCES

Grant, B. and R. Prentice, 1996: Mesocyclone characteristics of mini supercell thunderstorms. Preprints, *15th Conf. on weather analysis and forecasting*, Norfolk, VA, Amer. Meteor. Soc., 362-365.

Guyer, J.L., and J.M. Davies, 2006: Environment characteristics associated with tornado events near closed cold core 500 mb lows. Preprints, *23nd Conf. on Severe Local Storms*, St. Louis MO, Amer. Meteor. Soc.

McCaul E. W. Jr., 1991: Buoyancy and shear characteristics of hurricane-tornado environments. *Mon. Wea. Rev.,* **119,** 1954–1978.

McCaul E. W. Jr., and M. L. Weisman, 1996: Simulations of shallow supercell storms in landfalling hurricane environments. *Mon. Wea. Rev.,* **124,** 408–429.

McCaul E. W., and M. L. Weisman, 2001: The sensitivity of simulated supercell structure and intensity to variations in the shapes of environmental buoyancy and shear profiles. *Mon. Wea. Rev.,* **129,** 664–687.

McCaul E. W. Jr., and C. Cohen, 2002: The impact on simulated storm structure and intensity of variations in the mixed layer and moist layer depths. *Mon. Wea. Rev.,* **130,** 1722–1748.

Schneider, D., and S. Sharp, 2007: Radar signatures of tropical cyclone tornadoes in central North Carolina. *Wea. Forecasting,* **22,** 278–286.

Spratt S. M., D. W. Sharp, P. Welsh, A. Sandrik, F. Alsheimer, and C. Paxton, 1997: A WSR-88D assessment of tropical cyclone outer rainband tornadoes. *Wea. Forecasting,* **12,** 479–501.