10B.6 THE TORNADO WARNING PROCESS DURING A FAST-MOVING LOW-TOPPED EVENT: 11 APRIL 2001 IN IOWA

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1. INTRODUCTION

On 10-11 April 2001, numerous tornadic and severe thunderstorms occurred across the central U.S. Radar signatures with these fast-moving storms were small and/or weak, providing difficult challenges for warning meteorologists. With the exception of a single long-track tornadic supercell before 1800 UTC 11 April 2001, tornadoes in Iowa during the afternoon were associated with low-topped mini-supercells, or hybrid structures embedded in fast moving thunderstorm lines.

Twelve tornadoes occurred in the Des Moines National Weather Service (NWS) area of warning responsibility (roughly the central half of Iowa). This paper will focus on nine of those tornadoes, and their associated storms, which occurred between 1900-2130 UTC. The challenge to the warning meteorologist becomes apparent when one considers that most of the tornadoes only lasted a couple of minutes, storms were moving to the north at greater than 25 ms^{-1}, and up to 16 storms exhibited mesocyclonic characteristics occurred simultaneously (Fig. 1).

Predominant storm structures will be discussed. Tornadoes will be related to operator-identified mesocylone tracks and to rotational velocity at, and 10 minutes prior to tornado occurrence. The Des Moines Office's operational response to the tornado threat will also be discussed. This brief paper will conclude with recommendations for warning decisions during this type of event.

2. SYNOPTIC ENVIRONMENT

The storm environment and tornadic threat was well forecast by the Storm Prediction Center and local forecasters. Only a brief overview will be provided. Aloft, a closed upper level storm system moved northeast from Colorado during the day on 11 April. A jet maximum, with winds speeds in excess of 50 ms^{-1} from 500 mb on up, rotated northeast into Iowa during the afternoon hours.

A strong surface low moved from central Kansas into southeast Nebraska during the day. An associated warm front, which extended roughly east-west along the Iowa/Missouri border at 1600 UTC, moved into central and north central Iowa by 2000 UTC. Storms were isolated along the warm front, but thunderstorms erupted all along a dryline oriented northwest-southeast as it moved from southwest into central Iowa during the afternoon (Fig. 2). Dewpoints climbed into the lower 60s (°F) south of the warm front and ahead of the dryline, producing CAPE up to 1500 Jkg^{-1} in the warm sector.

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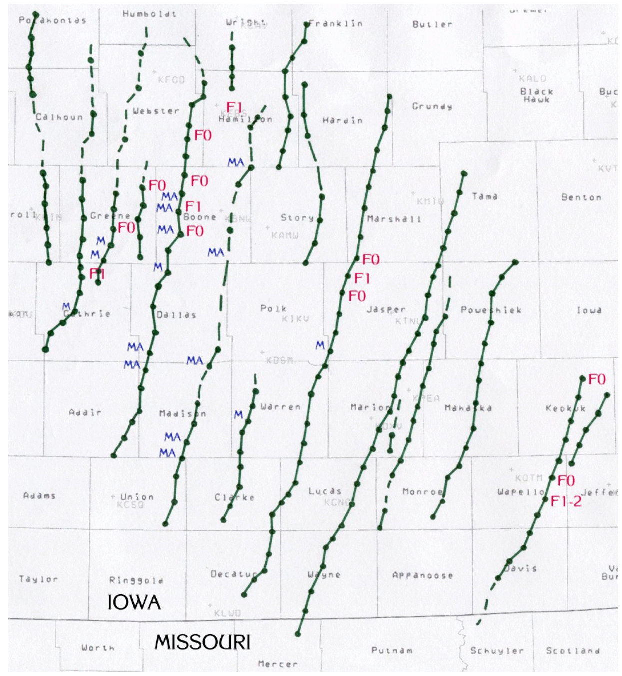

Figure 1. Operator identified low-level mesocyclone tracks on 11 April 2001 between 1900-2130 UTC. Dots indicate location of the rotation center every 5 minutes. Dash indicates that a "cell" was still identifiable on radar, but no velocity couplet was found. "FO" or "F1" to the right of the tracks indicate location of tornadoes and Fujita scale intensity. "M" left of track indicates WSR-88D mesocyclone detection, "MA" has a base above 5 km.

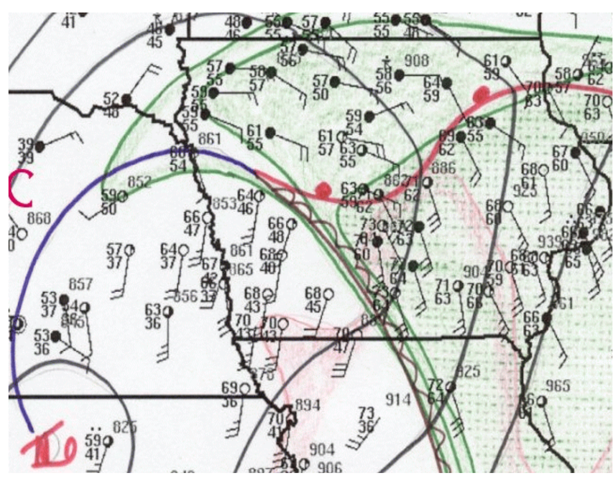

Figure 2. Surface map for 2000 UTC 11 April 2001

Bulk shear was quite high with values in excess of 30 ms^{-1} in the 0-6 km layer. Storm-relative Helicity ranged from 250-350 m^2s^{-2}. Values were similar north of the warm front (weaker low-level winds from the east) to those just ahead of the dryline (strong low-level winds from the southeast).

Forecasters expected dryline storms to be low-topped mini supercells due to the lowered equilibrium levels and high shear environment as the upper low approached. Potential for rapid tornadogenesis was also possible, based upon time of day, low-level cyclonic convergent flow, LCL/LFC heights and available 0-3 km CAPE (Davies, 2002). Conditions were expected to be most favorable near the dryline/warm front intersection northwest of Des Moines. Figure 3 is a modified 2000 UTC RUC sounding by Jon Davies. It is representative of the pre-dryline environment near Ottumwa.

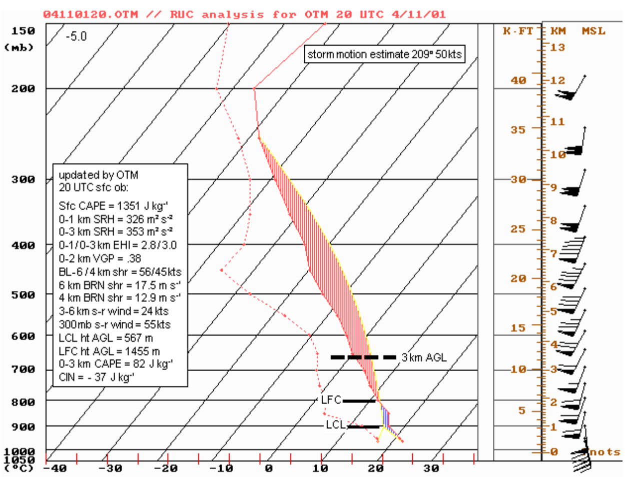

Figure 3. RUC sounding modified with surface data from Ottumwa at 2000 UTC 11 April 2001. Created by Jon Davies and used with his permission

3. STORM TYPES

A detailed analysis of WSR-88D data using the National Weather Service's Weather Event Simulator identified three main storm types in central Iowa between 1900-2130 UTC on 11 April 2001. All of the storms were small in horizontal and vertical extent (tops below 9 km). Signatures in the radar imagery were too small and subtle to reproduce in this preprint format. Please contact the lead author for access to color images.

To the west and northwest of the Des Moines radar, storms organized into a thin, nearly continuous line. Numerous persistent areas of low to mid level rotation developed along the line and moved north, resulting in comma head reflectivity structures embedded within the line. Although small and narrow, the structures fit one mode of evolution for high-precipitation supercells as described by Moller et al. (1994). Rotation was shallow, and rarely extended deeper than 3-4 km.

A few of the stronger rotation centers produced short-lived F0 or F0-1 tornadoes (Fig. 1). One mesocyclone produced 4 brief tornadoes in Boone and Webster counties between 2000 and 2030 UTC. Storm chasers from Iowa State University saw two tornadoes. These occurred behind (south of) a line of low hanging clouds and rain. Rotational velocity at the time of tornado for this portion of the line ranged as high as 16-18 ms^{-1} at a range of 40-60 km and a height of 600-900 m agl. However, most rotational velocities were only 11-16 ms^{-1}, and the velocity couplet was comprised of only a few pixels.
Numerous other cells and other volume scans showed similar velocity signatures without a tornado. Radar signatures weakened considerably after 2000 UTC, even though tornadoes continued to develop, all complicating the warning decision process.

Storms to the southeast of Des Moines showed much greater separation along the line. Several of the stronger storms contained deep, persistent rotation of some magnitude, and could be considered supercells. Two of these supercells persisted for the entire 2.5 hour period of sampling. The supercells produced only two tornadoes east of Des Moines between 1900-2130 UTC.

The first tornado, 40 km east of Des Moines, produced an intermittent track of F0-1damage for 11 minutes. It was associated with a classic mini-supercell, as discussed by Burgess et al. (1995) and Foster and Moller (1995). This isolated, circular storm contained a mesocyclone, well defined weak echo region and a hook echo for several volume scans. Storm diameter was less than 7 km (reflectivity) while the velocity couplet was sometimes less than 2 km in diameter. The tiny WSR-88D velocity couplet was at times quite strong, and broadened with height. Even at close range to the radar, the low-level mesocyclone occasionally was comprised of only one inbound and one outbound pixel of maximum velocity. Rotational velocity reached 23 ms^{-1} ten minutes before the tornado developed. An off-duty NWS employee described the storm as "high-based and producing very little rain" only 15 minutes before the tornado developed.

Farther southeast, storms were slightly deeper and supercells were interspersed with multi-cell storms. The most noteworthy tornado of the day, of F0 to marginal F2 intensity, struck the town of Agency. Two women were killed when the wall of a small community building collapsed. The tornado lasted only 8 minutes. Structure of the parent storm is difficult to ascertain, due to distance from the radar. The storm was 75-85 nm from both the Des Moines and Davenport WSR-88D radars, and sampling of the lowest elevation cut was almost 3 km above ground level (agl).

Mid and upper levels of the storm exhibited some high-precipitation supercell characteristics. These included mid-level rotation and a persistent S-shape in the mid-level reflectivity maximum. Rotational velocity was at a maximum during the tornado (16 ms^{-1}), but weaker by 2-4ms^{-1} before the tornado. An increase in rotational velocity (Figure 4) occurred at the same time as the tornado developed, and provided no lead time before the tornado. A trace from the Davenport WSR-88D was nearly identical. Radar structure below 3 km is unknown. Spotters reported little if any condensation funnel with this tornado.

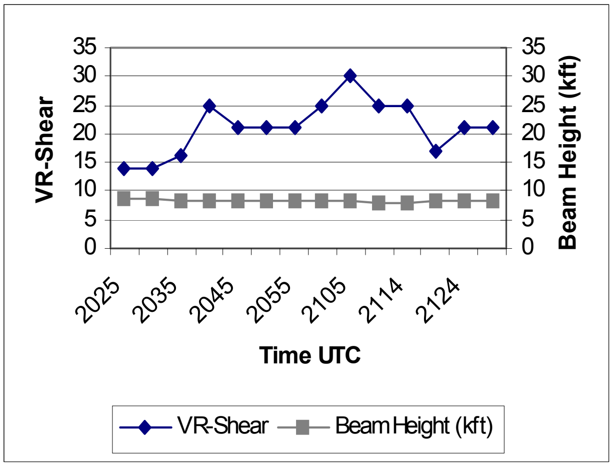

Figure 4. Graph of Rotational Velocity (kt) at 0.5 degree elevation from the KDMX WSR-88D on 11 April 2001 for the mesocyclone associated with the Agency tornado. Plots also show the height of the beam (kft). The tornado occurred between 2100-2108 UTC.

4. MESOCYCLONE TRACKS -VS- TORNADOES

The warning decision process was very complex and fast-paced on 11 April 2001. Figure 1 shows that the sheer number of mesocyclonic storms was one factor. Warning meteorologists evaluated numerous rotating storms for severe weather and tornadic potential every few minutes, simultaneous with the issuance of warnings and severe weather statements. In addition, Figure 1 shows that the number of tornado occurrences and the tornado durations were extremely small compared to the number and lifetime of the mesocylones. Essentially, even on this "outbreak" day, tornadoes were a rare event compared to the number of operator-identified mesocyclones

The observations above highlight the need for warning meteorologists to discriminate between mesocyclones with a tornadic threat, and those without. Given the range and beam-filling considerations mentioned in section 3 above, this was a very difficult task. Due to the same considerations, the WSR-88D mesocyclone algorithm triggered on only half of the volume scans between 1900-2130 UTC. Several of the mesocyclones were at high levels in the storms (above 5 km on this day) and of questionable value. No mesocyclones were detected after 2025 UTC when two of the more significant tornadoes occurred. No Tornado Vortex Signatures (TVSs) were detected by the algorithms. This made identification of most of the mesocyclones and detection of potential tornadoes a manual process. As mentioned in Section 2, the near-storm environment was continuously evaluated as well.

5. ROTATIONAL VELOCITY AT THE TIME OF TORNADOES

Once the near-storm environment, past history and spotter reports are considered, rotational velocity can be utilized to gauge a storm's tornadic potential. Figure 5 shows the maximum rotational velocity for each of the ten tornadoes, at the time of tornado touchdown. The range is fairly wide, from 11 to 18 ms^{-1} (21-35 kt). Given that there were numerous other storms, and other times without tornado, having similar rotational velocity, it appears that this parameter was of limited operational use. It was also difficult to identify tightening or deepening of the circulations, due to the small horizontal and vertical size of the circulations.

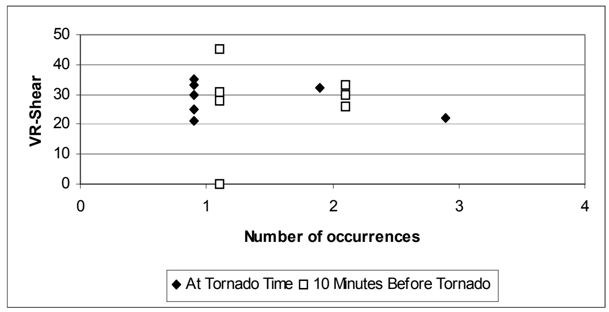

Figure 5. Maximum rotational velocity (kt) within the mesocyclone associated with tornadoes between 1900-2100 UTC 11 April 2001.

In order to provide tornado warning lead times, signatures need to be present before the tornado. Figure 5 also shows the maximum mesocyclone rotational velocity for each of the tornadoes, ten minutes before the time of tornado touchdown. Most values here are similar to those at the time of tornado, with the exception of one particularly strong value (the mini-supercell just east of Des Moines), and one in which no rotation was discernible preceding the tornado. Again, with one exception, these values are considered weak to moderate rotation even for mini supercells, and are probably of limited use.

6. OPERATIONAL RESPONSE

After the early long-track tornado dissipated, severe weather operations at the National Weather Service in Des Moines were reorganized in preparation for another round of severe weather. An all-staff weather briefing was held, and operational positions assigned. Two warning teams were set up, each with responsibility for one half of the warning real estate. Each team was comprised of a warning meteorologist, and an assistant, who's duties included completion of warning/statement text, inclusion of spotter reports, and outgoing calls to spotters for information. An additional communicator, NOAA Weather Radio controller, short-term forecaster and HAM radio volunteers were also utilized.

Convective outlooks and tornado watches from the Storm Prediction Center highlighted the potential for an outbreak of tornadoes, and the tornado watch in effect before the tornadoes used "Particularly Dangerous

Situation" wording. Hazardous Weather Outlooks (HWO) from the NWS in Des Moines also keyed on the tornado threat. In addition, the HWO informed spotters that storms would be fast moving and small, that tornadoes would be quick-hitting and short lived, and that spotting would be difficult.

For the event, 17 tornado warnings were issued, including 27 counties. Most warnings focused to the northwest of Des Moines, near the intersection of the warm front and dryline. The event evolution was accurately anticipated, but the False Alarm Rate (FAR) remained fairly high (0.48). Still, two deaths occurred and two people were injured in Wapello County, minutes before a tornado warning was issued. The warning was based upon a report of a tornado, rapidly relayed to the NWS by local law enforcement.

6. WARNING DECISION RECOMMENDATIONS

What does the warning meteorologist do when WSR-88D signatures are weak, identifications by mesocyclone algorithms and tornado detection algorithms are infrequent, and tornadoes are fast moving with short lifetimes? Based upon this case, and operational experience with several similar cases in Iowa, the following items should be considered and provide opportunities for further research.

- Use the near-storm environment to anticipate where rotating storms are are most likely to produce tornadoes.
- Consider, in advance of storm development, warning "thresholds." Pre-determine (and then adjust) which signatures, depth and intensity of rotation, and storm lifetimes will prompt a tornado warning. For low-topped mini-supercell environments like 11 April 2001, the threshold should initially be quite low, given the likelihood of tornadoes and the potential for a significant event.
- It is strongly suggested that the warning team for an event come to a consensus on the warning threshold as a group. This will provide consistency in the warning operation and broad support for warning decisions on a given day. Experience has shown that without this consensus, the thresholds of individual forecasters vary widely, which could lead to inconsistent customer service.
- Previous to 2020 UTC, the WSR-88D mesocyclone algorithm provided some useful tornado warning guidance. Four of five *low-level* algorithm detected mesocyclones were followed by brief tornadoes within a few volume scans. Meanwhile, only one of nine *high-level* algorithm detected mesocyclones (bases above 5 km) were followed by tornadoes. Despite several rotating storms after 2020 UTC, there were no more algorithm detected mesocyclones.
- The WSR-88D Tornado Detection Algorithm (TDA) did not trigger between 1900-2230 UTC, and was not used as guidance.
- Clearly understand the radar limitations for mini-supercell events. Due to sampling limitations, including beam height and beam width, tight circulations may be washed out or undetectable.
- Storms with clearly defined mini-supercell structure (well-defined weak echo region, mesocyclone with consistent vertical continuity, hook echo, velocity couplets) eventually produced a tornado on 11 April 2001. Identification of this structure, and issuance of a tornado warning would have produced long lead times, but very high false alarm rates.
- For the area east and southeast of Des Moines, two of three storms with the largest separation from other storms produced tornadoes for a portion of their lifetimes.

In summary, storms with the best mesocylone/mini supercell characteristics, plus separation from other storms and (infrequently) algorithm low-level mesocyclone detection, were the storms that briefly produced tornadoes on 11 April 2001. Those storms deserved the highest priority for tornado warnings. Other storms approached these characteristics many times, and may have also warranted tornado warnings given the favorable environment on 11 April 2001.

7. REFERENCES

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8. ACKNOWLEDGMENTS

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