P9.1 WARNING DECISION MAKING PROCESSES AT WFO JACKSON, MS DURING THE TORNADO OUTBREAK OF 24 NOVEMBER 2001

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1. INTRODUCTION

A significant outbreak of severe thunderstorms and tornadoes occurred across parts of the lower Mississippi Valley, Mid-South, and Gulf Coast regions on 24 November 2001. A number of strong and violent tornadoes occurred during the region on this day, with several fatalities and millions of dollars in damage being the result.

For the county warning and forecast area (CWFA) of the Jackson, MS, (JAN) National Weather Service (NWS) Weather Forecast Office (WFO), the main impact of this outbreak occurred during the early morning hours between 0000 LST and 0800 LST. During this time period, eight tornadoes occurred across parts of extreme southeast Arkansas, extreme northeast Louisiana, and parts of northwest and central Mississippi. Two of these tornadoes produced damage rated as F4 on the Fujita-Pearson (FPP) Damage scale, while two more produced damage rated as F3. One of the F4 tornadoes moved through a highly populated area in the northwest part of the Jackson, MS metropolitan area. A total of five people were killed in the Jackson CWFA during this event, and 95 people were injured.

The four strong to violent tornadoes which occurred on this morning were associated with three long-lived supercell thunderstorms which moved across the region. This paper will look at the warning decision making challenges associated with these storms. This will include discussions of radar data and the use of the National Severe Storm Laboratory's Warning Decision Support System (WDSS) radar analysis system, which is utilized in Jackson for warning operations.

2. PRE-STORM ENVIRONMENT

One of the most important steps in performing effective warning decision making is to properly anticipate convective initiation and mode. Correct anticipation of the convective environment allows for proper staffing alignment and good situational awareness for the warning meteorologists. This step proved to be one of the most difficult for this event.

Most of the area which suffered the tornado outbreak in the Jackson CWFA was in a "slight risk" of severe thunderstorms on outlooks from the National Centers for Environmental Prediction (NCEP) Storm Prediction Center (SPC) valid 23 November 1200 UTC through 24 November 1200 UTC. However, the focus was on southern Missouri and western Arkansas for an outbreak of severe weather. This area (in a "moderate risk") was forecast to be closer to a mid level shortwave trough and associated deepening surface low which was forecast to move from northwest Kansas to northwest Missouri during the night of 23 November.

Additionally, data from the NCEP Eta model indicated that this region would have more favorable wind profiles and stronger instability than areas farther to the southeast. Forecasts from this model initialized 12 to 24 hours prior to the event indicated that Convective Available Potential Energy (CAPE) would only range from 300 J kg^{-1} to 1200 J kg^{-1} in the area where the tornadoes eventually occurred, with storm relative environmental helicity (SREH) values between 300 and 500 m^{2}s^{-2}. Even in the shorter term, the RUC model initialized as close as three hours to the event only indicated CAPE and SREH values in this range. In actuality, as can be seen in Fig. 1, values of CAPE and SREH were much higher over the region than forecast by the models.

The combination of these factors made anticipating the magnitude of this event quite difficult. WFO JAN did correctly anticipate the potential for tornadic supercells during this event as early as the evening of 22 November, and conveyed this information to users and customers through products such as the Hazardous Weather Outlook. However, the lack of forecast guidance indicating an outbreak of significant tornadoes meant that situational awareness was likely not at as high of a level as would ordinarily be seen at the outset of an event such as this.

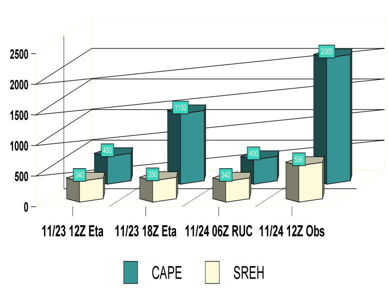

Fig 1. Graph of model forecasts of CAPE and SREH at JAN with 1200 UTC 24 Nov JAN observed values.

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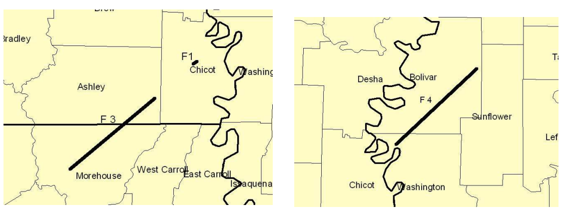
3. WARNING DECISION MAKING

As mentioned above, the strong and violent tornadoes associated with this event were produced by three supercell storms. Distinct warning challenges were associated with each one.

3.1 Supercell #1 - Arklamiss Storm

The track of the tornadoes associated with the first supercell (hereafter S1) can be seen in Figure 2.



A **B**

Fig. 2. Track of tornadoes from S1 across northeast Louisiana and southeast Arkansas (A), and northwest Mississippi (B). Maximum FPP scales as shown.

This supercell was the first storm to affect the Jackson CWFA during this event. The initial tornado developed in Morehouse Parish, LA at approximately 0640 UTC.

The initial tornado development with this supercell occurred while the storm was approximately 175 km from the Jackson, MS WSR-88D radar. At this range, the center line of the radar beam is at an altitude of approximately 3.5 km (assuming standard propagation). In the critical 30 min prior to tornadogenesis during which warning decisions must be made, the storm was even farther away, precluding any radar sampling of the lower levels of the storm.

However, time-height trends of rotational velocity from WDSS clearly indicated the presence of a mesocyclone with this storm. While rotational velocity values were not particularly strong, ranging from 12 to 15 m s^{-1} at the lowest elevation to 10 m s^{-1} at higher levels, the mesocyclone was deep, extending from the lowest elevation to approximately 9 km for several volume scans prior to the initial tornadogenesis. Additionally, the availability of .25 km (.13 nmi) base reflectivity data in WDSS made apparent the presence of a bounded weak echo region in the storm. The presence of these features enabled forecasters to accurately identify the storm as a supercell.

Without radar sampling of the lower levels of the storm, knowledge of the near storm environment becomes even more critical to the warning decision process. As discussed above, situational awareness was likely not as high in this event as might ordinarily be observed in a significant tornado outbreak. Still, observational data did indicate that conditions were favorable for tornadoes with any supercells that developed in this environment (e.g., RUC initialization at 0600 UTC showed 0-3 km SREH values of nearly 400 m^2s^{-2} over northeast Louisiana). In the end, the identification of a supercell in an environment favorable for tornadoes resulted in WFO JAN issuing a tornado warning for this storm with approximately 24 min lead time. This was in spite of the fact that rotational velocity values never exceeded 12 m s^{-1} at 0.5 degrees (deg) on the KJAN radar prior to warning issuance, or 15 m s^{-1} prior to tornadogenesis.

After tornadogenesis, the storm tracked northeast into Ashley County, AR, producing tornadic damage through 0713 UTC (see Fig. 2). By the time the initial tornado dissipated, the storm was approximately 155 km from the radar, with the beam still at an altitude of about 3.1 km. Rotational velocity values did increase as the storm moved somewhat closer to the radar, peaking at 22 m s^{-1} at 0.5 deg at 0712 UTC. Based on these trends in rotational velocity, easily seen in WDSS time-height trends, and supportive reflectivity structures, tornado warnings were issued for the southeast Arkansas counties downstream from Morehouse Parish.

Rotational velocity values remained nearly constant after tornado dissipation, before increasing again between 0720 and 0730 UTC. A peak in rotational velocity of 31 m s^{-1} was observed over Chicot County, AR, at 0731 UTC at 0.5 degrees, at an elevation of approximately 2.9 km. A second tornado occurred at this time (see Fig. 2), but was weak and on the ground for only around 2 min.

Although no damage occurred between 0733 UTC and 0755 UTC, rotational velocity values at 0.5 deg remained strong, never dropping below 23 m s^{-1} and peaking at 33 m s^{-1} at 0755 UTC. At this time, the storm was still about 155 km from the radar. Reflectivity data became quite impressive during this time as well, indicating strong weak echo region structures and Vertically Integrated Liquid (VIL) values in excess of 60 kg^2m^{-2}. Tornado warnings were issued downstream for Washington and Bolivar counties in northwest Mississippi.

At 0755 UTC, the third tornado developed from this supercell. This tornado would be on the ground for over 40 km, until 0832 UTC. A damage survey performed for this tornado indicated F4, at times bordering on F5, damage from about 0800 to 0825 UTC. During this time period, rotational velocity values dramatically weakened, reaching a minimum of 12 m s^{-1} at 0817 UTC with the storm moving slightly farther from the radar (range of 165 km by 0825 UTC). Additionally, VIL values decreased into the lower to middle 40s.

A cursory examination of the trends associated with the storm during the 0800 to 0825 UTC timeframe might have indicated to the warning forecaster that the storm was weakening, and that warnings should not be continued or extended. However, past research and experience has shown that strong rotation may become concentrated in the lower levels of the storm during the tornadogenetic process, and not be visible if the storm is at a relatively long range from the radar. In this case, rotational velocity values at the lowest elevation available to the warning forecaster showed a marked decrease during the time that a high end F4 tornado was on the ground. Reports of damage from the area being affected by S1 kept situational awareness at a high level, and warnings were continued for Bolivar County, and issued for the next county, Sunflower. However, it can be difficult to recognize in realtime that “weakening” on radar does not always directly correlate to true weakening of a supercell storm, as will be seen with S2 below.

After 0825 UTC, the storm showed some signs of increasing rotational velocity values, peaking at 17 m s^{-1} at 0837 UTC. This occurred even though the storm was moving away from the radar, ending up at a range of 185 km at 0837 UTC with the beam centerline at a height of 3.5 km. Shortly after this time at 0842 UTC, a fourth tornado was produced in extreme northern Sunflower County, just as the storm was exiting the Jackson CWFA.

3.2 Supercell #2 - Northeast Louisiana/West Central Mississippi Storm

Supercell #2 (hereafter S2) initially developed around 0700 UTC over northeast Louisiana. The storm tracked northeast toward west central Mississippi, and by 0830 UTC had a well developed mesocyclone. Rotational velocity values between 0830 and 0915 UTC ranged from 15 to 20 m s^{-1} at 0.5 deg (with the radar beam at an elevation of about 2 km). The circulation was quite deep, with values between 10 and 15 m s^{-1} at elevations up through 9 km. Rotational velocities in the lower elevations increased further between 0915 and 0930 UTC, reaching a peak of 26 m s^{-1} at 0930 UTC at 0.5 deg.

By the time the mesocyclone developed in this storm, reports had been received indicating that significant tornadoes had occurred with S1. Based on this, situational awareness reached a higher level that the environment in this area likely favored damaging tornadoes. Tornado warnings were issued along the path of this storm from 0824 to 1000 UTC.

After 0930 UTC, the rotational velocities associated with this storm decreased, and the depth of the mesocyclone became shallower. By 0952 UTC, the depth of the mesocyclone had decreased from a peak of near 9 km to 3.5 km. Rotational velocities decreased to 14 m s^{-1} at 0.5 deg, which had a center beam height of around 2.5 km. VIL and overall reflectivity values also decreased during this time. In contrast to S1, no reports of severe weather were received along the path of the storm, although the area traversed by the storm is a very sparsely populated area from which reports are often not received during the night.

At the time this apparent weakening trend was noted on radar, the storm was moving out of Issaquena County, MS toward Sharkey and Washington counties. Based on radar trends indicating a weakening storm, the warning meteorologist changed philosophy on the storm, and issued a severe thunderstorm warning for Washington and Sharkey counties at 0951 UTC.

Between 0952 and 1017 UTC, rotational velocity in the lower levels held relatively constant at around 16 m s^{-1} at 0.5 deg. Shear values on the storm ranged between .005 and .008 s^{-1}, and gate to gate velocity difference ranged from 23 to 29 m s^{-1} . The depth of the mesocyclone also remained relatively shallow, with the rotation only detected through 4 km by 1012 UTC. Reflectivity values continued to decrease with the storm as well, with the VIL value down to 15 kg^2m^{-2} at 1017 UTC. Based on these trends, no warning was issued for Humphreys County. However, the reflectivity structure of the storm changed during this time, with a rear inflow notch, likely indicative a strengthening rear flank downdraft, apparent with the storm by 1017 UTC.

Around this time, a tornado producing F3 damage developed just southwest of the town of Isola, in northern Humphreys County (Fig. 3). On the next radar volume scan, at 1022 UTC, the rotational velocity at 0.5 deg increased to 24 m s^{-1}; the circulation had also tightened somewhat, with shear values reaching .015 s^{-1}, and gate to gate velocity difference reaching 49 m s^{-1}. The VIL value on the storm at this time was 12 kg^2m^{-2}. The tornado dissipated at 1025 UTC, and by the next volume scan at 1027 UTC, very little in the way of rotation was detectable at any elevation angle. By 1040 UTC, the storm itself had dissipated.

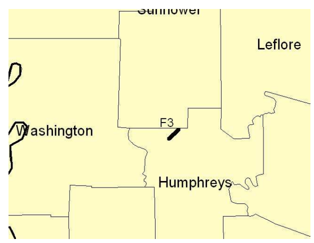


Fig 3. Same as Fig. 2, only for S2 over west central Mississippi.

Clearly, the fact that no warning was in effect during this tornado was mainly due to the perceived weakening of the storm based on radar trends, combined with lack of reports. However, as has been noted in past research, supercell storms sometimes show a “cyclic” nature of weakening and reintensifying. Furthermore, as will be discussed further below, many reflectivity and velocity parameters can show weakening during the “collapse” phase of a supercell while tornadogenesis is occurring.

3.3 Supercell #3 - Jackson Metropolitan Area Storm

S3 initially developed over southwest Mississippi around 0930 UTC. The storm moved northeast toward the Jackson area, and quickly showed supercellular characteristics. By 1005 UTC, a deep mesocyclone was in place, with rotational velocity values of 13 to 18 m s^{-1} extending from 1.5 to 7.5 km.

As the storm entered Hinds county (see Fig. 4) around 1030 UTC, both velocity and reflectivity data clearly indicated a well developed supercell storm. A reflectivity cross section taken at this time showed a well defined BWER, with reflectivity values of 65 dBZ extending to an altitude of 8.5 km. WDSS time-height trends of rotational velocity began to show a strong increase in rotation just above the 0.5 deg elevation angle (an altitude of 750 m), with values of 17 to

23 m s^{-1} from 1.5 km to 6 km at 1027 UTC. Based on these trends, a tornado warning was issued for Hinds County, MS at 1030 UTC.

After this time, the storm moved northeast across central Hinds County, continually moving closer to the Jackson WSR-88D, which is located in extreme western Rankin County (see Fig. 4). By 1110 UTC, the storm was located over northeast Hinds County and approaching southern Madison County. At this time, the storm was less than 20 km from the Jackson 88D. The 0.5 deg elevation angle was at an altitude of about 150 m AGL, and the storm was not being sampled by the radar above 8 km due to the "cone of silence."

1110 UTC was the "decision time" for warning for the next downstream county, Madison. At this time, only one report of severe weather, some minor wind damage, had been received. The storm had consistently shown reflectivity characteristics indicative of a supercell, including a BWER and "hook echo." Additionally, a three body scatter spike, indicative of large hail, and reflectivity values above 65 dBZ in the mid levels had been observed.

However, in contrast to S1 and S2, the main increase in the rotational velocity with S3 had been noted well above 0.5 deg. Very strong rotational velocity values of 25 to 38 m s^{-1} were observed at 1110 UTC between 1.5 and 4.5 km, with very little in the way of rotation seen below 1 km. With situational awareness at a very high level due to earlier events, and a very well developed supercell, a tornado warning was issued for Madison County at 1110 UTC.

At around 1125 UTC, a tornado producing F4 damage developed over southern Madison county, as seen in Fig. 4. Prior to tornadogenesis, WDSS time-height trends showed limited rotation or shear at 0.5 deg, and this was borne out by subjective analysis. However, the 1118 UTC scan showed a marked increase in rotation to 20 m s^{-1} at this level, while at 1123 UTC the value peaked at 22 m s^{-1}. Shear values also increased to .025 s^{-1}. Throughout the time the tornado was occurring, WDSS time-height trends of velocity parameters showed peak values between 1 and 2.75 km, with somewhat weaker values at the lowest elevations (i.e., 0.5 and 1.5 deg).

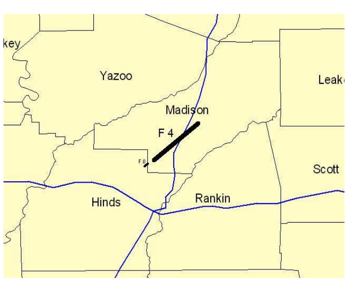


Fig. 4. Same as Fig.2, only for S3 over central Mississippi.

4. Conclusions

The three supercell storms of the morning of 24 November 2001 provided distinctly different warning decision making challenges. Successful warnings were provided for S1 and S3, while no warning was in effect during a brief F3 tornado produced by S2.

S1 never moved closer than 155 km from the radar, with radar sampling never occurring below 2.9 km. The fact that rotational velocity values significantly decreased at 0.5 deg during the time an F4 tornado was on the ground serves to demonstrate the challenges associated with such a storm. The fact that the storm occurred in a sparsely populated area, after Midnight LT, and in an area with very few storm spotters simply exacerbates the challenge in warning for such a storm. Near-storm environment data takes on an even more important role in such a situation. In a situation like this, storms identified as supercells at this distance from the radar, in a highly favorable tornadic environment, may simply need to be warned for until dissipation, with limited regard for radar derived rotational velocity trends.

As has been documented in past research (e.g., Lemon and Doswell 1979), tornadoes with supercells often occur during the "collapse" of the BWER and echo top. This was demonstrated with S2, as VIL and echo top values decreased for several volume scans prior to tornadogenesis. During this collapse, rotational velocity values may peak in the lower levels while decreasing in the mid levels as tornadogenesis occurs. At a significant distance (e.g. more than 100 km) from the radar, the radar beam may be too high to see the low level increase in rotation, with the warning meteorologist seeing instead a decrease in rotational velocity values at the lowest elevation. As S2 shows, in a very favorable environment for tornadic development, warning meteorologists should only give limited weight to short term weakening trends of derived reflectivity and velocity parameters for well developed supercells, particularly for storms more than 100 km from a radar.

A very different warning challenge was posed with S3. Here, radar sampling of the lower levels of the storm was excellent, with the 0.5 deg angle likely near or below cloud base during the time tornadogenesis was occurring. In this instance, warning meteorologists had to be aware that the lack of rotation at the lowest elevation angles did not mean that tornadogenesis was not imminent, as any strong rotation at 0.5 deg might not be visible until the tornado was already forming.

All three cases demonstrate that algorithm output and trends in derived parameters such as rotational velocity, shear, VIL, etc., are only one part of the warning process. Meteorologists well trained in mesoscale and storm scale meteorology are needed to properly interpret changes in storm structure and key storm parameters, and to integrate near storm environment data into a sound warning assessment. New training tools such as the Weather Event Simulator provide opportunities to expose meteorologists to warning challenges such as these outlined here. Additionally, access to advanced warning decision aids such as WDSS can assist the warning process. The availability of high resolution data and easy monitoring of critical storm-scale and mesoscale parameters in time and space through multi-panel displays, cross-sections, and tables, allow the warning meteorologist to more easily process radar and near-storm environment data, and effectively utilize it in the warning process.