

# MEMPHIS NATIONAL WEATHER SERVICE PERSPECTIVE OF THE SEVERE WEATHER OUTBREAK OF MAY 2003: FOCUS ON THE F4 MADISON COUNTY, TENNESSEE TORNADO

Jonathan L. Howell, Gregory R. Garrett, Scott J. McNeil and Daniel N. Valle

NOAA/National Weather Service Weather Forecast Office  
Memphis, Tennessee

## Abstract

*Several supercell thunderstorms, some producing strong and violent tornadoes, ravaged portions of northeast Arkansas, southeast Missouri, west Tennessee, and north Mississippi during the period 4-8 May 2003. The May 2003 tornado outbreak was responsible for thirty-five tornadoes that caused eleven fatalities, more than one-hundred injuries, and over one-hundred million dollars in property damage. This tornado outbreak ranked as the second largest to impact the Mid-South over the past 30 years. The most devastating thunderstorm to affect the region occurred on 4 May 2003. This supercell thunderstorm produced an F4 tornado that moved through Jackson, Tennessee, in Madison County. This tornado was responsible for all of the fatalities and tremendous property damage.*

*This paper will focus on the synoptic, mesoscale, and storm-scale environments preceding the Madison county supercell thunderstorm and how they influenced the storm's evolution and intensity. Finally, a discussion will be provided to show how proper recognition of these environments may positively impact warning decisions.*

## 1. Introduction

Severe thunderstorms that produce damaging winds, large hail, and tornadoes are common across the Mid-South (east Arkansas, the Missouri Bootheel, west Tennessee, and north Mississippi). Severe weather can occur throughout the year, with maxima during spring and late fall (Brooks 1999). Only about 10% of all tornadoes are significant (F2 or greater), yet they are responsible for the majority of deaths in the United States, with violent tornadoes claiming 67% of the total (Concannon et al. 2000). Violent tornadoes (F4 and F5 tornadoes) are responsible for producing devastating to incredible damage as defined by the Fujita Scale of Tornado Intensity (Grazulis 1993). In May 2003, a significant storm system produced strong to violent tornadoes across the area.

The 4-8 May 2003 tornado outbreak is ranked as the second worst to strike the Mid-South during the past thirty years. This tornado outbreak achieved this ranking because it produced the second most number of tornadoes in a single multi-day event. This outbreak also ranks as the longest multi-day tornado event during the 1974-2003 period, with tornadoes impacting

the area on five consecutive days (National Climatic Data Center 2003). This outbreak was second only to the January 1999 tornado outbreak in which forty-six tornadoes impacted the area over a three day period. Thirty-five tornadoes were documented during the period 4-8 May 2003 (Fig. 1). One tornado was rated at F4 intensity, two tornadoes at F3 intensity, six tornadoes at F2 intensity, and twenty-seven tornadoes at F1 or F0 intensity. The outbreak killed eleven people, injured more than one hundred, and caused over \$100 million in property damage.

The tornado that caused the greatest loss of life and property struck on the evening of 4 May 2003. Jackson, Tennessee (pop. 59,700), and nearby communities in Madison County bore the brunt of the damage and experienced all of the fatalities. F4 damage resulted from this tornado (Fig. 2).

The following assessment will provide an overview of the synoptic and storm-scale environment preceding the tornado event. This will be followed by an analysis of atmospheric stability and a detailed radar interpretation. A special perspective will also be given on storm-scale boundary interactions within the thunderstorm's environment.

## 2. Pre-Storm Environment

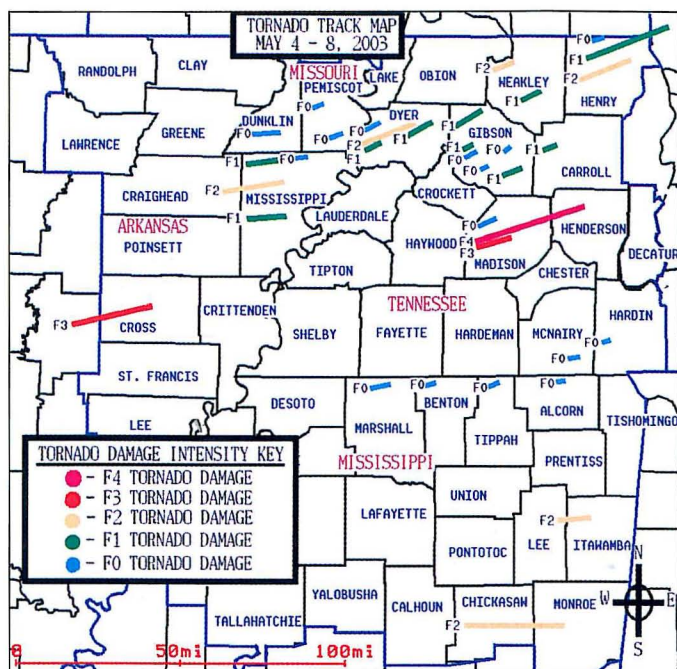
### a. Surface conditions

The regional surface analysis from 0000 UTC 5 May 2003 showed a warm front extending southeast across southeast Missouri, northeast Arkansas, and northwest Tennessee, from a deepening 990 mb low centered over northwest Missouri. Along and south of the front, temperatures and dewpoints were unseasonably high. Southerly winds advected warm, moist air northward from the Gulf of Mexico. Surface observations taken between 0000 UTC and 0300 UTC showed that temperatures and dewpoints increased an average of one to three degrees in three hours across the area south of the front. By 0300 UTC, one hour prior to the F4 Madison County tornado, temperatures rose to near 80°F (27°C), with dewpoints that exceeded 70°F (21°C) (Fig. 3).

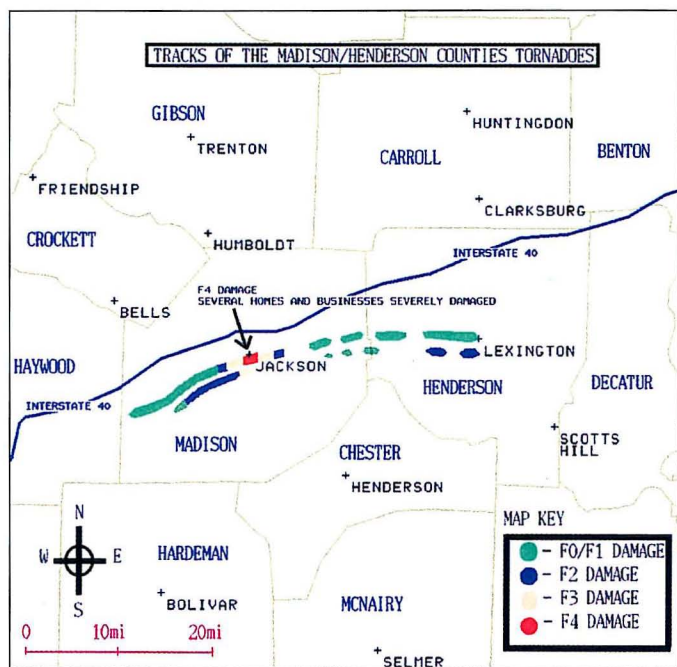
### b. Upper air conditions

The upper-level environment was also conducive to the development of severe weather. This was due to a



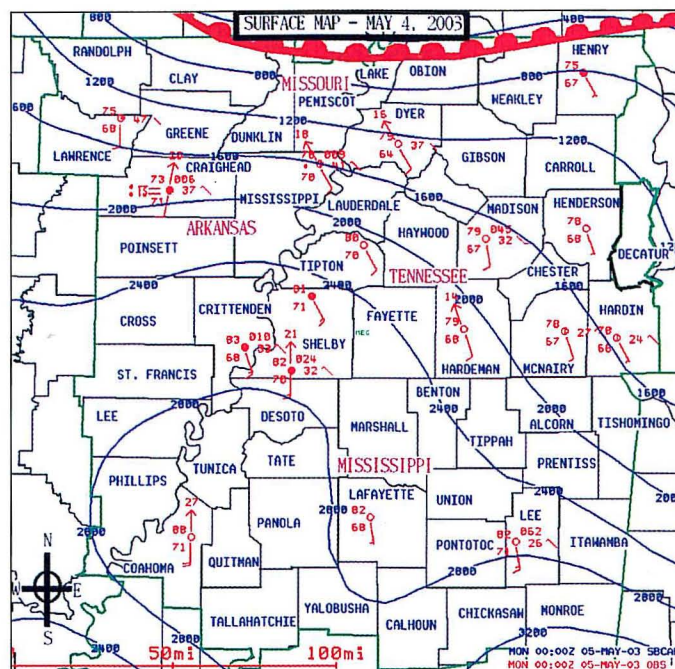


**Fig. 1.** 4-8 May 2003 Tornado Track Map. The lines above indicate individual tornado tracks. These tornado tracks have been color coded based on tornado intensity as determined by local storm surveys. Tornado intensities have been ranked using the Fujita tornado intensity scale.



**Fig. 2.** Madison-Henderson County F4/F3 tornado tracks. The map above shows a close up of the damage (as rated using the Fujita Tornado Intensity Scale) produced by the tornadic thunderstorm that moved across Madison and Henderson counties. The tornado paths are indicated by the solid lines and color coded for tornado intensity.

strengthening low-level jet stream, the approach of a highly amplified upper-level trough with a strong embedded shortwave, and positioning of the left exit region of a 250



**Fig. 3.** Surface analysis of the Mid-South region valid at 0000 UTC 05 May 2003. Surface observations showing locations of a warm front and positioning of a very warm, moist, and unstable airmass have been provided. Surface observations are station plots showing temperature, dewpoint, wind, pressure, and current weather information. Frontal symbols have also been plotted to show the delineation between differing air masses. The solid lines are indicative of CAPE (Convective Available Potential Energy) values across the area.

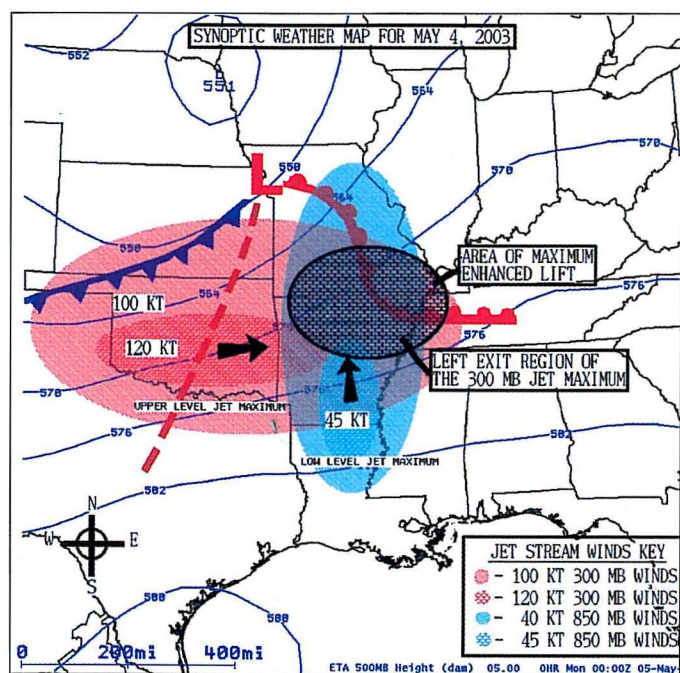
mb jet streak (Fig. 4) over the area, which is favorable for enhanced lift (Bluestein 2000). These features acted in conjunction with the low-level instability resulting in explosive thunderstorm development.

Southerly 850 mb winds in excess of  $25 \text{ m s}^{-1}$  (50 kt) overspread east Texas and southwest Arkansas on the afternoon of 4 May 2003. These low-level winds strengthened above  $35 \text{ m s}^{-1}$  (70 kt) as they shifted east over the lower and middle Mississippi River Valley by 0300 UTC. The 850 mb dewpoint also increased to  $16^{\circ}\text{C}$  ( $61^{\circ}\text{F}$ ) as the winds strengthened.

The 500 mb pattern at 0000 UTC 5 May 2003 was characterized by a deep, negatively tilted, long-wave trough over the north and central Plains, with strong mid-level ridging across the Ohio and Mississippi Valley regions. The long-wave trough was amplified by a  $65 \text{ m s}^{-1}$  (125 kt) 250 mb jet streak that was ejecting out of the base of the trough across the southern Plains.

The Mid-South came under the left exit region of the 250 mb jet streak as the 500 mb trough translated east by 0300 UTC. Diffluence and divergence were enhanced across this region and contributed to large scale ascent (Bluestein 1993). In addition, as a strong shortwave approached, 500 mb heights fell significantly. The falling heights were indicative of the cold core aloft overspreading the near surface warm sector, which further destabilized the atmosphere late into the evening.





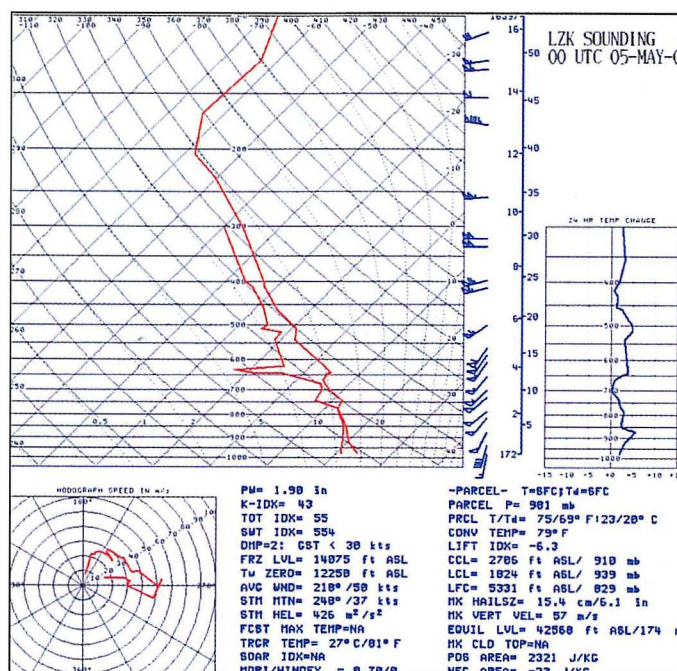
**Fig. 4.** Composite weather map valid at 0000 UTC 05 May 2003. This map shows a compilation of the synoptic weather environment across the Mid-South. Air masses are separated by frontal symbols, the shaded areas indicate jet stream winds of varying intensity, and the hatched area shows a region of maximum large-scale atmospheric lift.

### c. Sounding information

The 0000 UTC 5 May 2003 Little Rock, Arkansas (LZK), radiosonde (Fig. 5) showed significant deep layer shear, impressive low-level helicity, and unstable atmospheric conditions. Data from the sounding showed a 0–6 km shear value of  $29 \text{ m s}^{-1}$  (56 kt), veering winds with height, and a 700–500 mb lapse rate of  $7.8^\circ\text{C km}^{-1}$ . These large values indicated the increased threat for a major tornado outbreak (Craven 2000).

Other indications of the favorable severe weather environment included a surface-based CAPE (SBCAPE) of  $2632 \text{ J kg}^{-1}$  and a surface-based Lifted Index (LI) of  $-6^\circ\text{C}$  that was observed from the 0000 UTC LZK sounding. It was found that major tornado outbreaks are typically associated with moderate to high CAPE ( $1500\text{--}3500 \text{ J kg}^{-1}$ ) and helicity (NOAA/NWS Louisville 2004a). Environments that exhibit LI values between  $-6$  and  $-9$  are characteristic of very unstable environments (NOAA/NWS Louisville 2004b). The K-Index value from the 0000 UTC LZK sounding was 43 and the Total Totals value was 55, indicating that severe thunderstorms were likely. The values assessed from the 0000 UTC LZK sounding were supportive of a very unstable atmosphere that aided the development of strong updrafts.

Storm Relative Helicity (SRH) from the 0000 UTC LZK sounding suggested that there was a threat for strong to violent tornadoes. The observed 0–3 km SRH from the 0000 UTC LZK sounding was  $426 \text{ m}^2 \text{ s}^{-2}$  favoring supercell development over ordinary cell development (Rasmussen and Blanchard 1998).



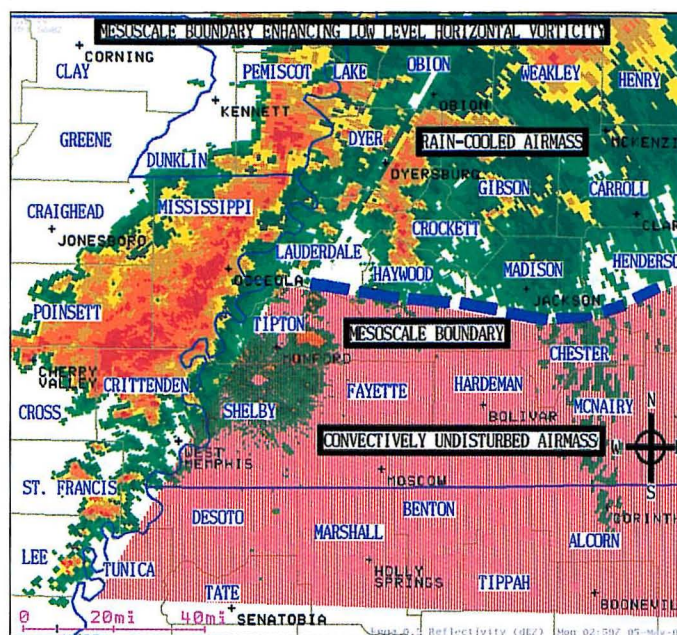
**Fig. 5.** Little Rock, Arkansas (LZK) atmospheric sounding at 0000 UTC 05 May 2003. The plotted lines are indicative of atmospheric temperature and moisture at LZK. Atmospheric winds are plotted along the right side of the skew-T log p diagram. Stability parameters are shown at the bottom along with a local hodograph.

The 0–1 km SRH observed on the 0000 UTC LZK sounding was  $281 \text{ m}^2 \text{ s}^{-2}$ . This value is quite significant when compared to the 0–1 km SRH values observed in work done by Edwards and Thompson (2000). The LZK sounding value exceeded the Edwards and Thompson 75<sup>th</sup> percentile value, and approached their upper extreme limit indicating an increased risk of significant tornadoes. These findings further support the importance of SRH in the low-level environment. This helps to explain why several tornadoes, some violent, developed on the evening of 4 May 2003 across the Mid-South.

### 3. Radar Interpretation

Thunderstorms were first detected by the KNQA WSR-88D radar (Millington, TN) across northeast Arkansas and the Missouri Bootheel around 2200 UTC 04 May 2003. These thunderstorms rapidly intensified as they moved northeast toward the Mississippi River by 0000 UTC 5 May 2003. Several of the thunderstorms acquired supercell characteristics as they moved northeast into an increasingly unstable and highly sheared environment. These supercell thunderstorms exhibited hook echoes evident in the base reflectivity (BREF) and strong, deep cyclonic rotation evident in the storm relative velocity (SRV) radar products. In addition, radar indicated that the thunderstorms were moving to the right of the mean wind flow. This enhanced the local helicity in the vicinity of these thunderstorms and led to strengthening of the updraft rotations which are characteristic of supercell thunderstorms (Klemp 1987). The supercell thunderstorms produced wind damage, large





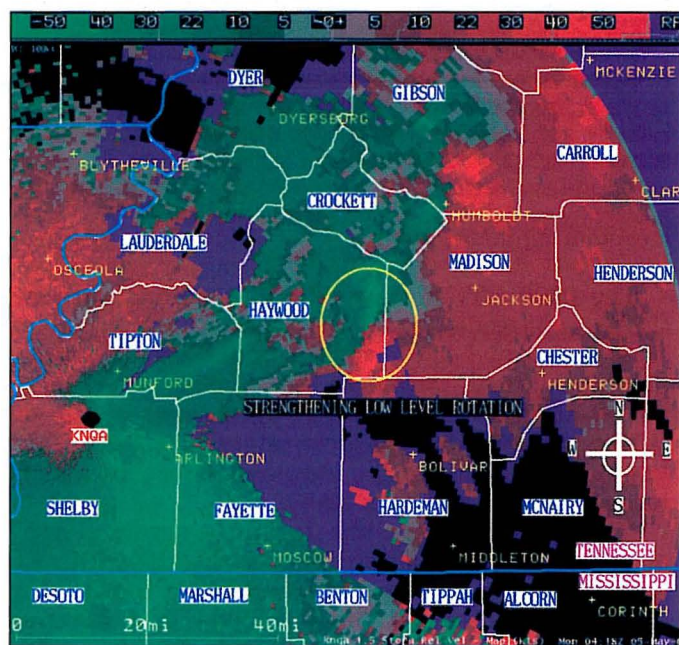
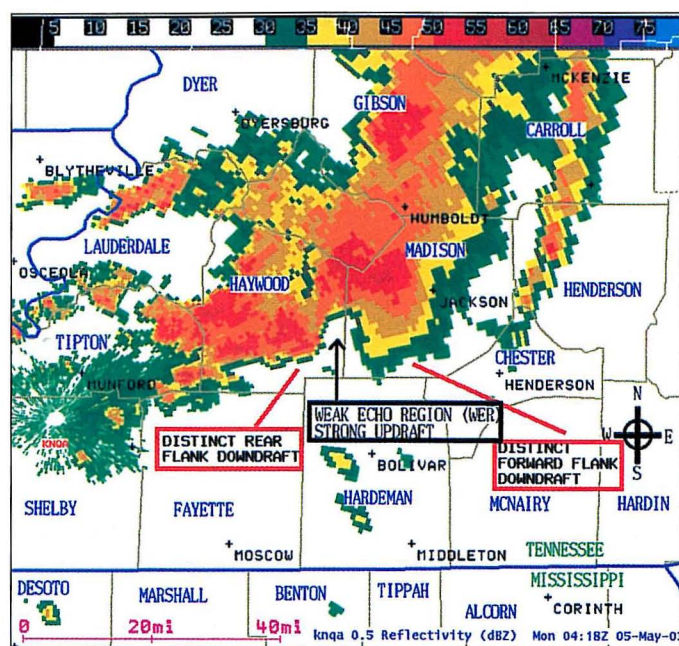
**Fig. 6.** 0.5° base reflectivity from KNQA at 0259 UTC 05 May 2003. Radar imagery indicates the presence of a mesoscale boundary that separates two distinct air masses. The mesoscale boundary is indicated by the elongated dashed line.

hail, and tornadoes as they moved to the northeast. Some of these supercells continued across the Mississippi River into northwest Tennessee by 0200 UTC.

After 0200 UTC, the initially discrete supercell thunderstorms evolved into a northeast-southwest oriented squall line with embedded supercell thunderstorms. By 0230 UTC, this squall line extended across the Mississippi river from northwest Tennessee into east Arkansas. Supercell thunderstorms embedded within the squall line moved northeast as the squall line traveled east. Additional reports of wind and tornado damage continued through 0330 UTC as the line of thunderstorms moved across extreme western Tennessee. Also worth noting was an area of rain that developed between 0230 UTC and 0300 UTC across the northern half of Haywood and Madison counties in west Tennessee. This likely established a mesoscale boundary that may have contributed to storm intensification (Fig. 6).

Between 0330 UTC and 0400 UTC, radar data indicated that the southern flank of the line was becoming oriented east-west across Mississippi County, Arkansas, and Tipton County, Tennessee. By 0400 UTC, the southern flank of the line had separated into discrete supercells, with the most intense storm moving into western Haywood County, Tennessee.

Between 0403 UTC and 0418 UTC, the Haywood County storm rapidly intensified as it ingested warm, moist, and convectively undisturbed air from the southeast. Base reflectivity data began to show an inflow notch developing on the southern flank of the storm as the updraft began to strengthen (Howieson and Tipton 1998). A strong updraft became evident as the reflectivity core dramatically increased from 55-60 dBZ at 24 kft (7315 m) to 60-65 dBZ above 30 kft (9000 m). Pronounced storm-



**Fig. 7.** Radar imagery for KNQA at 0418 UTC 05 May 2003 with (a) 0.5° base reflectivity showing a distinct weak echo region (WER), and (b) 1.5° storm relative mean velocity showing strengthening low level rotation (~7 kft AGL). Also in (b), the rotational signature has been circled in for easy identification. The colors indicate movement with respect to the radar, with green colors showing movement towards the radar and red colors away from the radar. Different color shades denote the speed at which radar targets are moving towards (green color) or away (red color) from the radar.

scale boundaries also became apparent in reflectivity data as distinct rear flank and forward flank gust fronts became well established within the storm (Fig. 7a). Prior to 0403 UTC, only weak, broad cyclonic rotation was observed with this storm. Between 0403 UTC and 0418 UTC, SRM data showed a strengthening mesocyclone





Fig. 8. As in Fig. 7b, but at 0428 UTC 05 May 2003 at 0.5° elevation.

with the strongest velocity couplet in the lowest levels of the storm (Fig. 7b), indicative of a non-descending mesocyclone (Trapp et al. 1999).

At 0423 UTC the storm had moved out of Haywood County and into Madison County in west Tennessee. The radar data showed a distinct hook echo at the 0.5° elevation slice with a bounded weak echo region (BWER) from 1.5° to 3.4°. SRM data continued to show a strengthening mesocyclone. By 0428 UTC, the mesocyclone couplet had tightened with greater than  $25 \text{ m s}^{-1}$  (50 kt) inbound winds immediately adjacent to  $25 \text{ m s}^{-1}$  (50 kt) outbound winds at 0.5° elevation. Post storm surveys correlated with radar data indicated that the tornado formed near Denmark, Tennessee, (Fig. 8) in southwest Madison County at this time.

Between 0433 UTC and 0438 UTC, 0.5° reflectivity showed that the thunderstorm continued to exhibit classic supercell structure with distinct and balanced forward and rear flank boundaries (Fig. 9a). A significant inflow notch directed inward toward the intersecting storm scale boundaries and a well defined hook echo were still apparent. A 0.5° SRM indicated greater than  $50 \text{ m s}^{-1}$  (100 kt) of rotational velocity (Fig. 9b).

At approximately 0440 UTC, Madison County emergency management officials reported a large tornado and tremendous damage in downtown Jackson, Tennessee (Fig. 10). This storm continued to produce tornado damage through 0503 UTC before dissipating east of Lexington, Tennessee, in Henderson County.

#### 4. Discussion

It is important to point out that prior to the rapid development and strengthening of the mesocyclone, the supercell thunderstorm encountered a pre-existing mesoscale boundary. In addition, storm-scale bound-

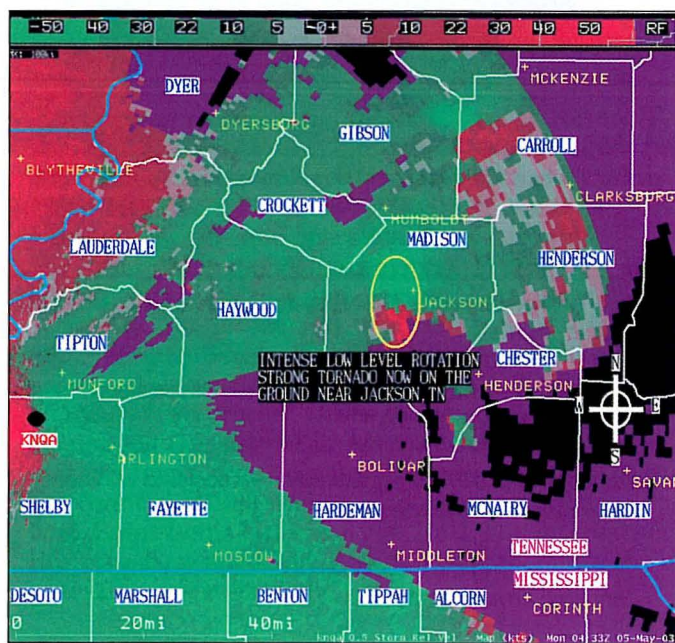
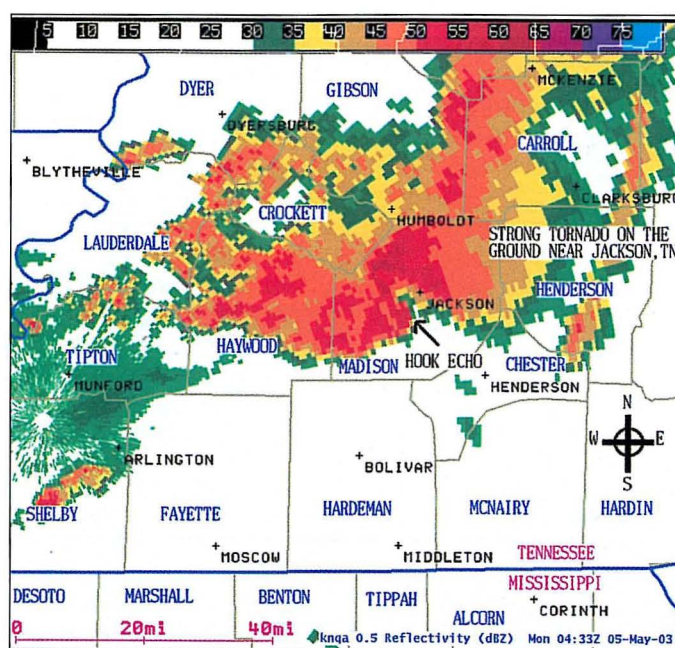


Fig. 9. As in Fig. 7, but at 0433 UTC 05 May 2003 and (b) at 0.5° elevation.

aries became well defined, including the forward flank gust front.

As the radar data indicated, a large area of rain preceded the supercell thunderstorm that moved into Madison County. This may have resulted in a mesoscale boundary that formed on the southern edge of the rain area, with rain cooled air to the north and warm environmental air to the south (Fig. 6). Radar imagery indicated that when the supercell thunderstorm encountered this mesoscale boundary around 0413 UTC, the low-level mesocyclone strengthened, as described by Moller et al. (1990) and Rasmussen et al. (1998) (Fig. 11).





**Fig. 10.** F4 tornado damage in downtown Jackson, Tennessee, in Madison County. Eleven fatalities and multiple injuries resulted from this tornado as well as the severe damage or complete destruction of several structurally sound buildings.

**Table 1.** Nondescending Mesocyclone Operational Checklist (Trapp et. al. 1999)

1. Many nondescending mesocyclones are associated with supercell thunderstorms.
2. Almost half of all TVS signatures are associated with nondescending mesocyclones.
3. Nondescending mesocyclones often develop in highly sheared environments.
4. Be aware of enhanced storm-scale boundaries just prior to the low-level tightening of the mesocyclone.
5. Situations in which supercell thunderstorms intersect pre-existing low-level boundaries favor the development of nondescending mesocyclones.
6. Special attention should be given to mesocyclone strengthening within the entire column, both in the low-levels and aloft, in short durations of time (i.e. from one volume scan to the next).

Also between 0408 UTC and 0418 UTC, the rear flank and forward flank gust fronts became well defined (Fig. 7a). Markowski et al. (1998) during VORTEX-95 found that the forward flank gust front could provide sufficient additional horizontal vorticity for tornadogenesis when

deep layer shear is very high. It appears the enhanced horizontal vorticity that was generated along the forward flank gust front was ingested into the strong updraft and led to tornadogenesis around 0428 UTC (Cunningham and Wolf 1998) (Fig. 8).

## 5. Summary

The severe weather outbreak of 4-8 May 2003 produced an unprecedented number of damaging tornadoes across much of the central and southern United States. These tornadoes were responsible for several fatalities and tremendous loss of property. Of particular interest was the F4 tornado that impacted Madison County, Tennessee. This storm exhibited important development along mesoscale and storm-scale boundaries. Warning meteorologists need to be aware of these features and understand how they will affect storm structure, intensity, and evolution.

Supercells with nondescending mesocyclones also challenge the decision making process of a warning meteorologist. To maintain adequate tornado warning lead times, the warning meteorologist must be prepared for the rapid development of tornadoes produced from these storms. Special attention to the pre-storm environment will aid in the warning decision process. An operational checklist (Table 1) has been created to improve recognition by operational meteorologists of environments favorable for the development of nondescending mesocyclones. Also provided are radar characteristics associated with developing nondescending mesocyclones.



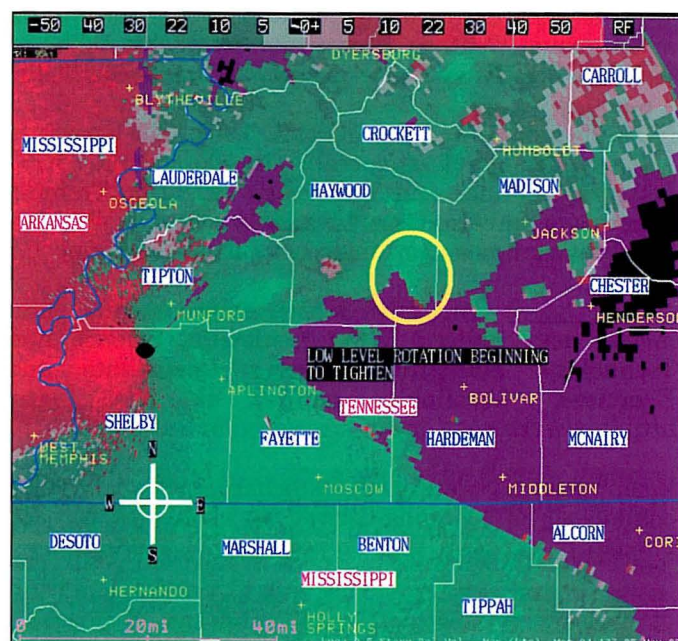


Fig. 11. 0.5° storm relative mean velocity from KNQA at 0413 UTC 05 May 2003; velocity data are displayed as in Fig. 7(b).

In the case of the 4 May 2003 supercell event, advanced warning lead time was achieved through proper recognition of environmental conditions. Hopefully, with continued training, experience, and improved environmental awareness, severe weather warnings and lead times will improve.

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### Authors

Jonathan Howell is a Journeyman Forecaster at the NOAA/National Weather Service (NWS) Forecast Office in Memphis, Tennessee and has held this position since 2005. He has been with the NWS since 2002, serving as a Meteorologist Intern in Memphis, Tennessee from 2002 through early 2005. Prior to coming to the NWS, he worked as an Air Pollution Meteorologist with both the Memphis and Shelby County Health Department (2000-2002) and the Alabama Department of Environmental Management (2000). He earned his B.S. degree in Earth Sciences (with a concentration in meteorology) from California University of Pennsylvania in 1997 and an M.S. degree

in Geosciences (with a concentration in operational meteorology) from Mississippi State University in 2000. His interests continue to be focused in severe weather research and operational meteorology.

Gregory Garrett is the Information Technology Officer (ITO) at the NOAA/National Weather Service Forecast Office in Jackson, Mississippi and has held this position since 2004. He has been with the NWS since 1990, serving as a Meteorologist Intern at the NWS Weather Service Office in Meridian, Mississippi (1990-1993), as a Journeyman Forecaster (1993-1995) and Senior Forecaster (1995-2002) at the NOAA/NWS Forecast Office in Jackson, Mississippi, and as the Information Technology Officer (2002-2004) at the NOAA/NWS Forecast Office in Memphis, Tennessee. He earned his B.S. degree in Meteorology from the University of Northeast Louisiana in 1989. His interests continue to be focused in severe weather research, operational meteorology, and computer sciences.

Scott McNeil is a Senior Forecaster at the NOAA/National Weather Service Forecast Office in Memphis, Tennessee and has held this position since 1998. He has been with the NWS since 1990, serving as a Meteorologist Intern at both the Juneau, Alaska (1990-1992) NOAA/NWS Forecast Office and the Valdez, Alaska (1992-1994) Weather Service Office, and as a Journeyman Forecaster (1994-1998) at the NOAA/NWS Forecast Office in Memphis, Tennessee. He earned his B.S. degree in Meteorology from Linden State College in 1989. His interests continue to be focused in severe weather research and operational meteorology.

Daniel Valle is a Journeyman Forecaster at the NOAA/National Weather Service Forecast Office in Memphis, Tennessee and has held this position since 2002. He has been with the NWS since 2001, serving as a Meteorologist Intern (2001-2002) at the NOAA/NWS Forecast Office in Gaylord, Michigan. He earned his B.S. degree in Aeronautics (with a major in meteorology) from Parks College of Saint Louis University in 1999 and an M.S. degree in Meteorology from Saint Louis University in 2001. His interests continue to be focused in severe weather research and operational meteorology.

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