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

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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, meso-scale, 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 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 (NCDC 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. Eleven persons were killed and more than one hundred injured, with 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. Also, a special perspective will 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 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 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 m s^{-1} (50 kts) overspread east Texas and southwest Arkansas on the afternoon of 4 May 2003. These low-level winds strengthened above 35 m s^{-1} (70 kts) as they shifted east over the lower and middle Mississippi River Valley by 0300 UTC. 850-mb dewpoints also increased to 16°C (61°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 m s^{-1} (125 kts) 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 short-wave approached, 500-mb heights fell significantly. The falling heights were indicative of the cold core aloft overspreading the near surface warm sector further destabilizing the atmosphere late into the evening.

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 m s^{-1} (56 kts), veering winds with height, and a 700-500-mb lapse rate of 7.8°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 J kg^{-1} and a surface-based Lifted Index (LI) of -6°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 (1500-3500 J kg^{-1}) and helicity (NWS Louisville 2004a). Environments that exhibit LI values between -6 and -9 are characteristic of very unstable environments (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 m^2 s^{-2} favoring supercell development over ordinary cell development (Rasmussen and Blanchard 1998).

The 0-1 km SRH observed on the 0000 UTC LZK sounding was 281 m^2 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 (2000) 75th 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 (SRM) 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 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 moved 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 et al. 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-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 with the strongest velocity couplet in the lowest levels of the storm (Fig. 7b), indicative of a non-descending mesocyclone (Trapp 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 m s^{-1} (50 kts) inbound winds immediately adjacent to 25 m s^{-1} (50 kts) 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. 0.5° SRM indicated greater than 50 m s^{-1} (100 kts) 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 boundaries 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 was also found by Moller et al. (1990) and Rasmussen et al. (1998);(Fig. 11).

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. The following operational checklist 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.

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 (ie. from one volume scan to the next).

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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Figures

Figure 1. May 4-8, 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.

Figure 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.

Figure 3. Mid South Surface Map - 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 airmasses. The solid lines are indicative of CAPE (Convective Available Potential Energy) values across the area.

Figure 4. Composite Weather Map - 0000 UTC, 05 May 2003. The following composite weather map shows a compilation of the synoptic weather environment across the Mid-South. Airmasses are separated by frontal symbols, the shaded areas indicate jet steam winds of varying intensity, and the hatched area shows a region of maximum large-scale atmospheric lift.

Figure 5. Little Rock, Arkansas (LZK) Atmospheric Sounding - 0000 UTC, 05 May 2003. The sounding from LZK showed large amounts of instability and tremendous speed and directional wind shear. The plotted lines are indicative of atmospheric temperature and moisture at LZK. Atmospheric winds are plotted along the right side of the Skew-T diagram. Stability parameters are shown at the bottom along with a local hodograph.

Figure 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 airmasses. The mesoscale boundary is indicated by the elongated dashed line. Radar returns are also displayed.

Figure 7. (a) 0.5° Base Reflectivity showing a distinct weak echo region (WER) and forward (FFD) and rear (RFD) flank boundaries, and (b) 1.5° Storm Relative Mean Velocity showing strengthening low level rotation ($\approx$7 kft AGL), from KNQA at 0418 UTC, 05 May 2003. The rotational signature has been circled 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.

Figure 8. 0.5° Storm Relative Mean Velocity from KNQA at 0428 UTC, 05 May 2003 shows strengthening low-level cyclonic rotation. Velocity data is displayed as in Fig. 7(b).

Figure 9. (a) 0.5° Base Reflectivity from KNQA at 0433 UTC, 05 May 2003. shows the development of a hook echo, and (b) 0.5° Storm Relative Mean Velocity data shows intense low-level rotation, with greater than 50 kts. of rotational velocity. Base Reflectivity and Velocity data are displayed as in Fig. 7(a) and 7(b).

Figure 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.

Figure 11. 0.5° Storm Relative Mean Velocity from KNQA at 0413 UTC, 05 May 2003, shows low-level rotation within the thunderstorm beginning to intensify as the thunderstorm began to intersect the mesoscale boundary that was stretched across portions of western Tennessee. Velocity data is displayed as in Fig. 7(b).

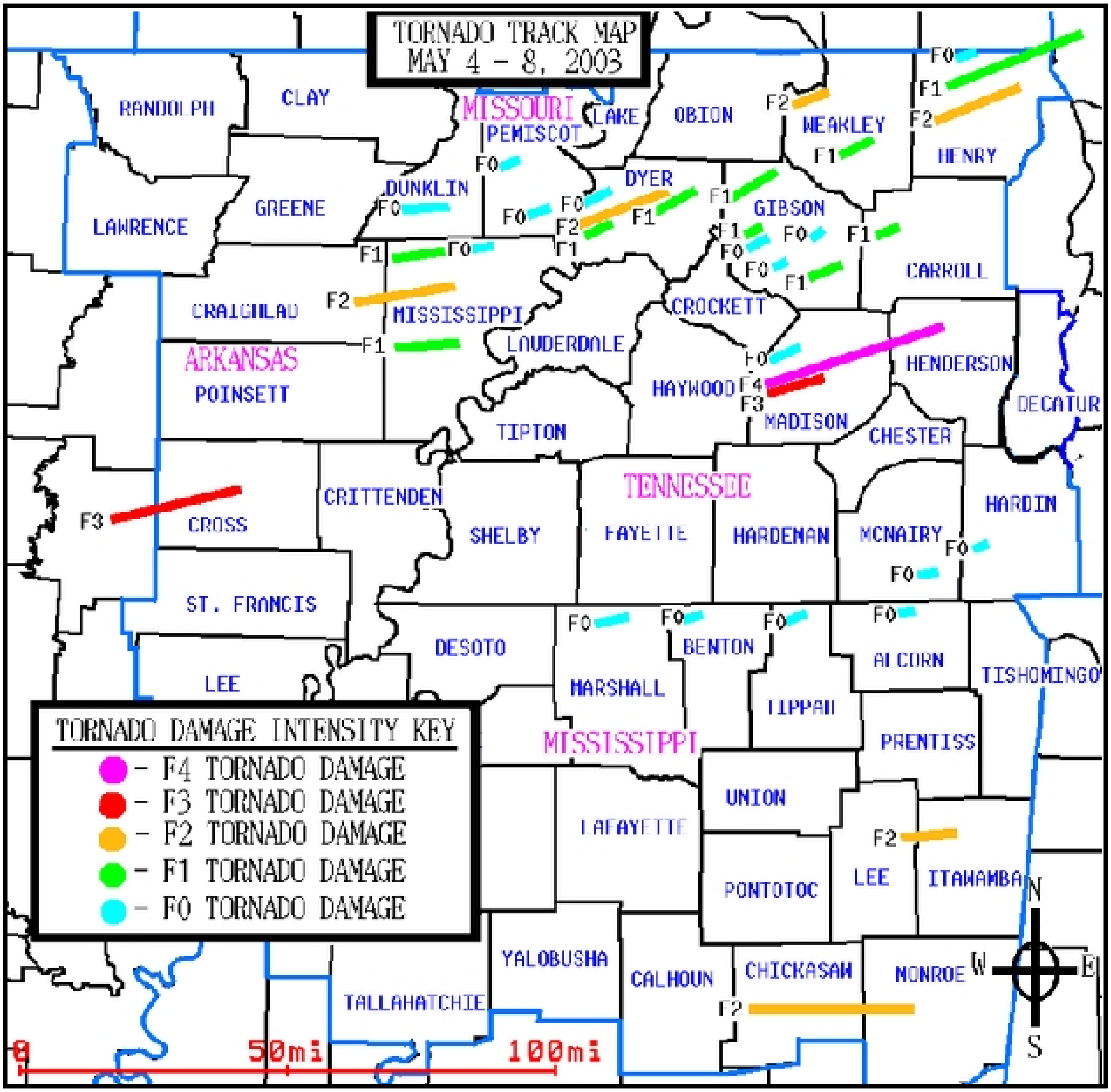

TORNADO TRACK MAP
MAY 4 - 8, 2003
MISSOURI
ARKANSAS
TENNESSEE
MISSISSIPPI
TORNADO DAMAGE INTENSITY KEY
- F4 TORNADO DAMAGE
- F3 TORNADO DAMAGE
- F2 TORNADO DAMAGE
- F1 TORNADO DAMAGE
- F0 TORNADO DAMAGE
0
50mi
100mi
N
S
W
E

Figure 1.

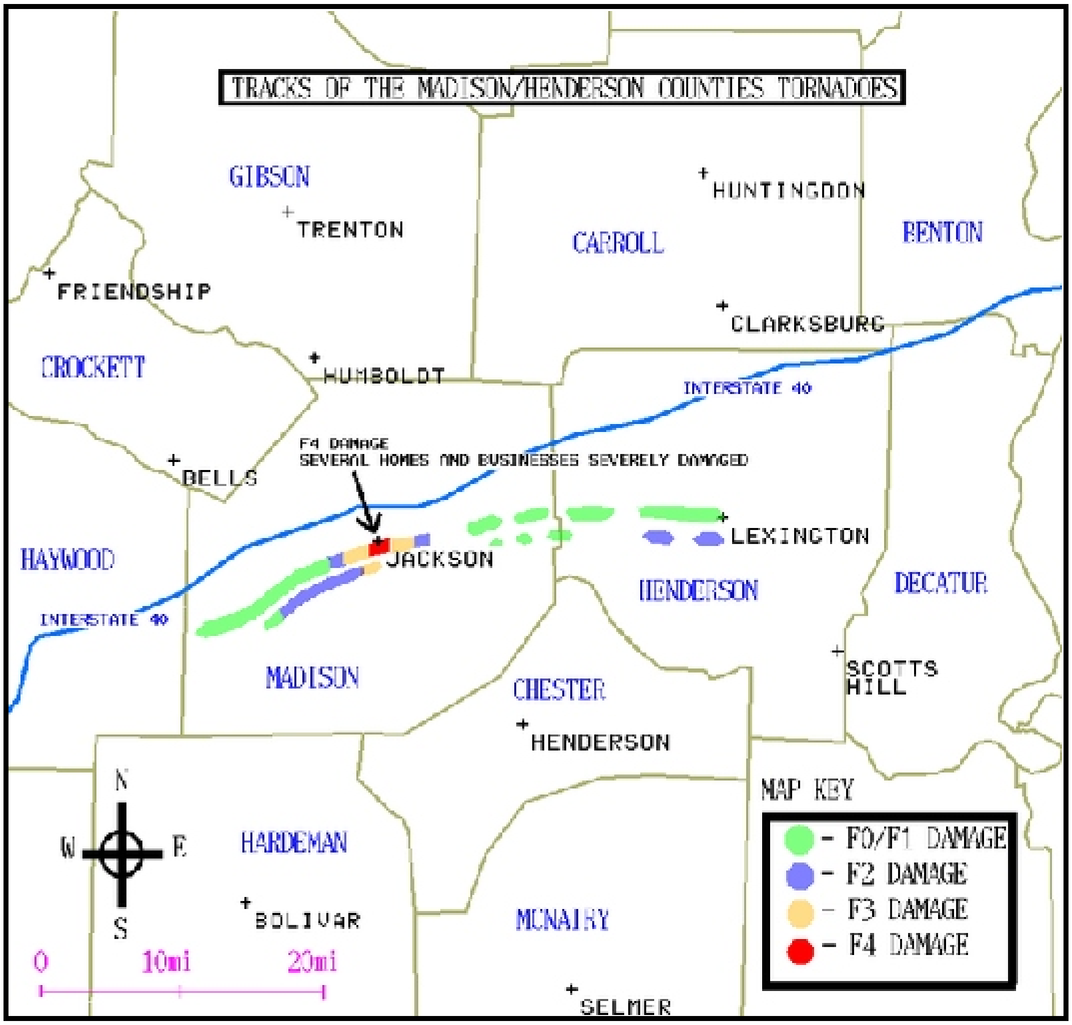
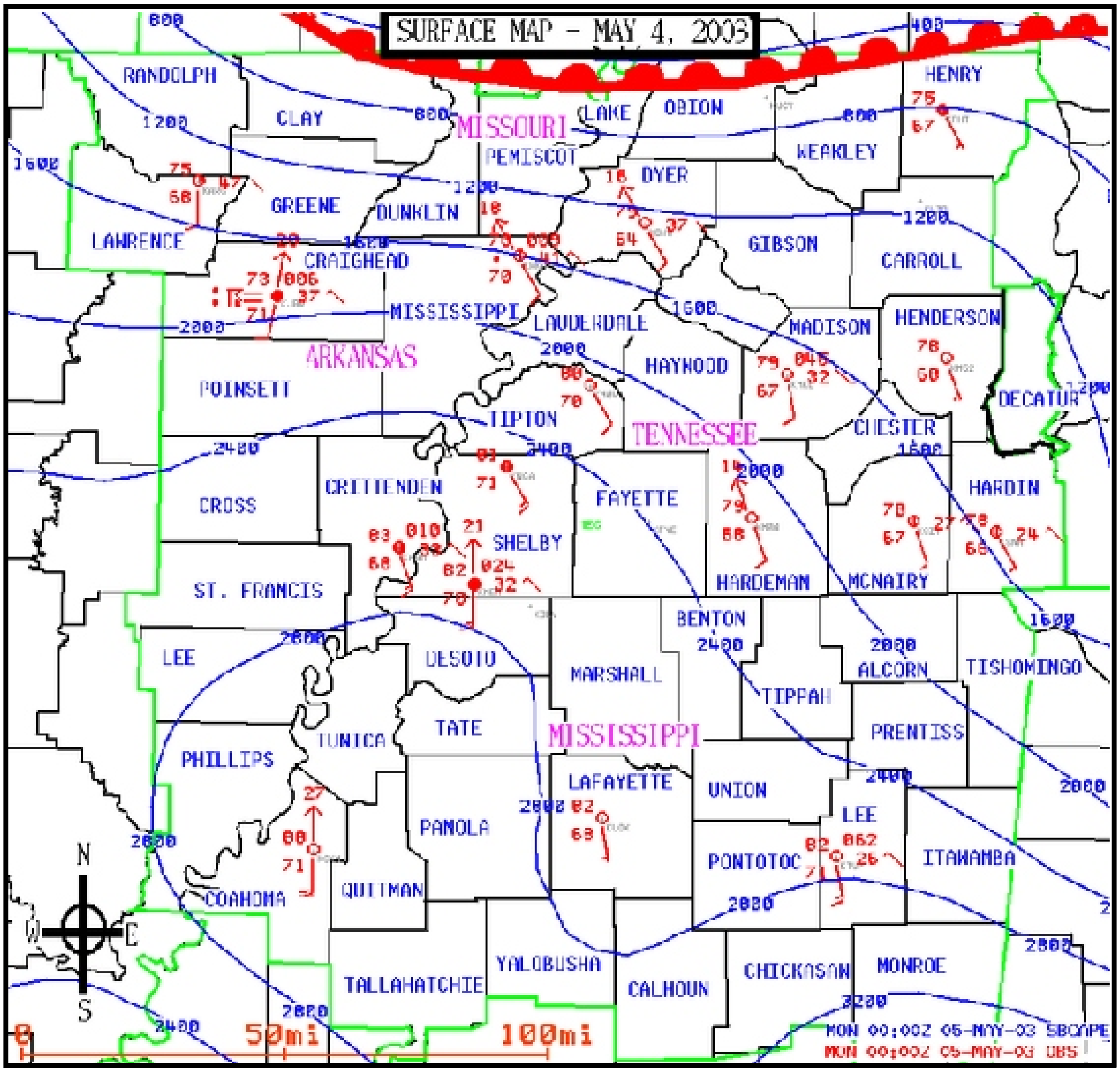

TRACKS OF THE MADISON/HENDERSON COUNTIES TORNADOES
GIBSON
TRENTON
HUNTINGDON
CARROLL
BENTON
FRIENDSHIP
CLARKSBURG
CROCKETT
HUMBOLDT
INTERSTATE 40
F4 DAMAGE
SEVERAL HOMES AND BUSINESSES SEVERELY DAMAGED
BELLS
LEXINGTON
JACKSON
HAYWOOD
HENDERSON
DECATUR
INTERSTATE 40
SCOTTS HILL
MADISON
CHESTER
HENDERSON
N
W
E
S
HARDEMAN
BOLIVAR
MCNAIRY
SELMER
0
10mi
20mi
MAP KEY
- F0/F1 DAMAGE
- F2 DAMAGE
- F3 DAMAGE
- F4 DAMAGE

Figure 2.


SURFACE MAP - MAY 4, 2003
MISSOURI
ARKANSAS
TENNESSEE
MISSISSIPPI
RANDOLPH
CLAY
LAKE
OBION
HENRY
PEMISCOT
WEAKLEY
DYER
GREENE
DUNKLIN
LAWRENCE
GIBSON
CARROLL
CRAIGHEAD
MISSISSIPPI
LAUDERDALE
MADISON
HENDERSON
POINSETT
HAYWOOD
DECATUR
TIPTON
CHESTER
CROSS
CRITTENDEN
FAYETTE
HARDIN
SHELBY
ST. FRANCIS
HARDEMAN
MCNAIRY
BENTON
LEE
DESOTO
MARSHALL
ALCORN
TISHOMINGO
TIPPAH
TUNICA
TATE
PRENTISS
PHILLIPS
LAFAYETTE
UNION
LEE
PANOLA
PONTOTOC
ITAWAMBA
COAHOMA
QUITMAN
TALLAHATCHIE
YALOBUSHA
CALHOUN
CHICKASAW
MONROE
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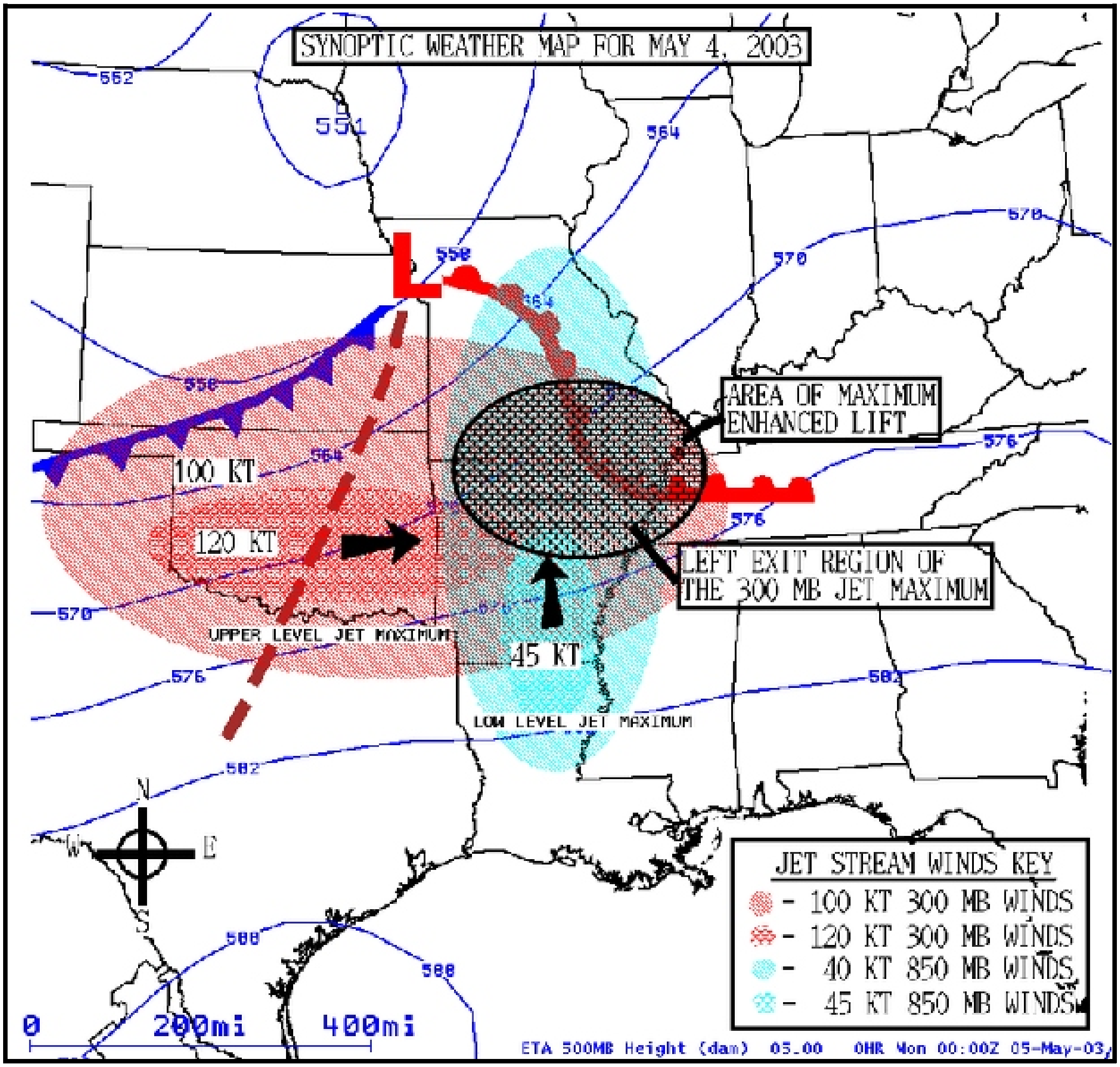
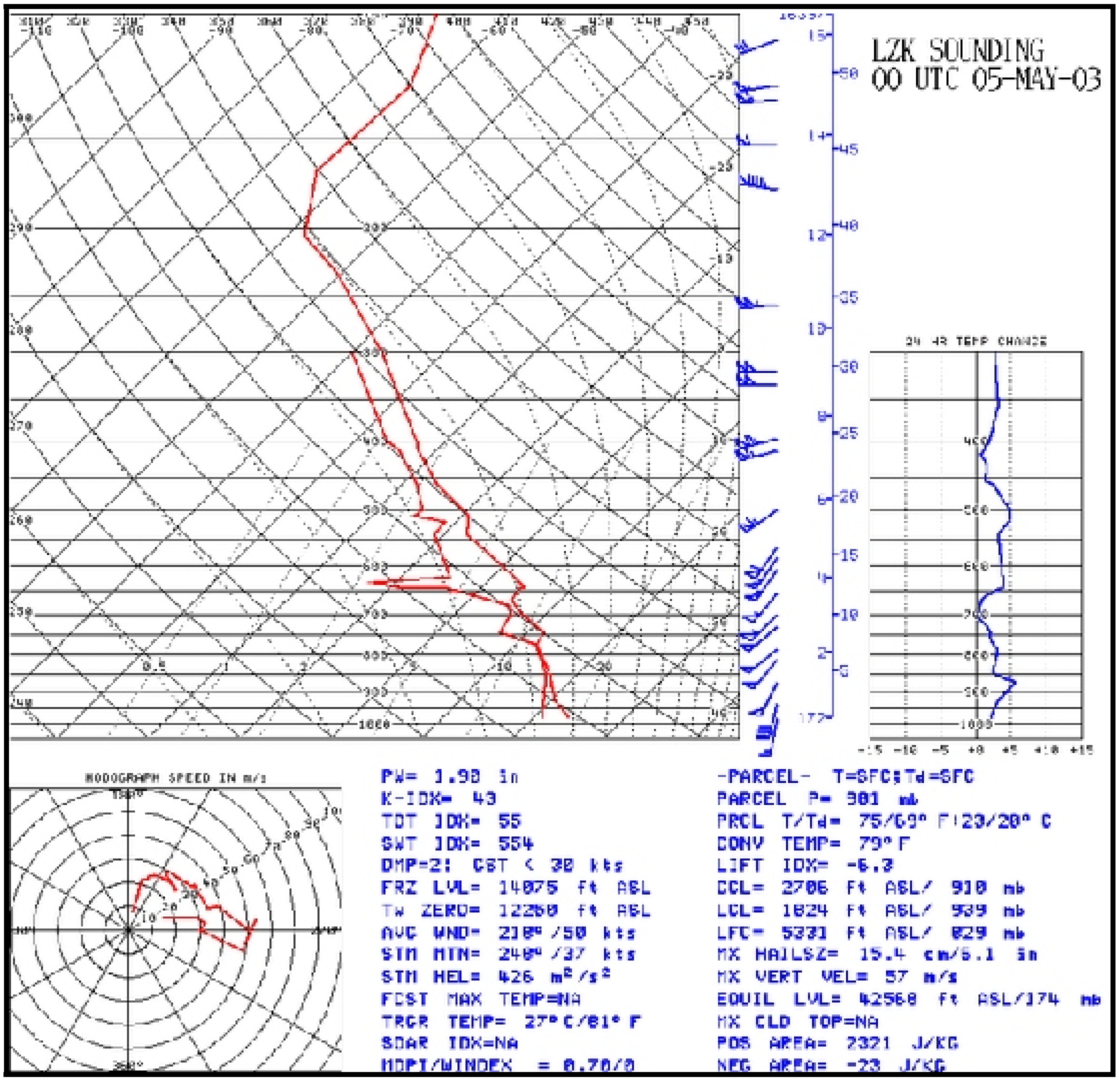
E
0
50mi
100mi
MON 00:00Z 05-MAY-03 SBCAPE
MON 00:00Z 05-MAY-03 OBS

Figure 3.



SYNOPTIC WEATHER MAP FOR MAY 4, 2003
AREA OF MAXIMUM ENHANCED LIFT
100 KT
120 KT
UPPER LEVEL JET MAXIMUM
45 KT
LOW LEVEL JET MAXIMUM
LEFT EXIT REGION OF THE 300 MB JET MAXIMUM
JET STREAM WINDS KEY
- 100 KT 300 MB WINDS
- 120 KT 300 MB WINDS
- 40 KT 850 MB WINDS
- 45 KT 850 MB WINDS
0
200mi
400mi
ETA 500MB Height (dam) 05_00 0HR Mon 00:00Z 05-May-03

Figure 4.



LZK SOUNDING
00 UTC 05-MAY-03
24 HR TEMP CHANGE
HODOGRAPH SPEED IN m/s
PW= 1.90 in
K-IDX= 43
TOT IDX= 55
SWT IDX= 554
DMP=2: GST < 30 kts
FRZ LVL= 14075 ft ASL
Tw ZERO= 12260 ft ASL
AVG WND= 210° /50 kts
STM MTN= 240° /37 kts
STM HEL= 426 m²/s²
FCST MAX TEMP=NA
TRGR TEMP= 27° C/81° F
SOAR IDX=NA
MDPI/WINDEX = 0.70/0
-PARCEL- T=SFC;Td=SFC
PARCEL P= 901 mb
PRCL T/Td= 75/69° F|23/20° C
CONV TEMP= 79° F
LIFT IDX= -6.3
CCL= 2706 ft ASL/ 910 mb
LCL= 1824 ft ASL/ 939 mb
LFC= 5331 ft ASL/ 829 mb
MX HAILSZ= 15.4 cm/6.1 in
MX VERT VEL= 57 m/s
EQUIL LVL= 42560 ft ASL/174 mb
MX CLD TOP=NA
POS AREA= 2321 J/KG
NEG AREA= -23 J/KG

Figure 5.

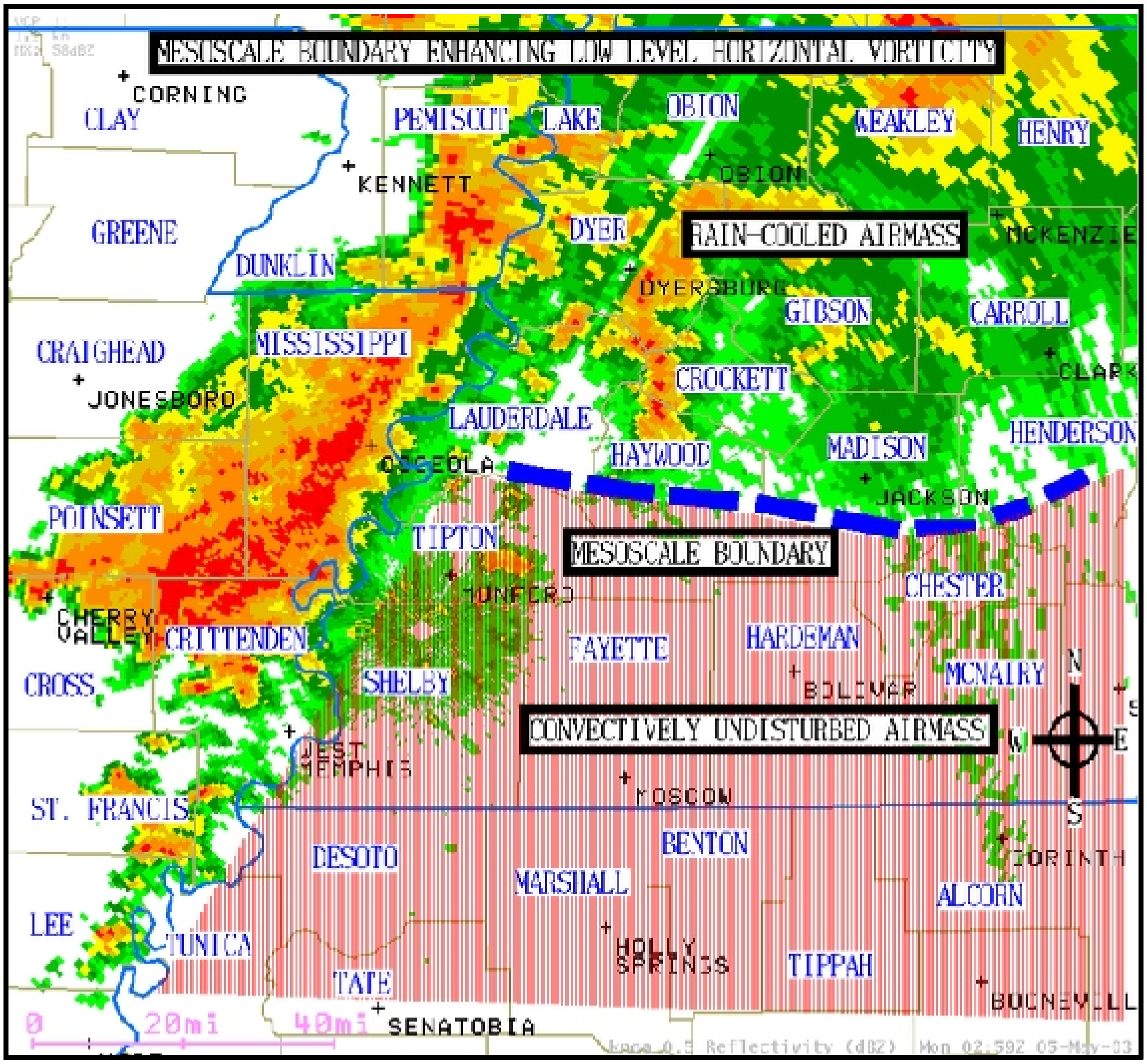

MESOSCALE BOUNDARY ENHANCING LOW LEVEL HORIZONTAL VORTICITY
RAIN-COOLED AIRMASS
MESOSCALE BOUNDARY
CONVECTIVELY UNDISTURBED AIRMASS
CORNING
CLAY
KENNETT
PEMISCOT
LAKE
OBION
WEAKLEY
HENRY
GREENE
DUNKLIN
DYER
MCKENZIE
DYERSBURG
GIBSON
CARROLL
CRAIGHEAD
JONESBORO
MISSISSIPPI
CROCKETT
CLARK
LAUDERDALE
HAYWOOD
MADISON
HENDERSON
OSCEOLA
JACKSON
POINSETT
TIPTON
CHESTER
CHERRY VALLEY
CRITTENDEN
FAYETTE
HARDEMAN
CROSS
SHELBY
BOLIVAR
MCNAIRY
WEST MEMPHIS
ROSCOW
ST. FRANCIS
DESOTO
BENTON
CORINTH
MARSHALL
ALCORN
LEE
TUNICA
HOLLY SPRINGS
TIPPAH
TATE
BOONEVILLE
0
20mi
40mi
SENATOBIA
N
S
E
W

Figure 6.

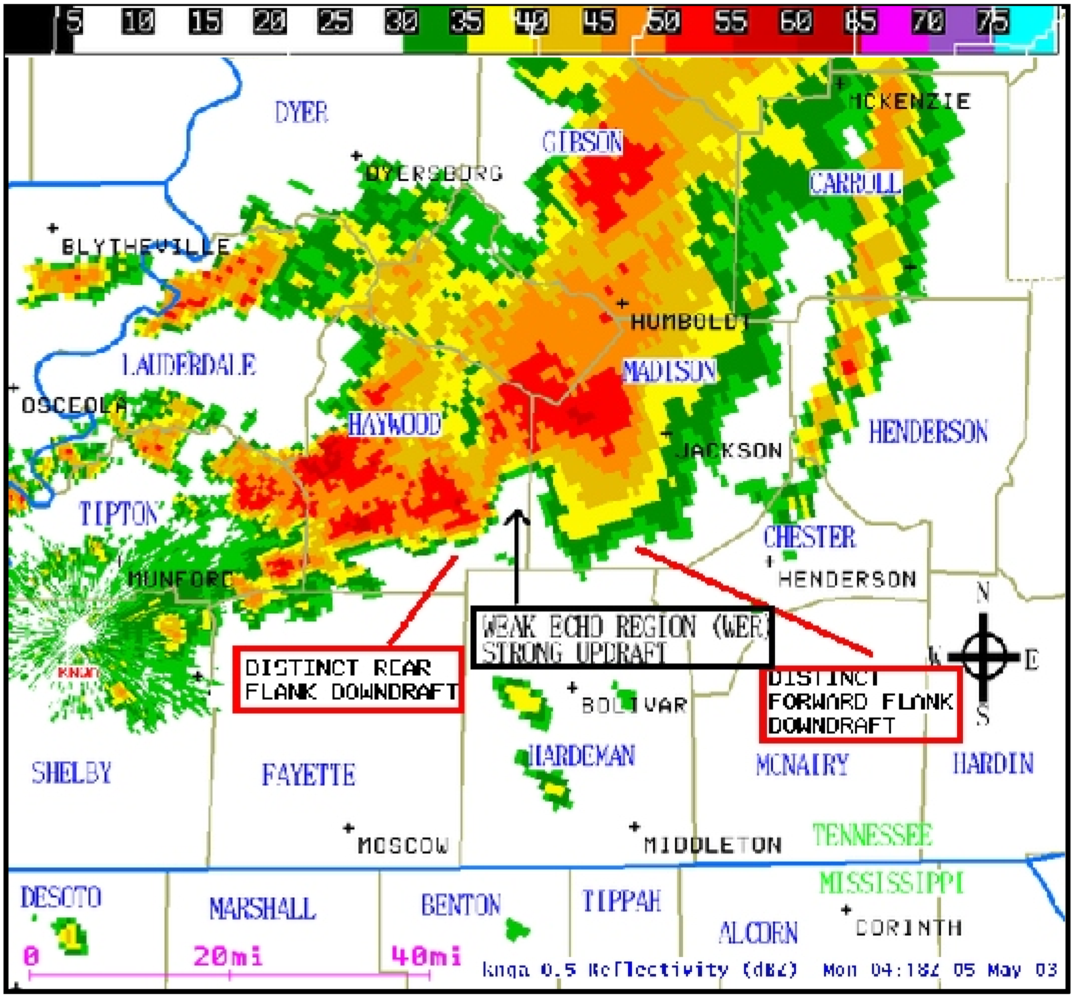

5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
DYER
DYERSBURG
GIBSON
MCKENZIE
CARROLL
BLYTHEVILLE
HUMBOLDT
LAUDERDALE
MADISON
OSCEOLA
HAYWOOD
HENDERSON
JACKSON
TIPTON
CHESTER
MUNFORD
HENDERSON
WEAK ECHO REGION (WER)
STRONG UPDRAFT
DISTINCT REAR
FLANK DOWNDRAFT
DISTINCT
FORWARD FLANK
DOWNDRAFT
N
W
E
S
BOLIVAR
SHELBY
FAYETTE
HARDEMAN
MCNAIRY
HARDIN
MOSCOW
MIDDLETON
TENNESSEE
MISSISSIPPI
DESOTO
MARSHALL
BENTON
TIPPAH
ALCORN
CORINTH
0
20mi
40mi
knqa 0.5 Reflectivity (dBZ) Mon 04:18Z 05 May 03

Figure 7 (a).

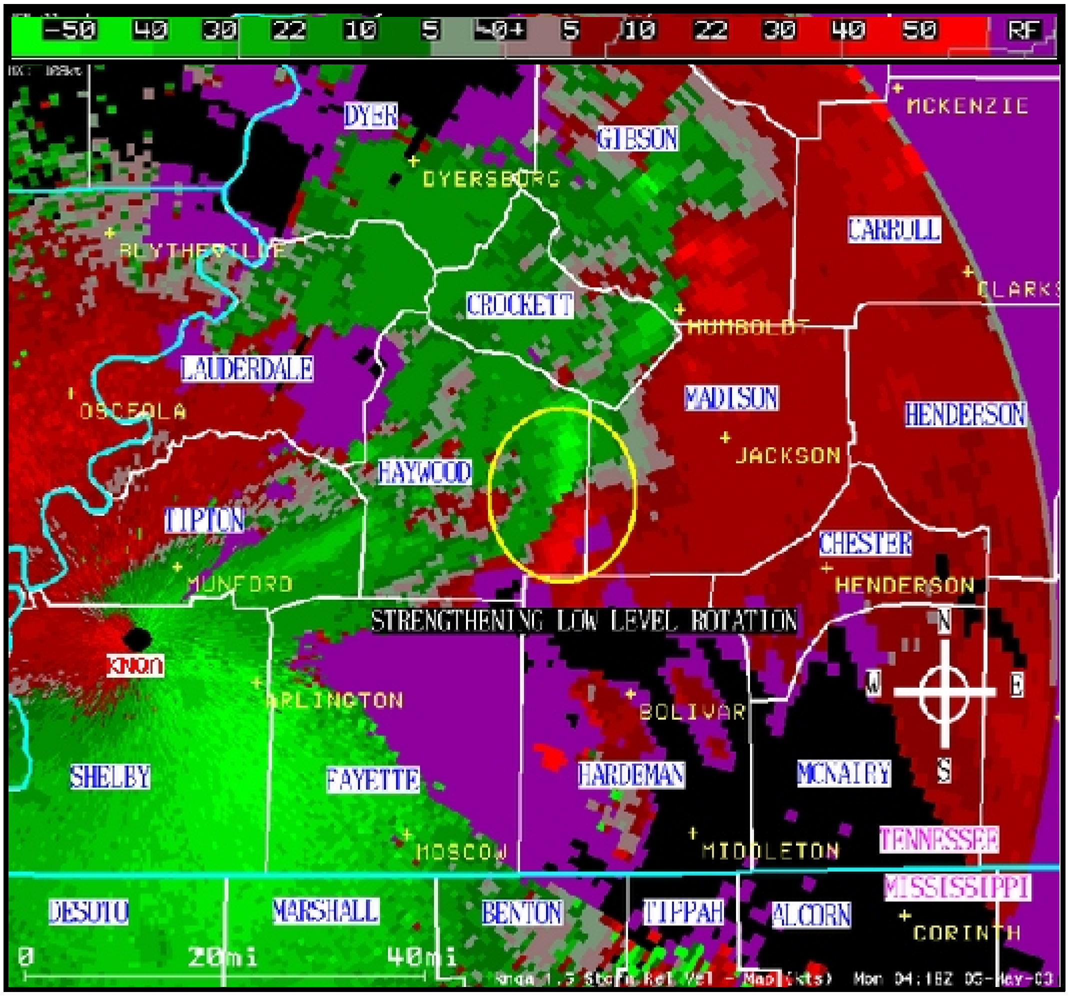

-50 40 30 22 10 5 -0+ 5 10 22 30 40 50 RF
DYER
GIBSON
MCKENZIE
DYERSBURG
CARROLL
BLYTHEVILLE
CROCKETT
HUMBOLDT
LAUDERDALE
MADISON
HENDERSON
OSCEOLA
JACKSON
HAYWOOD
TIPTON
CHESTER
MUNFORD
HENDERSON
STRENGTHENING LOW LEVEL ROTATION
N
W
E
S
KNQA
ARLINGTON
BOLIVAR
SHELBY
FAYETTE
HARDEMAN
MCNAIRY
MOSCOW
MIDDLETON
TENNESSEE
MISSISSIPPI
DESOTO
MARSHALL
BENTON
TIPPAH
ALCORN
CORINTH
0
20mi
40mi

Figure 7 (b).

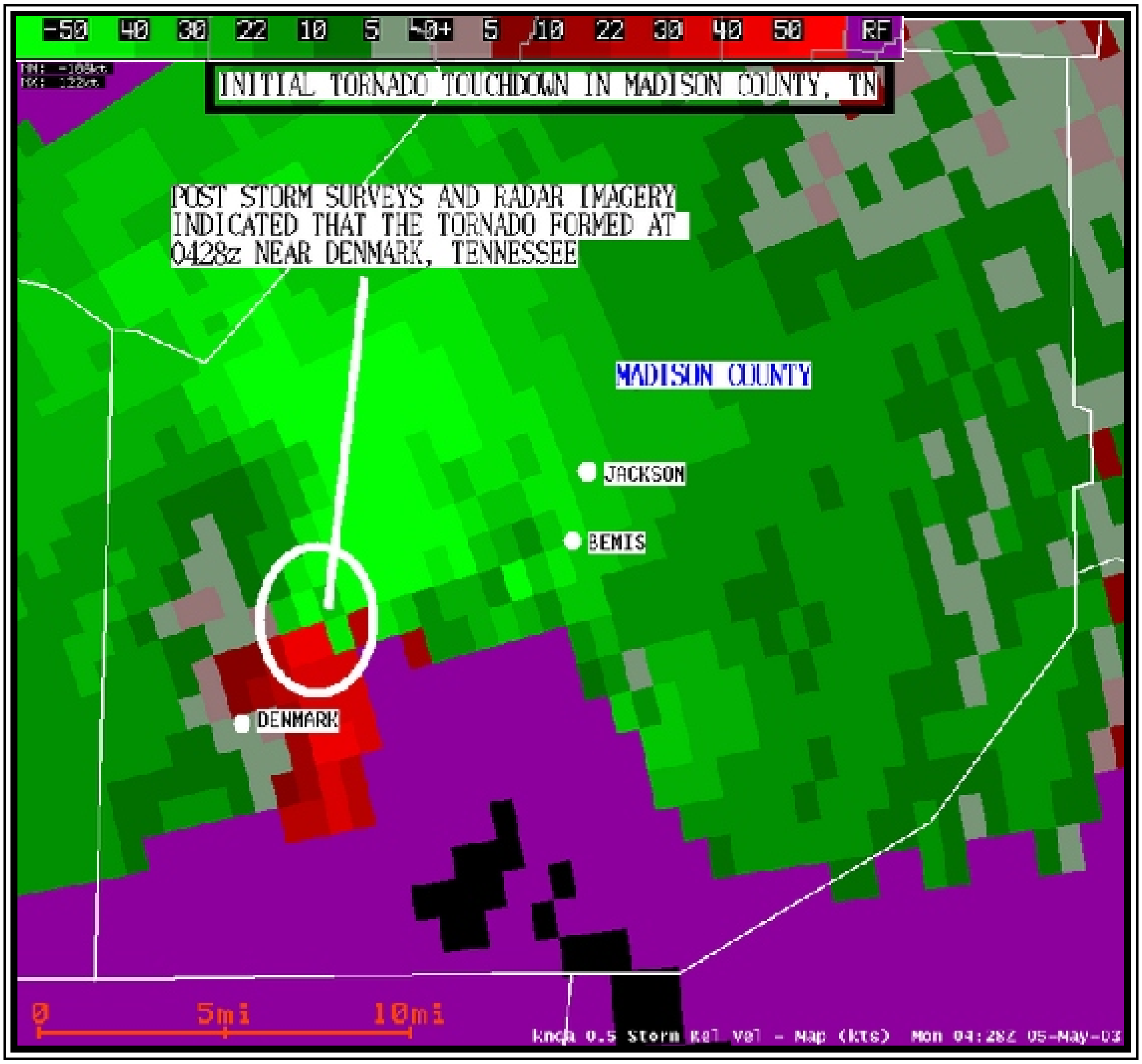

-50 40 30 22 10 5 -0+ 5 10 22 30 40 50 RF
INITIAL TORNADO TOUCHDOWN IN MADISON COUNTY, TN
POST STORM SURVEYS AND RADAR IMAGERY
INDICATED THAT THE TORNADO FORMED AT
0428z NEAR DENMARK, TENNESSEE
MADISON COUNTY
JACKSON
BEMIS
DENMARK
0 5mi 10mi

Figure 8.

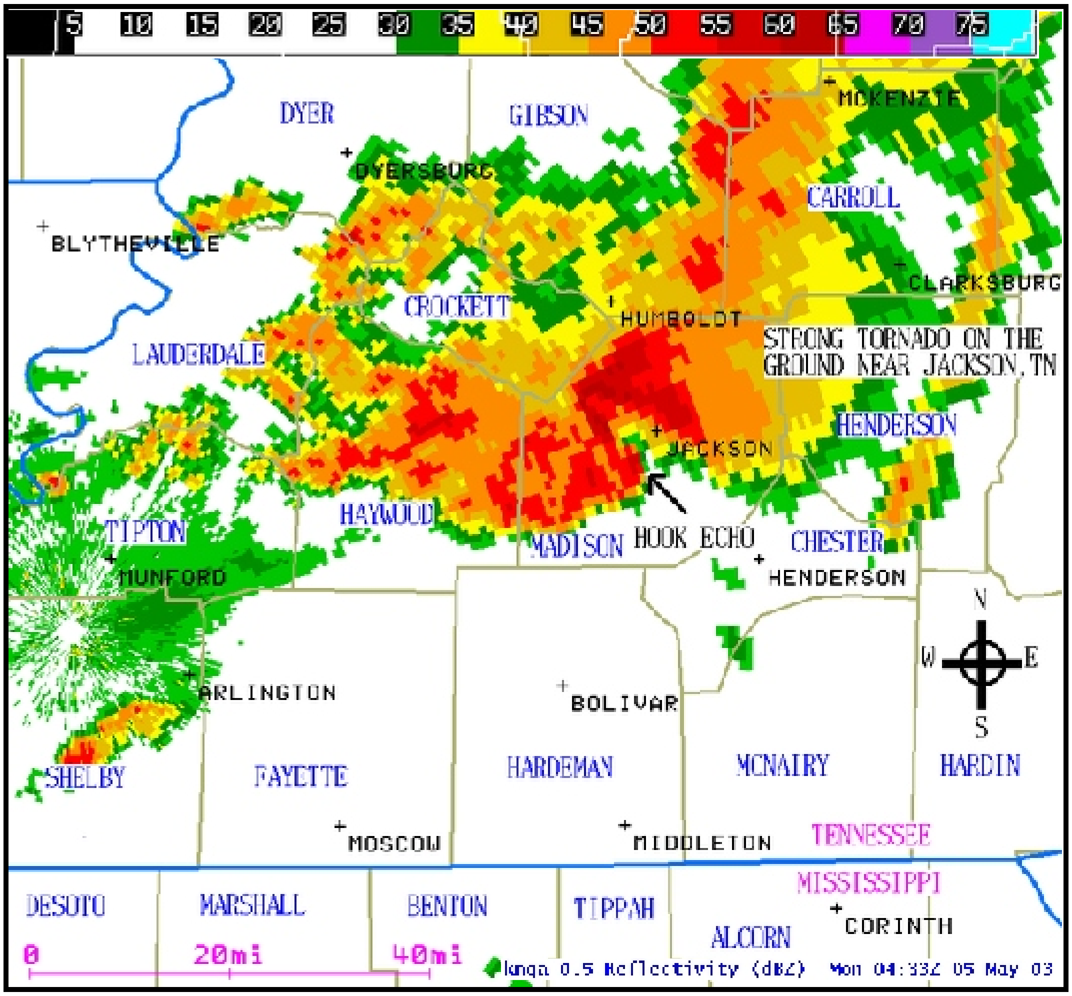

5 10 15 20 25 30 35 40 45 50 55 60 65 70 75
DYER
GIBSON
DYERSBURG
MCKENZIE
CARROLL
BLYTHEVILLE
CROCKETT
HUMBOLDT
CLARKSBURG
LAUDERDALE
STRONG TORNADO ON THE GROUND NEAR JACKSON, TN
HENDERSON
JACKSON
HAYWOOD
TIPTON
MADISON
HOOK ECHO
CHESTER
MUNFORD
HENDERSON
N
W
E
S
ARLINGTON
BOLIVAR
SHELBY
FAYETTE
HARDEMAN
MCNAIRY
HARDIN
MOSCOW
MIDDLETON
TENNESSEE
MISSISSIPPI
DESOTO
MARSHALL
BENTON
TIPPAH
ALCORN
CORINTH
0
20mi
40mi
kmqa 0.5 Reflectivity (dBZ) Mon 04:33Z 05 May 03

Figure 9 (a).

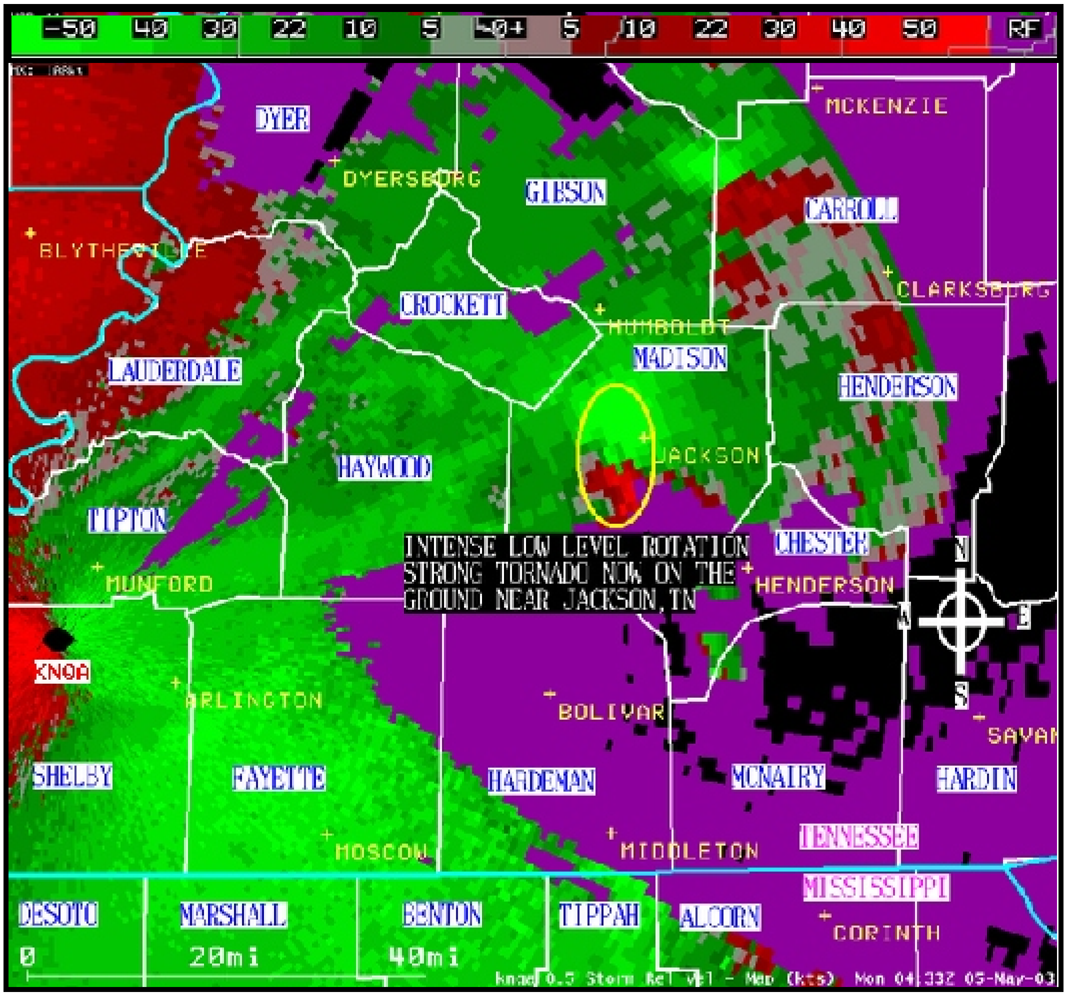
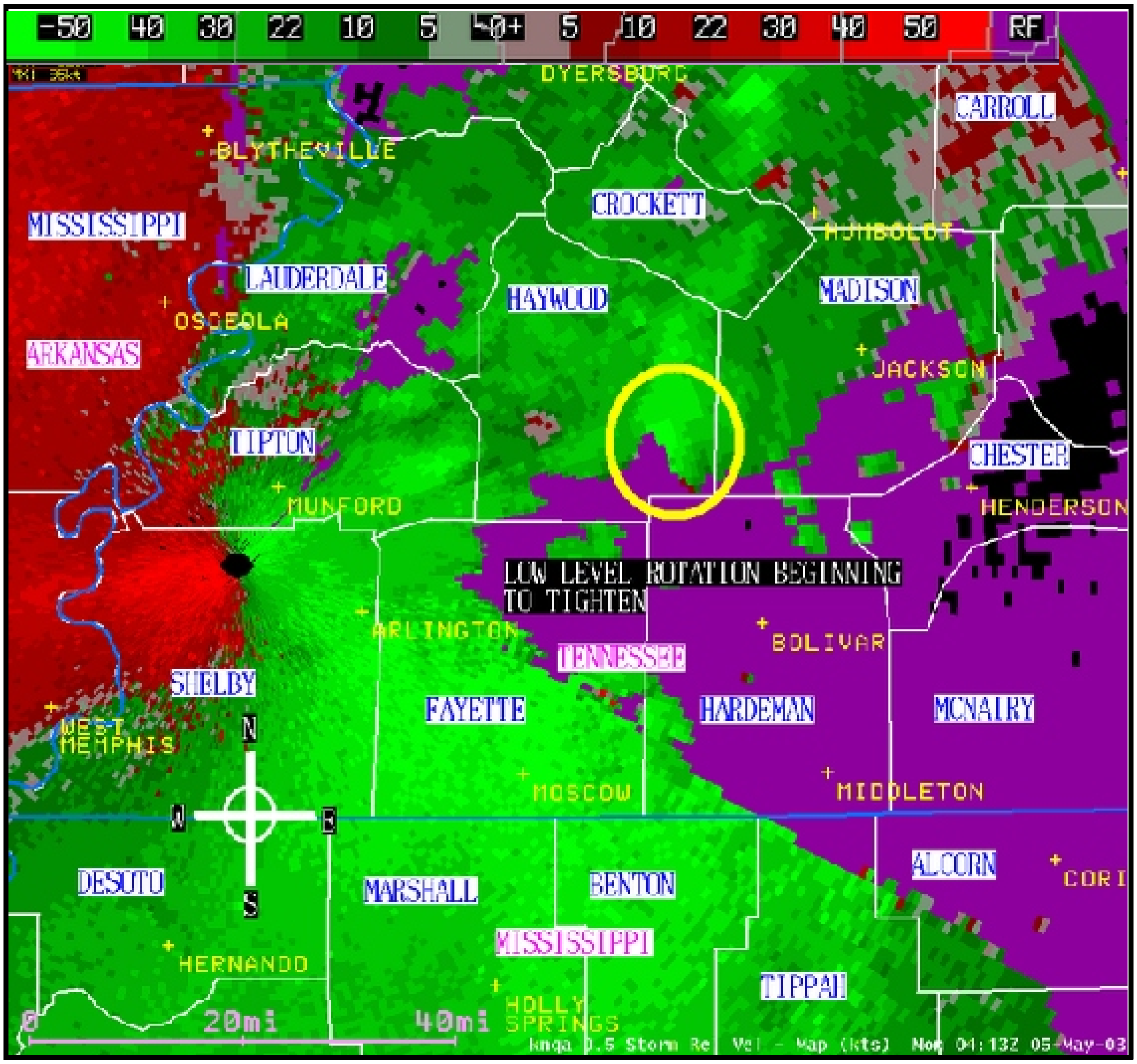

-50 40 30 22 10 5 -0+ 5 10 22 30 40 50 RF
DYER
DYERSBURG
GIBSON
MCKENZIE
CARROLL
BLYTHEVILLE
CLARKSBURG
CROCKETT
HUMBOLDT
MADISON
LAUDERDALE
HENDERSON
HAYWOOD
JACKSON
TIPTON
INTENSE LOW LEVEL ROTATION
STRONG TORNADO NOW ON THE
GROUND NEAR JACKSON,TN
CHESTER
MUNFORD
HENDERSON
KNQA
ARLINGTON
BOLIVAR
SHELBY
FAYETTE
HARDEMAN
MCNAIRY
HARDIN
MOSCOW
MIDDLETON
TENNESSEE
MISSISSIPPI
DESOTO
MARSHALL
BENTON
TIPPAH
ALCORN
CORINTH
0
20mi
40mi

Figure 9 (b).

Figure 10.



-50 40 30 22 10 5 -0+ 5 10 22 30 40 50 RF
DYERSBURG
CARROLL
BLYTHEVILLE
CROCKETT
HUMBOLDT
MISSISSIPPI
LAUDERDALE
HAYWOOD
MADISON
OSCEOLA
ARKANSAS
JACKSON
TIPTON
CHESTER
MUNFORD
HENDERSON
LOW LEVEL ROTATION BEGINNING
TO TIGHTEN
ARLINGTON
BOLIVAR
TENNESSEE
SHELBY
FAYETTE
HARDEMAN
MCNAIRY
WEST
MEMPHIS
N
W
E
S
MOSCOW
MIDDLETON
DESOTO
MARSHALL
BENTON
ALCORN
CORI
MISSISSIPPI
HERNANDO
TIPPAH
0
20mi
40mi
HOLLY
SPRINGS
Knqa 0.5 Storm Rel Vel - Map (kts) Mon 04:13Z 05-May-03

Figure 11.