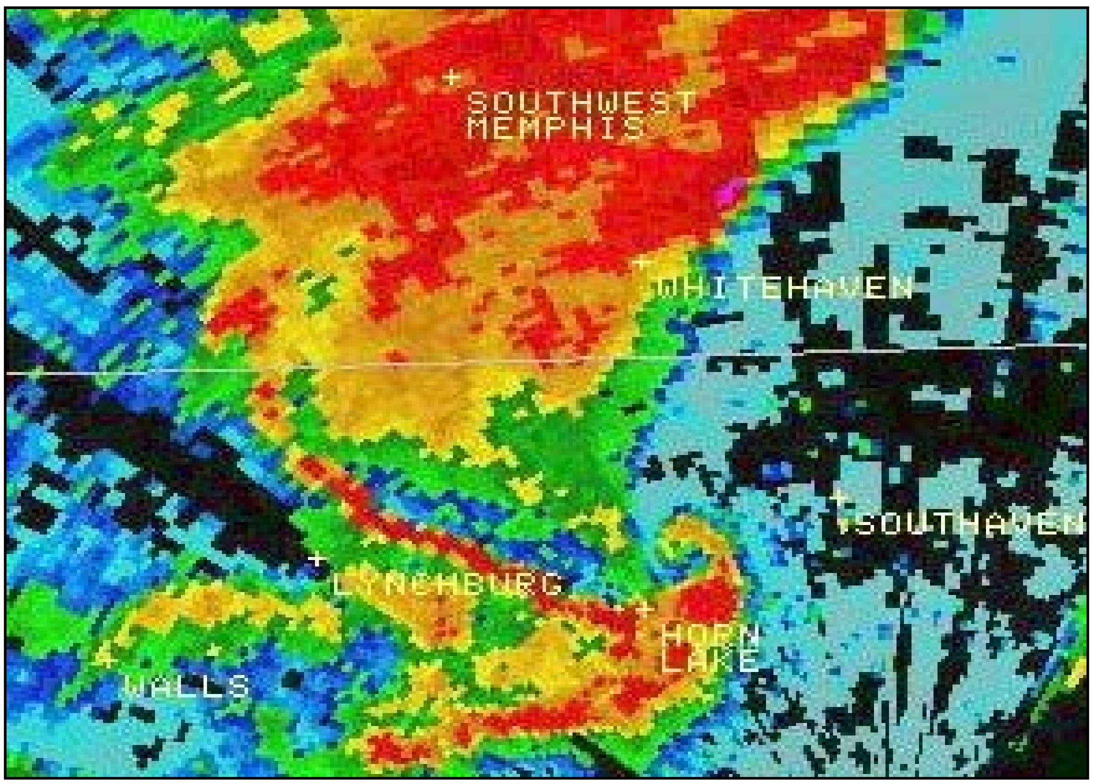
Service Assessment

Super Tuesday Tornado Outbreak of February 5-6, 2008



U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Weather Service
Silver Spring, Maryland

Cover Photograph: The Federal Aviation Administration's Terminal Doppler Weather Radar reflectivity image from Memphis, Tennessee, taken at 5:30 p.m. CST, on February 5, 2008. The "hook echo" in the bottom of the image represents a tornado which affected the southern suburbs of Memphis, including the Memphis International Airport and the National Weather Service Memphis Office.

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March 2009

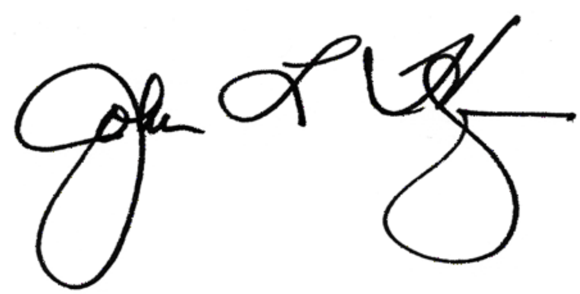
National Weather Service
John L. Hayes
Assistant Administrator

Preface

During a 12-hour period in the evening and early morning of February 5-6, 2008, 87 tornadoes occurred in nine states with 57 fatalities in four states. This is the second largest February tornado outbreak since 1950 (beginning year of official tornado database) in terms of fatalities and the largest since May 31, 1985. Fatalities occurred in Arkansas, Tennessee, Kentucky, and Alabama. There were five violent Enhanced Fujita (EF) Scale 4 tornadoes reported; two each in Tennessee and Alabama, and one in Arkansas. The EF4 tornado in Arkansas had a remarkable 122-mile continuous damage path; this was the longest path length of a tornado in the state since at least 1950. A deadly EF3 tornado that touched down northeast of Nashville, Tennessee, carved a 51- mile path of destruction claiming 22 lives. This was the deadliest tornado in the United States since a tornado in Evansville, Indiana, November 2005 killed 25 people.

Due to the magnitude of this event, a service assessment team was formed to evaluate the warning and forecast services provided to key decision makers and the public. In keeping with the National Oceanic and Atmospheric Administration's (NOAA) goals of developing hazard-resilient communities, the team was also tasked with trying to identify possible reasons for the large loss of life during this event.

The facts, findings, recommendations, and best practices from this assessment are offered with the goals of 1) improving the quality of warning and forecast products and services; and 2) enhancing the ability of the National Weather Service (NWS) to increase public education and awareness regarding issues associated with tornado safety. The ultimate goal is to help meet the NWS mission of protecting lives and property and enhancing the national economy.



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March 2009

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Service Assessment Team

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Service Assessment Report

1. Executive Summary

The mission of NOAA's National Weather Service (NWS) is to protect life and property by providing weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas. Forecasters at the 122 Weather Forecast Offices (WFOs) and 13 River Forecast Centers (RFCs) issue all local forecasts and warnings to the public. The National Centers for Environmental Prediction (NCEP), consisting of 9 prediction centers, provides central guidance, outlooks, and hazardous weather watches and warnings to the NWS organization and the public.

This tornado outbreak in the Mid-South and Tennessee Valley caused 57 fatalities, the second most in February on record (official tornado database begins in 1950). It is the largest tornado fatality total since May 31, 1985. The event began on February 5, 2008, (dubbed "Super Tuesday" because many states were holding Presidential primary elections), and continued into February 6. Eighty-seven tornadoes occurred in nine states causing the 57 fatalities in four states (**Appendix D**). The fatalities occurred during a 12-hour period across portions of Arkansas, Tennessee, Kentucky, and Alabama. Tennessee was hardest hit with 31 fatalities, followed by Arkansas with 14, Kentucky with 7, and Alabama with 5 (**Appendix E**). There were five violent Enhanced Fujita (EF) Scale 4 tornadoes: two each in Tennessee and Alabama, and one in Arkansas (**See Appendix F for EF scale**). The EF4 tornado in Arkansas had a 122-mile continuous damage path. Along the path of this tornado, a 158 mph wind gust was observed at a home weather station in Zion, Arkansas. A deadly EF3 tornado that touched down northeast of Nashville, Tennessee, carved a 51-mile path of destruction claiming 22 lives. This is the deadliest tornado in the United States since a tornado in Evansville, Indiana, November 2005, killed 25 people. Early damage estimates were $520 million.

The NWS formed a Service Assessment Team to evaluate its performance. The Team interviewed staff and reviewed products from NCEP's Storm Prediction Center (SPC); six WFOs (Little Rock, Arkansas; Memphis and Nashville, Tennessee; Paducah and Louisville Kentucky; and Huntsville, Alabama); the Center Weather Service Unit (CWSU) in Memphis; and partners and users of NWS products affected by the event. A task for this team was to assess the societal impacts of this event. The NWS continues to improve its forecast and warning services for significant tornado outbreaks; yet, as this event demonstrated, numerous fatalities are still occurring.

This tornado outbreak was anticipated and forecast days in advance. The SPC began focusing on the affected area in their Day 4-8 Convective Outlook, six days prior to the event. They continued emphasizing, refining, and enhancing the threat leading up to the event, ultimately issuing a high risk convective outlook for a large portion of the impacted area on the morning of Tuesday, February 5.

The initial lead time allowed the WFOs to prepare for severe weather operations and to indicate the risk of severe weather and tornadoes as much as four days in advance in their Hazardous Weather Outlooks (HWO). The WFOs contacted Emergency Managers (EMs) and media the morning of the event. EMs and media interviewed indicated they were well prepared for the severe weather that occurred Tuesday afternoon (February 5) through early Wednesday morning (February 6).

All of the tornado fatalities occurred within the boundaries of tornado watches and were preceded by tornado warnings. The average SPC tornado watch lead time to the first tornado within the watch was 2 hours. The mean lead time for tornado warnings covering fatalities was 17 minutes and the mean lead time for all tornado warnings issued by these offices was also 17 minutes. A listing of each assessed office's important statistics for this event is in **Appendix E**. The 2008 Government Performance Results Act (GPRA) goal for tornado warning lead time was 11 minutes.

This was the first major tornado outbreak since the institution of Storm-based warnings on October 1, 2007. The Storm-based warnings reduced the geographic area covered by the warnings compared to county-based warnings; however, the team uncovered some issues that impacted overall performance.

The factors listed below are critical in answering the question on why so many fatalities occurred in this event despite an overall excellent performance (indicated by partners and users interviewed) from the NWS.

- Sixty-three percent of the fatalities in this event occurred in manufactured homes.
- Most of the fatalities in this event occurred at night.
- Most of the areas affected by the deadly tornadoes were heavily forested.
- Over 50 percent of the people interviewed acknowledged that they associate tornado outbreaks with the springtime or summer months. This caused many of them to minimize the threat of this early February outbreak because of their perception that it was too early in the year and outside the "traditional" tornado season.

There were several success stories during this event. Parts of Union University in Jackson, Tennessee were devastated including some of the dormitories, but due to excellent planning and preparedness efforts, there were no fatalities. A tornado struck a high school in Muhlenberg County, Kentucky during a basketball game and due to a good shelter-in-place plan, there were no fatalities. Schools were dismissed in the Memphis City school district early Tuesday afternoon. Normally, buses would have been on the road when tornadoes struck the Memphis area around 5:30 p.m. Central Standard Time[1] if schools had not been let out early.

Overall, 16 recommendations have been made based on the team's findings. These recommendations should address deficiencies, improve NWS performance, and enhance NWS safety and outreach programs. Eight best practices have been identified as well. The NWS definitions of facts, findings, recommendations, and best practices can be found in **Appendix A**. A full list of facts, findings, recommendations, and best practices from this report is in **Appendix B.**

[1] All times referenced throughout the remainder of the report are in Central Standard Time.

2. Introduction

2.1 NWS Mission

The mission of the NWS is to protect life and property by providing weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters, and ocean areas. Forecasters at 122 WFOs and 13 RFCs issue all local forecasts and warnings to the public, as well as interface with local EMs and state and local governments to promote community awareness and understanding of local climates, forecasts and weather events.

The NWS is comprised of six Regional Headquarters, a National Headquarters, and the National Centers for Environmental Prediction (NCEP), consisting of nine prediction centers that provide guidance, outlooks, and hazardous weather watches and warnings to the entire NWS organization and the public.

2.2 Purpose of Assessment Report

The NWS conducts service assessments of significant weather-related events. A significant event results in at least one fatality, numerous injuries requiring hospitalization, extensive property damage, widespread media interest, or an unusual level of scrutiny of NWS operations (performance of systems, or adequacy of warnings, watches, and forecasts) by the media, emergency management agencies, or elected officials. Due to limited resources, it is impractical to assess all significant weather-related events. Service assessments evaluate the NWS performance and ensure the effectiveness of NWS products and services in meeting the mission. The goal of service assessments is to improve the ability of the NWS to protect life and property by implementing recommendations and best practices that improve products and services.

Due to the high number of fatalities during this event, the NWS assessed its performance. The purpose of this document is to present the facts, findings, recommendations, and best practices related to the following key areas:

- Effectiveness of NWS internal and external coordination/collaboration
- Effectiveness of NWS information dissemination
- Effectiveness of NWS office procedures
- Effectiveness of NWS severe-weather awareness activities
- Societal Impacts of NWS products and services

Overall, 16 recommendations have been made based on the team's findings. These recommendations should address deficiencies, improve NWS performance, and enhance NWS weather-safety outreach programs. There were also eight best practices identified.

2.3 Methodology

The NWS formed a service assessment team on February 13, 2008, to evaluate the NWS performance during the tornado outbreak of February 5-6, 2008. Team members assessed damage areas and interviewed EMs, the media, and the public in Arkansas, Kentucky, Tennessee, and Alabama, and interviewed staff from the WFOs located in Little Rock, Arkansas; Memphis and Nashville, Tennessee; Paducah and Louisville, Kentucky; and Huntsville, Alabama. The team also reviewed products and services from the WFOs, SPC, and the CWSU in Memphis.

Upon completion of the interviews and evaluations, the team discussed and agreed upon the significant findings and recommendations to improve effectiveness of NWS products and services. After a series of internal reviews, the service assessment was approved and signed by the NOAA Assistant Administrator for Weather Services and issued to the American public.

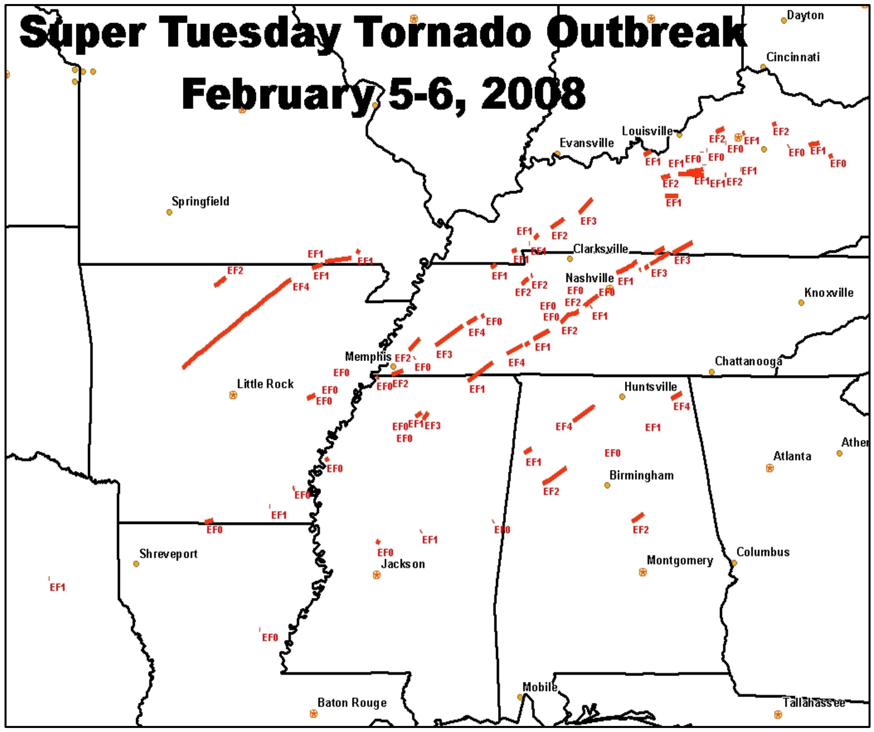
3. Summary of Tornadoes and Damage

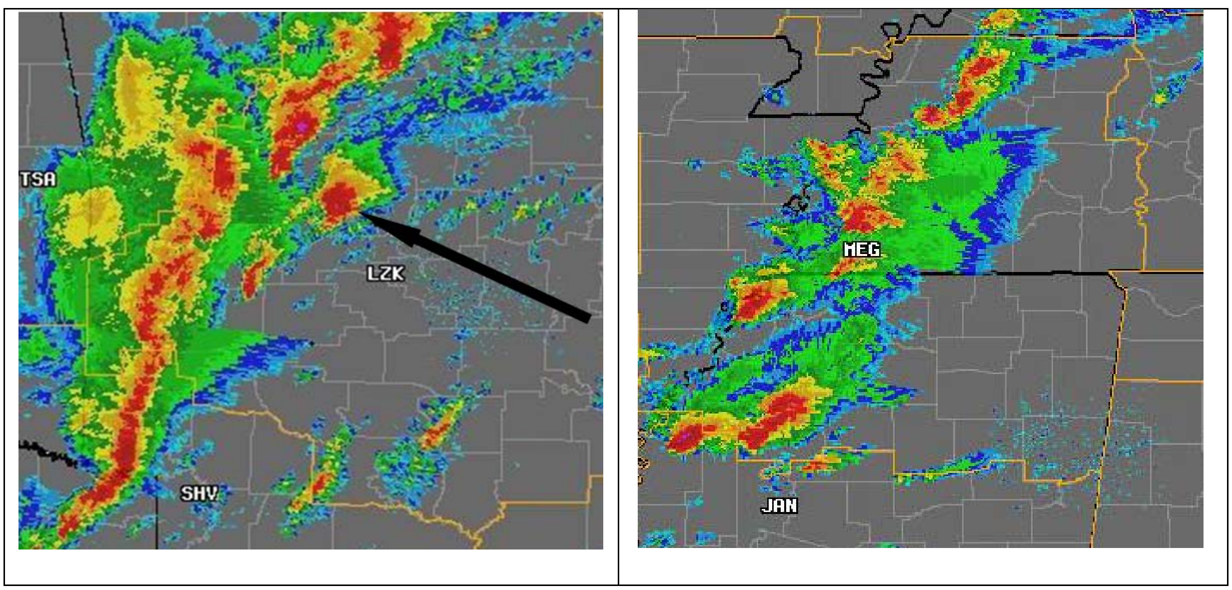
The "Super Tuesday" tornado outbreak of February 5-6, 2008, consisted of 87 tornadoes affecting parts of nine states (**Figure 1**). Tornado fatalities occurred during a 12-hour period (5 p.m. – 5 a.m.) in Tennessee (31), Arkansas (14), Kentucky (7), and Alabama (5) for a total of 57 fatalities (**Appendix D**). All fatalities occurred from tornadoes rated EF2 or greater. Five tornadoes were rated EF4 (**Appendix F**); two each in Tennessee and Alabama, and one in Arkansas. The 55-mph forward motion of the storms presented challenges to warning forecasters. All tornadoes producing fatalities were preceded by tornado warnings with a mean lead time of 17 minutes. There were also 126 reports of large hail and 267 reports of wind damage with this event. Damage estimates are $520 million.

Mean lead time takes into account the full duration of the tornado event. It is calculated by averaging the lead times for each minute the tornado is on the ground. Lead times are determined by subtracting the time when the warning was issued from the time the tornado touched down. For example, a Tornado Warning was issued at 1:00 p.m. and a tornado initially touched down within the warning polygon at 1:10 p.m. (The initial lead time is 10 minutes.) The tornado lasts for 10 minutes in the polygon until 1:20 p.m. There are lead times of 10 minutes, 11 minutes, 12 minutes, 13 minutes, etc. through 20 minutes. The average of those mean lead times is 15 minutes. Mean lead time is the measure used for GPRA goals.

The first three fatalities occurred in Atkins, Arkansas, around 5:02 p.m. on Tuesday, February 5, near the beginning of the path of a 122-mile long EF4 tornado. This tornado killed 13 people across west central and north central Arkansas **(Figure 2a**). Other supercell thunderstorms were developing across northern Mississippi and becoming tornadic (**Figure 2b**). A supercell thunderstorm is a thunderstorm that often produces severe weather; i.e., large hail, strong straight line winds, and/or tornadoes. It is different from a typical thunderstorm in that it has a tilted rotating updraft which allows the thunderstorm to be stronger and persist longer.

Figure 1. Tornado tracks and EF scales February 5-6, 2008.





Figures 2a (left) and 2b (right). WSR-88D reflectivity image from Little Rock, Arkansas, at 5:00 p.m., (left) showing tornadic supercell near Atkins, Arkansas; and Tornadic supercells developing over northwest Mississippi and southwest Tennessee at 5:00 p.m. (right).

An EF2 tornado moved across the Memphis area between 5:30 p.m. and 6:00 p.m. affecting the Memphis International Airport and a shopping mall. A warehouse in the Memphis area collapsed due to the tornado, killing three people. The control tower at the Memphis International Airport was evacuated as the tornado approached, and NWS personnel at the Memphis WFO evacuated their office for a 9-minute period between 5:51 p.m. and 6:00 p.m.

Tornadic supercells traveled rapidly across the remainder of the Memphis, Nashville, Paducah, and southern portions of the WFO Louisville CWA throughout the evening, resulting in substantial damage and numerous fatalities and injuries. Two other tornadic supercells were responsible for five fatalities.

During the overnight hours, an upper-air disturbance moved across northern Alabama and initiated supercell thunderstorm development south of a decaying line of thunderstorms. These supercells produced two EF4 tornadoes. The last tornado fatality occurred around 5:20 a.m. in eastern Jackson County, Alabama. Overall, there were 17 counties that experienced tornado fatalities: 7 in Tennessee, 6 in Arkansas, 2 in Kentucky, and 2 in Alabama.

The SPC issued 16 severe-weather watches for this event; 13 tornado watches and three severe thunderstorm watches. Two of the tornado watches issued Tuesday afternoon included the "Particularly Dangerous Situation (PDS)" wording and covered numerous significant tornadoes. Based on SPC station duty manual guidelines, the PDS wording is used in the rare situations when there is a high confidence forecast of multiple significant tornadoes. High confidence can be equated to a 75 percent success rate, or a goal of 3 out of every 4 PDS tornado watches verifying with multiple strong or violent tornadoes. PDS watches are issued most often in High Risk Outlook areas. All tornado fatalities during this event occurred within the boundaries of tornado watches.

4. Summary of Meteorological Conditions Preceding the Tornado Outbreak

Conditions favorable for the tornado outbreak began to develop February 3, as low pressure at the surface and aloft consolidated over the Rockies, and a surface high pressure moved toward the east coast. The circulation around these two features resulted in a prolonged period of southerly flow off the Gulf of Mexico ahead of the surface cold front that moved across the area on Tuesday, February 5 (**Figure 3**). The southerly flow provided a good supply of low-level moisture for severe thunderstorm development. By mid-day Tuesday, a broad, moist and moderately unstable air mass became established, with surface dew points near 65 °F as far north as Memphis, Tennessee (**Figure 4**). The dew point is the temperature to which a given parcel of air must be cooled, at constant barometric pressure, for water vapor to condense into water. Unusually high dew points are often an indication of an unstable air mass, which is necessary for severe thunderstorm formation. During the winter, dew point temperatures greater than 55 °F, even in the Mid-South, are unusually high.

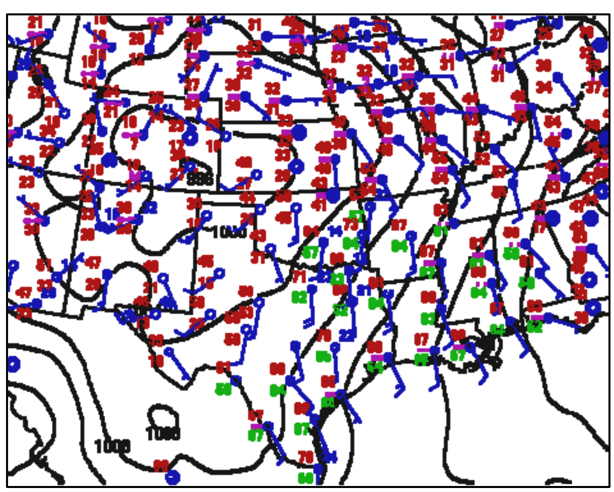


Figure 3, Surface map valid at 1200 UTC (6 a.m.), Monday, February 4, 2008. Warm, moist southerly flow is already established across the Gulf Coast ahead of surface low over Colorado.

At midday, a strong southerly low-level jet stream was established across the Gulf Coast and lower Mississippi Valley. A low-level jet stream is a current of fast moving (faster than its surrounding environment) air in the low levels of the atmosphere (approximately 3,000 to 5,000 feet above sea level). Low-level jet streams create wind shear (change in wind speed and direction with height) and lifting of surface air necessary for severe thunderstorm formation. Morning upper-air observations across the region showed a mid-level (5,000 to 10,000 feet above sea level) stable warm layer of air, which acted as a cap or lid to the rising air below it and suppressed thunderstorm formation. If other factors in the atmosphere break through this layer, the air will rise rapidly (similar to air rushing out of a hole in a balloon) and this often creates severe thunderstorms.

At 6 a.m. February 4, a surface low pressure and associated cold front were over the southern Rockies (**Figure 3**); the system moved to eastern Oklahoma by noon on February 5. By late afternoon of February 5, the atmosphere had become unstable enough to allow isolated supercell thunderstorms to form ahead of the approaching cold front and an intense line of thunderstorms formed along the cold front. The southerly low-level jet stream had increased to near 70 miles per hour (mph) and mid-level westerly winds increased to 90 mph (**Figure 4**). This resulted in strong vertical wind shear conducive to tornado development. The surface low pressure and cold front moved to central Arkansas creating a broad warm sector (area between cold front and warm front) (**Figure 5**), which allowed the storms to persist for great distances and produce either long track tornadoes or multiple tornadoes along their paths.

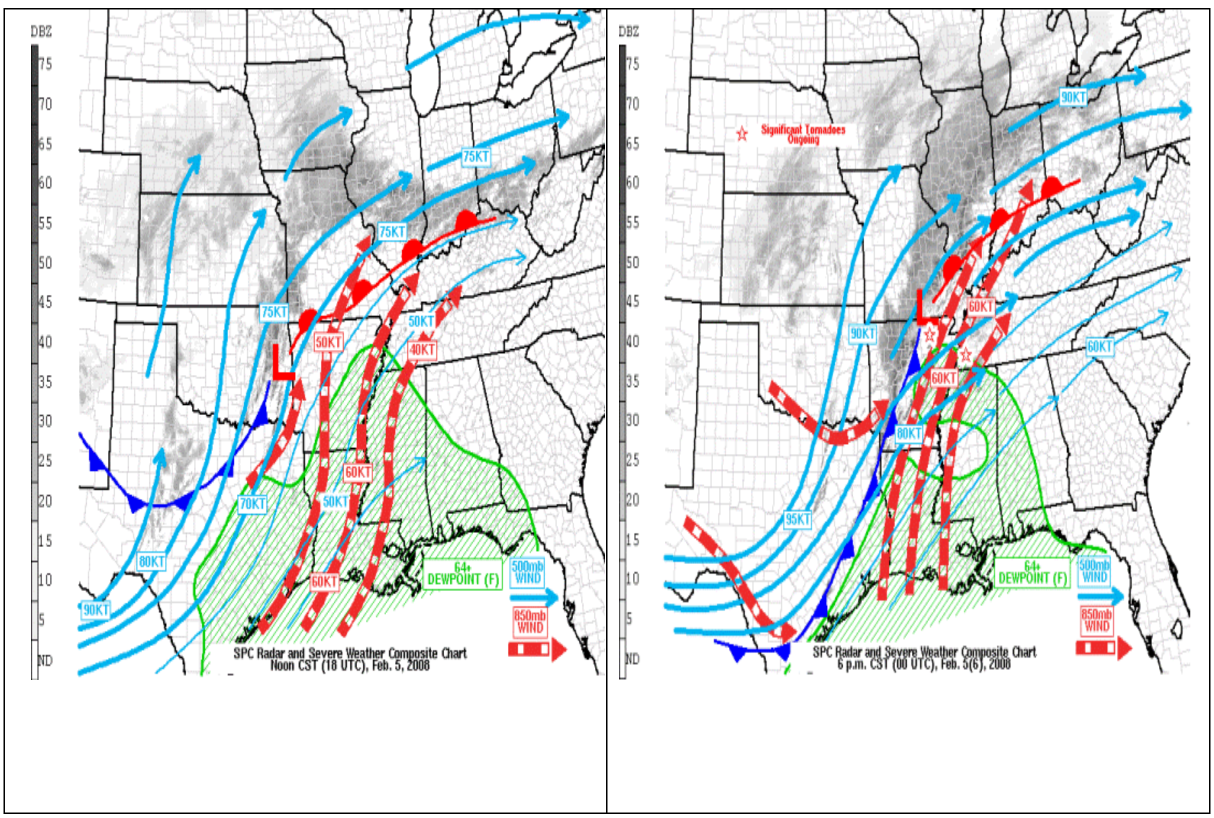


Figure 4. Composite map showing 850 millibar (mb) (red) and 500 mb (blue) streamlines, surface features, moisture axis (green shading), and radar (gray) at 1800 UTC (12 p.m.) and 0000 UTC (6 p.m.) Tuesday, February 5, 2008. Figure courtesy of the Storm Prediction Center (SPC).

5. Summary of Storm Prediction Center Products and Services

The SPC began focusing on the severe weather potential on Thursday morning, January 31, 2008, in their Day 4-8 Convective Outlook product. A severe weather risk area for day 6 Tuesday, February 5, captured the eventual outbreak region quite well. Highlighting the potential well in advance gave the WFOs ample time to prepare for the event and also allowed them to emphasize the threat in their Hazardous Weather Outlooks (HWO) days in advance.

Subsequent Day 4-8 severe weather outlook products issued by SPC on Friday and Saturday morning continued a risk of severe thunderstorms for Tuesday in the general area of the outbreak. The Day 3 Convective Outlook product valid from 6:00 a.m. Tuesday morning, until 6:00 a.m. Wednesday morning, indicated a slight risk for severe thunderstorms across the south central United States (**Figure 5**). The associated text of the Convective Outlook product stated: *"A widespread severe weather event including damaging winds and the potential for tornadoes is anticipated across a large part of this region."* A moderate risk of severe thunderstorms was introduced in the initial Day 2 Convective Outlook product issued at 12:53 a.m. Monday, February 4. The moderate risk area (**Figure 5**) included most of the area eventually affected by tornadoes. The forecast indicated that a widespread significant severe weather event was possible and that tornadoes were expected, with some being strong/significant.

It was decided during a conference call between SPC and several WFOs that a moderate risk of tornadoes would be maintained in the initial Day 1 Convective Outlook issued on Tuesday, February 5, but an upgrade to high risk might be required in later outlooks. The forecast text included: *"potentially strong and long-track tornadoes."*

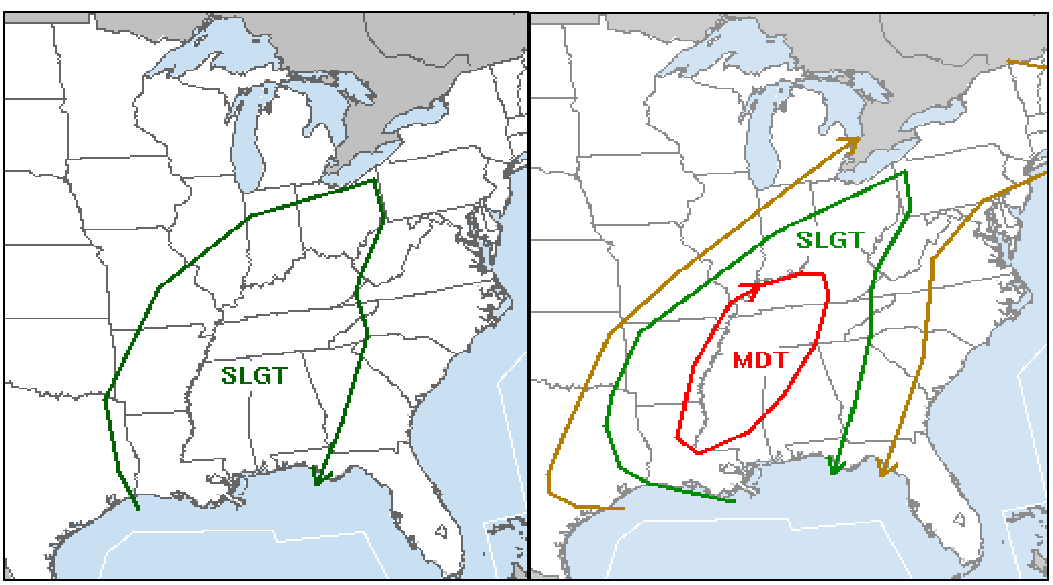


Figure 5. Day 3 (left) and Day 2 (right) Convective Outlooks from SPC valid 1200 UTC February 5, 2008 to 1200 UTC February 6, 2008.

The first high risk Severe Weather Outlook for the event was issued at 6:39 a.m. Tuesday, for portions of Arkansas and Mississippi (**Figure 6**). At 10:16 a.m., the high risk outlook was expanded into parts of western Kentucky and western Tennessee and covered much of the eventual tornado outbreak region (**Figure 6**). The next two Convective Outlooks issued at 1:39 p.m. and 6:47 p.m. Tuesday maintained a high risk outlook with the area adjusted accordingly based on current thunderstorm activity.

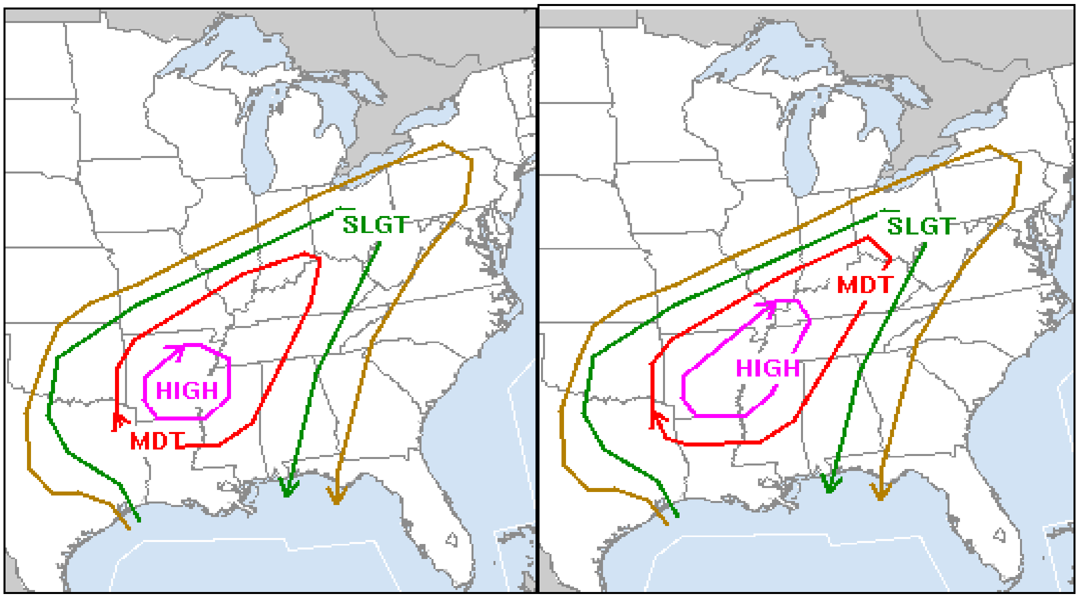


Figure 6. Day 1 Convective Outlooks from SPC valid 1300 UTC, February 5, 2008, until 1200 UTC, February 6, 2008, (left) and 1630 UTC, February 5, 2008, until 1200 UTC, February 6, 2008 (right).

The SPC issued 16 severe weather watches for the event. They issued 13 tornado watches and three severe thunderstorm watches. Two of the Tornado Watches, issued at 2:10 p.m. and 3:10 p.m., contained the PDS headline and covered much of the high risk outlook area. SPC's lead time for tornado watches where fatalities occurred averaged two hours for the first tornado occurrence in the watch area and four hours for the first tornado fatality within the watch area (**Table 1**).

Watch #	Lead time for first severe weather report	Lead time for First Tornado	Lead time for first tornado fatality
35	35 minutes	4 hours 36 minutes	4 hours 36 minutes
36	30 minutes	1 hour 22 minutes	2 hours 52 minutes
37	30 minutes	1 hour 38 minutes	2 hours 22 minutes
39	41 minutes	2 hours 5 minutes	6 hours 30 minutes
40	47 minutes	47 minutes	2 hours 47 minutes
41	1 hour 25 minutes	1 hour 25 minutes	5 hours 15 minutes
Average	45 minutes	1 hour 59 minutes	4 hours 4 minutes

Table 1. Lead times for tornado watches where fatalities occurred during the February 5-6, 2008 tornado outbreak. Times are in hours and minutes.

6. Facts, Findings, Recommendations, and Best Practices

6.1 WFO Tornado Products and Services

Wording in WFO warnings and statements indicating the urgency and danger of the situation was used sparingly throughout the event. Wording such as: "*extremely dangerous and life threatening situation*" should have been employed more often in tornado warnings and follow-up severe weather statements (SVS) given the amount of tornadoes and damage reports received in real-time, the steady-state nature of the supercells, and the high risk outlooks and PDS tornado watches in effect. Many call-to-action statements that did not convey the urgency of the event were used. During tornadic episodes where the forecasters have a high level of confidence an immediate and widespread response is critical, statements such as "this is an extremely dangerous and life threatening situation" would increase the level of significance of these products.

Finding 1: Relatively few of the tornado warnings or statements contained wording or call to action statements indicating the urgency and danger of the situation, even when tornadoes and damage were confirmed (i.e., "this is an extremely dangerous and life- threatening situation").

Recommendation 1a: NWS Instruction 10-511 should provide guidance on using wording and call to action statements in tornado warnings and SVSs that convey appropriate urgency and danger.

Recommendation 1b: Warning Decision Training Branch (WDTB) should develop training for warning forecasters on how and when to use explicit wording that conveys the urgency and danger of a situation.

During this event, there were examples of wording which indicated the urgency and danger of the situation. WFO Louisville issued a Special Weather Statement (SPS) for the two tornadic supercells that produced EF3 damage in Monroe and Allen counties (near the Tennessee border). The statement had the headline "*Strong storm, possibly with a tornado, over northern Tennessee and heading into southern Kentucky*." WFO Memphis issued two tornado emergencies in SVSs for the event, one for the city of Memphis and another for the city of Jackson. These were the first tornado emergencies ever issued by WFO Memphis. Both statements stated there was a tornado on the ground at a specific location and indicated where the tornado was moving and when it should be in specific locations. WFO Huntsville also issued a tornado emergency for Morgan County and the city of Decatur, Alabama, after it became clear that major damage had occurred in Lawrence County (later rated EF4). The text of the statement included: *"This storm has produced significant damage…and spotters report that the tornado is on the ground. Do not wait to take action...take cover now!"*

There were instances where tornadoes and damage had been confirmed, but associated tornado warnings and SVSs did not make that clear. Because of the uncertainty in those products, some users were not sure if there were confirmed tornadoes and damage or not. Radio station KARN in Little Rock would have preferred more definitive warnings. In western Kentucky, some media outlets were not clear about the confirmation of tornadoes and damage.

Many of the people interviewed did not respond to a single piece of information, such as a warning, before taking shelter. Instead, they looked for further evidence of verification. Clear wording such as "*a tornado has been confirmed…*" or "*a tornado is on the ground at...and is moving…*" will make it clear there is a confirmed tornado and lessen the chances of someone taking valuable time to verify there is an immediate danger instead of seeking shelter.

Finding 2a: Some media partners interviewed prefer more definitive tornado warnings and SVSs.

Finding 2b: A majority of the tornado warnings contained wording such as "*Doppler Radar indicated a severe thunderstorm capable of producing a tornado*." It is phrases such as this that make it unclear whether or not there is a tornado on the ground.

Recommendation 2: The NWS should provide guidance on wording that increases the chances of improved public response during tornadic events where tornadoes have been confirmed. Clear wording such as "*a tornado has been confirmed…*" or "*a tornado is on the ground at...and is moving…*" should increase the probability that a warning will get an appropriate and immediate response.

WFO Nashville issued Tornado Warnings for Sumner County, Tennessee (borders Allen County to the south) at 1:05 a.m. and 1:32 a.m. for the thunderstorm that eventually produced the EF3 tornado in Allen County. There were no reports of tornadoes in Sumner County during these warnings, and WFO Louisville was not convinced the thunderstorm was tornadic. WFO Louisville later became convinced the thunderstorm was tornadic and issued a Tornado Warning for Allen County at 1:38 a.m. The fatalities occurred at 1:45 a.m.

Media outlets in Bowling Green, Kentucky, expressed a desire for WFOs to be able to extend warning polygons into neighboring CWAs. They thought that lead time was lost in the Allen County tornado warning because of the state line and CWA boundary limitations. Current NWS policy does not allow WFOs to issue products for neighboring WFO CWAs unless they are in a back-up mode.

The team found that there was no coordination between WFO Nashville (Southern Region) and WFO Louisville (Central Region) on the Allen County tornado warning. Media in southern Kentucky felt coordination between WFOs having responsibilities for counties along the Tennessee and Kentucky border needed improvement. The team did not find clear reasons for the lack of coordination. The team also found the regional boundary between the two offices played no role in the lack of coordination.

Preliminary findings from the team for the NWS Service Assessment, *Mother's Day Weekend Tornado May 10, 2008*, indicate a similar issue regarding a lack of coordination between WFOs. As in this event, better coordination between the two offices could have improved their overall services.

Finding 3: There was no coordination between WFO Nashville and WFO Louisville on the Allen County tornado warning.

Recommendation 3: NWS should require regions to develop severe weather coordination procedures between neighboring offices.

6.1.1 Tornado Emergency Wording

A tornado emergency is a headline containing the phrase "Tornado Emergency for..." followed by specific information about areas in the tornado's path. This designation is usually added to the SVS that is used to follow-up a tornado warning. The first tornado emergency was issued by WFO Norman for the devastating tornado which hit Moore, Oklahoma, on May 3, 1999.

As mentioned previously in the document, WFOs Memphis and Huntsville issued tornado emergencies within SVSs for densely populated areas. Some of the media in Arkansas inquired why tornado emergencies were not issued for the communities along the path of the long-track EF4 tornado in Arkansas. The WFO Little Rock personnel felt that the tornado emergency was to be reserved for tornadoes impinging on densely populated areas. This is the general perception of all WFOs. During this event, there was no national guidance on when to use tornado emergency wording. NWS Instruction 10-511, Severe Weather Products Specification, is scheduled for an update by March 31, 2009 and will include guidance on using tornado emergencies.

Fact: During this event, there was no clear national guidance on when tornado emergency wording should be used.

6.2 Tornado Watches Issued by SPC

Emergency Managers and NWS meteorologists interviewed stated the SPC provided outstanding service during this event with timely and accurate watches. Watch collaboration between SPC and WFO forecasters was exceptional in respect to early watch issuances.

Emergency Managers, the media, and WFO staff members in Kentucky indicated they were satisfied with the overall tornado watch philosophy from SPC. However, EMs in Arkansas, Tennessee, and northern Alabama felt tornado watches have become too large in size and too long in duration. The EMs and the media indicated that areas within the watch, especially on the eastern side with a typical eastward moving weather system, are often under a watch for several hours before storms threaten. The issuance of a tornado watch triggers action in several areas, including the opening of Emergency Operation Centers (EOC) and shelters, and the beginning of media coverage. Further, in the Mid-South and Gulf Coast, school closure decisions are being made based in part on a forecast of tornadoes. The consensus was that if there is no expectation of severe weather for several hours, then a watch should be issued later when the threat is more imminent.

The NWS discussed the concerns of tornado watches being too large in size and too long in duration at the NWS Partners Meeting in June 2008. It was the consensus of the group at the time that no immediate changes to the size or duration of tornado watches should be made.

However, due to the concerns of NWS partners discussed earlier, an NWS team was formed to assess the varied needs of critical partners with respect to the convective watch program.

Surveys have been developed to help quantify EM's and broadcast meteorologist's requirements. One survey was conducted for a segment of broadcast meteorologists under the auspices of the National Weather Association during its annual meeting in October 2007, where 45 surveys were completed. A second survey is being conducted with emergency management officials attending the International Association of Emergency Managers (IAEM) conference. The results of these surveys will be used to reassess partner needs and requirements.

There are several non-meteorological factors that impact the size of a severe weather watch. For example, WFO Huntsville has a preference for smaller watches with shorter time durations while WFO Paducah prefers all of their County Warning Area be contained in a convective watch if any portion is being considered for a watch by SPC. This makes the watch coordination and issuance process complex, and finding one clear methodology that satisfies all users will take considerable study.

Some users expressed tornado watches issued by SPC were too large in size and too long in duration. The NWS discussed concerns of tornado watches being too large in size and too long in duration at the NWS Partners Meeting in June 2008. It was the consensus of those in the meeting that no immediate action should be taken to alter the current process. The SPC will continue to explore options to improve the future watch process.

6.3 Storm-based warnings

On October 1, 2007, the NWS transitioned from a county-based warning and verification system to a Storm-based warning and verification system for Tornado, Severe Thunderstorm, and Flash Flood warnings. Specifically, warnings issued for these events are now only effective for the area delineated by the Advanced Weather Interactive Processing System (AWIPS) WarnGen polygon. This tornado outbreak was a significant test of the Storm-based warning system.

This approach substantially reduced the geographic area under tornado warnings during the event. **Table 2** shows the County Area Reduction (CAR) for tornado warnings for this event at each of the six WFOs. For example, WFO Little Rock has a CAR of 67.7 percent, which means that the area warned for during this event (tornado warnings only) was reduced by 67.7 percent. Based on the data in **Table 2**, it is obvious that this aspect of Storm-based warnings was effective during the tornado outbreak.

WFO	Polygon Area mi^2	County Area mi^2	CAR (percent)
Little Rock	8,433.36	26,077.9	67.7
Memphis	33,788.45	81,137.6	58.4
Nashville	10,069.10	30,412.7	66.9
Paducah	6,799.10	15,720.7	56.8
Louisville	12,391.46	30,044.3	58.8
Huntsville	3,306.68	11,209.5	70.5

Table 2. Total polygon area and County Area Reduction (CAR) for tornado warnings during this event at each of the WFOs assessed. County area is the area that would have been warned under the old county-based warning system.

County-based warning philosophies continue to be in practice and in some cases, that philosophy provides better service to partners. Many warnings during this event were truncated by the forecaster at county boundaries on the downstream end of the polygon. Given a speed of 55 mph of the tornadic supercells and their steady-state nature, warning polygons should have concentrated on the area affected and not the county boundaries. However, it is not possible to send tone alerts or activate EAS through NWR based exclusively on the polygon boundaries. Sending alerts and activating EAS through NWR is still dependent on county boundaries. Also, some of the television stations could not display warning polygons and are still highlighting whole counties when only a portion is actually in the warning. In some instances, forecasters excluded certain portions of counties from the polygons to better fit NWR alerting capabilities and/or local TV station display capabilities. A small polygon that clips four or five counties would appear as a large warned area on some TV broadcasts because all of the counties would be illuminated.

Finding 4a: The Storm-based warning approach does not allow NWR to alert exclusively within the warning polygon, and not all TV stations have the capability to display warning polygons. Some TV stations still highlight the entire county even if only a portion of the county is affected by a warning.

Finding 4b: In some instances, forecasters excluded certain portions of counties from the polygons to better fit NWR alerting capabilities and/or local TV station display capabilities.

Recommendation 4a: The NWS should develop more efficient methods of using Storm-based polygon warnings in NWR activations.

Recommendation 4b: The NWS should encourage TV stations and their vendors to develop the capability to display NWS polygon warnings.

The examples in **Figure 7** show a county-based influence with warnings truncated or drawn around county boundaries with storms nearly exiting the polygon before a downstream warning is issued.

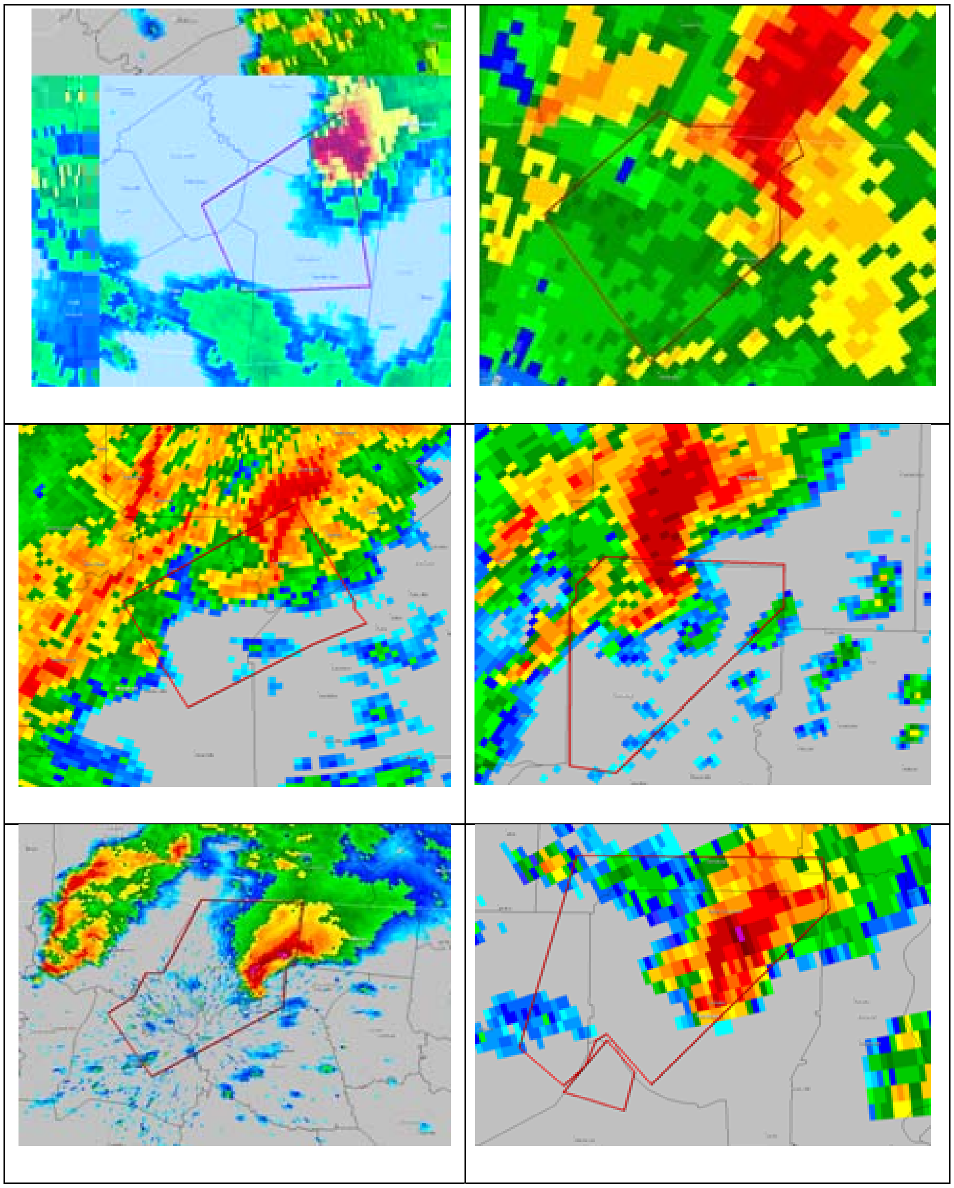


Figure 7. Top left: The next warning polygon for this tornado was issued three minutes after this image. **Top right:** Severe storm entering Allen County, Kentucky. WFO Louisville was issuing a tornado warning at this time. **Middle left:** Tornadic thunderstorm nearing the edge of the warning polygon. New warning polygon issued three minutes after this image. **Middle right:** Tornado on the ground in Conway County, Arkansas near the edge of the warning polygon. New warning was in the process of being issued. **Bottom Left:** Clear hook echo. WFO Nashville issued a new warning four minutes after this image. **Bottom right:** WFO Memphis issued a new tornado warning downstream five minutes after this image.

Many tornado warnings varied from established training practices in order to account for the rapid evolution and fast movement of the thunderstorms. In some situations, the fast storm motion was not accounted for. For example, some warning forecasters waited until a storm was close to exiting one polygon before issuing a warning polygon downstream. This had a negative impact on lead time given the fast storm motions. Tornado warning lead times on the upstream portion of the polygons were dramatically reduced in some instances (to 5 minutes or less) as tornadoes moved from one polygon into another. In some cases, the leading edge of a polygon had little advance warning. In another case, a large tornado warning polygon was issued for portions of 11 counties for multiple embedded mesocyclones along the squall line, which is contrary to guidance from the WDTB. Training from WDTB encourages using multiple polygons along the track of the mesocyclones as opposed to one. However, the team found no significant concerns from the users. Since the initial Storm-based warning training, offered by WDTB, focused on initial warnings and not subsequent ones, and did not explicitly provide training on how to warn for fast-moving tornadic storms, the training should be updated for events such as this.

Finding 5: Many tornado warnings varied from established WDTB training practices and many did not account for the rapid storm motions.

Recommendation 5: WDTB should update their Storm-based warning training to include the following: 1) the importance of warning well downstream in the case of fast-moving tornadic supercells, 2) the importance of anticipating the need for new warnings well before a given storm moves out of a current polygon, 3) overlapping warnings to ensure no gaps between warnings, and 4) not removing counties from a polygon unless the forecaster has total confidence that the storm will not impact that area.

6.4 Services Provided by the Memphis Center Weather Service Unit

The Memphis International Airport is home to the worldwide headquarters of the shipping company Federal Express (FedEx) and is the busiest cargo airport in the world. Parts of the airport were hit by an EF2 tornado at approximately 5:35 p.m. on February 5. The Air Traffic Control Tower personnel abandoned the tower and took shelter while the tornado moved across the airport.

The Center Weather Service Unit (CWSU) in Memphis is located near Memphis International Airport, within the Federal Aviation Administration (FAA) Air Route Traffic Control Center (ARTCC). CWSUs are a part of the NWS and their meteorologists provide a constant source of weather information to the air traffic controllers and to the Traffic Management Unit (TMU) of the FAA. During this severe weather event, the numerous thunderstorms had a significant impact on the flight and airport operations within the ARTCC area of responsibility. In particular, FedEx's incoming traffic peaks in the late evening; during that time on February 5, a line of severe thunderstorms was moving through the Memphis area.

ARTCC air traffic controllers gave high praise for the efforts of the CWSU meteorologists. The air traffic controllers specifically mentioned their accuracy with timing of high impact weather phenomena and with sudden changes in conditions. One controller noted, *"The CWSU guys were dead on…"* regarding the timing of the thunderstorms. That same controller mentioned, *"We would be blind without them."* The CWSU provided numerous briefings throughout the event. With the guidance provided by the CWSU, the controllers were able to schedule departure and arrivals, routes, and flight plans according to the expected impact from the storms.

The CWSU meteorologists were also in direct communication with the controllers in the air traffic control tower. This communication was invoked several times throughout the event, and was mostly initiated by the CWSU. On numerous occasions, the CWSU meteorologists coordinated with the WFO and with the Aviation Weather Center (AWC) in Kansas City, Missouri, to ensure proper information exchange.

During the event, meteorologists at the CWSU used a commercial radar display program. This software provided supplemental radar displays, which were very beneficial. The meteorologists were able to discern important storm features, including the extent of the storm anvil, hail, overshooting tops, and shear.

Staff at the CWSU stayed beyond normal operating hours in support of the ARTCC. The Memphis Airport Manager spoke highly of the services provided by the CWSU and the WFO.

Best Practice 1: The use of a radar display program by CWSU Memphis meteorologists during this event was beneficial in detecting storm features such as anvil extent, hail cores, overshooting tops, and shear.

6.5 Situational Awareness of WFOs

Each of the offices used an Event Coordinator during the tornado outbreak and sectored their warning operations. Two to four radar operators were used at each WFO during the event. WFOs Memphis, Paducah, and Louisville used assistant warning forecasters (where a second person sits next to the warning forecaster, handles the text portion of warnings and statements, and provides “another set of eyes” on the radar). This is a particularly effective methodology and enhances situational awareness.

Best Practice 2: WFOs Memphis, Paducah, and Louisville used assistant warning forecasters to lessen the workload typically placed on one forecaster during events such as this one.

Most WFOs during this event had extra staffing in place well in advance. All had extra staffing during the tornado outbreak. This proved to be valuable in handling the rapidly increasing workload associated with the outbreak.

Some of the WFOs assessed have a total of six AWIPS workstations. Personnel at those offices stated that having six workstations was valuable in handling the workload. Most WFOs have five AWIPS workstations, and those with five assessed during this event stated additional workstations would have made their operations more efficient. However, there were no significant problems caused by an office not having six workstations.

Best Practice 3: All WFOs assessed had extra staffing during the tornado outbreak. This proved to be valuable in handling the rapidly increasing workload associated with the outbreak.

Fact: Personnel at WFOs with six AWIPS workstations stated that having six workstations was valuable in handling the workload. Those with five workstations assessed during this event stated additional workstations would have made their operations more efficient.

Each office used a situational awareness display to assist them during the operations of the event. A situational awareness display combines several monitors operational staff can use to view real-time information, such as local media reports and the latest web page updates from various offices. This reduces the time necessary for investigation and increases potential lead time of warnings.

Best Practice 4: All offices had some form of situational awareness display to help assist in warning operations.

Finding 6: None of the six WFOs used a standardized software package during this event. The software packages (e.g., Severe Clear, which is currently being evaluated by an NWS IWT) have the ability to show warning polygons from both the home and neighboring offices, provide alerts when warning and statement products are due or about to expire, and plot storm reports. Because they are Geographical Information System (GIS) based, there are a wide variety of mapping options. Situational awareness software has abilities that could be beneficial to severe weather operations.

Recommendation 6: The NWS should evaluate the benefits of all WFOs having a situational awareness display and standard situational awareness software and determine if they are valuable in severe weather operations.

6.6 Internal Communication

On Tuesday, February 5, five of the six WFOs held conference calls and Internet briefings with EMs, emergency responders, and local media. These briefings reached many decision makers with as many as 110 people attending the briefing held by WFO Paducah. WFO Little Rock did not conduct a briefing. Instead, the WCM sent a Severe Weather Outlook e-mail to an extensive list of EMs and other partners at 8:10 a.m. Tuesday morning, highlighting the potential for significant tornadoes. He also sent similar messages the two previous mornings. This notification method has been used for several years at WFO Little Rock and it is very well received by the emergency management agencies. Brandon Baker, Conway County, Arkansas EM stated, *"We live and die by those e-mails."*

The combined efforts of the SPC and the WFOs to get the word out early on the potential for a severe weather outbreak proved to be an excellent example of NCEP and the local offices working together to serve the American public. Nearly all of the media and EMs knew this event was a possibility 2-4 days in advance and made preparations accordingly. The high risk Severe Weather Outlook issued by the SPC Tuesday morning with the WFOs conveying the seriousness of the situation in their briefings, mobilized the emergency management agencies, media, and school officials, and also raised the awareness level of the general public.

At 5:41 p.m. February 5, WFO Memphis notified WFO Little Rock that service backup may be required. A tornado was likely going to affect WFO Memphis. At that time, WFO Little Rock was very busy with severe weather but was well prepared to quickly assume responsibility. Their quick readiness was due to routine training of assuming back-up responsibilities at another WFO. WFO Nashville, WFO Memphis' secondary back-up office, actually assumed WFO Memphis' responsibilities when WFO Memphis evacuated (5:51 p.m.). WFO Nashville assumed responsibility for nine minutes.

Best Practice 5: WFO Little Rock was well prepared to quickly assume back-up responsibility from WFO Memphis because they include short-fuse back-up exercises as part of their severe weather training.

6.7 External Communication

Five of the six WFOs used Iowa Environmental Mesonet (IEM) Chat instant messaging during the tornado outbreak. IEM Chat is an Internet-based collaboration tool that facilitates real-time communication between operational meteorologists. It is not affiliated with the NWS, but many WFOs across the Nation have signed up for the service provided by Iowa State University. The NWS is currently pursuing standard instant messaging software for use at all offices.

Instant messaging provided an excellent service to the media and also benefitted the WFOs. During this event, WFOs monitored chat rooms of WFOs being affected by the severe weather to increase situational awareness on the storms that would later impact their own CWA. This reduced the need for coordination calls and internal instant messaging using the AWIPS-based 12Planet software. Further, IEM Chat provided verification that products issued by the WFOs had been transmitted properly because they were displayed in the office's chat room once received at the IEM site.

The media was very complimentary of the IEM Chat service. Brad Huffines, Chief Meteorologist for WAAY-TV in Huntsville, Alabama, said: *"It's beautiful. It gives all of the information we need. You know, we have a lot of competition during normal weather. But when it gets like this, competition goes out the window. It's a place that allows the media and the NWS to share and help each other."* T.J. Schuck from WKYT-TV in Lexington, Kentucky, said: *"I don't know what I'd do without it. Chat keeps us going with storm reports during the event."*

In the NWS Service Assessment report, "Tornadoes in Southern Alabama and Georgia, March 1, 2007" released in November 2007, the assessment team recommended the NWS investigate the benefits of using a standard instant messaging system. Based on this recommendation, the NWS has developed an instant message system called NWSChat. NWSChat was released on November 12, 2008. It will be evaluated by the NWS during a 12 month experimental period beginning December 1, 2008. At the end of the experimental period, the NWS will determine whether or not NWSChat will become operational in all NWS offices.

Best Practice 6: IEM Chat was used by five of six offices during this event and was a beneficial tool to both the WFOs and the media.

WFO Little Rock is part of the Arkansas Wireless Information Network (AWIN) and communicated warnings through this system via a state police radio during the event. This methodology was advantageous because first responders were directly monitoring the broadcasts and able to take action more quickly than if messages were relayed through the traditional National Warning Service (NAWAS).

Best Practice 7: WFO Little Rock used a wireless information network associated with the state of Arkansas to distribute important information. This information was received faster than using NAWAS.

6.8 Dissemination

This event occurred during "Super Tuesday" for the Presidential primaries. Coverage of primary election results appeared to have little negative impact on the dissemination of warnings from the media. Television stations went to "wall-to-wall" continuous storm coverage as the event unfolded in their broadcast area and suspended any ongoing election coverage. A couple of TV stations have a policy of not going on air continuously for severe weather, but during this event they were on the air frequently to provide warning updates. Radio stations were broadcasting live and generally not using a satellite feed. All 54 radio stations in the Arkansas Radio Network broadcasted NWS information during the event. Several radio stations also simulcast local television during the height of the tornado outbreak to provide the listening public up to the minute warning information.

No significant NWR problems were discovered by the assessment team. NWR was attributed to possibly saving a man's life. Mr. Willard Tucker from Five Points, Alabama (Lawrence County) was asleep in his home when the NWR sounded an alert at about 3:00 a.m. A tornado was on the ground just southwest of his location and he immediately took shelter. His home was severely damaged by the tornado. Mr. Tucker stated: "*That weather radio saved my life! I really and truly believe that -- and I've told everybody. I told people – if you ain't got a weather radio and you ain't got the money to buy one, I'll buy one for you.*"

Best Practice 8: The Louisville, Paducah, and Huntsville WFOs partnered with local media and local officials to take advantage of the post-event window of opportunity to raise awareness about NWR and distribute NWR receivers in the community.

6.9 Tornado Frequency and Severe Weather Awareness in the Mid-South

This tornado event across the Mid-South illustrates the findings of a recently published study by Dr. Walker Ashley in the December 2007 issue of the American Meteorological Society's journal, *Weather and Forecasting*. Dr. Ashley, a meteorologist at Northern Illinois University, found that while the "tornado alley" region of the Great Plains has the most frequent occurrence of tornadoes, most tornado fatalities occur in the nation's Mid-South region, which includes parts of Arkansas, Tennessee, Alabama, and Mississippi. The states of Kentucky and Georgia also have a high frequency of tornado fatalities. "*The country's most vulnerable region* *for tornado-related fatalities and killer tornado events basically stretches from Little Rock to Memphis to Tupelo to Birmingham*," Ashley said **(Figure 8)**.

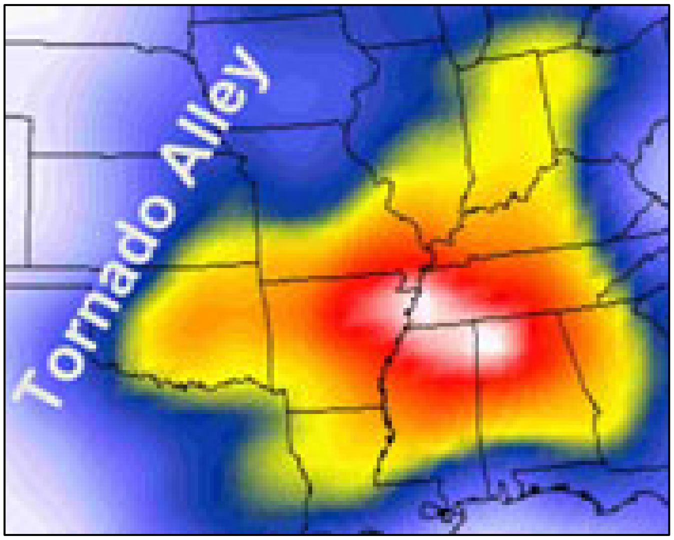


Figure 8. Relative frequency of killer tornado events, 1950-2004. White area indicates area with greatest frequency of tornado-related fatalities during the period. Red area had the second greatest frequency of tornado-related fatalities. © Copyright [2007] American Meteorological Society (AMS).

Dr. Ashley's research noted several factors that combine to make the Mid-South particularly vulnerable to tornado fatalities:

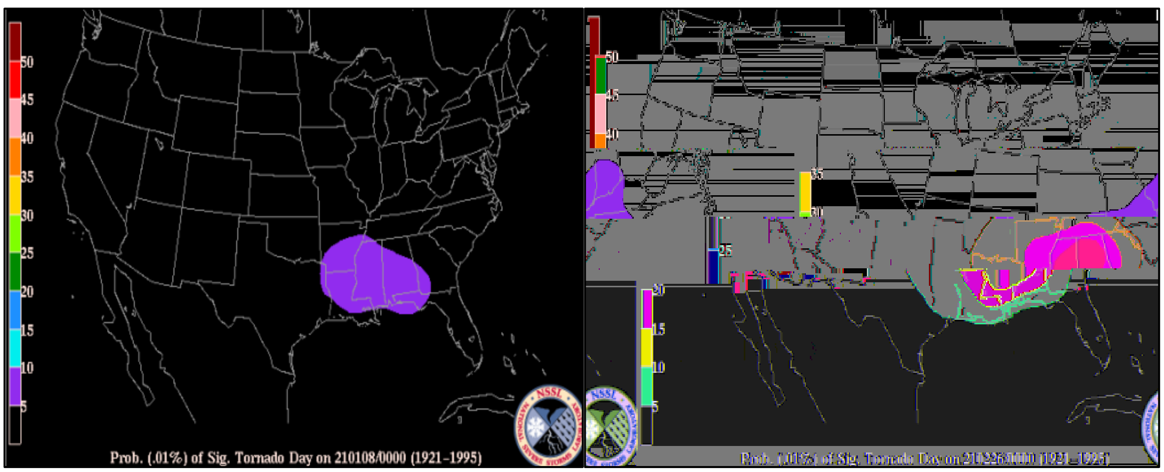
- **Manufactured home density.** The southeast United States has the highest percentage of manufactured homes compared with any other region east of the Continental Divide.
- **Nighttime tornadoes.** The southeast United States has a higher likelihood of killer nighttime tornadoes.
- **Forested areas.** Whereas regions within the Great Plains by definition are lacking in tree cover, the Mid-South region is more forested, leading to reduced visibility both for the public and spotters.
- **Complacency.** In contrast to other parts of the country, the South lacks a focused "tornado season," which can lead to complacency.
- **Early season storms.** Storms that occur before the national peak in the severe storm season, which spans May and June, may catch people off guard during a tornado event.

The factors below are consistent with Dr. Ashley's results and help explain why there were so many fatalities during this event despite the NWS providing excellent (indicated by users interviewed) lead times on outlooks, watches, and warnings.

- Sixty-three percent of the fatalities occurred in manufactured homes.
- Most of the fatalities occurred at night.
- Most of the areas affected by the deadly tornadoes were heavily forested.
- Many people interviewed acknowledged that they minimized the threat of this early February outbreak because of their perception that it was outside the "traditional" tornado season.
- Over 50 percent of the people interviewed indicated it was too early in the year for tornadoes and, as a result, minimized the threat.

Research from the National Severe Storms Laboratory (NSSL) indicates that the risk of fatality from a tornado for those inside a manufactured home is 15 to 20 times greater than for those in permanent structures. Only 7 percent of U.S. residents live in manufactured homes, but nearly 50 percent of tornado fatalities occur in manufactured homes. In the NWS Service Assessment report, "Tornadoes in Southern Alabama and Georgia, March 1, 2007" released in November 2007, the team recommended the NWS promote the benefits of using hardened safe rooms as tornado shelters. Hardened safe rooms can be especially beneficial for manufactured home communities, for residences with standard grade construction, and for nonresidential buildings in which many people often gather (schools, office buildings, etc.). The NWS has included information on hardened safe rooms in its severe weather publications and outreach programs.

From Arkansas to Tennessee south and eastward, the threat for significant tornadoes increases after the New Year with a rapid increase during the month of February. In January, threats for tornadoes are at a minimum, but not zero, across the Gulf Coast and lower Mississippi Valley (**Figure 9**). In contrast, the threat for a significant tornado day increases substantially through the month of February, so that by the end of February (**Figure 9**), the threat is much greater than a month prior over portions of the Gulf Coast States.



Figures 9. Probability of significant tornadoes on January 8 (left) and probability of significant tornadoes on February 26 (right). Probability is calculated for tornadoes during the period 1921-1995. Courtesy of Harold Brooks, NSSL.

The data in these figures is analyzed from 1921 to 1995. During the winter seasons (Dec. 21-Mar. 22) of the period 1995-2008, there has been a tornado outbreak with at least one fatality in the States of Arkansas, Tennessee, Kentucky, Mississippi, Alabama, Georgia, or Florida in each year except 2002 and 2004 (based on severe weather reports from SPC).

Each state that experienced this outbreak holds a Severe Weather Awareness Week in February or early March. All of the awareness week activities were scheduled to take place after this tornado outbreak and there were only two states in this area that hold Severe Weather Awareness campaigns during the fall. Mississippi and Alabama hold a Severe Weather Awareness Day during the last week in October. Both states participate, and their emergency management agencies are an active part of the activities. Statewide tornado drills are conducted. The activities help to raise the public's awareness of fall and winter tornadoes.

Fact: The Mid-South region has the highest frequency of tornado related fatalities in the United States.

Finding 7a: Tornado fatalities have been occurring more frequently during the month of February in recent years across the Gulf Coast, lower Mississippi Valley, and lower Tennessee Valley.

Finding 7b: Each fall, a Severe Weather Awareness Day is held in Alabama and Mississippi during the last week of October. Both states participate, and their emergency management agencies are an active part of the activities. The activities of the day increase awareness of the potential for tornadoes to occur in the fall and winter.

Recommendation 7a: The NWS should increase its education and outreach on winter season tornadoes and the increasing risk of winter season tornado related fatalities in the southeastern United States.

Recommendation 7b: The NWS should encourage emergency management agencies in the States of Arkansas, Louisiana, Tennessee, Georgia, Florida, and Kentucky to hold Severe Weather Awareness campaigns in the fall in addition to that held in the spring. The activities should focus on the risk of tornadoes and tornado-related fatalities that often occur in these states throughout the winter.

6.10 Societal Impacts of NWS Products and Services

The 57 people who died in the February 5-6, 2008, tornado outbreak represent the greatest loss of life in the United States in over 20 years from a single tornado episode. Assessing the circumstances surrounding these fatalities provides clues to NWS improvements in its products and services. The goal is to have more effective decisions made by users. This section assesses people’s knowledge, perceptions, and decision making regarding the tornado event, with an emphasis on: 1) what information was available and how it was interpreted, 2) how people perceived the situation on that day and what decisions people made, and 3) sheltering options available to them. These aspects were assessed through semi-structured interviews with members of the public in the CWAs that were assessed.

The primary objective was to interview family, friends, and neighbors of the 57 victims to learn about why, how, and where the deaths occurred. **Appendix D** includes a complete breakdown of this information by fatality, as well as socio-demographic information. Although the primary focus was on the fatalities, a wealth of empirical information was gained from the survivors about their own knowledge, perceptions, and decision making during the tornado event.

6.10.1 Receiving and Interpreting Information

A first step in assessing people's warning response is to determine where people received their information and how it was interpreted. Most people reported receiving information about the tornadoes from multiple sources, with the primary source being local television (used by 51 percent of the respondents). The secondary source was from other people (i.e., friends, neighbors, and family members) both by phone and in person. Often, people who heard warnings on radio and television called friends and family located in the path of the tornado to warn them of the impending danger. Four of the 41 people interviewed indicated that NWR was a primary source for information about the tornadoes.

According to some of the victim's friends, relatives, and neighbors, 18 victims received a warning and 3 did not. Spotting the tornado, if no other warning was heard earlier, is not considered a warning for this report. It is unknown whether or not the other 36 victims received a warning.

Of the 18 people who definitely heard a warning, 6 were alerted by siren, 5 were contacted by other people (i.e., friends, family, and neighbors), and 2 received the warning via television. For five people, the source of the warning was unknown. **Table 3** shows how the 18 people who received a warning responded to that information. Eleven people heeded the warning in some way; three people did not. Finally, 10 of the people who heard the warning sought shelter in a "safer" shelter option (a safer location relative to the location where one is currently; e.g., a frame home is considered a safer shelter than a manufactured home), 5 people did not seek shelter.

Response	Yes	No
Heeded the warning	11	3
Sought shelter	10	5

Table 3. Responses of the 18 tornado victims known to have heard a warning during this event. The team was unable to determine if 4 of the 18 heeded the warning or not, and if 3 sought shelter or not.

Sirens were available as a warning device in some of the communities. However, in many of the rural areas away from towns, sirens were largely unavailable. In the areas where sirens were located, six people used them as a warning device (in some cases multiple times), and two people indicated it was their primary source of warning information. Tornado outdoor warning sirens were designed for people outdoors who cannot hear broadcasted tornado warnings. The sirens are not meant to warn people indoors, although one may hear the siren inside if they are in close proximity. The vast majority of people believed that the siren system was designed to warn people who were indoors. Two local EMs who were asked about this issue confirmed people often have this misconception.

6.10.2 Perceptions and Decisions

Because this deadly tornado outbreak occurred in early February, the team evaluated how people perceived the early season event and how it affected people's decision making. A majority of the people indicated they associate tornado outbreaks with the springtime (i.e., March or later) or summer months. Although several people noted the potential for severe weather, many people minimized the threat of this early February outbreak because they perceived it was outside the "traditional" tornado season.

Another important factor in how people respond to warnings is whether or not they personalize the threat. Several people specifically noted the need to seek confirmation of a warning, most notably through their visually spotting the tornado or hearing sirens. For example, a woman in Atkins, Arkansas, initially heard about the tornado from the local TV news and then from a local radio station. The siren sounded approximately an hour before the tornado occurred, but she opted not to shelter at that point. Fifteen minutes later, the siren sounded again and, at that point, her son-in-law called. They decided to shelter in his home next door. As the tornado approached, her son-in-law spotted the tornado, and only then did they make the decision to move to her private storm cellar a couple hundred feet away. This case illustrates how people may require multiple sources of information throughout their decision making process to assess their personal risk, and how a single source of information will not necessarily spur protective action. It also demonstrates that NWS warnings and statements should be definitive, with wording that has the greatest potential to elicit an immediate response, during tornado outbreak situations.

People minimized their personal risk due to the perception of tornadoes always affecting someone else. Tornadoes are not uncommon in these areas and many people were aware that tornadoes do occur, but perceived them as occurring to other people and not to themselves. This optimism bias[2] was reflected in comments by several residents, including one from Christian County, Kentucky who indicated, "*They [tornadoes] always seem to hit down the road*." As another example, a family from Hardin County, Tennessee said they had heard on the radio that the tornado was in their county of residence in a town just upstream of where they lived "*…but we didn't think it was going to be here*."

6.10.3 Sheltering

The team looked at whether the people interviewed had alternate sheltering options and, if so, what they were. **Table 4** shows two categories of sheltering options that were considered. One is classed as a "safest" (a basement, storm cellar, or safe room) shelter option and the other is classed as a "safer" shelter option. For example, a frame home is a considered a safer shelter than a manufactured home. Of the 41 people interviewed who received warning information and/or who personally observed a tornado, the vast majority did seek shelter in the best location available to them. For the majority of these people, these locations consisted of an interior hallway on the main floor of their home, a bathroom, or some other designated safe area. Less

[2] Optimism bias is a term from the field of risk perception. It refers to the psychological phenomenon in which people believe that their personal risk from an activity or hazard is less than the risk faced by others.

than half of the interviewees had access to a basement, cellar, or reinforced safe room for sheltering. Very few people who received some sort of warning information opted not to shelter.

The team also looked at the structure in which the victims died (**Appendix D)** and what alternate sheltering options were available to them. Of the 57 fatalities, the team was able to determine "safest" sheltering options for 42 of them. Only 8 people (19 percent) of those 42 had access to the "safest" shelter option. Basements are uncommon in these areas, so these "safest" shelters were all either private or community storm shelters. The majority of victims analyzed for "safest" shelter options, 34 out of 42 (81 percent), did not have any "safest" shelter options.

Shelter option	Yes	No
"Safest" shelter (i.e., basements, cellars, safe rooms)	8	34
"Safer" shelter (i.e., relative to current location)	17*	21

Table 4. Shelter options for the 57 fatalities, stratified by "safest" and "safer" shelter availability. The team was unable to determine if 15 of the 57 fatalities had a "safest" shelter option available and if 19 had a "safer" shelter option available.* Includes the 8 "safest" shelters.

The team was able to determine "safer" shelter options for 38 of the 57 fatalities. Of those 38, 17 people (45 percent) had what could be considered a "safer" shelter option. This number includes the eight people who had the "safest" option; another nine had a "safer" option relative to where they died. Eight of these nine were in manufactured homes but had a better built structure (i.e., brick or wood frame home, church) available for them to shelter in. The other victim was a man in a warehouse who died after sheltering in a different location from the designated safe area in the interior of the building. Nevertheless, more than half of the victims analyzed for "safer" shelter options, 21 of 38 (55 percent), did not have a "safer" shelter option available to them.

The widespread use of manufactured homes in the southeast United States, coupled with the overall lack of safe sheltering options and the numerous strong to violent tornadoes, were likely contributors to the number of deaths in this event. The majority of the people who died, as well as the survivors who were interviewed, did not have a basement, cellar, or safe room available to them in which to shelter.

Manufactured homes can be very unsafe during a tornado. Thirty-six people (63 percent) were in manufactured homes when they died. Another 15 people died in wood or brick frame homes, 4 died in warehouses, 1 died in his vehicle, and 1 victim's location was unknown. Damage surveys revealed that many of the frame homes damaged or destroyed by the tornadoes could be considered standard grade construction quality.

The NWS is promoting the benefits of hardened safe rooms for use as tornado shelters (See Federal Emergency Management Agency publication: *Residential Safe Rooms: Background and Research*). The positive effects of hardened safe rooms were recognized in the NWS service assessment report "*Tornadoes in Southern Alabama and Georgia, March 1, 2007*." A recommendation in that report suggests the NWS increase its education and outreach on the use of hardened safe rooms as tornado shelters. A more widespread use of hardened safe rooms during this event could have reduced the number of fatalities, as hardened safe rooms are an effective tornado shelter. A hardened safe room is lined and topped with concrete, has no windows, and is designed to withstand severe sustained wind and wind gusts. However, the ability to afford installing personal hardened safe rooms may be a limiting factor for some of the most vulnerable population. Thus, supporting other agencies' efforts to improve people's ability to obtain hardened safe rooms is encouraged.

The large loss of life during this event underscores that the death toll is not entirely dependent on the quality of outlooks, watches, and warnings. Rather, people's interpretations, perceptions, decision making, and sheltering options also influence the number of fatalities in a severe weather event. To this end, societal impacts research and analysis can provide valuable information to the NWS in post-event assessments.

Finding 8a: Over half (53 percent) of the people asked clearly stated that they associate tornadic outbreaks with the springtime (i.e., March or later) or summer months. Many people also acknowledged that they minimized the threat of this early February outbreak because of their perception that it was outside the "traditional" tornado season.

Finding 8b: This event illustrates how people may require multiple sources of information throughout their decision making process to assess their personal risk, and how a single source of information will not necessarily spur protective action.

Finding 8c: Eighty one percent of victims analyzed (42 of the 57 overall fatalities) did not have a "safest" shelter option. Fifty-five percent of the victims analyzed (38 of the 57 overall fatalities) did not have a "safer" shelter option.

Finding 8d: Societal impacts research and analysis, such as the information in Findings 8a, 8b, and 8c, can provide valuable information to the NWS.

Recommendation 8a: A pool of societal impacts experts should be established. NWS should use experts from this pool for service assessments. A pool of NWS employees with experience in social science data collection methods should also be established.

Recommendation 8b: The NWS should use a common set of societal impacts survey questions for all future service assessments, similar to those used in this assessment. This would allow the NWS to continue to build a database of societal impact information to help support service and product improvements in the future.

Recommendation 8c: The socio-demographic data from **Appendix D** of this report should be carefully studied to identify trends in how the fatalities occurred, and to identify improvements the NWS could make in the warning program.

Recommendation 8d: The NWS should expand participation with academic and other partners in social science to study the complete warning process from issuance to response, and systematically incorporate those findings into NWS products and services.

Recommendation 8e: The NWS should consider adding a societal impacts program to operational branches of NWSH and the Regions, in order to organize and focus these efforts.

7. Successful Results Based on NWS Products and Services

During this event, there were several situations when warnings were heeded and the actions taken most likely saved lives. Union University in Jackson, Tennessee, with approximately 1,200 students, was struck by an EF4 tornado at 7:02 p.m. Although some people sustained injuries, there were no fatalities, and the university attributes this success to two main factors: (1) the weather predictions, which they described as being very good; and (2) the university's information gathering, preparedness, and actions. The university was aware of the tornado threat throughout the day. They received their information through various sources, but their primary warning information during the event came from TV Channel 3 out of Memphis. The combination of ample warning lead time and a detailed, practiced plan likely saved many lives, especially considering the amount of destruction that occurred on campus.

Figure 10. Damage to dormitories at Union University in Jackson, Tennessee. Courtesy of WFO Memphis.

At 7:32 p.m., a Tornado Warning for Muhlenberg County, Kentucky was received at the schools through NWR and local television stations. At that time, North High School had just concluded a junior varsity basketball game and was waiting for the varsity game to begin. Approximately 1,200 people were in attendance in the gymnasium. Based on the tornado warning information, a decision was made to shelter those in attendance. The safe school plan called for no one to be allowed to leave the school. Athletic directors, sheriff deputies, and state troopers manned the exits while attendees were directed in an orderly fashion into hallways, locker rooms, stairwells, and showers. Local officials confirmed that the tornado moved across North High School at approximately 7:53 p.m. Every tree around the high school was uprooted. A 30' x 30' section of the gymnasium roof was peeled back. Batting cages were thrown into buses, and a scoreboard was found in the parking lot. The school's actions, which were based on warning information provided by WFO Paducah, likely saved lives that evening.

The Memphis City Schools dismissed early on Tuesday several hours before the tornadoes impacted the area. The school administrator responsible for making that decision used the WFO Memphis website and a consultation with the Shelby County EM as input into the decision making process. Schools began dismissing at 12:30 p.m. Skies were clear at the time of the dismissals and this resulted in some local media criticism, but it was emphasized that the district has 115,000 students and just mobilizing the buses takes one and a half hours. Buses would still have been on the road when the tornadoes struck the Memphis area shortly after 5:30 p.m., if schools had not let out early.

Closing schools or dismissing students early on potential tornado outbreak days is becoming more commonplace in the southeast United States. While the Memphis example described above is a success story, there is also a growing concern among NWS personnel and NWS partners that dismissing students early from school could do more harm than good in some situations. Many homes in the rural South are of lightweight construction and offer little, if any, shelter against tornadoes. In some cases, the students would be better protected in well-constructed schools that have an organized and practiced tornado emergency plan. Therefore, the team believes that dismissing school early may not provide the safest environment for students in many circumstances.

8. Summary

Eighty-seven tornadoes struck the Mid-South and Tennessee Valley in roughly a 12-hour period from the afternoon of Tuesday February 5, 2008, through the early morning of February 6, 2008. There were 5 violent EF4 tornadoes, 5 EF3 tornadoes, and 15 EF2 tornadoes. Fifty-seven people were killed in four states, making this event the deadliest tornado outbreak since May 31, 1985. All fatalities occurred with tornadoes of at least EF2 intensity.

An NWS service assessment team reviewed products and services from six NWS Forecast Offices: Little Rock, Arkansas; Memphis and Nashville, Tennessee; Paducah and Louisville, Kentucky; and Huntsville, Alabama; the CWSU in Memphis; and the SPC in Norman, Oklahoma. Numerous interviews were conducted with the media, EMs, other customers and partners, and the general public in the areas visited. The majority of those interviewed were satisfied with the warning and forecast services provided during this tornado outbreak.

The team has made 16 recommendations to improve NWS products and services during tornado outbreaks such as this. These focus on technological and policy aspects of operations, training, severe weather awareness, and how society reacts to NWS tornado warnings.

Appendix A

Definitions

Best Practice - An activity or procedure that has produced outstanding results during a particular situation which could be used to improve effectiveness and/or efficiency throughout the organization in similar situations. No action is required.

Fact - A statement that describes something important learned from the assessment for which no action is necessary. Facts are not numbered, but often lead to recommendations.

Finding - A statement that describes something important learned from the assessment for which an action may be necessary. Findings are numbered in ascending order and are associated with a specific recommendation or action.

Recommendation - A specific course of action, which should improve NWS operations and services, based on an associated finding. Not all recommendations may be achievable, but they are important to document. If the affected office(s) and OCWWS determine a recommendation will improve NWS operations and/or services, and it is achievable, the recommendation will likely become an action. Recommendations should be clear, specific, and measurable.

Appendix B

Facts, Findings, Recommendations, and Best Practices

Facts

Fact: During this event, there was no clear national guidance on when tornado emergency wording should be used.

Fact: Some users expressed tornado watches issued by SPC were too large in size and too long in duration.

Fact: The NWS discussed concerns of tornado watches being too large in size and too long in duration at the NWS Partners Meeting in June 2008. It was the consensus of those in the meeting that no immediate action should be taken to alter the current process. The SPC will continue to explore options to improve the future watch process.

Fact: Personnel at WFOs with six AWIPS workstations stated that having six workstations was valuable in handling the workload. Those with five workstations assessed during this event stated additional workstations would have made their operations more efficient.

Fact: The Mid-South region has the highest frequency of tornado related fatalities in the United States.

Findings and Recommendations

Finding 1: Relatively few of the tornado warnings or statements contained wording or call to action statements indicating the urgency and danger of the situation, even when tornadoes and damage were confirmed (i.e., "this is an extremely dangerous and life- threatening situation").

Recommendation 1a: NWS Instruction 10-511 should provide guidance on using wording and call to action statements in tornado warnings and severe weather statements that convey appropriate urgency and danger.

Recommendation 1b: WDTB should develop training for warning forecasters on how and when to use explicit wording that conveys the urgency and danger of a situation.

Finding 2a: Some media partners interviewed prefer more definitive tornado warnings and SVSs.

Finding 2b: A majority of the tornado warnings contained wording such as "*Doppler Radar indicated a severe thunderstorm capable of producing a tornado*." It is phrases such as this that make it unclear whether or not there is a tornado on the ground.

Recommendation 2: The NWS should provide guidance on wording that increases the chances of improved public response during tornadic events where tornadoes have been confirmed. Clear wording such as "*a tornado has been confirmed…*" or "*a tornado is on the ground at...and is moving…*" should increase the probability that a warning will get an appropriate and immediate response.

Finding 3: There was no coordination between WFO Nashville and WFO Louisville on the Allen County tornado warning.

Recommendation 3: NWS should require regions to develop severe weather coordination procedures between neighboring offices.

Finding 4a: The Storm-based warning approach does not allow NWR to alert exclusively within the warning polygon, and not all TV stations have the capability to display warning polygons. Some TV stations still highlight the entire county even if only a portion of the county is affected by a warning.

Finding 4b: In some instances, forecasters excluded certain portions of counties from the polygons to better fit NWR alerting capabilities and/or local TV station display capabilities.

Recommendation 4a: The NWS should develop more efficient methods of using Storm-based polygon warnings in NWR activations.

Recommendation 4b: The NWS should encourage TV stations and their vendors to develop the capability to display NWS polygon warnings.

Finding 5: Many tornado warnings varied from established WDTB training practices, and many did not account for the rapid storm motions.

Recommendation 5: WDTB should update their Storm-based warning training to include the following: 1) the importance of warning well downstream in the case of fast-moving tornadic supercells, 2) the importance of anticipating the need for new warnings well before a given storm moves out of a current polygon, 3) overlapping warnings to ensure no gaps between warnings, and 4) not removing counties from a polygon unless the forecaster has total confidence that the storm will not impact that area.

Finding 6: None of the six WFOs used a standardized software package during this event. The software packages (e.g., Severe Clear, which is currently being evaluated by an NWS IWT) have the ability to show warning polygons from both the home and neighboring offices, provide alerts when warning and statement products are due or about to expire, and plot storm reports. Because they are Geographical Information System (GIS) based, there are a wide variety of mapping options. Situational awareness software has abilities that could be beneficial to severe weather operations.

Recommendation 6: The NWS should evaluate the benefits of all WFOs having a situational awareness display and standard software package and determine if they are valuable in severe weather operations.

Finding 7a: Tornado fatalities have been occurring more frequently during the month of February in recent years across the Gulf Coast, lower Mississippi Valley, and lower Tennessee Valley.

Finding 7b: Each fall, a Severe Weather Awareness Day is held in Alabama and Mississippi during the last week of October. Both states participate and their emergency management agencies are an active part of the activities. The activities of the day increase awareness of the potential for tornadoes to occur in the fall and winter.

Recommendation 7a: The NWS should increase its education and outreach on winter season tornadoes and the increasing risk of winter season tornado related fatalities in the southeastern United States.

Recommendation 7b: The NWS should encourage emergency management agencies in the states of Arkansas, Louisiana, Tennessee, Georgia, Florida, and Kentucky to hold Severe Weather Awareness campaigns in the fall in addition to the spring. The activities should focus on the risk of tornadoes and tornado related fatalities that often occur in these states throughout the winter.

Finding 8a: Over half (53 percent) of the people asked clearly stated that they associate tornadic outbreaks with the springtime (i.e., March or later) or summer months. Many people also acknowledged that they minimized the threat of this early February outbreak because of their perception that it was outside the "traditional" tornado season.

Finding 8b: This event illustrates how people may require multiple sources of information throughout their decision making process to assess their personal risk, and how a single source of information will not necessarily spur protective action.

Finding 8c: Eighty one percent of victims analyzed (42 of the 57 overall fatalities) did not have a "safest" shelter option. Fifty-five percent of the victims analyzed (38 of the 57 overall fatalities) did not have a "safer" shelter option.

Finding 8d: Societal impacts research and analysis, such as the information in Findings 8a, 8b, and 8c, can provide valuable information to the NWS.

Recommendation 8a: A pool of societal impacts experts should be established. NWS should use experts from this pool for service assessments. A pool of NWS employees with experience in social science data collection methods should also be established.

Recommendation 8b: The NWS should use a common set of societal impacts survey questions for all future service assessments, similar to those used in this assessment. This would allow the NWS to continue to build a database of societal impact information to help support service and product improvements in the future.

Recommendation 8c: The socio-demographic data from **Appendix D** of this report should be carefully studied to identify trends in how the fatalities occurred and to identify improvements the NWS could make in the warning program.

Recommendation 8d: The NWS should expand participation with academic and other partners in social science to study the complete warning process from issuance to response, and systematically incorporate those findings into NWS products and services.

Recommendation 8e: The NWS should consider adding a societal impacts program to operational branches of NWSH and the Regions, in order to organize and focus these efforts.

Best Practices

Best Practice 1: The use of a radar display program by CWSU Memphis meteorologists during this event was beneficial in detecting storm features such as anvil extent, hail cores, overshooting tops, and shear.

Best Practice 2: WFOs Memphis, Paducah and Louisville used assistant warning forecasters to lessen the workload typically placed on one forecaster during events such as this one.

Best Practice 3: All WFOs assessed had extra staffing during the tornado outbreak. This proved to be valuable in handling the rapidly increasing workload associated with the outbreak.

Best Practice 4: All offices had some form of situational awareness display to help assist in warning operations.

Best Practice 5: WFO Little Rock was well prepared to quickly assume backup responsibility from WFO Memphis because they include short-fuse backup exercises as part of their severe weather training.

Best Practice 6: IEM Chat was used by five of six offices during this event and was a beneficial tool to both the WFOs and the media.

Best Practice 7: WFO Little Rock used a wireless information network associated with the state of Arkansas to distribute important information. This information was received faster than using NAWAS.

Best Practice 8: The Louisville, Paducah, and Huntsville WFOs partnered with local media and local officials to take advantage of the post-event window of opportunity to raise awareness about NWR and distribute NWR receivers in the community.

Appendix C

Acronyms

ARTCC	Air Route Traffic Control Center
AWIN	Arkansas Weather Information Network
AWIPS	Advanced Weather Interactive Processing System
CAR	County Area Reduction
CWA	County Warning Area
CWSU	Center Weather Service Unit
EF	Enhanced Fujita Tornado Scale
EM	Emergency Manager
EOC	Emergency Operations Center
FAA	Federal Aviation Administration
FedEx	Federal Express shipping company
GIS	Geographical Information System
GPRA	Government Performance Results Act
HWO	Hazardous Weather Outlook
IAEM	International Association of Emergency Managers
IEM	Iowa Environmental Mesonet
IWT	Integrated Work Team
LSR	Local Storm Report
mb	Millibar
MIC	Meteorologist in Charge
mph	Miles per hour
NAWAS	National Warning Service
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NSSL	National Severe Storms Laboratory
NWR	NOAA Weather Radio All Hazards
NWS	National Weather Service
OCWWS	Office of Climate, Water, and Weather Services
PDS	Particularly Dangerous Situation
SOO	Science and Operations Officer
SPC	Storm Prediction Center
SPS	Special Weather Statement
SVS	Severe Weather Statement
TMU	Traffic Management Unit
UTC	Coordinated Universal Time
WarnGen	Warning Generation Software
WCM	Warning Coordination Meteorologist
WDTB	Warning and Decision Training Branch
WFO	Weather Forecast Office
WSR-88D	Weather Surveillance Radar, 1988 Doppler

Appendix D

Fatality Statistics

Community	County	ST	Age	Gender	EF	Structure	Sought Shelter	Safer Shelter[1]	Safest Shelter[2]	Warning Heard[3]	Warning Heeded[4]
Pisgah	Jackson	AL	60	F	4	Frame home	unknown	none	n/a	phone call from friend	unknown
Aldridge Grove	Lawrence	AL	49	F	4	Mobile home	no	None	n/a	No	no
Fairfield	Lawrence	AL	86	F	4	Mobile home	unknown	None	n/a	unknown	n/a
Aldridge Grove	Lawrence	AL	19	M	4	Mobile home	no	None	n/a	No	no
Aldridge Grove	Lawrence	AL	40	M	4	Mobile home	no	None	n/a	No	no
Gassville	Baxter	AR	77	F	2	Mobile home	no	storm shelter, 1/2 mile away	storm shelter, 1/2 mile away	unknown	n/a
Hattieville	Conway	AR	84	M	3	Mobile home	no	brick home next door, 20 yards away	n/a	TV	yes
Hattieville	Conway	AR	68	F	3	Mobile home	no	brick home next door, 20 yards away	n/a	TV	yes
Zion	Izard	AR	32	M	3	Mobile home	unknown	storm shelter, 100 yards away	storm shelter, 100 yards away	unknown	n/a
Rose Trail	Izard	AR	51	M	4	Mobile home	unknown	None	n/a	unknown	n/a
Atkins	Pope	AR	56	M	2	Mobile home, intermodal shipping container	yes	None	n/a	unknown	n/a
Atkins	Pope	AR	43	F	3	Frame home	unknown	storm shelter, 100 yards away	storm shelter, 100 yards away	Siren	unknown
Atkins	Pope	AR	11	F	3	Frame home	unknown	storm shelter, 100 yards away	storm shelter, 100 yards away	Siren	unknown
Atkins	Pope	AR	40	M	3	Frame home	unknown	storm shelter, 100 yards away	storm shelter, 100 yards away	Siren	unknown
Atkins	Pope	AR	78	F	?	Mobile Home	unknown	unknown	unknown	unknown	unknown

Community	County	ST	Age	Gender	EF	Structure	Sought Shelter	Safer Shelter[1]	Safest Shelter[2]	Warning Heard[3]	Warning Heeded[4]
Mountain-view	Stone	AR	50	F	4	Frame home	yes	None	n/a	unknown	n/a
Clinton	Van Buren	AR	81	F	3	Frame home	unknown	None	n/a	unknown	n/a
Clinton	Van Buren	AR	29	M	4	Boat factory, office room near exterior wall	yes	interior break room, 20 yards away	n/a	personal communi cation	Yes
Clinton	Van Buren	AR	37	F	2	Mobile home	unknown	None	n/a	unknown	n/a
4S Holland	Allen	KY	2	M	3	Mobile home	no	None	n/a	unknown	n/a
4S Holland	Allen	KY	53	F	3	Mobile home	no	None	n/a	unknown	n/a
5S Holland	Allen	KY	50	M	3	Mobile home	no	brick home next door, 100 yards away	n/a	unknown	n/a
5S Holland	Allen	KY	58	F	3	Mobile home	no	brick home next door, 100 yards away	n/a	unknown	n/a
Greenville	Muhlen-burg	KY	69	M	3	Mobile home	no	stick built home with 2 concrete walls in the mobile home park	n/a	unknown	n/a
Greenville	Muhlen-burg	KY	62	F	3	Mobile home	no	stick built home with 2 concrete walls, in mobile home park	n/a	unknown	n/a
Greenville	Muhlen-burg	KY	40	F	3	Mobile home	no	stick built home with 2 concrete walls, in mobile home park	n/a	unknown	n/a
9 N of Somerville	Fayette	TN	70	M	3	Pickup truck in shed	unknown	n/a	n/a	unknown	n/a
Cerro Gordo, 4 NW Savannah	Hardin	TN	55	M	4	Mobile home	no	comm.. center, 1/4 mile away	community center, 1/4 mile away	personal comm (family)	No
Cerro Gordo, 4 NW Savannah	Hardin	TN	74	M	4	Mobile home	no	comm. center, 1/4 mile away	community center, 1/4 mile away	unknown	n/a
Cerro Gordo, 4 NW Savannah	Hardin	TN	75	M	4	Mobile home	no	private storm cellar, 1/2 mile away	private storm cellar, 1/2 mile away	personal comm (family)	No

Community	County	ST	Age	Gender	EF	Structure	Sought Shelter	Safer Shelter[1]	Safest Shelter[2]	Warning Heard[3]	Warning Heeded[4]
Lafayette	Macon	TN	70	M	3	Mobile home	unknown	n/a	n/a	unknown	n/a
Lafayette	Macon	TN	42	F	3	Mobile home	no	n/a	n/a	unknown	n/a
Lafayette	Macon	TN	4	F	3	Mobile home, interior closet where they sought shelter	yes	n/a	n/a	Yes, but source unknown	Yes
Lafayette	Macon	TN	79	F	3	Mobile home	unknown	interior room in adjacent church	n/a	unknown	n/a
Lafayette	Macon	TN	35	M	3	Mobile home	No	n/a	n/a	unknown	n/a
Lafayette	Macon	TN	54	M	3	Frame home	unknown	n/a	n/a	unknown	n/a
Lafayette	Macon	TN	59	M	3	Mobile home (cinder block structure)	unknown	n/a	n/a	unknown	n/a
Macon County	Macon	TN	19	M	3	Frame home, interior closet	yes	n/a	n/a	Yes, but source unknown	Yes
Macon County	Macon	TN	58	F	3	Unknown	unknown	n/a	n/a	unknown	n/a
Lafayette	Macon	TN	23	M	3	Frame home	unknown	n/a	n/a	unknown	n/a
Lafayette	Macon	TN	49	M	3	Mobile home, interior closet where they sought shelter	yes	n/a	n/a	yes	Yes
Lafayette	Macon	TN	54	M	3	Frame home	unknown	n/a	n/a	unknown	n/a
Lafayette	Macon	TN	90	M	3	Frame home	unknown	n/a	n/a	unknown	n/a
Hunters-ville Community	Madison	TN	84	F	3	Frame home (wood), interior closet	yes	n/a	n/a	yes	Yes
Hunters-ville Community	Madison	TN	75	M	3	Frame home (wood)	unknown	n/a	n/a	unknown	n/a
Memphis	Shelby	TN	38	M	2	Ware-house, break-room on lowest level	yes	n/a	n/a	yes	Yes

Community	County	ST	Age	Gender	EF	Structure	Sought Shelter	Safer Shelter[1]	Safest Shelter[2]	Warning Heard[3]	Warning Heeded[4]
Memphis	Shelby	TN	23	M	2	Ware-house, break-room on lowest level	yes	n/a	n/a	yes	Yes
Memphis	Shelby	TN	60	F	2	Ware-house, break-room on lowest level	yes	n/a	n/a	yes	Yes
Castalian Springs	Sumner	TN	33	M	3	Frame home	no	n/a	n/a	yes	No
Castalian Springs	Sumner	TN	23	F	3	Frame home, interior bathroom	yes	n/a	n/a	yes	Yes
Castalian Springs	Sumner	TN	26	M	3	Mobile home	unknown	n/a	n/a	unknown	n/a
Castalian Springs	Sumner	TN	72	F	3	Mobile home	unknown	n/a	n/a	unknown	n/a
Castalian Springs	Sumner	TN	52	F	3	Mobile home	unknown	n/a	n/a	unknown	n/a
Castalian Springs	Sumner	TN	57	M	3	Mobile home	unknown	n/a	n/a	unknown	n/a
Castalian Springs	Sumner	TN	49	M	3	Mobile home	unknown	n/a	n/a	unknown	n/a
Hartsville	Trousdale	TN	84	F	3	Mobile home	unknown	n/a	n/a	unknown	n/a
Hartsville	Trousdale	TN	86	M	3	Mobile home	unknown	n/a	n/a	unknown	n/a

[1] A "safer" shelter is classified as a safer location relative to the location where one is currently. For example, a frame home is considered a safer shelter than a mobile home.
[2] A "safest" shelter is classified as a basement, storm cellar, or safe room.
[3] A warning is defined as whether one had adequate time to shelter in their preferred location.
[4] Heeding a warning is if one takes any action that suggests one thinks the warning might be true (e.g., seeking confirmation of information, further disseminating information, taking protective action).

Appendix E

Event Statistics

WFO	Little Rock	Memphis	Nashville	Huntsville	Louisville	Paducah	Totals
Tornadoes	4	23	13	4	18	8	70
Fatalities	14	9	22	5	4	3	57
Injuries	160	69	66	16	21	26	358
Homes damaged	599	73	275	110	230	258	1,545
Homes destroyed	308	15	300	87	50	95	855
Damage Estimates	$102M	$295M	$34M	$11M	$19M	$10M	$471M
Mean Lead Time	17 minutes	20 minutes	15 minutes	20 minutes	9 minutes	21 minutes	17 minutes

* Mean lead time is for tornado warnings which covered fatalities. All tornadoes that produced fatalities were covered by tornado warnings. There were 87 total tornadoes, 17 in WFO CWAs that were not evaluated in this report. The total damage estimate is $520 million, $49 million in WFO CWAs that were not evaluated in this report.

Appendix F

Enhanced Fujita (EF) Tornado Scale

FUJITA SCALE			DERIVED EF SCALE		OPERATIONAL EF SCALE	
F Number	Fastest 1/4-mile (mph)	3 Second Gust (mph)	EF Number	3 Second Gust (mph)	**EF Number**	**3 Second Gust (mph)**
0	40-72	45-78	0	65-85	**0**	**65-85**
1	73-112	79-117	1	86-109	**1**	**86-110**
2	113-157	118-161	2	110-137	**2**	**111-135**
3	158-207	162-209	3	138-167	**3**	**136-165**
4	208-260	210-261	4	168-199	**4**	**166-200**
5	261-318	262-317	5	200-234	**5**	**Over 200**

The Enhanced Fujita-scale (also known as the EF scale) is a set of wind estimates (not measurements) based on tornado wind damage. It uses three-second gusts estimated at the point of damage based on a judgment of different levels of damage. Levels of damage are judged based on 28 damage indicators (not shown here). These estimates vary with height and exposure. The three-second gust is not the same wind as in standard surface observations. Standard measurements are taken by weather stations in open exposures, using a directly measured “one minute mile" speed.