Service Assessment

Mother's Day Weekend Tornado in Oklahoma and Missouri, May 10, 2008

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

Cover Photograph: Survivors of Picher tornado. (Photo courtesy of *Tulsa World News*.)

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October 2009

National Weather Service
John L. Hayes, Assistant Administrator for Weather Services

Preface

Mother's Day Weekend, May 10-11, 2008, brought severe weather to many sections of the country. The greatest impact was in northeast Oklahoma and southwest Missouri. A tornado, rated EF4 on the Enhanced Fujita scale, moved southeast from the town of Picher, Oklahoma, into southwest Missouri. The tornado caused 21 fatalities. The areas affected by this tornado were covered by a tornado watch and multiple tornado warnings. The average lead time was longer than the goals established by the Government Performance and Results Act.

The National Oceanic and Atmospheric Administration's National Weather Service mission is to provide weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. The National Weather Service formed a six-member service assessment team to evaluate its performance during this event. The team focused on the societal responses and impacts of this event. The team tried to determine why there were so many fatalities despite the timely watches and warnings that were issued by the National Weather Service.

John L. Hayes
Assistant Administrator
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October 2009

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Service Assessment Team

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Service Assessment Report

1. Executive Summary

Service assessments are generally initiated when a significant weather-related event results in at least one fatality, numerous injuries requiring hospitalization, extensive property damage, or widespread media interest. Assessments may also be initiated when the media, emergency management (EM) community, or elected officials indicate a concern with the operations of the National Oceanic and Atmospheric Administration's (NOAA) National Weather Service (NWS). These operations include the performance of systems or the adequacy of warnings, watches, and forecasts. This assessment evaluated NWS performance and effectiveness during a tornado event in Oklahoma and Missouri on May 10, 2008, Mother's Day weekend. The tornado moved from northeast Oklahoma to southwest Missouri, killing 21 people and causing an estimated $61 million in damage. On the Enhanced Fujita Tornado Scale (EF) (**Appendix E**), the tornado reached a peak intensity of EF4. The area affected by this tornado was covered by a tornado watch and multiple tornado warnings.

The NWS mission is to provide weather, hydrologic, and climate forecasts and warnings for the United States, its territories, adjacent waters and ocean areas, for the protection of life and property and the enhancement of the national economy. The NWS formed a six-member service assessment team to evaluate the performance of the NWS during this event. A primary focus was placed on the societal responses to the event and the impact of these responses. The team tried to determine why there were such a high number of fatalities despite the fact that watches and warnings were in effect.

The team evaluated Weather Forecast Offices (WFO) Tulsa, Oklahoma, and Springfield, Missouri, as well as the National Centers for Environmental Prediction (NCEP) Storm Prediction Center (SPC). All three offices issued tornado watches, warnings, and/or outlooks for this event. All 21 fatalities for the event occurred where tornado watches and warnings were in effect. (Specific lead times to fatalities are listed in **Appendix D**.**)** SPC issued a tornado watch nearly 6 hours before the first tornado touchdown in the area. WFO Tulsa issued a tornado warning with a mean lead time of 14 minutes, and WFO Springfield followed by issuing a tornado warning with a mean lead time of 24 minutes. Both WFOs exceeded the 2008 Government Performance and Results Act (GPRA) goal for tornado warning lead time (mean lead time), which was 11 minutes.

The team found that tornado warnings issued by a WFO are only a small part of the information used by individuals in making decisions during extreme weather events. Personal communication was often critical in convincing people to take action. NWS employees called local EMs to brief them about a developing/changing situation involving the tornado, and people contacted family members thought to be in the path of the tornado.

SPC issued a tornado watch almost 6 hours before the tornado touchdown. This long lead time allowed considerable time for preparedness and planning. However, there was relatively quiet and benign weather preceding the tornado. This caused some members of the public and the EM community to believe there was no longer a threat for severe weather.

Hazardous Weather Outlooks (HWO) issued by WFOs Springfield and Tulsa 3 to 4 days in advance identified the potential for severe weather on May 10. HWOs issued on May 9, targeted large hail and damaging winds as the primary hazards, but the mention of tornadoes in the headlines did not occur until the morning of the event. The early morning HWO of May 10, issued by WFO Tulsa, emphasized the severe weather threat through the use of the headline, *"Severe thunderstorms expected today, tornadoes possible."*

The important facts and findings of this report are:

- A lull (about 3 hours in duration) in the severe weather occurred, creating a perception the severe weather was over. Some of the people interviewed indicated they went about their normal business after the first round of severe weather had ended.
- The Picher supercell straddled the Kansas-Oklahoma border with radar indications of severe weather in the WFO Springfield and Tulsa county warning areas. This overlap necessitated two tornado warnings.
- Many EMs were familiar with the Storm-based warning concept. Those who expressed an opinion indicated approval and support of the Storm-based concept; however, their actions tended to focus on geographic descriptors and/or the pathcast, not the area covered by the entire warning polygon.
- EM actions (e.g., sounding sirens, determining spotter locations) were driven by the anticipated path of the tornado, not the tornado warning polygon. In some cases, EMs did not use NWS tornado warnings to anticipate the path of the tornado. Instead, sirens were sounded based on radar analysis by local EMs/fire officials, spotter observations, or actions of upstream EMs.
- The tornado entered Newton County, Missouri, about eight miles farther south than indicated by the pathcast. The tornado, however, did occur in a tornado warning polygon.
- Trained severe weather spotters went to a location south of the anticipated tornado path to track the tornado safely. Some of the spotters were very close to the actual tornado track. One of the fatalities at Route 43 and Iris Road in Newton County, Missouri, was a trained storm spotter who was positioned in that location.
- The NWS description of the area under the warning did not correlate well with residents' perceptions of their own locations. Several of the residents who heard the warning did not believe themselves to be at risk. They understood that the track was in the northern part of Newton County. However, they did not perceive their own locations to be in the northern part of Newton County. They thought the tornado would not affect them.
- The delay in deploying a service assessment team yielded a smaller than preferred interview sample size. The team was formed on May 20, ten days after the tornado.
- Family and social networks made a difference in disseminating watches and warnings and in encouraging people to take action. Most people use multiple sources of information, frequently looking for confirmation of the information received from the first source, no matter its origin.
- People interviewed generally expect tornadoes to travel in a northeasterly direction, and to look like classic tornadoes: funnel cloud extending to ground. These preconceived notions about what a tornado looks like and the path this tornado was expected to take adversely influenced preparedness actions.

- Despite knowledge that tornadoes are common in this area and despite experience with previous watches and warnings, people did not personalize the threat and thus did not perceive themselves to be at serious risk based solely on watches or warnings. Many of those interviewed, including EMs and other public officials mentioned they had experienced numerous tornado watches and warnings where "nothing happened."
- Nine of the fatalities (42%) occurred in automobiles; 11 (52%) occurred in manufactured homes; one fatality occurred in a frame home.

Overall, 13 recommendations have been made based on the team's findings. These recommendations address deficiencies; they seek to improve NWS performance and to enhance NWS safety and outreach programs. Seven 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 findings, recommendations, and best practices from this report can be found in **Appendix B.**

2. Introduction

2.1 NWS Mission

The NWS protects life and property and enhances the national economy by providing weather, hydrologic, and climate forecasts and hazardous weather warnings to the United States, its territories, adjacent waters and ocean areas. NWS data and products form a national information database and infrastructure that can be used by other governmental agencies, the private sector, the public, and the global community.

The NWS is organized into 122 local WFOs, which have forecast and warning responsibility for certain areas in proximity to the office (referred to as a county warning areas (CWA)), and 13 River Forecast Centers (RFC), which provide WFOs hydrologic forecasts and guidance for major river basins across the country. NCEP, consisting of nine prediction centers, provides central guidance, outlooks, and hazardous weather watches and warnings to the NWS organization and the public.

2.2 Purpose of Assessment Report

A service assessment is an evaluative learning tool designed to identify and share best-case operations, procedures, and practices; and address service deficiencies. It is not intended to be a meteorological/hydrological study nor a catalog of charts and tables detailing the history of an event. A service assessment evaluates the performance and services of NOAA's NWS offices affected by the event.

Service assessments are generally initiated when a significant weather-related event results in at least one fatality, numerous injuries requiring hospitalization, extensive property damage, or widespread media interest. Assessments may also be initiated when the media, EM community, or elected officials scrutinize the operations of the NOAA's NWS. These operations include the performance of systems and the adequacy of warnings, watches, and forecasts. It is impractical to assess all significant weather related-events. This team was asked to document and evaluate the performance and overall effectiveness of NWS services and operational procedures with respect to the tornado in Oklahoma and Missouri on May 10, 2008.

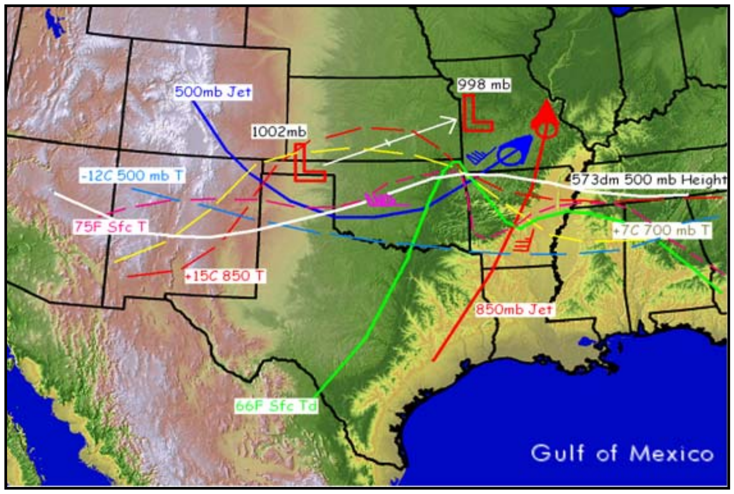
2.3 Methodology

The NWS formed an assessment team on May 20, 2008, to evaluate the NWS' performance during the Mother's Day weekend tornado event of May 10, 2008, in Oklahoma and Missouri. The team interviewed the staff from WFOs in Springfield, Missouri; Tulsa, Oklahoma; and at SPC. The assessment team visited damaged areas and interviewed EMs, the media, and the public in the impacted areas. The team also reviewed products and services from the WFOs and SPC.

3. Summary of Meteorological Conditions Preceding the Tornado

On Saturday, May 10, 2008, a strengthening surface low pressure system moved across Oklahoma to western Missouri (**Figure 1**). Ahead of the surface low, a warm, moist, unstable air mass moved north from Texas over eastern Oklahoma and western Missouri. Surface dew points were near 70°F in eastern Oklahoma and western Missouri by the afternoon. 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 necessary for severe thunderstorm formation. Dew points near 70°F provide plenty of low level moisture necessary for severe thunderstorm formation.

Figure 1. Composite chart of observed upper air parameters valid at 7 p.m. Central Daylight Time, May 10, 2008. Notice the overlap of environmental conditions favorable for severe weather in extreme northeast Oklahoma.



A strong upper level system (about 20,000 feet above sea level) over Kansas interacted with the surface system, providing wind shear needed for severe thunderstorm and tornado development. Wind shear is the change in wind speed and direction with height. The greater this change, the more rapid the lifting of surface air and the greater the potential for rotation in developing thunderstorms. Supercell thunderstorms that produce tornadoes need ample surface moisture (high dew points), strong lift and rotation of surface air, and some type of focus near the surface to start thunderstorm development. A supercell thunderstorm is one that often produces severe weather (i.e., large hail, strong straight line winds, and/or tornadoes). A supercell thunderstorm is different from a typical thunderstorm in that it has a tilted rotating updraft, allowing the thunderstorm to be stronger and persist longer.

The focus that sparked the development of supercell thunderstorms was a "dryline" that moved across Oklahoma during the day. A dryline separates a dry air mass, usually west of the line, from a moist air mass, usually east of the line. A dryline acts like a plow churning up the moist unstable air ahead of it, initiating thunderstorm development. With other necessary ingredients in place, supercell thunderstorms began developing in south central Kansas by 2 p.m. Central Daylight Time (CDT)[1]. The storms moved into eastern Oklahoma and western Missouri by late afternoon.

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

4. Summary of Tornado Outbreak

Eighteen tornadoes touched down in the WFOs Tulsa and Springfield CWAs on May 10, with 14 of those tornadoes affecting the Tulsa CWA. More than 460 severe weather events were reported during this outbreak, which stretched from eastern Oklahoma and Kansas to the southeast Atlantic Coast (**Figure 2**).

This report focuses on one violent tornado that moved through northeast Oklahoma and southwest Missouri on Saturday, May 10, 2008 (**Figure 3**). The tornado, which reached EF4, devastated the town of Picher, Oklahoma, resulting in six fatalities. The tornado continued into southwest Missouri, causing another 15 fatalities, the vast majority in Newton County, Missouri. All 21 fatalities for the event occurred where tornado watches and warnings were in effect. (Specific lead times to fatalities are listed in **Appendix D**.) SPC issued a tornado watch nearly 6 hours before the first tornado touchdown in the area. WFO Tulsa issued a tornado warning with a mean lead time of 14 minutes, and WFO Springfield followed by issuing a tornado warning with a mean lead time of 24 minutes. Both WFOs exceeded the 2008 Government Performance and Results Act (GPRA) goal for tornado warning lead time (mean lead time), which was 11 minutes.

Mean lead time is calculated by averaging the lead times for each minute the tornado is on the ground. For example, if 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. If the tornado lasts for 11 minutes in the polygon, until 1:20 p.m., there are lead times of 10 minutes, 11 minutes, 12 minutes, 13 minutes and so on through 20 minutes. The average of those lead times is 15 minutes (i.e., 10+11+12+13+14+15+16+17+18+19+20)/11= 15 minutes). Mean lead time is the measure used for GPRA goals.

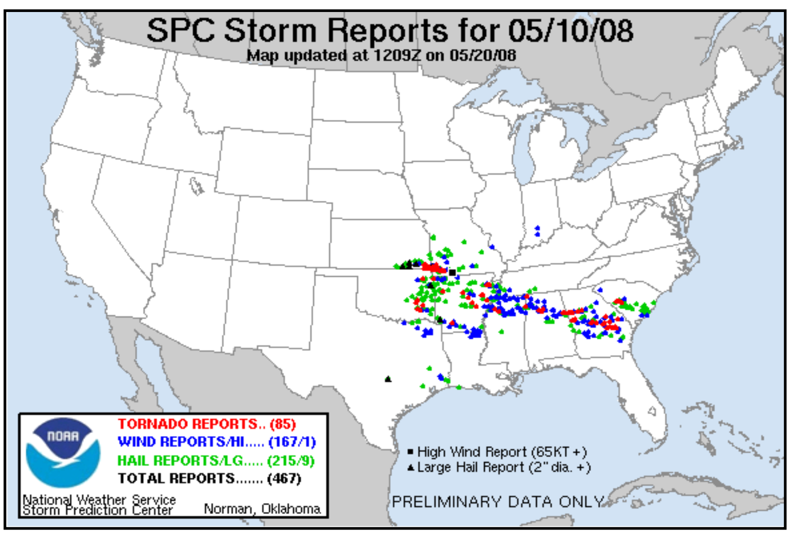


Figure 2. Severe Weather reports, May 10, 2008. Tornado reports are shown in red, damaging wind reports in blue, and hail reports in green. Courtesy of SPC.

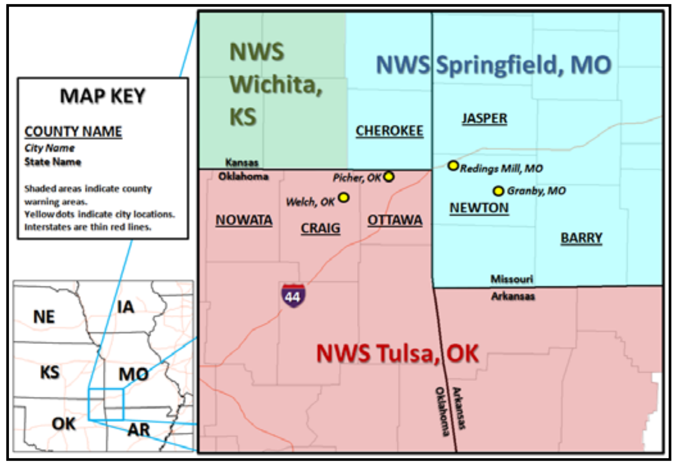


Figure 3. Map of the Springfield, Missouri, and Tulsa, Oklahoma, CWAs, which include four different states. Pertinent counties, cities, and interstate highways are highlighted. Courtesy of WFO Milwaukee, Wisconsin.

Tornado damage surveys were conducted using expertise from WFOs Tulsa and Springfield. Each office had personnel experienced in conducting surveys of violent tornadoes. The determination of an EF4 tornado was coordinated among WFOs Tulsa and Springfield and NWS Southern and Central Region Headquarters prior to public dissemination of the finding. Altogether, the tornado was on the ground for 98 minutes, with a path length of 77 miles, affected a total of four counties over a two state area (**Figure 4**) and caused $61 million in damage.

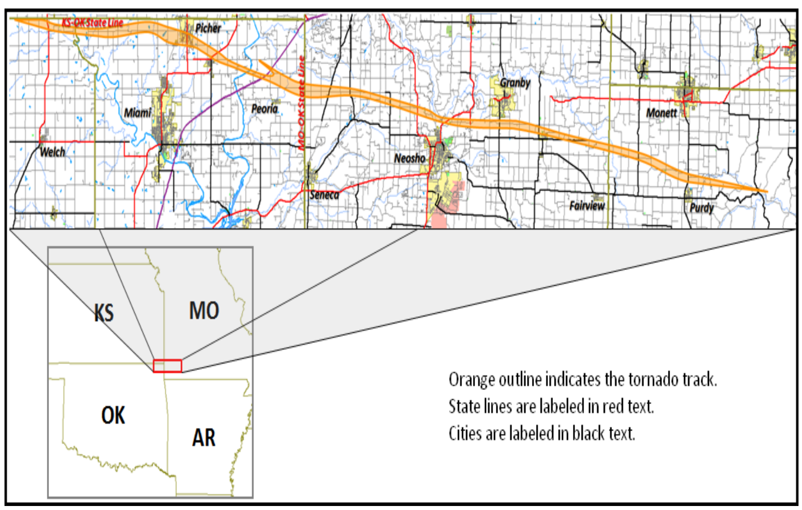


Figure 4. Track of the tornado from northeast Oklahoma into southwest Missouri. The tornado reached a peak intensity of EF4. It was on the ground for 98 minutes and covered 77 miles. Courtesy of WFO Milwaukee, Wisconsin.

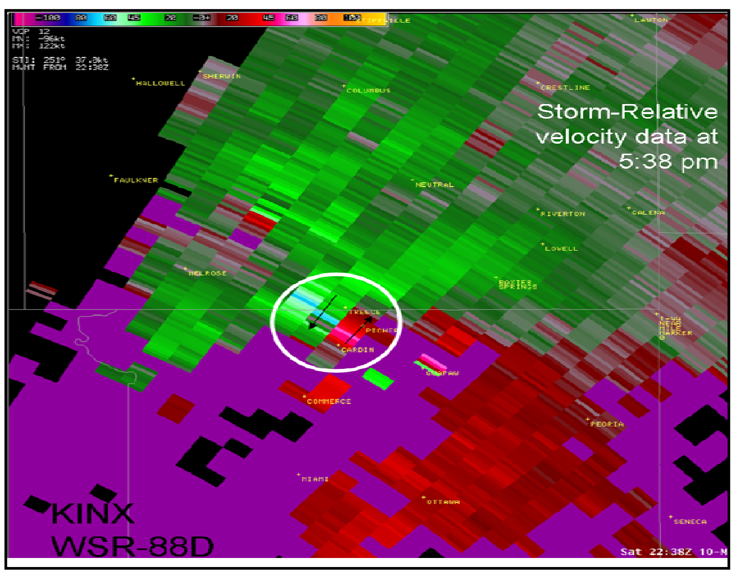
4.1 The Picher-Newton County Supercell

The supercell that eventually moved through Picher, Oklahoma, and Newton County, Missouri (causing 21 fatalities), began around 4 p.m. Saturday, May 10, in northern Washington County, Oklahoma, near the Kansas border. It formed near the surface low pressure center and just ahead of the dryline. The storm moved east-northeast and merged with another thunderstorm (not a supercell) in Craig County, Oklahoma, along the Kansas-Oklahoma border at 5:17 p.m., intensifying rapidly by 5:21 p.m. (**Figure 5**). The tornado touched down at 5:20 p.m. in WFO Tulsa's CWA, 9 miles north northwest of Welch, Oklahoma.

Figure 5. From WFO Tulsa, Oklahoma, Weather Surveillance Radar (WSR-88D), Storm Relative Velocity map at 0.5 degree elevation at 5:21 p.m. The opposing colors of red and green indicate air moving away from the radar (red) and toward the radar (green). Areas where red and green are coupled indicate rotation within a thunderstorm, which often precedes a tornado. The radar is located to the lower left in this image.

The tornado entered Picher, Oklahoma, around 5:40 p.m. (**Figure 6**). The parent thunderstorm also started to move south of due east. In operational meteorology, this is called a "right turning" thunderstorm and is an indication a thunderstorm's rotation has become strong enough to cause it to veer in a direction different from the ambient steering winds. Tornadoes form from the internal rotation of a thunderstorm. The stronger the rotation, the greater the chance a tornado can form and the greater the potential the tornado has to become strong. The "right turning" of this thunderstorm created some significant challenges in the decision-making of the WFOs and is discussed more in section 5.2. At 5:54 p.m., the tornado crossed the Oklahoma and Missouri border and entered into Newton County, Missouri (WFO Springfield's CWA).

Figure 6. From WFO Tulsa, Oklahoma, WSR-88D, Storm Relative Velocity map at 0.5 degree elevation at 5:38 p.m., 2 minutes before the tornado entered Picher, Oklahoma. The circled area shows where the tornado was at this time.



5. Facts, Findings, Recommendations, and Best Practices

5.1 Storm Prediction Center

The Day 3 Convective Outlook from SPC issued on Thursday, May 8, placed northeast Oklahoma and southwest Missouri in a slight risk area for severe weather. The slight risk was continued in the Day 2 Convective Outlook on Friday, May 9, as well as the initial issuance of the Day 1 Convective Outlook on Saturday, May 10. The area impacted by the tornado was upgraded to a moderate risk of severe weather in the Day 1 Convective Outlook about 2 hours prior to the tornado touchdown.

SPC indicated in its 11 a.m. Saturday, May 10, Mesoscale Discussion that a tornado watch would likely be issued. Shortly before the watch was issued, SPC conducted a watch coordination conference call with the WFOs in the proposed watch area to discuss the type of severe weather watch to be issued. A tornado watch was agreed to on the call. A Tornado Watch was issued for northeast Oklahoma and southwest Missouri at 11:30 a.m., about 6 hours in advance of the tornado event.

Some forecasters felt there was not enough time on the watch conference call to discuss the appropriate type of watch to be issued. SPC and WFOs had to choose between a severe thunderstorm watch and tornado watch. The decision was complicated by the expected types of severe weather during the watch period. Severe weather in the form of hail and strong straight line winds was expected in the late morning with an increasing potential for tornadoes in the afternoon.

Fact—SPC issued a Mesoscale Discussion outlining the likely need for a watch about 25 minutes prior to convening a watch coordination conference call to discuss the type of watch required.

Fact—There was insufficient time on the watch coordination conference call to thoroughly review watch options.

Best Practice 1—During complicated severe weather scenarios, WFOs should contact SPC soon after the issuance of the Mesoscale Discussion but prior to the watch coordination call to discuss the severe weather threat and watch options. Discussion topics should include: which counties to include, watch type (Tornado or Severe Thunderstorm), and valid time.

The severe weather unfolded across eastern Oklahoma and southwest Missouri as anticipated on the watch conference call—a period of severe thunderstorms in the late morning with hail and damaging winds; a lull in activity in mid-afternoon, which created the perception the worst weather was over; and tornadoes in the late afternoon. This perception problem is discussed further in Section 5.5.

Fact—About a 3 hour lull in the severe weather occurred creating a perception the severe weather was over. Some of the people interviewed indicated they went about their normal business after the first round of severe weather was over.

5.2 Weather Forecast Offices

Hazardous Weather Outlooks (HWOs) issued by WFOs Springfield and Tulsa 3-4 days in advance identified the potential for severe weather on May 10. HWOs issued on May 9, targeted large hail and damaging winds as the primary hazards, but the mention of tornadoes in the headlines did not occur until the morning of the event. The early morning HWO of May 10 issued by WFO Tulsa emphasized the severe weather threat through the use of the headline, *"Severe thunderstorms expected today, tornadoes possible."*

Best Practice 2—WFO Tulsa highlighted the tornadic threat through the use of headlines in the HWO.

Prior to becoming a tornadic storm, the Picher supercell straddled the Kansas-Oklahoma border with radar indications of severe weather in the WFO Springfield and Tulsa CWAs. The unique life cycle of the Picher supercell and its proximity to the CWA boundaries of WFOs Tulsa and Springfield posed some challenges in warning decision-making for both offices. In the immediate time period leading up to the initial warning issuance, the bulk of the Picher supercell was north of the Kansas-Oklahoma line. WFO Springfield issued a Tornado Warning for Cherokee County, Kansas, at 5:14 p.m. As the storm intensified and became a "right turning" thunderstorm, the threat to WFO Tulsa's CWA became more apparent. WFO Tulsa issued a Tornado Warning for Craig and Ottawa Counties in Oklahoma at 5:26 p.m., 6 minutes after the first tornado touchdown near Welch, Oklahoma, in Craig County. Negative initial lead times are not calculated in the verification of NWS warnings. The lowest initial lead time is 0 minutes, which was the case here. The tornado warning was in effect for 14 minutes before the tornado caused the fatalities in Picher, Oklahoma.

Fact—The Picher supercell straddled the Kansas-Oklahoma border with radar indications of the potential for severe weather in both states, and consequently two different CWAs.

Fact—WFO Tulsa issued a tornado warning 6 minutes after the first touchdown of the tornado in Welch, Oklahoma, but the warning was in effect for 14 minutes before it caused fatalities in Picher. Tornado warning lead times from WFO Springfield were 19 minutes for Newton County and 10 minutes for Barry County. All fatalities caused by this tornado were covered by tornado warnings with a mean lead time of 18 minutes.

Best Practice 3—WFO Tulsa issued a "review of severe weather safety rules" via a Public Information Statement at 1:00 p.m., May 10, alerting the public to an "outbreak of severe weather." WFO Tulsa issues these safety rules prior to expected significant severe weather outbreaks.

WFO Springfield did not conduct briefings with EMs prior to this event. WFO Springfield's criterion to hold a conference call is moderate certainty of "unusually intense, widespread life threatening hazardous weather." In the view of Springfield staff, that level of certainty was not reached before the event. WFO Tulsa provided EMs with web-based pre-recorded briefings. These audio and visual briefings were available to EMs at their convenience.

Fact—EMs indicated that NWS briefings were very important during this event and are among the most important tools for communicating hazardous weather threats.

Fact—The NWS is investigating the feasibility of implementing standard presentation software throughout all its offices to improve communication of hazardous weather threats.

The tornado touched down 9 miles north-northwest of Welch, Oklahoma, in Craig County at 5:20 p.m. WFO Tulsa issued a Tornado Warning for Craig and Ottawa Counties in Oklahoma at 5:26 p.m., 14 minutes prior to the fatalities in Picher, Oklahoma. The initial tornado warning clearly stated the life-threatening nature of the tornado: *"storm spotters are tracking a very dangerous tornado . . . ."* Follow-up severe weather statements (SVS) continued to highlight the *"large and extremely dangerous tornado."*

WFO Springfield issued three Tornado Warnings at 5:35 p.m., 6:07 p.m., and 6:21 p.m. as the tornado tracked toward and across Newton and Barry Counties in Missouri. The tornado entered Newton County at 5:54 p.m. Text of the tornado warnings noted that this was *"a confirmed tornado,"* and "*extremely dangerous.*" Follow-up SVSs also reinforced the idea that this was a confirmed tornado with statements including: *"Skywarn spotters continued to track a tornado"* and *"emergency management confirmed a tornado."*

Fact—In the NWS Service Assessment report, "Super Tuesday Tornado Outbreak of February 5-6, 2008," it was recommended the NWS provide guidance on wording to improve public response during confirmed tornadic events. Clear wording such as "*a tornado has been confirmed . . .*" or "*a tornado is on the ground at . . . and is moving . . .*" will add credibility to a warning or statement and increase the chances of appropriate and immediate responses.

Best Practice 4—Tornado warnings and SVSs issued by WFOs Springfield and Tulsa provided confirmation of a tornado and its dangerous nature. The actions of both NWS offices were consistent with the Super Tuesday report recommendation.

Sectored operations (dividing the CWA into smaller areas of responsibility and assigning personnel to manage only those specific areas) were initiated at WFOs Springfield and Tulsa. Warning operations at Springfield were sectored based on warning mode and storm location. At times up to three warning teams were in operation. Warning operations at Tulsa were sectored based on storm location.

Sectored operations were effective in managing the 18 tornadoes and more than 100 severe thunderstorm reports in the Springfield and Tulsa CWAs. WFOs Tulsa and Springfield issued a combined total of 51 severe thunderstorm and tornado warnings and severe weather statements between 5:00 p.m. and 6:00 p.m., illustrating the rapidly changing nature of the situation and the importance of having warning operations sectored during times of intense workload.

Best Practice 5—Sectored operations were employed by both offices to effectively issue warnings during this widespread major severe weather event.

Both WFO Tulsa and Springfield issued early afternoon HWOs to maintain awareness of the evolution of morning and early afternoon thunderstorms producing hail, followed by a period of quiet weather. The HWOs emphasized a chance of tornadoes developing by late afternoon, especially within a tornado watch area. After stating the threat of severe hail and severe wind gusts, WFO Springfield's HWO escalated the threat level between 3:00 p.m. and 7:00 p.m., noting the potential for *"hail to the size of golf balls and wind gusts to 80 mph along with isolated tornadoes."* WFO Tulsa's HWO also pointed out the early afternoon hail threat and mentioned, *"these storms will quickly become severe with very large hail to baseball size, destructive winds to 80 miles an hour and tornadoes all likely . . . between 4 and 7 pm."*

Best Practice 6—WFOs Springfield and Tulsa issued HWOs during the tornado watch to alert the public to the ongoing threat of hail early in the afternoon, with a greater risk of violent weather, including tornadoes, in the late afternoon and early evening.

WFO Springfield designated a Public Information Officer (PIO) to address inquiries during and after the event. Creating the PIO position was a result of Incident Command System training undertaken by the Springfield staff. The PIO provided a single authoritative NWS voice with full knowledge of the event. The PIO originated the release of all storm-related information: Local Storm Reports and Public Information Statements.

Best Practice 7—The PIO was a central source of information for external and internal partners. Media representatives appreciated working with one person to obtain storm damage reports, EF-scale ratings, and live on-air interviews.

5.3 Communication and Dissemination

In a tornadic situation, the goal of communication is to explain the threat so the public understands the message and acts upon it. Communication between EMs and the local WFO is critical. Interviews with EMs, media partners, and the general public identified several issues associated with the communication process.

Finding 1—WFO Springfield called EMs in Newton and Barry Counties immediately prior to issuing the tornado warning with information about the tornado and the forecast. This phone call carried substantial weight in the decision-making process for the EMs because more information was discussed than is typically contained in tornado warning notifications. Typically, notifications confirm receipt of the warning, convey a quick overview of the counties affected, and specify the warning valid time.

Recommendation 1—The NWS should communicate with EMs and other key decision-makers to highlight unusual or fast-changing situations involving extreme weather events.

Communication between WFOs Tulsa and Springfield was minimal during a critical period of time; no significant exchange of information occurred prior to the tornado moving out of Tulsa's CWA and into Springfield's CWA. There was no evidence that spotter reports (or reports from EMs and other officials) were shared between the two offices during the critical time when the tornado was near the Kansas-Oklahoma border and prior to its movement into Missouri.

Finding 2—Limited communication between WFOs Tulsa and Springfield resulted in two tornado warnings—in effect at the same time—depicting a tornado in two different locations, moving in two different directions and speeds, with two different sets of communities potentially impacted.

Recommendation 2—When a severe weather event is moving from one CWA to another, the WFOs should communicate with each other to ensure a full and complete exchange of relevant information. This is especially true in cases where a storm is moving parallel and in close proximity to a boundary between CWAs.

Currently, it is optional to include pathcast information in tornado warnings. Pathcasts highlight specific cities, towns, and locations where the tornado is expected to be at certain times. As with any weather forecast, uncertainty exists in the expected location of the tornado, and there is no guarantee the tornado will be at the highlighted locations at the specified times. WFO Springfield typically includes pathcast information in tornado warnings; WFO Tulsa's policy excludes the mention of pathcasts. The information included in the Tornado Warning issued by WFO Springfield at 5:35 p.m. for Northern Newton County, Missouri, included a pathcast that extrapolated the tornado path in an easterly direction. As the storm became a "right turning" thunderstorm, its path changed to east-southeast. As the tornado moved from Oklahoma into Missouri, WFO Springfield issued an SVS at 5:59 p.m. with conflicting information. The SVS indicated the tornado was "1 mile west of Redings Mill," which was consistent with the pathcast in the Tornado Warning issued at 5:35 p.m. The SVS contained additional location information indicating "an EM reported a tornado at the intersection of Bethel and Iris road west of Redings Mill." This text was confusing because the street intersection—which was on the actual tornado path—is roughly 8 miles south-southwest of Redings Mill and well south of the original pathcast. A new Tornado Warning issued at 6:07 p.m. for southern Newton County, Missouri, had more accurate pathcast information; by this time, however, 20 of the 21 fatalities associated with the tornado had occurred.

EM actions—sounding sirens, placing spotters—were driven by the anticipated path of the tornado, not the tornado warning polygon. In some cases, EMs did not use NWS tornado warnings to anticipate the path of the tornado. Instead, sirens were sounded based on radar analysis by local EMs/fire officials, spotter observations, or actions of upstream EMs. Sirens were sounded in locations in *northern* Newton County by EMs based on the text of the Tornado Warning for northern Newton County issued at 5:35 p.m. by WFO Springfield. In some cases, the locations where sirens were sounded were mentioned in the pathcast. Only after the tornado had entered extreme west-central Newton County and first damage reports were received by EMs, were sirens sounded in towns in central Newton County along the path of the tornado.

Fact—The tornado entered Newton County farther south than anticipated by county EMs.

Fact—Although the tornado was in the warning polygon, the tornado was south of the 5:35 p.m. tornado warning pathcast by roughly 8 miles.

Fact—Spotters went to a location based on the anticipated path of the tornado, but wound up much closer to the actual tornado track. One of the fatalities at Route 43 and Iris Road in Newton County, Missouri, was a trained storm spotter situated in that location.

Fact—Due to local office policy, WFO Tulsa does not include pathcast information in tornado warnings. Conversely, WFO Springfield typically does include pathcast information in tornado warnings. These practices are consistent with national policy that indicates pathcasts are optional.

Fact—The current warning pathcast policy was developed more than 10 years ago, when severe weather warnings were county-based.

Finding 3—Pathcasts in tornado warnings are used by some WFOs, but not others. The policy making pathcasts optional was developed in a county-based warning environment. Storm-based warning polygons may provide some of the functionality contained in a pathcast.

Recommendation 3—A team should be formed to review pathcast policy and explore how to best communicate, within the state of the science, the forecasted location and timing of tornadoes in Storm-based warnings.

Finding 4a—EM actions, (sounding sirens, placing spotters) were driven by the anticipated path of the tornado, not the tornado warning polygon.

Finding 4b—Many EMs were familiar with the Storm-based warning concept. Those who expressed an opinion indicated approval and support of the Storm-based warning concept; however, their actions tended to focus on geographic descriptors in the warning (e.g., northern Newton County) and/or the pathcast, not the area covered by the entire warning polygon.

Finding 4c—The NWS description of the area under the warning did not correlate well with residents' perceptions of their own locations. Several of the residents who heard the warning did not believe themselves to be at risk. They understood that the track was in the northern part of Newton County. However, they did not perceive their own locations to be in the northern part of Newton County. Therefore, they thought the tornado would not affect them.

Recommendation 4—The NWS should emphasize to EMs and other key decision-makers that an entire area in and near a warning polygon is under risk of the warned phenomenon. Decision-makers should be concerned with the entire warned area.

Finding 5—EMs were surprised by the east-southeast track of the storm; however, repeated references to a *sharp* turn to the southeast were not found in the plotted tornado damage track.

Recommendation 5—Training for EMs and Skywarn spotters needs to stress that right-turning storms can result in south of east motion. (In operational meteorology, this is called a "right turning" thunderstorm and is an indication a thunderstorm's rotation has become strong enough to cause it to veer in a direction different from the ambient steering winds.)

Fact—EMs frequently mentioned the word "fatigue." EMs used the terms "watch fatigue," "warning fatigue," and "siren fatigue." The reference to fatigue indicated that NWS issued many watches or warnings during which no significant weather occurred.

Fact—Decision-makers perceived some of the warnings as false alarms, clearly driving some of the decision-making described in section 5.5, "Societal Responses and Impacts."

Fact—Communication between EMs across state lines is problematic. Missouri, Kansas, and Oklahoma are using or will be using new radio equipment with different radio frequencies for first responders. Older radio systems allowed neighboring EMs across state lines to hear each other—a capability that will be lost. EMs from Newton County, Missouri, monitored activity in northeast Oklahoma when the tornado moved through. That capability will be lost within the next year.

5.4 Dissemination

The NWS has included TV media and EMs in an experimental instant message system; however, there has been less emphasis on including print media. On-line editions of newspapers provide current up-to-the minute information just as TV and radio do. The *Joplin Globe*, for example, received millions of web page hits in the wake of the tornado outbreak and was a clearinghouse for other media outlets to link to their stories about the tornado damage.

Fact—The NWS has developed NWSChat, an instant message system, for use in all NWS offices. NWSChat began its experimental stage on December 1, 2008. The experimental period will continue through December 15, 2009, during which time this software will be evaluated to determine the usefulness and appropriateness of this form of information exchange.

Finding 6—Newspapers are moving more toward electronic print and are developing more robust Web sites and 24-hour weather coverage.

Recommendation 6— NWS should explore potential partnerships with newspaper media for NWSChat.

5.5 Societal Responses and Impacts

The societal impacts portion of this assessment relied on interviews with the general public, newspaper and TV media, and EMs, as well as a review of newspaper and TV media coverage. Many of those affected by the tornado were unaware of NWS watches and warnings that were in effect. Others believed they were not at risk. Regardless of whether they knew a warning was in effect, residents relied on multiple sources of information to make decisions. In Picher, Oklahoma, the combination of the town's sirens being activated, visual confirmation of an approaching tornado, and the sounds of other residents fleeing in automobiles led a substantial part of the town's population to drive south out of the tornado's path and to safety. In Newton County, Missouri, conflicting and limited information—lack of tornado warning information, lack of sirens in rural areas, uncertainty regarding the appearance of the tornado—resulted in a number of people not getting out of the tornado's path and subsequent death and injury.

The Mother's Day weekend tornado caused 21 deaths, 6 in Ottawa County, Oklahoma, in the town of Picher, 14 in Newton County, and 1 in Barry County, Missouri. Given the long path, rapid forward motion, and amount of destruction wrought by the tornado, there could have been even more deaths. An important component of this assessment is to evaluate what was done by those who died as opposed to those who survived after the warnings were issued.

The analysis focused on developing an understanding of how people received information about the warning and the event, how they perceived their situations with respect to the threat, and what decisions were made and actions taken. Approaches used to collect the information were 1) examination of newspaper reports and other documentation of the actions taken by those who died in the event, 2) interviews with EMs and first responders, and 3) interviews using a convenience sample of those who were directly affected by the tornado.

The sample for interviews of those affected was chosen by following the track of the tornado. The team stopped at homes where people were working outside. Each person was asked a series of questions (not necessarily in a specific sequence) about their experiences before, during, and after the tornado, as well as their previous tornado experience and level of preparation. The team interviewed 14 people in Newton County. Some of these people were within the violent (EF4) damage path and others were within the weaker (EF1) damage area. Because the team visited the affected region almost 3 weeks after the event, those people whose homes were destroyed were not available to be interviewed. They had already retrieved any valuable possessions and left the site.

Finding 7—The delay in deploying a Service Assessment team and limited time allocated for the field assessment yielded a smaller than preferred interview sample size.

Recommendation 7—To provide a representative sample of sufficiently large size for an analysis of societal responses and impacts, Service Assessment teams ideally should be deployed to the site within a few days, and no more than 1 week, after an event.

The following facts, findings, and recommendations are based on the sample size available to the team. These facts, findings, and recommendations are presented here to develop a foundation for future NWS societal responses and impacts analysis.

The following presentation of results contains sources of information; perceptions; and decision-making and actions. Observations and experiences of the EMs and other first responders are included in these sections where appropriate. Following that section are details of the actions taken by those who died in the tornado, to the extent that these details can be gleaned from available information. Although the findings are divided into different sections, they are clearly and closely interrelated.

5.5.1 Information Sources and Interpretations

To understand how people responded to warnings, it is important to know how they received the information and what it meant to them.

Fact—More than half of those interviewed were not aware of the tornado warning in effect for areas of northeast Oklahoma and southwest Missouri. Only two of the interviewees had seen the warning on TV[2], and two had weather radios that alerted them (one of whom had also received the warning via TV). One individual was watching The Weather Channel on satellite TV rather than on cable; he said he saw no warning.[3]

Fact—EMs endorsed the use of cell phones as warning devices given that coverage in rural areas is now generally good. This kind of technology could help to overcome differing perceptions of location by sending alerts to those in the watch and warning areas.

Fact—NWS is exploring the concept of NWS Mobile Alerts to provide text messaging of watches, warnings, and advisories.

Sirens were mentioned by several interviewees and EMs as being important warning devices, but they are not widespread throughout the affected area. There are no sirens where the 14 deaths in Newton County occurred. On the other hand, sirens are believed by the EMs to have been effective in Picher and in Barry County. In Picher, sirens were sounded roughly 10-12 minutes prior to the tornado striking the community; with a total of three separate cycles sounded. This was only the third time in 12 years that the sirens had been sounded in Picher for a tornado threat. The sirens gave people sufficient time to take action, and most got in cars and drove away from the storm. People on the periphery of town, however, could not hear the siren, but were alerted by residents in departing vehicles.

Sirens were mentioned by the people interviewed in Granby (Newton County, Missouri) as alerting them to the threat. According to the Granby Fire Chief, Granby's sirens went off

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[2] This contrasts with the findings of previous studies which list TV as the primary source (Legates and Biddle, 1999; Hammer and Schmidlin, 2002, and the Super Tuesday Service Assessment Report, 2009). The difference likely exists because the tornado struck in the early evening on a Saturday, which prior to that, was a beautiful day so many were not home or were outside.

[3] A similar situation may be true for those in cars who listen to satellite radio.

twice, about 10 minutes before the tornado hit. He had heard some residents say that the sirens saved them. Unfortunately, the sirens were disrupted by a power outage that day; one respondent said she thought that things were all clear when the sirens stopped.

Fact—Sirens are outdoor warning systems and most effectively warn people who are outside. The sirens are not loud enough, under most conditions, to be heard inside a sealed, air-conditioned home that is more than a couple of blocks away from the siren.

Finding 8—Sirens are an important component of the total warning process in those areas that have them. The EMs were in agreement that sirens are critical and effective, but at times residents can misunderstand the signal.

Recommendation 8—NWS should update appropriate education and outreach material to include the benefits and limitations of sirens, as well as information on EM operational and activation considerations in the total weather warning process.

An important source of information to about half of the interviewees was personal communication by family members, neighbors, and friends. In one instance, an individual called his daughter in Joplin because of the warning. He was not aware that he was at an equal or greater risk. In almost all cases, the phone calls led the recipients to act. An example is a woman who was at a friend's house with her family, her son, and six other 10-year-old boys celebrating her son's birthday. Had they not received a phone call, they would likely have been heading home into the tornado. Similarly, an elderly couple was alerted by their neighbor. They did not have time to go to the basement in their neighbor's house; however, they were able to protect themselves in their home.

During the survey, it became clear no one relied solely on one source of information. Where a warning was heard, the resident checked outside to see what was happening. Following a phone call, the resident turned on the TV or went outside to view weather conditions. Even with sirens, people checked for environmental cues. In this event, the sun was shining most of the afternoon, complicating the ultimate response.

Finding 9a—Family and social networks made a difference in disseminating the watch and warnings and in encouraging people to take action.

Finding 9b—Most people use multiple sources of information, frequently looking for confirmation of the information received from the first source, no matter its origin. Unfortunately, this can take valuable time.

Recommendation 9—NWS should develop education and outreach material encouraging people to notify family, friends, and neighbors of the danger without jeopardizing their own safety. The educational and outreach material should also emphasize the importance of immediately acting upon a single source of information when the communicated threat is imminent.

5.5.2 Perceptions

In Picher, there were sirens and a visible tornado, so people were more willing to respond quickly. In Missouri, however, things were quite different. There were several misunderstandings about the threat posed by the storm system. These misunderstandings led people to believe they were at less risk than they were. Despite Storm-based warnings that included the area hit by the tornado, the text reference in the warning of "Northern Newton County" confused several people. These people were in the tornado polygon warning area but did not perceive themselves as living in "Northern Newton County." At least one person mentioned that he figured the tornado would go "Northeast like it always does." Thus, some of those who heard warnings did not believe they were at risk.

These perceptions were complicated by two other factors: 1) the sunny afternoon was the first nice weekend in a while and people were reluctant to abandon outdoor activities, and 2) ultimately, the size, appearance, and speed of movement of the tornado in Newton County. Some people ignored warnings due to the calm weather. Two interviewees reported that the tornado did not look like a tornado. One drove into it thinking it was a very heavy downpour. There was rain but one reported that it was not heavy (he was on the edge of it), and the other reported that it looked serrated. Neither saw a "classic" tornado formation, probably due to its width (and possibly its "aberrant" movement from the west-northwest at a high speed). In fact, one of the interviewees understood why people would have stopped on the road to wait for the rain to pass rather than trying to drive out of the path of the tornado.[4]

Six of the interviewees said it was not until they actually saw the tornado that they believed there was a threat. For most of these individuals, this occurred after they had already been notified, either by an official warning or by a phone call. These people did not personalize the threat until they saw it. All those interviewed stated that tornadoes occur in their region. There have been numerous watches and warnings in the past with siren activations; however, none of the interviewees had previously experienced a tornado directly.

5.5.3 Decision-making and Actions

Decisions were made by people throughout the entire warning period—decisions to keep the TV on, to watch the sky, to go to the store, to travel, and to stay outside. The decisions made and actions taken once the threat was personalized are of the greatest interest. This recognition of threat occurred at different times for those at risk. Based on comments by interviewees, and discussions with EMs, the team learned that many residents unfortunately had little time to take protective action.

When the sirens sounded in Picher, many people drove out of the path of the tornado. Although the NWS does not recommended using vehicles to flee from approaching tornadoes, in this case it proved to be very effective. Between 75 and 125 cars were estimated to have left Picher in the 10 minutes between sounding the sirens and impact. In Newton County all but one of the people interviewed in or near the path of the tornado took protective action, or intended to, but did not have enough time once the threat was recognized. Those who had cellars or

[4] Several of the deaths in cars resulted from people stopping on the road, discussed in a later section.

basements went into them. Two of those who did not have a cellar or basement had plans to go to a neighbor's house, but did not make it in time. Two others tried to protect themselves with furniture. One individual knew the tornado was coming and went back to sit in his chair, deciding that it was too late to do anything. Another person realized there was nothing he and his wife could do but wait it out in their mobile home.

Except for these last three people, all of those interviewed took protective action or intended to protect themselves; for some, circumstances made their plan impossible, but they had a plan. In addition, five had a basement or cellar. Two people had access to a neighbor's basement. Only three of those interviewed had a NOAA Weather Radio All-Hazards (NWR) at the time of the event. One person who owned an NWR said it was packed away because he was moving. Interestingly, the man who took the least protective action by going back to sit in his chair had his NWR on and next to him.

Fact—After receiving warning information or seeing the tornado, all but three of the people interviewed sought shelter or tried otherwise to protect themselves.

5.5.4 Fatalities

There were 21 deaths as a result of this event: 6 in Picher, Oklahoma, and 15 in Missouri. Of these, 9 (43 percent) were in cars, one of which was a firefighter trying to warn people of the approaching tornado. It is unknown if any in the cars, except for the firefighter, had heard warnings. Three of those who died in Picher were in a car. There was a fourth person in the car, a 13-year-old girl who survived. It is believed, though not verified, that those in the car were trying to get to a safe place. It is notable that there were not more deaths in vehicles, given the number reported leaving Picher to get out of the path of the tornado and the difficulty people in Newton County had identifying the storm as a tornado.

Nearly half of those who died were in manufactured homes that were destroyed. This unfortunate situation is not surprising given that manufactured homes are considered among the worst places to be during a tornado. In fact, according to the SPC, between 1999 and 2008, 49 percent of tornado fatalities in the United States occurred in manufactured homes, the largest percentage of any location. It is believed that all of the victims were aware of the warning, and that some did the best they could to protect themselves within their manufactured homes. In Picher, a family went into a closet, but was thrown in different directions. The father and child survived, the mother did not. The one person who died in a frame home was on the second floor of the house; the victim may have been safer on the first floor.

It is unknown if those who died in manufactured homes had alternate sheltering options, whether a neighbor's storm cellar or home. Three people died when a tree fell on the structure in which they were sheltering. In one case, once they heard the storm, four members of a family took refuge in a barn because they were unable to make it back to their house in time. One was struck by a tree and died.

Warnings had been issued and/or sirens had been activated in all of the counties, with the lead time reported in Picher of about 10 to 12 minutes (14-minute lead time from initial issuance of the warning to when the first fatalities occurred). Factors mentioned earlier, such as people not listening to local TV or radio, being outside and enjoying a clear Saturday afternoon, and specific characteristics of the storm, including its appearance, perceived lack of precipitation, and direction and speed of movement, contributed to the lack of preparation for appropriate sheltering. In addition, because it was a holiday weekend, TV coverage was more limited than it probably would have been during a weekday. The extent to which each of these factors influenced decisions is important, but impossible to determine.

Finding 10a—People interviewed generally expect tornadoes to travel in a northeasterly direction and have a classic appearance—a well-defined funnel cloud extending to the ground. These preconceived notions about what tornadoes look like and the actual path of the tornado adversely influenced people's actions during this event.

Finding 10b—Despite residents' knowledge that tornadoes occur in this area and their previous experience receiving tornado watches and warnings, people did not always personalize the threat. The residents did not perceive themselves to be at serious risk based solely on a NWS watch or warning. Many of those interviewed, including EMs and other public officials, mentioned that they have been under numerous tornado watches and warnings where "nothing happens."

Finding 10c—Several factors, including the calm, clear weather prior to the tornado, the direction of movement, and the width of the storm, which were confusing to some, contributed to delayed responses to warnings and insufficient preparation for appropriate shelter.

Recommendation 10—The NWS should create educational material and develop public awareness campaigns addressing preconceived notions about the appearance and movement of tornadoes. This information should stress the importance of always preparing for tornadoes despite calm weather prior to severe weather and despite previous false alarms.

5.5.5 Addressing Societal Responses and Impacts

Many of the findings related to societal impacts and responses to warnings can be addressed over the short to medium terms through the recommendations presented above. However, some of the issues and problems that were identified can be resolved only with longer term actions centering on an understanding of human behavior. The recommendations that follow parallel those presented throughout this report.

As noted in Finding 4c, the NWS description of the area under the warning did not correlate with residents' perceptions of their locations. The recommendation associated with this issue relates to NWS and EMs' understanding and presentation of the warning area.

Recommendation 11—Because of differing views of relative location between those issuing the watches and warnings and those receiving them, verbal and written descriptions of locations at risk need to be carefully crafted and supplemented with graphics that depict the anticipated location as well as the uncertainty. NWS should work with communications experts to test various modes of presentation and dissemination of this kind of information.

It became clear throughout this assessment that people who were at risk did not necessarily view themselves as being at risk until they had some visual or other confirmation of the tornado. It is not until individuals personalize the risk that they will act. Sometimes this is too late, a complicating factor that is important to those issuing warnings.

Recommendation 12—A comprehensive approach addressing public awareness, as well as individual elements of the total warning process, is needed to alter perceptions so that people better understand their risk. NWS should evaluate how its various components contribute to an approach that includes human perceptions and response.

Lead times for this event exceeded the 2008 GPRA goal. Some respondents noted that they were aware of the watch and warnings, but, because of the afternoon's mild weather, they did not pay them sufficient heed.

Recommendation 13—NWS meteorologists should work with communications experts and behavioral experts to evaluate the impact of different lead times on reliability of warnings and on human responses. This should include determining the correct balance between increasing lead time without adversely increasing false alarms and creating "warning fatigue."

These recommendations will lead to a better understanding of how the NWS can more effectively protect lives and property.

6. Summary

The loss of 21 people in a tornado is tragic. More than 100 homes were destroyed in Picher, many of them manufactured homes. Photographs of damaged and destroyed structures in Missouri provide a similar picture. Given the magnitude of the event, the death toll could have been far worse. The following factors played a role:

1. Time of day: The late afternoon/early evening occurrence meant that people could see the storm before it hit, so many had time to protect themselves.

2. The day of the week: Because it was a Saturday, many people were not at home, but were at events such as a graduation in Purdy, Missouri, and a truck show in Miami, Oklahoma, thus not in the path of the tornado.

3. The Mother's Day weekend: Many people were away from home because of Mother's Day.

A number of factors came together to complicate warning of the tornado and response to those warnings: political boundaries, extremely active storm systems within the CWAs, the timing of the tornado, and EM activities. Building upon the recommendations made in this report will position the NWS to improve operations and services to help save lives and property.

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

Findings, Recommendations, and Best Practices

Findings and Recommendations

Finding 1—WFO Springfield called EMs in Newton and Barry Counties immediately prior to issuing the tornado warning with information about the past behavior of the tornado and expected future behavior. This phone call carried substantial weight in the decision-making process for the EMs because it contained more information and importance than typical tornado warning notifications. Typically, notifications confirm receipt of the warning, convey a quick overview of the counties affected, and specify the warning valid time.

Recommendation 1—The NWS should communicate with EMs and other key decision-makers to highlight unusual or fast-changing situations involving extreme weather events.

Finding 2—Limited communication between WFOs Tulsa and Springfield resulted in tornado warnings—in effect at the same time—depicting a tornado in two different locations, moving in two different directions and speeds, with two different sets of communities potentially impacted.

Recommendation 2—When a severe weather event is moving from one CWA to another, the appropriate WFOs should contact each other to ensure a full and complete exchange of relevant information. This is especially true in cases where a storm is moving parallel and in close proximity to a boundary between CWAs.

Finding 3— Pathcasts in tornado warnings are used by some WFOs, but not others. The policy making pathcasts optional was developed in a county-based warning environment. Storm-based warning polygons may provide some of the functionality contained in a pathcast.

Recommendation 3—A team should be formed to review pathcast policy and explore how to best communicate, within the state of the science, the forecasted location and timing of tornadoes in Storm-based warnings.

Finding 4a—EM actions, (sounding sirens, placing spotters) were driven by the anticipated path of the tornado, not the tornado warning polygon.

Finding 4b—Many EMs were familiar with the Storm-based warning concept. Those who expressed an opinion indicated approval and support of the Storm-based warning concept; however, their actions tended to focus on geographic descriptors in the warning (e.g., northern Newton County) and/or the pathcast, not the area covered by the entire warning polygon.

Finding 4c—The NWS description of the area under the warning did not correlate well with residents' perceptions of their own locations. Several of the residents who heard the warning did not believe themselves to be at risk. They understood that the track was in the northern part of Newton County. However, they did not perceive their own locations to be in the northern part of Newton County. Therefore, they thought the tornado would not affect them.

Recommendation 4—The NWS should emphasize to EMs and other key decision-makers that an entire area in and near a warning polygon is under risk of the warned phenomenon. Decision-makers should be concerned with the entire warned area.

Finding 5—EMs were surprised by the east-southeast track of the storm; however, repeated references to a *sharp* turn to the southeast were not found in the plotted tornado damage track.

Recommendation 5—Training for EMs and Skywarn spotters needs to stress that right-turning storms can result in south of east motion. (In operational meteorology, this is called a "right turning" thunderstorm and is an indication a thunderstorm's rotation has become strong enough to cause it to veer in a direction different from the ambient steering winds.)

Finding 6—Newspapers are moving more toward electronic print and are developing more robust websites and 24-hour weather coverage.

Recommendation 6—NWS should explore potential partnerships with newspaper media for NWSChat.

Finding 7—The delay in deploying a Service Assessment team and limited time allocated for the field assessment yielded a smaller than preferred interview sample size.

Recommendation 7—To provide a representative sample of sufficiently large size for an analysis of societal responses and impacts, Service Assessment teams ideally should be deployed to the site within a few days, and no more than 1 week, after an event.

Finding 8—Sirens are an important component of the total warning process in those areas that have them. The EMs were in agreement that sirens are critical and effective, but at times residents can misunderstand the signal.

Recommendation 8—NWS should update appropriate education and outreach material to include the benefits and limitations of sirens, as well as information on EM operational and activation considerations in the total weather warning process.

Finding 9a—Family and social networks made a difference in disseminating the watch and warnings and in encouraging people to take action.

Finding 9b—Most people use multiple sources of information, frequently looking for confirmation of the information received from the first source, no matter its origin. Unfortunately, this can take valuable time.

Recommendation 9—NWS should develop education and outreach material encouraging people to notify family, friends, and neighbors of the danger without jeopardizing their own safety. The educational and outreach material should also emphasize the importance of immediately acting upon a single source of information when the communicated threat is imminent.

Finding 10a—People interviewed generally expect tornadoes to travel in a northeasterly direction and have a classic appearance—a well-defined funnel cloud extending to the ground. These preconceived notions about what tornadoes look like and the actual path of the tornado adversely influenced people's actions during this event.

Finding 10b—Despite residents' knowledge that tornadoes occur in this area and their previous experience receiving tornado watches and warnings, people did not always personalize the threat. The residents did not perceive themselves to be at serious risk based solely on a NWS watch or warning. Many of those interviewed, including EMs and other public officials, mentioned that they have been under numerous tornado watches and warnings where "nothing happens."

Finding 10c—Several factors, including the calm, clear weather prior to the tornado, the direction of movement, and the width of the storm, which were confusing to some, contributed to delayed responses to warnings and insufficient preparation for appropriate shelter.

Recommendation 10—The NWS should create educational material and develop public awareness campaigns addressing preconceived notions about the appearance and movement of tornadoes. This information should stress the importance of always preparing for tornadoes despite calm weather prior to severe weather and despite previous false alarms.

Recommendation 11— Because of differing views of relative location between those issuing the watches and warnings and those receiving them, verbal and written descriptions of locations at risk need to be carefully crafted and supplemented with graphics that depict the anticipated location as well as the uncertainty. NWS should work with communications experts to test various modes of presentation and dissemination of this kind of information.

Recommendation 12— A comprehensive approach addressing public awareness, as well as individual elements of the total warning process, is needed to alter perceptions so that people better understand their risk. NWS should evaluate how its various components contribute to an approach that includes human perceptions and response.

Recommendation 13— NWS meteorologists should work with communications experts and behavioral experts to evaluate the impact of different lead times on reliability of warnings and on human responses. This should include determining the correct balance between increasing lead time without adversely increasing false alarms and creating "warning fatigue."

Best Practices

Best Practice 1— During complicated severe weather scenarios, WFOs should contact SPC soon after the issuance of the Mesoscale Discussion but prior to the watch coordination call to discuss the severe weather threat and watch options. Discussion topics should include: which counties to include, watch type (Tornado or Severe Thunderstorm), and valid time.

Best Practice 2—WFO Tulsa highlighted the tornadic threat through the use of headlines in the HWO.

Best Practice 3—WFO Tulsa issued a "review of severe weather safety rules" via a Public Information Statement at 1:00 p.m., May 10, alerting the public to an "outbreak of severe weather." These safety rules are issued prior to expected significant severe weather outbreaks.

Best Practice 4—Tornado warnings and SVSs issued by WFOs Springfield and Tulsa provided confirmation of a tornado and its dangerous nature. The actions of both NWS offices were consistent with the Super Tuesday report recommendation.

Best Practice 5—Sectored operations were employed by both offices to effectively issue warnings during this widespread major severe weather event.

Best Practice 6—WFOs Springfield and Tulsa issued HWOs during the tornado watch to alert the public to the ongoing threat of hail early in the afternoon, with a greater risk of violent weather, including tornadoes, in the late afternoon and early evening.

Best Practice 7—The PIO was a central source of information for external and internal partners. Media representatives appreciated working with one person to obtain storm damage reports, EF-scale ratings, and live on-air interviews.

Appendix C

Acronyms

CDT	Central Daylight Time
CWA	County Warning Area
EF	Enhanced Fujita Tornado Scale
EM	Emergency Management/Manager
GPRA	Government Performance and Results Act
HWO	Hazardous Weather Outlook
mb	Millibar
MIC	Meteorologist-in-Charge
mph	Miles per hour
NCEP	National Centers for Environmental Prediction
NOAA	National Oceanic and Atmospheric Administration
NWR	NOAA Weather Radio All-Hazards
NWS	National Weather Service
NWSChat	Instant Message System developed by NWS
OCWWS	Office of Climate, Water, and Weather Services
PIO	Public Information Officer
RFC	River Forecast Center
SOO	Science and Operations Officer
SPC	Storm Prediction Center
SVS	Severe Weather Statement
UTC	Coordinated Universal Time
WCM	Warning Coordination Meteorologist
WFO	Weather Forecast Office
WSR-88D	Weather Surveillance Radar, 1988 Doppler

Appendix D

Event Statistics

WFO	Tornadoes	Warnings Issued	POD	FAR	Initial Lead Time (minutes)	Mean Lead Time (minutes)
Tulsa	14	24	0.84	0.46	15.47	15.43
Springfield	4	9	0.99	0.56	20.80	25.28

Table 1. Composite tornado statistics for all tornado warnings and tornadoes in the Tulsa and Springfield CWAs on May 10.

County	NWS Office	Initial Lead Time (minutes)	Mean Lead Time (minutes)	Fatalities	Fatality Lead Time (minutes)
Craig	Tulsa	0	0	0	N/A
Ottawa	Tulsa	0	14	6	14
Newton	Springfield	19	24	14	20-30
Barry	Springfield	10	22	1	21

Table 2. Tornado warning lead times for the EF4 tornado which caused the fatalities in Oklahoma and Missouri May 10, 2008.

Appendix E

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 Tornado Scale is a set of wind estimates (not measurements) based on 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.

Appendix F

References

Hammer, Barbara and Thomas W. Schmidlin. 2002. Response to warnings during the 3 May 1999 Oklahoma City tornado: reasons and relative injury rates. *Weather and Forecasting* 17(3): 577-581.

Hayes, John L. "Service Assessment: Super Tuesday Tornado Outbreak of February 5-6, 2008." National Weather Service. March, 2009. http://www.weather.gov/os/assessments/pdfs/super_tuesday.pdf

Legates, David R. and Matthew D. Biddle. 1999. *Warning Response and Risk Behavior in the Oak Grove-Birmingham, Alabama Tornado of 8 April 1998.* Quick Response Report #116. Natural Hazards Center, Boulder, CO. http://www.colorado.edu/hazards/research/qr/qr116/qr116.html.