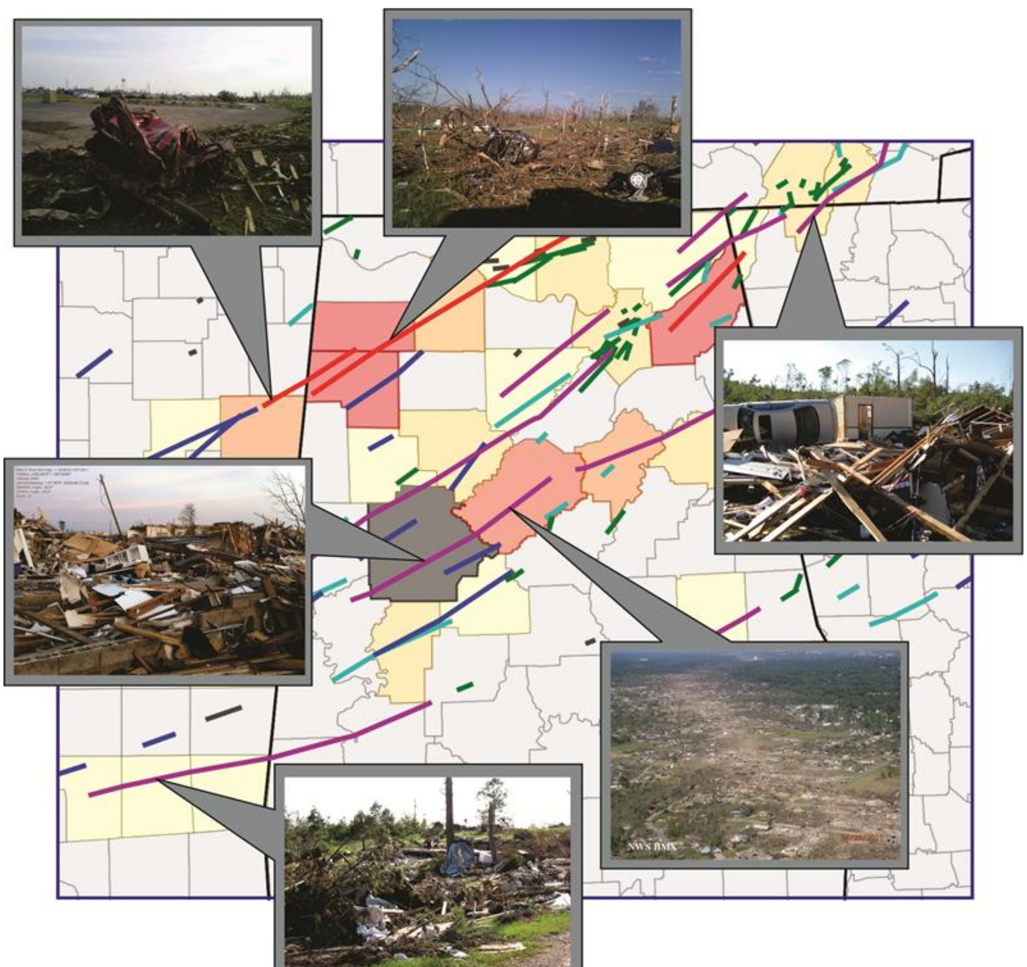
Service Assessment

The Historic Tornadoes of April 2011



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

Cover Photographs: Tornado tracks and damage pictures from eastern Mississippi, central and northern Alabama, and northern Georgia. Map: National Severe Storms Laboratory. Photos: NWS Birmingham, AL; NWS Huntsville, AL; NWS Peachtree City, GA; Richard Okulski; Kevin Scharfenberg; Gary Woodall

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December 2011

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

Preface

During a 4-day period from April 25-28, 2011, more than 200 tornadoes occurred in five southeastern states. The deadliest part of the outbreak was the afternoon and evening of April 27, when a total of 122 tornadoes resulted in 313 deaths across central and northern Mississippi, central and northern Alabama, eastern Tennessee, southwestern Virginia, and northern Georgia. Three additional lives were claimed by tornadoes in the pre-dawn hours of April 27 bringing the daily total to 316. There were 15 violent (Enhanced Fujita Scale 4 or 5) tornadoes reported. Eight of the tornadoes had path lengths in excess of 50 miles. Two of the tornadoes–one in northern Alabama and another that struck the Tuscaloosa and Birmingham areas in Alabama–each claimed more than 60 lives.

The magnitude of this event resulted in the formation of a multi-agency Service Assessment Team 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 vision for a Weather-Ready Nation and the goals of supporting the development of hazard-aware communities, the team was also tasked to identify the societal impacts of NWS products and services. The team investigated possible reasons for the large loss of life during this event.

Significant tornado events impacted portions of the southeast United States on April 15, and the St. Louis metropolitan area on April 22. A devastating tornado struck Joplin, MO on May 22. The National Weather Service conducted service reviews following each of these events. The NWS regional reviews of the *North Carolina/South Carolina/Virginia U.S. Tornado Outbreak*, led by Mickey Brown (NWS Eastern Region Deputy Director), and the *St. Louis Metropolitan Area Tornado Event*, led by Rick Shanklin (Warning Coordination Meteorologist, NWS WFO Paducah, KY), are included in this service assessment as appendices. The regional review for the *Joplin, Missouri, Tornado – May 22, 2011*, led by Richard Wagenmaker (Meteorologist in Charge, NWS WFO Detroit, MI), was publicly released in September 2011 and not included in this document.

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; 2) enhancing collaboration with local, state, and federal preparedness partners; and 3) increasing public education and awareness regarding issues associated with tornado safety. The ultimate goal is to help the National Weather Service meet its mission to protect lives and property and enhance the national economy.

for Laura K Furgione

John L. Hayes
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Executive Summary

On April 27, 2011, a series of devastating tornadoes struck the southeastern United States. This tornado event was one of the deadliest in the country since systematic tornado record keeping began in 1950. With 316 fatalities (31 in Mississippi, 234 in Alabama, 32 in Tennessee, 15 in Georgia, and 4 in Virginia), it ranks with the 1974 Super Tornado Outbreak and resulted in more deaths than the 1965 Palm Sunday Outbreak. In addition, there were more than 2,400 injuries. Damages from this outbreak totaled over $4.2 billion.

The National Weather Service (NWS) formed a Service Assessment Team to evaluate its performance. To strengthen NWS relationships with other federal agencies involved with disaster work, for the first time this assessment had a co-leader from the Federal Emergency Management Agency. The team interviewed staff and reviewed products from the Storm Prediction Center (SPC), Weather Forecast Offices at Memphis and Morristown, TN, Jackson, MS, Huntsville and Birmingham, AL, and Peachtree City, GA. The team gathered feedback from partners and users of NWS products including media outlets, Emergency Managers at the state and local level, first responders, and the public. One of the team's tasks was to assess societal impacts of this event.

This tornado outbreak was anticipated and forecast days in advance. The SPC began focusing on the affected area in its convective outlook products 5 days prior to the event. It continued emphasizing, refining, and enhancing the threat leading up to the event, ultimately issuing a high risk convective outlook on the morning of April 27 for a large portion of the impacted area.

The Weather Forecast Offices (WFO) in the affected area prepared for severe weather operations and indicated the risk of severe weather and tornadoes as much as 5 days in advance. Hazardous Weather Outlooks, Web images, pre-recorded multimedia briefings, and webinars discussed the potential impacts. Emergency Managers and media staff interviewed indicated they were well prepared for the severe weather that occurred.

All tornado fatalities occurred within the boundaries of tornado watches and were preceded by tornado warnings. There were several tornado watches issued in the afternoon before severe weather began. The lead time, the time from the initial three watch issuances to the first tornadoes in those watches, averaged 2.4 hours. Watch lead times to the first significant tornado in each area ranged from 3-6 hours. The mean lead time for tornado warnings in the assessment area was 22.1 minutes. The probability of detection was 89 percent and the false alarm ratio was 49 percent.

Despite the excellent performance of the SPC and WFO staff, the tornadoes resulted in a substantial death toll. Contributing factors to the high number of casualties included:

- A large number of rare, long-track, violent tornadoes
- Tornado tracks intersecting densely populated areas
- Damage to warning dissemination sources
- Individuals in the affected areas who did not respond to warnings until confirmed by

more than one communication source

- People in the paths of the storms who waited for visual confirmation before taking protective action
- The rapid pace of the storms, which moved at 45-70 mph, giving people who waited for secondary confirmation a smaller window of time in which to take shelter
- Residences that did not have adequate storm shelters

So many deaths resulting from an event in which the NWS performed well suggested that societal and sociological factors regarding warning response played a role. To address this, the NWS included four social scientists on the assessment team: one each from NWS, the Centers for Disease Control and Prevention, the University of Northern Alabama, and the University of Delaware. This team had the largest number of social scientists ever included on a Service Assessment, reflecting the depth of sociological information in this report. Appendix C describes procedures for data collection and assessment methodologies employed by the social scientists.

The team determined that WFOs and state and local emergency management had developed excellent relationships. The team also found opportunities for improved use of NWS products and services in planning and training for natural hazards.

There were several success stories during this event. The relationships fostered by WFOs with their media and emergency management partners allowed for efficient exchange of information before and during the tornadoes. WFOs in impacted areas used webinars, multimedia presentations, Web graphics, and social media services to disseminate information to key partners and the public. Emergency management and media partners unanimously praised these decision support services. Members of the public who heeded the warnings and took cover in underground storm shelters survived the most violent tornadoes.

The team submitted 24 recommendations to address NWS performance, safety, and outreach programs. In addition, the team identified 14 best practices. Appendix B offers definitions of facts, findings, recommendations, and best practices followed by a complete listing of findings, recommendations, and best practices found in the main body of the report. Appendices D and E contain summaries of the tornado events that impacted the St. Louis metropolitan area and North Carolina/South Carolina/Virginia, respectively.

Service Assessment Report

1. Introduction

1.1. NWS Mission

The National Weather Service (NWS) provides 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. NWS data and products form a national information database and infrastructure, which can be used by other governmental agencies, the private sector, the public, and the global community.

1.2. Purpose of Assessment Report

The NWS conducts Service Assessments of significant weather-related events that result in multiple fatalities, numerous injuries requiring hospitalization, significant impact on the economy of a large area or population, extensive national public interest or media coverage, or an unusual level of attention to NWS operations (performance of systems or adequacy of warnings, watches, and forecasts) by media, the emergency management community, or elected officials. Service Assessments evaluate the NWS performance and ensure the effectiveness of NWS products and services in meeting our 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.

This document presents findings and recommendations resulting from the evaluation of NWS performance during the tornado event on Wednesday, April 27, 2011, in central and northern Mississippi, central and northern Alabama, southern and eastern Tennessee, and northern Georgia. The tornadoes resulted in 316 fatalities, thousands of injuries, and billions of dollars in damage.

The objectives of this assessment are to identify significant findings and issue recommendations and best practices related to the following key areas:

- Timeliness, quality, accuracy, and usefulness of NWS forecasts and warnings
- Effectiveness of NWS internal and external coordination and collaboration
- Effectiveness of forecasting and warning procedures at NWS offices
- Identification and evaluation of opportunities for improved collaboration among federal, state, and local agencies

1.3. Methodology

The NWS formed an assessment team on April 29, 2011, consisting of employees from NWS field offices, the Office of Climate, Water, and Weather Services (OCWWS) in NWS Headquarters (NWSHQ), the NWS Warning Decision Training Branch, and four members of the social science community. The 13-member team completed the following:

- Performed on-scene evaluations from May 6-12, 2011
- Conducted interviews with staff from WFOs in Peachtree City, Georgia; Birmingham and Huntsville, Alabama; Morristown and Memphis, Tennessee; and Jackson, MS; and with the Storm Prediction Center (SPC) and Hydrometeorological Prediction Center (HPC),

which had primary responsibility for providing forecasts, warnings and decision support to the residents and Emergency Managers (EM) of the affected areas

- Interviewed EMs, the media, and the public, as well as other government agency representatives and assessed the damaged areas
- Evaluated products and services issued by the WFOs, SPC, and HPC.
- Agreed on significant findings and recommendations to improve the 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 published for public review.

2. Summary of Tornadoes and Damages

The April 27, 2011, tornado outbreak was the peak of a 4-day episode of significant severe weather that impacted the southern plains and southeastern United States. Six WFOs were primarily affected: Memphis, TN (MEG), Jackson, MS (JAN), Huntsville, AL (HUN), Birmingham, AL (BMX), Morristown, TN (MRX), and Peachtree City (Atlanta), GA (FFC). The event was one of deadliest tornado events since formal record keeping began in 1950. A total of 316 fatalities resulted (31 in Mississippi, 234 in Alabama, 32 in Tennessee, 15 in Georgia, and 4 in Virginia). In addition, there were more than 2,400 injuries. Damages from this outbreak totaled over $4.2 billion.

Nationwide, 199 tornadoes developed across 14 states on April 27. Storm survey teams confirmed a total of 122 tornadoes from the afternoon and evening of April 27 in the County Warning Areas (CWA) of the offices listed above, (referred to in this report as the "assessment area"). Of the 316 deaths reported, 313 were associated with the afternoon/evening tornadoes. In all, 31 of these tornadoes were rated as EF3 or stronger. Eleven tornadoes were rated EF4 and four were rated EF5. The average EF4 and EF5 tornado path length was 66 miles. A map of the tornado tracks is shown in **Figure 1**.

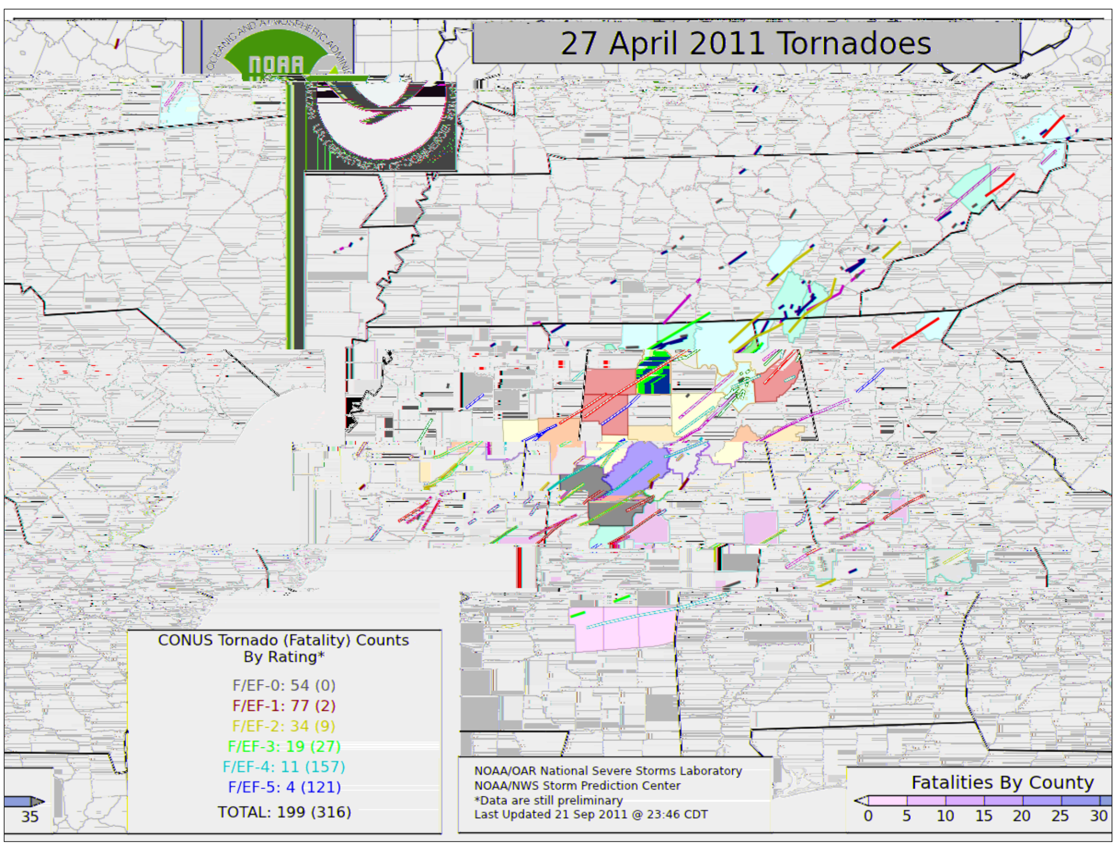


Figure 1: Tornado tracks from the April 27, 2011, tornado outbreak. Tornado reports are from 12 a.m. April 27 through 12 a.m. April 28.

A round of severe thunderstorms moved through the western and central portions of the assessment area in the pre-dawn hours of April 27 (**Figure 2**). In its own right, this was a notable tornado event. The early morning storms produced over two dozen tornadoes, with 3 tornado-caused fatalities and more than 40 injuries. Widespread damage occurred across central and northern Mississippi, central and northern Alabama, and southern middle Tennessee. The morning storms caused power outages affecting not only the public, but also several NOAA Weather Radio All Hazards (NWR) transmitters. In some of these areas, power was not restored by the time the more significant afternoon/evening storms moved through the area.

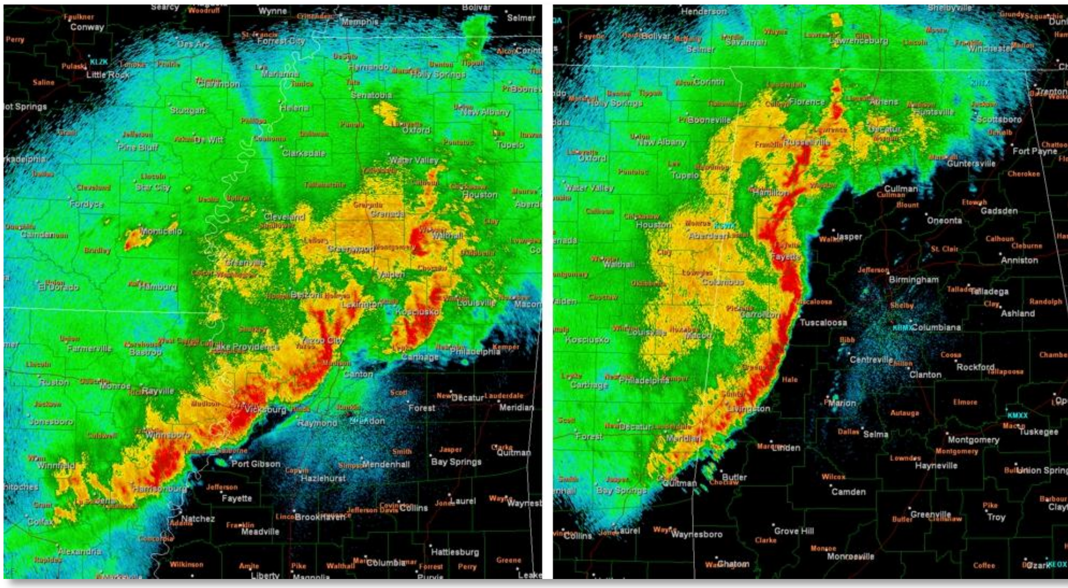


Figure 2: Radar images of early morning storm complex: left, Jackson, MS; right, Birmingham, AL, 4:59 a.m. Central Daylight Time (CDT), April 27, 2011.

Tornadoes on April 27 resulted in 316 deaths. Of these, 313 occurred with storms in the afternoon and evening. **Table 1** shows the five deadliest tornadoes of the outbreak. Note that these five were responsible for 208 fatalities. In addition to being violent, these tornadoes moved through several densely populated areas. Damage was enormous; preliminary estimates are in excess of $4.2 billion.

Table 1: Statistics associated with the five deadliest tornadoes of the April 27 outbreak

Time (CST)	Counties	EF-Scale	Fatalities
2:20 – 4:00 p.m.	Marion, Franklin, Lawrence, Limestone, Madison AL	5	72
3:50 – 4:45 p.m.	Tuscaloosa, Jefferson AL	4	66
6:19 – 6:56 p.m.	DeKalb, AL	5	26
2:45 – 3:00 p.m.	Monroe MS, Marion AL	5	23
5:30 – 6:00 p.m.	St. Clair, Calhoun AL	4	21

3. Summary of Meteorological Conditions

An active multi-day spring severe weather event in the southern Plains and southeastern

United States was most intense on April 27. The last of several upper-level storms moved east out of the southern Rockies. The air associated with this upper storm was colder than the previous systems, which led to rapid destabilization of the atmosphere in the early morning hours. An unusually strong surface low-pressure system formed in western Arkansas as the upper-level storm approached (**Figure 3**). As this low formed in the morning, southerly winds increased dramatically in the lower portion of the atmosphere, from around 15 mph at the surface to 45 mph approximately 3,000 feet above ground level. The change of wind direction and speed with height, known as vertical wind shear, helped create highly organized storms that could develop strong rotation in the lower and mid-levels. The approaching upper-level storm brought strong westerly winds at high altitudes, helping ensure that long-lived thunderstorms would occur.

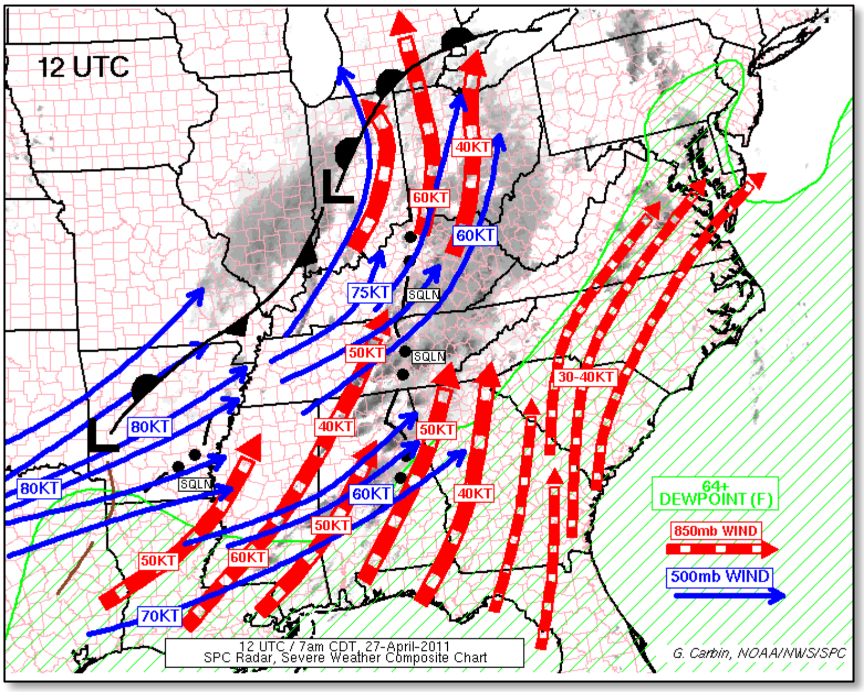


Figure 3: Composite weather analysis for 1200 Coordinated Universal Time (UTC) (7 a.m. CDT), April 27, 2011 (courtesy of Greg Carbin, SPC)

In the pre-dawn hours of April 27, a line of severe thunderstorms developed in central Mississippi and moved through western and central Alabama (**Figure 4**). In the wake of the morning storms, the strong low-level jet quickly restored rich low-level moisture helping to rapidly destabilize the atmosphere. In addition, an outflow boundary was left behind in northern Mississippi and Alabama that helped provide a focus for another round of severe storms in the late morning. Farther south, weak downward motion in the atmosphere allowed for near-maximum sunshine and heating of the low-level air (**Figure 5**).

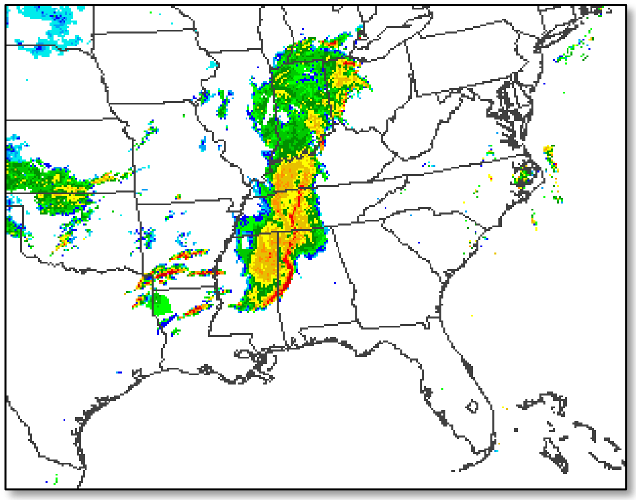


Figure 4: Radar mosaic from 1130 UTC (6:30 a.m. CDT), April 27, 2011

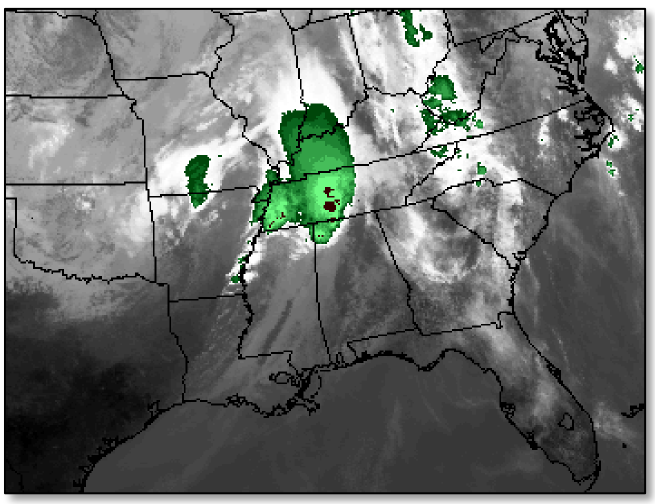


Figure 5: Shown is infrared satellite image from 1615 UTC (11:15 a.m. CDT), April 27, 2011. The dark shades over the assessment area indicate little significant cloud cover.

Figure 6 shows the composite weather map from the evening of April 27. As the upper level system approached, the destabilization of the atmosphere described above occurred. The vertical wind shear increased even further, with wind speeds ranging from 20 mph at the surface to 70 mph approximately 3,000 feet above ground level. This meant an extraordinarily high potential for strong low-level rotation in the storms. Winds increased to more than 100 mph at 34,000 feet, which ensured that developing storms would be very long-lived. These exceptionally favorable ingredients would be present over much of the southeastern United States through the day and evening of Wednesday, April 27, suggesting that a large number of long-lived supercell thunderstorms capable of producing violent tornadoes were likely.

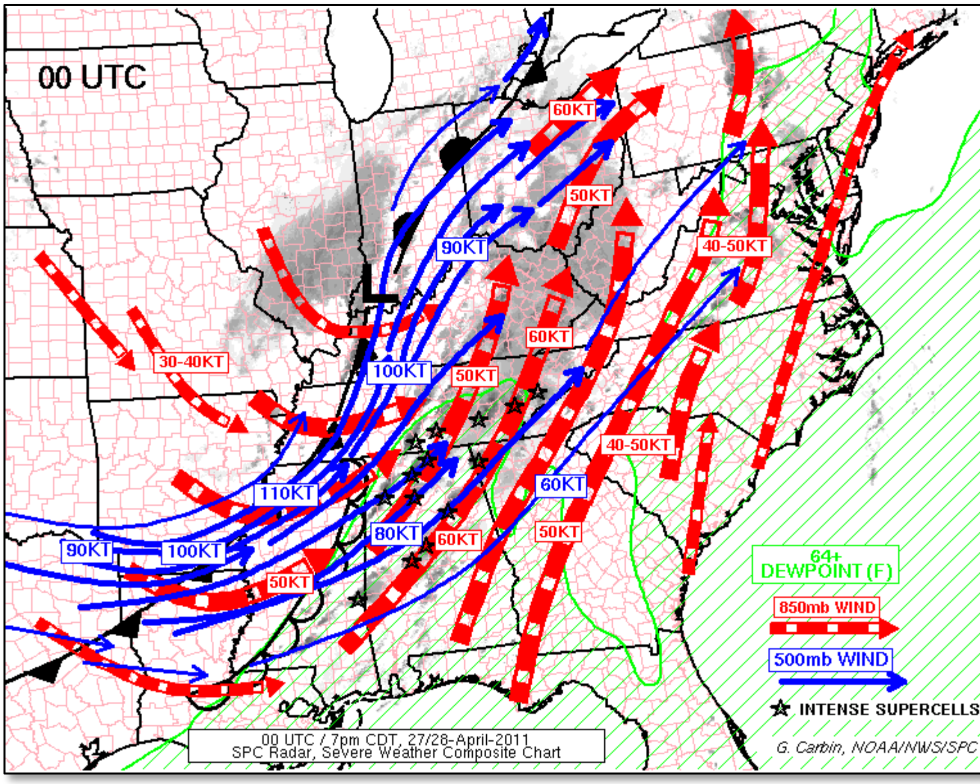


Figure 6: Composite weather analysis from 0000 UTC, April 28 (7:00 p.m. CDT, April 27) (courtesy of Greg Carbin, SPC)

4. Facts, Findings, Recommendations, and Best Practices

4.1.1. Pre-Season Awareness Activities

All WFOs in the assessment area performed aggressive pre-season preparedness activities. These activities included:

4.1.2. Severe Weather Awareness Weeks

All of the state governments, in concert with the NWS, observed Severe Weather Awareness Weeks in February. During these weeks, additional outreach to the media and the public emphasized severe hazards and NWS products and services. EMs participated and distributed NWS brochures.

In addition to the standard NWS brochures, several WFOs prepared and distributed their own preparedness material. Led by WFO Nashville, the Tennessee offices produced and distributed a severe weather awareness brochure. WFO BMX worked with the Alabama WFOs and partners to develop a hazardous weather booklet. WFO JAN led a similar project in Mississippi. All of the publications covered weather hazards, such as tornadoes, lightning, and flooding, and provided safety tips for each of the hazards. The brochures helped localize the severe weather threats for each area. The WFOs provided copies of the publication to EMs and media partners.

Finding 1: Several EMs and media representatives stated the growing number of weather awareness weeks (e.g., flood, lightning, fire) were diluting the messages and causing the events to lose their effectiveness.

Recommendation 1: OCWWS and NWS Regions should collaborate with key local partners to review the number of awareness weeks and determine if they should be consolidated into fewer, higher-impact events.

4.1.3. Media Outreach

WFOs had pre-established, strong relationships with their respective media markets. Activities included visits to television stations and joint public outreach gatherings (e.g., NWR programming clinics) and media workshops.

4.1.4. SKYWARN® Spotter Training

SKYWARN training is conducted by each office in its CWA. WFOs HUN, BMX, JAN, and MRX begin their SKYWARN training in January or February, conducting up to two dozen training sessions in which several hundred spotters are trained each year. This training is usually provided once every other year, in a particular county, and is sponsored through county emergency management agencies. WFO MEG stated it conducts spotter training classes when requested by local officials. WFO FFC generally clusters several adjacent counties into one training session on an as-requested basis; however, this training is not provided uniformly to all counties.

Conducting sufficient spotter training classes can be a challenge in a large CWA, especially if the spotter training visits are not combined with other outreach activities for maximum efficiency, such as EM coordination, media visits, school preparedness talks, etc. The NWS has recently developed an introductory online spotter training course, and the NWS has access to remote video conferencing capability. These options make spotter training more feasible for remote or sparsely populated areas.

Finding 2: Several counties in the assessment area had no organized spotter or storm reporting networks and had received no spotter training in at least 2 years.

Recommendation 2: WFOs should arrange to provide storm spotter training classes for each of their counties at least every other year.

4.1.5. StormReady® Program

All counties in the WFO HUN CWA and the University of Alabama at Huntsville are StormReady, as are roughly two-thirds (24 of 37) of the counties in the WFO MRX CWA and the University of Tennessee. Over a third (36 of 97) of the counties in the WFO FFC CWA are StormReady. The consensus of partners and WFO staff was that StormReady had enhanced the public's ability to receive and react to storm warnings.

WFO BMX has been very active in the StormReady Program. The WFO has recognized 28 StormReady sites: 21 counties, 4 cities and 3 universities including the University of Alabama at Tuscaloosa. All counties where EF4 or EF5 damage occurred had achieved the StormReady designation. Local EMs mentioned the fact that being StormReady helped prepare the citizens for hazards of this nature.

As mentioned above, the University of Alabama at Tuscaloosa is a StormReady university. It has an aggressive campus-wide notification protocol, including text messaging, email, phone, electronic signage, and public address. These systems were activated on April 27, giving students and faculty opportunity to take shelter. The university's EM stated "*We use StormReady as a recruiting tool. This gives parents some peace of mind while their kids are at school*."

4.1.6. Emergency Management

All WFOs were found to have effective working relationships with their emergency management community. Outreach included visits to local emergency management offices, attending state emergency management meetings, and conducting NWS emergency management workshops. At these sessions, NWS staff offered training and presentations of new and updated NWS products and services.

As part of its pre-season awareness campaign, WFO JAN conducted its annual EM weather workshop in February. There were approximately 100 participants. WFO FFC provided 8-10 hazardous weather awareness classes for law enforcement, firefighters, and EMs at the State Public Safety Training Center. State emergency management agencies frequently included NWS employees in their Natural Hazards Exercises.

4.1.7. School Administrators

The WFOs had pre-established relationships with school administrators in their respective CWAs. These relationships facilitated effective communication during the April 27 outbreak, as noted in Section 4.10.

4.1.8. Adopt-a-County

Because WFO FFC has 96 counties in its CWA, the office fosters working relationships with EMs through an "Adopt-a-County" program. Each forecaster is assigned several counties within the CWA, and the forecaster serves as the primary WFO liaison for those counties. This program helps distribute workload among the operational staff. WFO FFC forecasters learn more about the forecast area, emergency management, and the capabilities in each county. EMs are introduced to new forecast and warning practices and are able to address forecast and dissemination concerns. The Adopt-a-County program is used by other WFOs.

4.1.9. Emergency Management Web Briefing Pages

WFOs MRX and HUN have EM Briefing pages on their Websites. Links to pertinent severe weather information (SPC outlooks, Watch, Warning, Advisory map, Hazardous Weather Outlook, radar, SKYWARN activation, etc.) are grouped together for convenience.

Best Practice: WFO BMX offered a series of pre-recorded multimedia presentations on a variety of hazardous weather-related topics. The office distributed the presentations to EMs, law enforcement, and fire agencies. Several EMs provided positive feedback on these presentations.

4.2. Situational Awareness of WFOs

WFOs in the assessment area used situational awareness displays (SAD) in their operations areas. WFO BMX has a large television that can display local stations. Another screen displays "Severe Clear," a program that allows the staff to keep abreast of the warnings in effect. The office used the Internet to monitor live streams of local storm chasers.

In addition to its SAD, WFO HUN used the University of Alabama–Huntsville's ultra-high-speed Internet connection to monitor remote media broadcasts, high-resolution radar feeds, and other data streams.

Best Practice: WFO MRX developed a local program to monitor the near-storm convective environment. The program, called "Storm Monitor," is viewable on the Advanced Weather Interactive Processing System (AWIPS) and displays 17 key parameters for more than a dozen selected points within the CWA.

WFO operations areas generally were arranged in a "bullring" format, with an open area in the center and workstations facing outward toward the walls. This design can make coordination among workstations difficult. Employees at some workstations had difficulty viewing the SAD monitors. While the assessment team recognizes that a standard layout would be impractical, the team encourages WFOs to consider other layouts to enhance intra-office communication and accessibility to SAD monitors.

WFO staff was able to verify the scope of the overall event by monitoring media sources. Television provided a valuable supplement to spotter and EM reports. Confirmation of tornadoes came quickly through television and Internet news sites. WFO MRX staff stated it was not able to monitor television broadcasts from Chattanooga and was not immediately aware of the scope of tornado damage in that area.

Finding 3: WFO MRX was unable to monitor local media broadcasts from Chattanooga. This impacted the staff's situational awareness regarding the violence of the unfolding event. WFO JAN employees faced a similar situation with storms in the Meridian, MS area. At least 20 WFOs have TV markets in their CWAs that cannot be viewed at the WFO.

Recommendation 3: NWS should provide WFOs with the equipment and bandwidth to monitor television outlets in their CWAs but outside of their local media markets.

NWR is an important tool for automated warning dissemination. When numerous warnings are issued and other activities (e.g., spotter contacts, partner briefings) must be done, it can be difficult for WFO staff to ensure that all warnings are properly broadcast on NWR.

Best Practice: WFOs FFC and JAN used online monitors to verify that warnings were broadcast successfully on NWR.

Reports of major storm damage in sparsely populated areas or after dark sometimes received delayed coverage by television and Internet sources. To aid in more timely awareness of damage, WFO FFC used an online system to monitor 911 dispatches. The staff stated this service was very useful in improving their situational awareness.

Best Practice: WFO FFC used a 911 tap to monitor reports coming into the 911 centers, thus receiving real-time notification of emergency dispatches.

4.3. Internal WFO Operations and Planning

As recommended in the *Super Tuesday Tornado Outbreak of February 5-6, 2008*, and the *Greater Nashville Record Floods: May 1-4, 2010,* Service Assessments, WFOs made extensive use of severe weather operations plans before and during the event. WFOs in the assessment area created staffing plans several days before the event and, in some cases, pre-determined their duty assignments. The WFOs also kept Information Technology Officers (ITO), Electronics Technicians (ET), and/or Electronics Systems Analysts (ESA) on station to provide immediate technical support. WFO HUN adopted an "All Hands on Deck" philosophy, with the ITO working the communications desk and the ESA assisting with various duties in the operations area. WFO MRX used a similar philosophy; their ITO helped answer phones and assisted the forecasters for several hours during the event. This paradigm was a first for the office.

The WFOs made extensive use of event coordinators during warning operations. The coordinators kept the operations focused, reviewed staffing levels, and evaluated fatigue among the warning forecasters.

Fact: At affected WFOs, event coordinators kept the operations focused, reviewed staffing levels, evaluated fatigue among warning forecasters, and periodically rotated staff members to different positions in the office.

WFOs HUN and BMX used a buddy system at their warning workstations, with primary and secondary warning forecasters. The second forecaster served as an extra pair of eyes; the forecasters monitored each other for fatigue. WFO HUN incorporated the role of Public Information Officer (PIO) into its operations to help coordinate the constant stream of media requests during and after the outbreak.

WFO BMX initially began the warning process in a two-team sectorized configuration; however, as the event unfolded, situational awareness determined the need for a third team. These teams focused on specific areas and provided rapid updates on tornado location, movement, and damage.

Fact: WFOs successfully divided warning responsibilities among multiple forecasters. The WFOs defined warning sectors using both geography and hazard type, and adjusted sectors as the situation unfolded.

Enhanced staff planning did not end after the event. Affected offices developed survey plans for the following day. The plans ensured there were sufficient staff for operations and storm surveys, and that contact information was readily available. WFO management provided the plans to employees via status boards, and to external partners via Public Information Statements.

Staff put in a tremendous effort to provide a full suite of products and services during this event. On April 27, WFOs in the assessment area logged a total of 350 hours of overtime. Post-event activities from April 28 to April 30 required an additional 978 hours of overtime. The extra work time, and the stress associated with the tornado event, took an emotional toll on the staff. Details are described in Section 4.12.

4.4. Key Operational Systems

The widespread nature of the tornado outbreak led to significant disruptions in power and communications infrastructure.

4.4.1. Weather Surveillance Radar - 1988 Doppler (WSR-88D)

On the night of April 26, the Morristown, TN, WSR 88D Doppler weather radar (KMRX) suffered an oil pump failure. The ET staff worked through the night and successfully repaired KMRX, which was operational through the event.

Two WSR-88Ds malfunctioned during the event. The WSR-88D Doppler weather radar in Birmingham, AL (KBMX) went down, but WFO BMX ETs, as part of the severe weather operations team, restored the radar after approximately 10 minutes.

The WSR-88D Doppler weather radar near Hytop, AL (KHTX) suffered a communications failure at 5:15 p.m. CDT, as a result of the widespread infrastructure damage in the area. The communications outage lasted through the remainder of the event. The closest WSR-88D to KHTX is the Nashville, TN radar, 82 nautical miles (94 miles) to the north-northwest. Other neighboring radars were more than 87 nautical miles (100 miles) away. This outage had a significant impact on the warning operations at WFOs HUN, MRX, and FFC, and affected the Chattanooga-area media's ability to broadcast precise information regarding tornado threat locations.

Finding 4: There was no redundancy along a portion of the fiber-optic communications link between the KHTX radar and WFO HUN. This means there is no access to these radar data when the fiber-optic communications link is down.

Recommendation 4: NWS should ensure alternative methods of data delivery to the WFOs from all remote radars.

4.4.2. Backup Operations

When WFOs HUN and BMX were threatened by tornadoes, both offices required service backup as staff took shelter. WFO JAN provided backup for WFO HUN and issued a warning on WFO HUN's behalf. WFO FFC, the primary backup for WFO BMX, had problems displaying low-level, super-resolution radar data from the KBMX radar and could not assume backup. WFO HUN was then asked to provide secondary backup, but this affected WFO HUN's operations due to the level of its own severe weather threat and operations. The Network Control Facility (NCF) quickly resolved the WFO FFC radar issue, allowing WFO FFC to back up WFO BMX. WFO FFC issued a warning on WFO BMX's behalf.

Finding 5: Required service backup for WFO BMX was difficult for other WFOs to provide because of equipment issues at the primary backup WFO and weather threats at the secondary backup WFO.

Recommendation 5: NWS should review its current plans for tertiary backup sites. Whenever possible, tertiary sites should be far enough from affected offices so they are not impacted by the same weather event.

4.4.3. AWIPS

Many WFOs regularly use non-baseline AWIPS (NA) workstations during warning operations. Typically, WFOs have five or six standard AWIPS workstations that are fully supported by NWS regional and national headquarters. The NA workstations often are purchased with local WFO funds based on office needs. NA workstations do not receive information technology support from AWIPS NCF and must be maintained by local WFO staff.

Fact: The number of NA workstations varies widely among WFOs.

In interviews with the assessment team, WFO FFC staff stated that it has three NA workstations available during severe weather outbreaks. The WFO FFC Meteorologist in Charge (MIC) said, "*We could not have done the WFO Birmingham backup without those [NA] workstations.*" The WFO HUN MIC told the assessment team that, although available space would be a concern, an NA workstation in operations would have been extremely helpful when asked to back up WFO Birmingham. Similar statements were made during the *Super Tuesday Tornado Outbreak of February 5-6, 2008,* Service Assessment, in which advantages of having an additional workstation were discussed.

Finding 6: As discussed in the *Super Tuesday Tornado Outbreak of February 5-6, 2008,* Service Assessment, the varying number of AWIPS workstations in WFOs resulted in corresponding effectiveness in sectorizing and providing service backup.

Recommendation 6: NWS should re-evaluate the number of baseline/supported workstations at WFOs, to ensure a sufficient number for hazardous weather operations, impact-based decision support, and backup needs.

4.4.4. NWR

NWR transmissions suffered significant impacts from storm damage, power failures, and communications outages. **Table 2** below summarizes these impacts.

Table 2: Details associated with NWR outages in the assessment area.

Transmitter	Time of Outage	Time Restored	Reason for Outage
Florence (HUN)	4/27, 6:44 a.m.	4/29, 8:00 a.m.	Power outage, generator failed
Winfield (BMX)	4/27, 8:23 a.m.	4/27, 5:50 p.m.	Communications failure
Cullman (HUN)	4/27, 2:45 p.m.	5/5 (temporary tower)	Struck by tornado (**Figure 7**), temporary tower set up
Huntsville (HUN)	4/27, 5:15 p.m.	5/3	Power outage, switched to generator, communications failure
Winchester (HUN)	4/27, 5:25 p.m.	5/1	Power outage, switched to generator, communications failure
Fort Payne (HUN)	4/27, 6:30 p.m.	5/1	Power outage

Figure 7: Destroyed NWR transmitter tower at Cullman, AL (courtesy of WFO Huntsville, AL)

The early morning round of severe storms caused initial infrastructure damage, not all of which was repaired in time for the afternoon/evening event. The afternoon storms caused additional damage. In all, more than 100 high-tension power transmission line towers were destroyed, most across northern Alabama. Cell phone and radio towers also were damaged or destroyed, hindering warning dissemination and limiting communications in the days after the tornadoes. The impacts of the outages were widespread and unprecedented, requiring local EMs to take extreme measures to keep critical services operational. For example, one county EM had to take time away from his Emergency Operations Center duties to retrieve a portable generator from his home and connect it to the county's emergency communications tower.

Finding 7: Destruction of communication lines between WFOs and their NWR sites prevented dissemination of weather information, even at towers where backup power was available.

Recommendation 7: NWS should ensure the Weather Radio Improvement Project includes backup NWR capabilities that do not rely on local or regional power or communications infrastructure.

4.5. WFO Tornado Products and Services

On April 27, the six WFOs in the assessment area issued 303 separate tornado warnings. Based on preliminary statistics, the probability of detection (POD), defined as the percentage of warned tornado events divided by the total number of tornado events, was 0.889. In other words, nearly 9 out of every 10 tornado events were covered by warnings. The false alarm ratio (FAR), defined as the number of unverified tornado warnings divided by the total number of tornado warnings, was 0.489. Initial lead time, defined as the time between warning issuance and tornado event occurrence, was 19.9 minutes. Mean lead time was 22.1 minutes. Mean lead time takes into account the full duration of the tornado event, calculated by averaging the lead times for each minute the tornado is on the ground.

Fact: WFOs in the assessment area issued a large number of tornado warnings. The warning verification statistics exceeded the NWS goals for POD, FAR, and lead time.

Tornado warnings and follow-up statements usually included an appropriate list of locations in the warning area; however, there were some exceptions where Warngen, the warning-generation software used by WFOs, omitted the largest locations in a warning polygon from the list. A Tornado Warning by WFO FFC at 9:31 p.m. EDT, April 28 stated, "*Local law enforcement reported a tornado 20 miles southwest of Talking Rock.*" Talking Rock, however, was not mentioned in the locations list, presumably because the bullet was titled, "Other locations in the warning include..." A Tornado Warning issued 2:43 p.m. CDT, for northern Cullman County, Alabama, positioned a tornado 15 miles southwest of Cullman; however, the locations list did not mention Cullman, nor did it contain the "*Other locations in the warning include...*" segment.

Finding 8: The text of several tornado and severe thunderstorm warnings did not contain the largest towns within the warning polygon, even when the towns were used as reference points in previous bullets. These omissions made it more difficult for users to locate the most dangerous parts of the storms.

Recommendation 8: WFOs should review their AWIPS location databases and ensure the largest communities in their counties have the highest priority for selection by Warngen.

The Warngen database contains a list of locations to include in warnings; however, the database does not differentiate between large and small locations. When cities are included in warnings, the whole city is listed, rather than specific sites.

Best Practice: In the warning immediately prior to the tornado striking Tuscaloosa, WFO BMX added to the list of locations to be impacted the McFarland Mall, Bryant-Denny Stadium, and Deerlick Creek Campgrounds. WFO HUN included the Redstone Arsenal in numerous warnings.

In their warnings and statements, WFOs generally used “locations in the warning” listings more frequently than pathcasts. Of the offices in the assessment area, WFOs JAN, MRX, and BMX used pathcasts most often. The pathcasts were generally accurate at specifying locations and expected arrival times. The WFOs issued frequent follow-up statements to keep the pathcasts current. There were a couple of problems, however. A Tornado Warning issued at 6:39 p.m. EDT, by WFO MRX, contained a pathcast naming three locations to be affected through 6:55 p.m. EDT. The next statement, however, was not issued until 7:00 p.m. EDT, resulting in a 5-minute period with no valid pathcast information. Another Tornado Warning issued by WFO BMX, at 4:15 p.m. CDT, contained a pathcast for a supercell in western Tuscaloosa County. A new supercell, however, formed within the warning polygon. With two threats in one polygon, pathcasts became difficult to manage.

The “Tornado Emergency” wording in warnings and follow-up statements was used during the event, but its use was not consistent among WFOs or from one product to another. Some WFOs used “Tornado Emergency” for the entire area in a warning polygon, while others focused on the communities within the storm’s path. WFO JAN stated that population centers could experience significant casualties regardless of their exact population and thus employed “Tornado Emergency” more often. Another issue was the inclusion of “Tornado Emergency” in follow-up severe weather statements, when it was not in initial warnings.

Finding 9: Forecasters had differing interpretations of the instructions in NWS Directive 10-511 concerning “Tornado Emergency.” This inconsistency caused confusion among those media partners whose market areas were covered by multiple WFOs.

Recommendation 9: NWS regional headquarters should ensure that WFOs in their areas of responsibility consistently apply instructions for the application and use of “Tornado Emergency.” NWS regional headquarters should inform OCWWS of any requirements to clarify or provide more detail on the use of “Tornado Emergency” in NWS Directive 10-511.

WFOs BMX and FFC used the wording “Doppler radar indicated” for the basis of their warnings and statements; however, staff were aware that large destructive tornadoes were on the ground based on spotter reports, debris ball signatures on radar, or through visual confirmation via television **(see Figure 8)**. The assessment team echoes the findings of the *Super Tuesday Tornado Outbreak of February 5-6, 2008,* Service Assessment: Usage of generic wording may lead people in the warned area to feel the threat is not as great as it actually is.

Finding 10: Several WFOs used the generic “Doppler radar indicated” wording in their tornado warnings despite evidence of a tornado in progress.

Recommendation 10: When WFOs have ground truth reports, they should refer to them in severe weather products, rather than “Doppler radar indicated.” OCWWS and the regions should review NWS Directive 10-511 and ensure the directive supports this recommendation.

Most WFOs were impacted by multiple rounds of severe weather. For example, WFO HUN had two severe squall line events in the morning, followed by the main supercell event in the afternoon. Storms moved between 45-60 mph during the afternoon, with peak storm movements up to 75 mph.

As a result, WFO HUN forecasters had to adapt to unusually high storm speed and adjust polygons accordingly. They typically shrank the length of the polygons to minimize overlap and customer confusion. With additional rounds of storms approaching from upstream, staff would not have been able otherwise to cancel warnings early without causing confusion among partners and customers.

Best Practice: WFO HUN issued short duration (30-45 minutes) tornado warnings for relatively small areas because of fast-moving storms. This enabled the WFO staff to provide focused products and frequent updates.

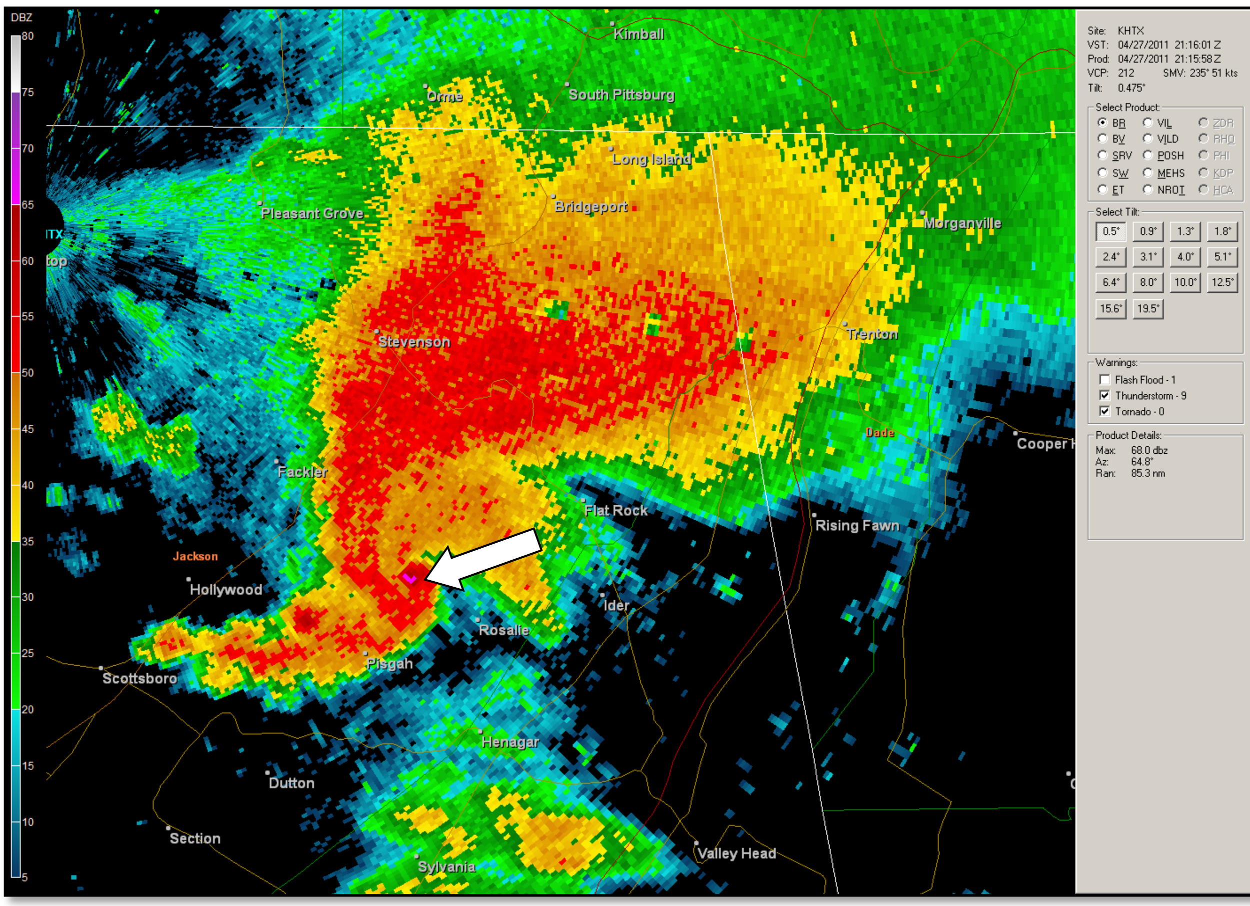


Figure 8: Depicted above is a radar image of a tornadic storm in northeastern Alabama. The stronger return in the tip of the hook-shaped echo is a "debris ball" signature (denoted by white arrow) caused by debris being lifted by a tornado.

Best Practice: WFO BMX issued new severe weather statements approximately every 10 minutes during tornado warning valid periods because of the rapidly-evolving situation. While this required considerable work, it resulted in consistent, fresh information for partners and customers.

Fact: Initially, WFO FFC issued a severe thunderstorm warning (SVR) and tornado warning (TOR) for each storm, the TOR for the circulation portion and the SVR for the hail core. The goal was to produce phenomenon-specific warnings for the tornadic and non-tornadic threat areas. Eventually, the workload became too great. WFO FFC then issued TORs for the entire storm, including hail cores, and manually removed locations they judged not to be in the highest tornado threat areas.

Reports from SKYWARN Spotters and amateur radio operators were an integral part of the warning decision process. The NWS and the Amateur Radio Relay League (ARRL) recently updated their Memorandum of Understanding. WFO MRX noted that amateur radio operators logged almost 12 hours at the office on Wednesday, April 27. The team appreciates the efforts of these dedicated individuals. The NWS is grateful for their invaluable support.

4.6. Products and Services by SPC

Products from SPC began mentioning the possibility of a significant severe weather event 5 days in advance. The Day 4-8 Thunderstorm Outlook on Saturday, April 23, stated that on Wednesday, April 27, "*widespread severe weather can be expected…including the potential for tornadoes*." The outlook on Sunday, April 24, contained similar wording.

Fact: SPC accurately forecast the Wednesday, April 27, outbreak in its severe weather outlooks beginning 5 days before the event.

The Day 3 Thunderstorm Outlook on Monday, April 25, featured a moderate risk for severe thunderstorms from central Alabama northward to central Kentucky. The outlook noted a "*concentrated significant threat for potentially strong tornadoes and widespread wind damage centered over the mid-South/Tennessee valley region…indicative of outbreak potential.*"

The Day 2 outlooks on Tuesday, April 26, continued to mention a moderate risk. The early morning outlook's moderate risk area extended from central Alabama to northern Kentucky and was expanded northward to northeastern Ohio at midday. The early morning discussion mentioned the possibility of a tornado outbreak, and the midday update discussed potential for a major severe weather outbreak with strong tornadoes. The SPC forecasters considered designating a high-risk area, but were uncertain about how the early morning storms would affect the afternoon environment.

The Day 1 outlooks contained an upgrade to a high risk for severe thunderstorms for northeastern Mississippi, central and northern Alabama, southeastern Tennessee, and northeastern Georgia. **Figure 9** shows the midmorning categorical outlook and **Figure 10** shows the probability of tornadoes within 25 miles of a particular location. Note that the high-risk area correlates well with the strong and violent tornado tracks shown in **Figure 1**. The 30 percent chance of tornadoes in the morning outlook, with an upgrade to 45 percent on the midday update, is particularly noteworthy.

The outlook discussions continued to contain strong wording. The discussions contained the phrases "*fast-moving supercells capable of strong to violent tornadoes*," "*long-track supercells* *capable of intense/damaging tornadoes*," and "*a tornado outbreak is expected*." Public Severe Weather Outlook products issued early morning and midday highlighted the threat areas and expected conditions using plain-language wording.

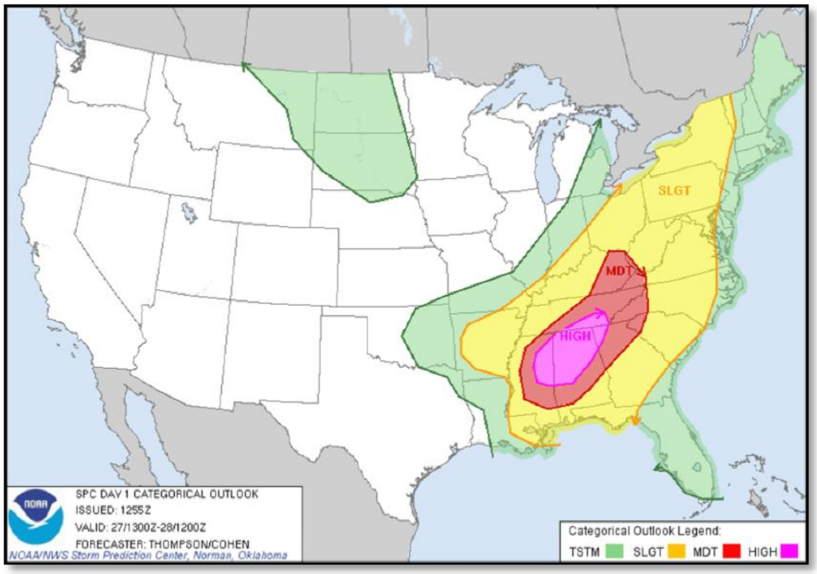


Figure 9: SPC Day One Severe Weather Outlook issued at 1255 UTC, 7:55 a.m. CDT, April 27

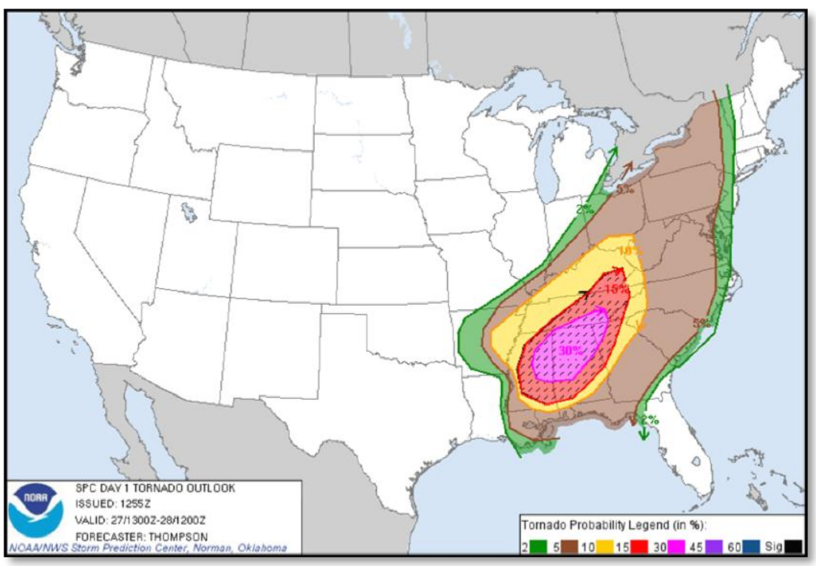


Figure 10: SPC tornado probability forecast issued at 1255 UTC, 7:55 a.m. CDT, April 27

From 8:30 a.m. through midnight on April 27, SPC issued 16 tornado watches and 2 severe thunderstorm watches. Four of the tornado watches contained the "Particularly Dangerous Situation" (PDS) wording reserved for an elevated chance of destructive tornadoes. The PDS tornado watches covered Mississippi, central and northern Alabama, northwestern Georgia,

middle and eastern Tennessee, and western North and South Carolina.
Fact: As the event approached, outlooks and discussions from SPC provided increasing detail regarding the expected extent and severity of the event.

In addition to the standard products, SPC staff recorded a multimedia briefing early in the morning of April 27 and posted it on its Website. Similar to the Public Severe Weather Outlook, the multimedia briefing illustrated the areas most at risk and highlighted potential impacts.

The SPC gave weather briefings during five multi-agency conference calls between April 23 and April 27. Conference participants included FEMA National and Regional Headquarters and state emergency management agencies. The SPC Website had more than 56 million hits on April 27, and SPC staff issued a record 40 mesoscale discussions, text and graphical products describing the near-storm environment and its evolution, during the event.

Finding 11: On occasion, SPC asked WFOs to add a few counties to existing watches so SPC could avoid having to issue a new watch. The speed at which WFOs completed this task varied.

Recommendation 11: OCWWS and the NWS Regions should ensure WFOs can issue watch extensions quickly, and should consider the need for backup procedures when workload prevents the affected WFO from quickly extending watches.

4.7. Decision Support and External Communication

All EM and media partners interviewed by the assessment team felt the Decision Support Services provided by WFOs (i.e., briefings, conference calls, webinars, web graphics, pre-recorded multimedia briefings, NWSChat, emails) were very beneficial. Favorable feedback was unanimous regarding the personal relationships with WFO staff, and partners stated that these relationships instilled a high level of trust. They also stated that advance knowledge of the upcoming severe weather event aided their pre-planning processes.

4.7.1. Pre-Warning Services

On April 27, initial tornado watches were issued with a mean lead time of 2.4 hours; lead times for the major impacts were larger. The watch lead time for Ringgold, GA was over 6 hours, Smithville, MS was more than 4 hours, and Tuscaloosa's was over 3 hours. Tornado warnings were issued, on average, 22 minutes in advance of the rapidly moving storms. While there were several examples of WFOs issuing products covering the period "in between the watch and warning," (i.e., the time between watch issuance and occurrence of severe weather) their application was inconsistent across the outbreak area. As a result of this void between the watch and warning time frames, television meteorologists routinely informed the public about upstream storms that would impact their market areas within 1 to 3 hours.

The assessment team, however, noted that there was a need for other partners to have severe weather information during this "intermediate" time. The NWS has learned that partners with large or immobile populations need a more time in which to make critical decisions related to warnings: hospitals, sports arenas, shopping centers, and university campuses are examples.

Best Practice: WFO HUN issued a Special Weather Statement (**Figure 11**) on the early morning storms approximately 1 hour before they approached, giving sufficient time for partners and customers in their CWA to prepare.

```
SPECIAL WEATHER STATEMENT
NATIONAL WEATHER SERVICE HUNTSVILLE AL
331 AM CDT WED APR 27 2011

ALZ001>004-270945-
LAUDERDALE-COLBERT-FRANKLIN AL-LAWRENCE-
INCLUDING THE CITIES OF...FLORENCE...MUSCLE SHOALS...RUSSELLVILLE...
MOULTON
331 AM CDT WED APR 27 2011

...TORNADIC SUPERCELLS RAPIDLY APPROACHING NORTHWEST ALABAMA...

THE NATIONAL WEATHER SERVICE IN HUNTSVILLE IS CURRENTLY TRACKING
SEVERAL SUPERCELL THUNDERSTORMS CAPABLE OF PRODUCING STRONG
TORNADOES...DESTRUCTIVE WINDS...AND VERY LARGE HAIL. THIS ACTIVITY IS
CURRENTLY LOCATED ACROSS NORTHEASTERN MISSISSIPPI...BUT WILL IMPACT
PORTIONS OF FRANKLIN...COLBERT...AND LAUDERDALE COUNTIES BETWEEN 4
AND 430 AM CDT...IF IT MAINTAINS ITS CURRENT TRACK. PLEASE CLOSELY
MONITOR WARNING INFORMATION FROM THE NATIONAL WEATHER SERVICE IN
HUNTSVILLE...AS THIS EVENT WILL UNFOLD RAPIDLY.
```

Figure 11: Special Weather Statement issued approximately 1 hour before the approach of supercell thunderstorms

Finding 12: The NWS has limited guidelines about providing information for storms between "watch" and "warning" timeframes. More complete guidelines would enable WFOs to provide official NWS guidance to partners who must make preliminary notifications to first responders and high-vulnerability locations.

Recommendation 12: NWS should refine the guidelines in its directives to provide more explicit instructions and examples of pre-warning information on approaching severe storms. These guidelines should also be incorporated into the WFOs' Weather Event Simulator training curricula.

4.7.2. Webinars

Webinars with partners began as early as Monday, April 25, and provided an overview of forecasts, developing weather hazards, timing, and forecaster confidence in the forecast scenario. Webinar slides were emailed to participants and were described as a "*tremendous tool*" by one EM, while another stated, "*We live and die by those briefings*."

Fact: Partners gave highly positive feedback regarding WFO-led webinars. WFOs emailed the webinar briefing slides to their partners. Many partners appreciated this service and redistributed the slides to other departments and agencies. The Dekalb County, AL Assistant EM described the briefing slides as "*golden nuggets*."

WFO MRX used the OCWWS Intranet email list program to maintain their webinar distribution list, which consists of several hundred EMs and spotters. The OCWWS program enabled WFO MRX staff to quickly distribute its briefing slides.

4.7.3. Web Graphics

Web graphics constructed and posted by many WFOs are known by names such as "Graphicasts," "Weather Stories," "Weather Images," or simply "Web Images." These images are graphical representations of weather forecasts in and near the area of responsibility of WFOs. Significant weather hazards are often noted on the images, with a brief description of potential impacts and safety tips.

Before and during the April 27 outbreak, WFOs in the assessment area made aggressive use of Web images. The offices highlighted the significant severe weather threat (**Figure 12**). Some of WFO FFC's graphicasts mentioned long track tornadoes and tornado safety rules. The uniqueness of that posting raised awareness that this event was going to be significant.

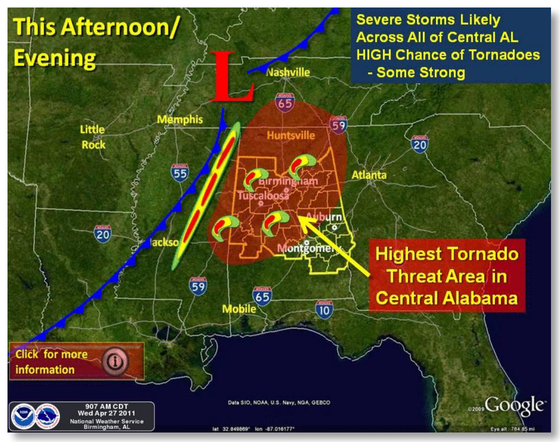


Figure 12: Pre-event Web graphics from WFOs FFC (left) and BMX (right)

Best Practice: While the outbreak was in progress, WFOs JAN and BMX prepared a series of "tactical scale" (focused on the CWA, valid for less than an hour) Web graphics that illustrated storm locations and potential impacts over the next 2-4 hours (**Figure 13**). These images kept their graphical Web presence as fresh as possible during the rapidly evolving event.

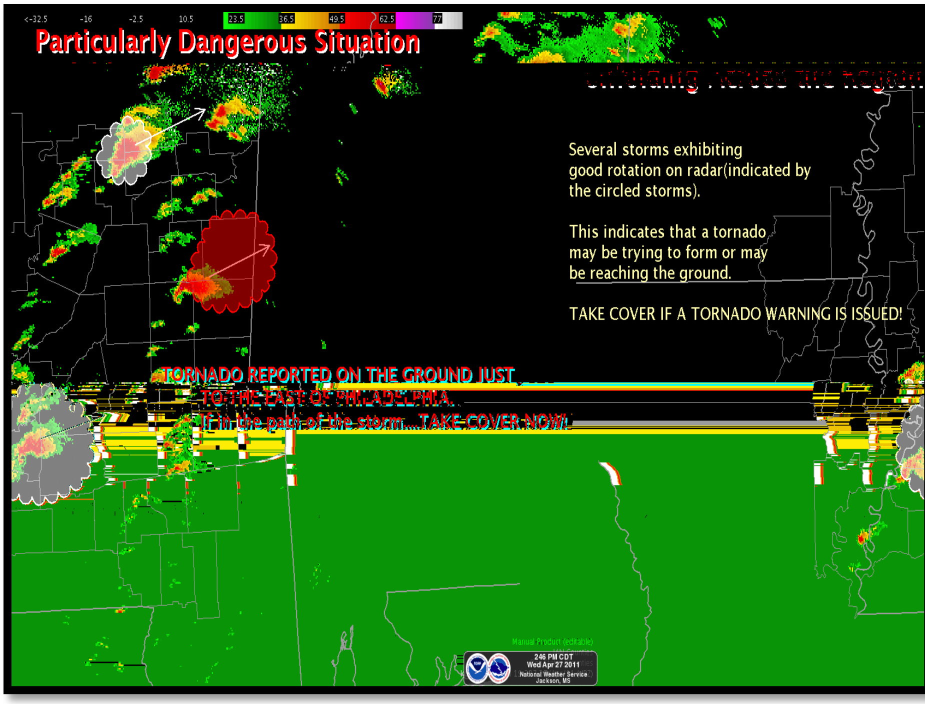


Figure 13: Tactical scale Web graphic from WFO JAN

4.7.4. Multimedia Web Briefings

Beginning as early as April 22, WFOs posted pre-recorded multimedia briefings to their Websites as a supplement to their live webinars. The briefings had content similar to the webinars described above. Partners stated they found the briefings useful. Language and information in the presentations mirrored the increasing severity of the threat. WFO BMX's briefing on the late morning of April 27 described the possibility of a "historic" outbreak of destructive tornadoes with thousands of downed trees and widespread long-term power outages expected.

Best Practice: WFO JAN published multimedia briefings in a variety of formats, including Shockwave, for its Web page, MP3 audio, and MP4 and M4V video for smartphones.

4.7.5. NWSChat

NWSChat proved to be an important tool in collaborating and distributing information, especially to the media since there are many media markets in the assessment area. Severe weather events prior to the April 27 event demonstrated the utility of NWSChat. Upon hearing of the benefits, partners signed up for NWSChat after these prior events.

WFOs BMX, ATL, and JAN have multiple chat rooms set up. One chat room is typically an open room, while other rooms are reserved for specific partner groups, e.g., hydrology partners or EMs.

Fact: Partners stated that NWSChat was an effective collaboration tool. Partners noted that WFOs BMX, JAN, HUN, and FFC had an active presence in the chat rooms covering their areas.

4.7.6. Direct Contacts and Emails

WFOs BMX and HUN regularly provided weather briefings to EMs on a statewide 800 MHz radio system before and during the event. These briefings provided vital information on timing, hazards, and potential damage that might occur. EMs noted the importance of these briefings.

The severity of this event prompted direct telephone calls and emails to EMs and school administrators. For example, during the mid-morning hours between severe episodes, the WFO HUN WCM sent an email emphasizing that additional severe thunderstorms and tornadoes were expected during the afternoon. Direct telephone briefings were given to school administrators responsible for school closings and early dismissal decisions.

Fact: County EMs stated personal calls from the WFOs helped convey the extreme severity of the approaching storms.

4.7.7. Standard Warning Products

Affected WFOs applied storm-based warning methodology in varying degrees. Some WFOs drew their warning polygons almost entirely based on the shape and motion of the main threats. Other WFOs allowed county borders to influence their warning polygons.

With the exception of the "Tornado Emergency" issues discussed in Section 4.5, all WFOs adhered to guidelines in choosing content for warnings and follow-up statements.

Best Practice: WFO JAN has an agreement with the Mississippi Highway Patrol to provide to the dispatch center a range of Interstate mile markers that are expected to be crossed by tornadoes.

Best Practice: WFO BMX used a combination of highway mile markers and exit numbers in its warnings.

4.7.8. Interactive NWS (iNWS)

Interactive NWS (iNWS) is a wireless dissemination tool for NWS hazardous weather information. iNWS allows key partners to receive NWS warnings for a user-defined area on their smartphones or other hand-held devices.

There were varying levels of iNWS usage among EMs in the affected area. Those EMs who used iNWS provided positive feedback. The Tuscaloosa EM used iNWS as part of his information toolkit. The Calhoun County, AL EM said that he *"loves iNWS"* and thinks it should be transformed into a public product. Other partners stated that they were intrigued by the potential of iNWS.

4.8. Dissemination

The peak of the Wednesday, April 27, event took place from early afternoon through the overnight hours. Therefore, television stations in the assessment area were well-positioned to cover the event. Many stations went with wall-to-wall coverage as the storms moved through their broadcast areas. The dissemination of NWS warnings and statements was supplemented by radar images, video from local storm chasers, and video from tower and traffic cameras.

As mentioned in Section 4.4.4, six NWR transmitters were impacted. These outages affected warning dissemination in areas serviced by these transmitters. In areas where NWR remained operational, EMs noted that NWR was an important means of getting information to the public. One problem partners have noted is that NWR alarms are activated on a countywide basis, while NWS warnings are issued using a storm-based polygon method. Thus, NWR warned portions of counties not covered by warnings. To compensate, EMs used other methods of warning receipt including iNWS, commercial smartphone applications, WFO Internet sites, and commercial media outlets. As will be discussed in Section 4.11.1.1, many public interviewees used multiple media sources for information, but relatively few had access to smartphone applications.

Finding 13: The public and EMs expressed confusion resulting from the inconsistency between the county-based NWR alarms and polygon-based warnings.

Recommendation 13: NWS should implement an upgrade to NWR allowing the system to broadcast warnings using a polygon-based method.

As a result of local grant programs, Franklin, Lauderdale, Lawrence, Madison, and Morgan counties in Alabama have a relatively large segment of the population that own NWR receivers. According to the deputy EM of Lawrence County, there were numerous county residents whose lives were saved because of NWR.

Numerous counties in Alabama, Georgia, and Tennessee used emergency telephone notification calling systems to notify residents when warnings were issued. The EM in Marion County, TN noted that it took 55 minutes for emergency telephone notification systems to call everyone registered in his county. Because there were multiple storms and warnings, citizens were confused by the calls.

4.9. Social Media

During the past few years, there has been increased recognition of social media and its potential as a communications tool. Social media networks have grown dramatically, with the most popular sites having subscribers in the hundreds of millions. The ability of users to quickly transmit, retransmit, and receive information via social media makes it a desirable means of relaying fast-breaking information.

Most television stations in the assessment area had a presence on Facebook and Twitter during the event. Television stations and some EMs used these media as an additional way to transmit warnings and relay information to communities. Television stations in Mississippi noted that their Facebook followers doubled during the event.

EMs also made good use of social media. For example, after the Winfield NWR outage, the only transmitter serving Marion County, the assistant county EM used his smartphone and his agency's Facebook and Twitter sites to disseminate NWS warnings and statements. The EM from Sequatchie County, TN posted NWS information regularly on his personal Facebook page, which had approximately 500 local followers. He also broadcast information on local police frequencies, which citizens monitored through radio scanners.

In early April 2011, after testing at a limited number of sites, NWSHQ approved a nationwide test of Facebook pages. WFOs in the assessment area had a limited amount of time to conduct on-station training and become operational before the event.

WFOs FFC, JAN, and BMX used their Facebook pages to post weather synopses and Web graphics. After the event, Facebook pages were brought online by WFOs MRX and HUN. All WFOs with Facebook capability used their sites to communicate damage path information after the fact.

Finding 14: Despite the popularity of social media and text messaging, the NWS has not taken full advantage of this capability.

Recommendation 14: NWS should formalize an agile, comprehensive policy to promote use of social media and text messaging as standard communication channels.

4.10. Operations and Responses of External Partners

4.10.1. Emergency Managers

As mentioned in Section 4.1, WFOs in the assessment area have extensive outreach programs. EMs stated that WFO staff work closely with them to provide training and programming of weather radios at local venues. WFO staff is available for other endeavors where an NWS presence is needed. Several EMs compared partnerships with the local WFO to family because the WFO staff provides so much personal attention. Virtually all EMs knew key NWS staff on a first-name basis.

During the assessment process, the team interviewed staff at 20 county EM offices and 4 state offices. There was significant agreement among these partners that the NWS was disseminating severe weather products and information in a timely manner.

The team found a high level of dedication among the EMs. The team also found a wide range of technical weather expertise, monitoring tools, and staffing and resource levels among local EMs. There were resource limitations within counties that may have reduced the ability of EMs to continue warning residents during the event period. Specifically, some county EMs had to perform other tasks, such as moving and activating emergency power generators, as storms approached. While staffing limitations may well be part of the economic reality, the team believes that EM operations would benefit from their having a baseline level of severe weather knowledge.

Finding 15: There were substantial variations in the level of weather-related capabilities from county to county.

Recommendation 15: NWS should partner with FEMA to refine and update the training curriculum, including drills and simulations, for EM hazardous weather competency and NWS decision support services.

State emergency management agencies used and processed NWS information differently. All agreed that relationships with State Liaison WFOs were valuable. The Alabama and Tennessee Emergency Management Agencies (EMA) tie actions to specific NWS products and informational briefings. By comparison, the Georgia EMA used the information in a less rigorous manner. The Alabama EMA Director stated that a simple weather dashboard or briefing page would be something the Governor would find useful.

4.10.2. School Officials

Numerous school districts dismissed students early because of the severe weather threat. Some schools cancelled classes on April 27 because of power outages from the early morning storms. During the afternoon, school administrators were faced with the difficult decisions of whether to release students to school buses, and when, or to hold them inside school buildings. WFOs provided valuable assistance for both decisions. The Madison, AL school superintendent stated, "*I don't know what we'd do without [the assistance]*."

Fact: Schools called the WFOs to get time windows of opportunity for releasing students.

4.10.3. Media

Mirroring the emergency management community, media partners throughout the assessment area stated that they had solid working relationships with their servicing WFOs. While some television meteorologists expressed some philosophical differences with their NWS partners, all agreed that the warning system was a team effort. Television meteorologists were unanimous in their praise for NWSChat, noting that it had become a standard part of their operations during severe weather.

4.11. Societal Impacts and Public Response

NWS's recognition of the value of social science in the assessment process has increased. For this event, four social scientists formed a sub-team to provide insights on NWS products and services. Information on the processes used for data collection, social science modeling, and methodology are detailed in Appendix C. The Service Assessment Team strongly recommends that this Appendix be read for a full understanding of the approach used by the social science sub-team in gathering and analyzing data and providing recommendations.

This section reviews protective action decisions made by the public. Most of the information is focused on the warning phase, despite the fact that many people had heard about the possibility of a tornado threat from outlook and watch products. Outlooks and watches typically led people to monitor or seek more information, but normally did not cause people to take protective actions. Warnings or the confirmed presence of a threat were needed to motivate people to take shelter.

4.11.1. Receiving Warning Information

4.11.1.1. Importance of Multiple Warning Sources

The team found people relied on many different sources of information to process the tornado threat including personal observations, television broadcasts, radio broadcasts, calls, visits, messages from friends and family, NWR, the Internet, and sirens. While television was a favored source for receiving weather information, demographic groups placed differing values on other sources such as radio, Internet, or NWR.

People who focused primarily on television news also used other sources to confirm information. Availability of multiple sources proved valuable for receiving updated information about the threat in real time. The team noted that family and friends played a large role in disseminating warning information and personalizing the risk. The team encourages the NWS and partners to capitalize on this natural response by urging the public to “phone a friend, save a life,” or something similar.

Individuals who relied on a single source of information were potentially cut off from knowledge that could have helped their decision making process. For example, a 48-year-old resident of Hackleburg, Alabama, missed a call from his friend because his cell phone service went down. He said he would have listened to his friend’s warning not to come home more than warnings from any other source. In contrast, a woman in Alabama stated that she could not get her NWR working so she relied on a generator and television for information.

Fact: People relied on a variety of sources to receive warning information. Power outages and infrastructure damage affected availability of television, Internet, commercial radio, cell phones, and NWR.

Fact: Peer warnings helped motivate people to take protective action. Nearby family and friends supplemented the warning system through personal contact.

4.11.1.2. Varied Access to Dissemination Sources

The availability of different communication distribution channels varied not only by preference, but also by systematic issues and inequalities. For example, there was a notable difference in NWR ownership between rural to urban survivors. Several rural respondents noted they simply could not afford to purchase an NWR despite wanting to own one.

Location in media markets significantly affected people’s abilities to receive information specific to their local communities. The perception was that the media tended to focus on larger urban areas and did not provide much, if any, information about smaller communities. This was more obvious for communities on the fringes of multiple markets.

Local officials used several methods to warn residents. In Tuscaloosa, AL, police cars drove up and down streets with bullhorns notifying citizens of the approaching tornado. By comparison, most jurisdictions relied on stationary outdoor warning sirens and media announcements.

Individuals received information about specific tornado threats from sirens, calls from friends, or television messages. Most respondents stated that they were pleased with the availability of warning data.

Based on conversations with the public, the social scientists on the team concluded that the NWS, media, and other partners did a good job making people aware of the possibility of tornadoes in the days preceding these events.

4.11.2. Message Comprehension

Despite successful receipt of information, responses varied based on the how well an individual understood a message’s intent. As noted in the *Mother’s Day Weekend Tornado in Oklahoma and Missouri, May 10, 2008,* and the *Super Tuesday Tornado Outbreak of February 5-6, 2008,* some residents acted immediately after hearing a warning by preparing or taking shelter as recommended. For others, receipt of a message led to personal assessment of the potential risk for a tornado and protective options. Many residents needed more information about the nature of the threat and used information from multiple sources to assess the level of safety or risk. Further details on this scenario are discussed below.

The NWS recognizes that variations in behavior emphasize the need to examine policies associated with watches and warnings to maximize the degree that information is understood, confirmed, believed, and personalized. It is also important to consider how the warning system supports public action by clarifying specific protective recommendations that will lead to greater safety.

4.11.2.1. Unclear Communication of Increased Certainty and Intensity

While interviewees were generally aware of the potential for severe weather, not all were aware that forecasts for this event were made with a considerably higher level of confidence when compared to forecasts of previous tornado events and included the likelihood of larger and more destructive tornadoes. In other words, people were not aware that the forecasts for this event were different from others.

Leading up to the April 27 event, SPC products contained strong wording outlining the hazards and potential impacts. WFOs in the assessment area increased their decision-support activities such as those outlined in Section 4.7. Taking this concept a step further, the team suggests that WFOs encourage key partners to relay potential impacts and recommended actions through their local dissemination systems. This would serve three important functions:

- Ensure a consistent message about the threat level.
- Communicate the increased confidence to help people personalize the threat.
- Assist the personal decisions to take protective measures such as going to a shelter.

4.11.2.2. Varying Siren Policies

Sirens are one of the major tools used by EMs to communicate threats to citizens who are outdoors. Many interviewees suggested they had difficulty interpreting sirens, which resonates with prior service assessment research and findings (i.e., *Super Tuesday Tornado Outbreak of February 5-6, 2008 and Mother's Day Weekend Tornado in Oklahoma and Missouri, May 10, 2008*). These difficulties took three forms:

- Many people expected to hear sirens for a potential tornado even in areas where no sirens existed.
- In some areas, sirens exist for threats other than severe weather, but people expected them to be sounded for tornadoes. For example, in Chattanooga, TN sirens only go off for Tennessee Valley Authority/nuclear plant issues, not severe weather.
- Even in areas where tornado sirens do exist, the team found a wide variation in warning siren activation criteria. For example, some counties sounded sirens for the whole county if a warning affected any place in the county. Different blast patterns were used to signify watches versus warnings. Other counties used sirens only for warnings. There were instances where these practices varied in adjacent counties. In many cases, the public was unaware of these variations and unsure what a siren meant.

As opportunities arise, NWS WFOs and Regions should work with local EMs and governments to develop uniform warning policies and conduct public outreach. As an example, WFO Fort Worth, TX collaborated with the North Central Texas Council of Governments when the council's emergency preparedness group developed common siren guidelines for the Dallas-Fort Worth area.

4.11.2.3. Language Barriers

This country has seen an increase in the Spanish-only speaking population over the past two decades. During the assessment, the team interviewed a non-English speaking person who found it difficult to understand the warning message. A visual warning was broadcast on the television screen he was watching. The person stated that he was watching an international Spanish channel when the tornado came. He said he had watched the polygons on the local news earlier that day, but was unsure what he was observing. It was the sound of the tornado that made him take protective action.

In addition to the production and distribution of Spanish language print materials, the social scientists on the team encourage local WCMs to continue developing culturally appropriate outreach programs. Another strategy could be to partner with EMs, civic organizations, churches, and community groups willing to serve as bridges into these communities.

4.11.2.4. Multiple Tornadoes

Many individuals' past severe weather experiences did not prepare them to respond to the threat of multiple tornadoes. The team found cases where people were unaware that multiple tornadoes were possible. Some people believed that after the first tornado the threat had passed. For others, the first event served to sensitize them and made them more likely to respond to future threats. In events where multiple rounds of storms are occurring, the NWS should focus on the larger-scale threat in addition to the specific storms.

4.11.3. Confirmation

4.11.3.1. Difficulties with Visual Confirmation

Visual confirmation of a threat is often the most significant motivator for protective action. As previously mentioned, many respondents needed visual confirmation of the tornado before seeking shelter. While warnings often put people on alert and motivated them to obtain more information, it was seeing the tornado or its effects that provided the impetus to seek shelter. It is important to note that visual confirmation of large tornadoes was particularly difficult in this event. Most people do not know what a large tornado looks like (i.e., a large, dark, low-hanging cloud) and were not expecting what they actually saw. People reported that they spent several minutes looking directly at the tornado before they realized what it was. In many cases, it was not until people saw debris flying that they recognized the threat. This fact, coupled with the speed of the storms, meant many people barely made it to shelters or did not make it to safety.

For example, despite hearing warnings all day, one man stated he did not take action until he saw the tornado approaching. At that point, he didn't have time to run to a nearby store, so he crawled into the bathtub. Another family reported that they had been monitoring television and radio as well as looking outside when they noticed a "*large dark storm cloud*" approaching. By the time they realized that the cloud was a tornado, the family barely made it to their storm shelter. As they pulled the door shut, they heard debris pounding against it. Reducing the number of people who wait for visual confirmation will be difficult. NWS can provide citizens with information to help them identify large tornadoes more quickly. Outreach materials should be created that illustrate the various appearances of large tornadoes.

Finding 16: Some people needed visual confirmation of the tornadoes before taking protective action. As a result of the rapid forward motion of the storms in this event and the fact that the appearance of many large tornadoes was not familiar, these people typically had a small window of time from when they realized they were seeing a tornado to when they got to a safe shelter.

Recommendation 16: NWS should update awareness and education materials to illustrate the variations in the appearance of large tornadoes.

4.11.4. Personalization

4.11.4.1. Communicating Geographic Specificity

Team interviews determined many people relied on specific geographic markers to determine if a threat was close enough to threaten them. These people wanted exact information about predicted paths and had specific neighboring towns, streets, or landmarks they judged as close enough to require them to act. Media outlets provided specific geographic locations in real time that listeners used to make decisions. The team found that some people did not know the name of their county or the counties and towns surrounding them. Additional research is needed to determine what geographic information should be provided to people so they can personalize threats. A short-term change could be an update of the AWIPS location database to include well-known city subdivisions, landmarks, and geographic features as some WFOs already have done.

Current warning products do not always prioritize locations with respect to the storm location or forecast track. For tornado warnings, the NWS should investigate alternative methods of displaying locations, including graphical warning displays. A possible adjustment would be modifying the location scripts in Warngen and in future warning tools. The modified scripts would focus on locations near the storm's forecast track and locations most likely to be impacted within a given period of time; e.g., the next 20 minutes. This process would require frequent follow-up statements to ensure the list of high-priority locations is kept up to date. In graphical warning depictions, WFO staff could use a swath of highest strike probability within the polygon.

Finding 17: Most people wanted very specific information about the forecast paths of tornadoes and believe this capability currently exists.

Recommendation 17: WFOs should review their AWIPS location databases to ensure a sufficient density and priority of smaller but known communities, well-known landmarks, and other common locations.

4.11.4.2. The False Alarm Effect

Many respondents noted warning systems were activated several times per year for tornado warnings that did not impact their neighborhood. For example, a 41-year old from Tuscaloosa, AL said warnings were marked by the "*usual things, police going around with little sirens, schools with sirens on the poles going off*." Others also mentioned that the sirens "*go off all the time*."

Analysis of verification data shows that tornado warning false alarm ratios (FAR) have been high the past few years. **Table 3** below shows FARs from offices within the assessment area.

Table 3: Tornado Warning FARs 2006-2010

YEAR	BMX	HUN	FFC	MRX	JAN
2006	.768	.643	.813	.958	.866
2007	.796	.667	.694	.563	.634
2008	.802	.592	.741	1.000	.752
2009	.833	.772	.779	.634	.802
2010	.859	.761	.919	.733	.708

The information above and in **Table 3** suggest that false alarms in the context of the end-to-end warning process need to be addressed; however, the team encourages a well-researched approach versus a hasty approach to any changes. There are three reasons for this:

- The warning process is limited by the state of the science and NWS detection capabilities. Even when large-scale conditions are known, it is difficult to tell if a particular storm will produce a weak, strong, or violent tornado.
- NWS has no information as to what level of false alarm reduction would lead to a meaningful improvement in public response. Further study is needed to determine what our target FAR should be.
- At a minimum, warnings increase the awareness of people in the warned area, and motivate them to assess their personal risk (*Mileti, D. S. and Sorensen, J. H., 1990; Lindell, M. K. and Perry, R. W., 2004*). Reduction of FAR would likely come with an increase in unwarned events, depriving people of the opportunity to assess and act. Reaction among the public to this change is unknown.

Thus, the preliminary data are contradictory. There is an intuitive sense that false alarms desensitize the public toward taking action as a result of NWS warnings. On the other hand, empirical evidence in behavioral research suggests higher levels of awareness occur as a result of increased warnings. As a result of this conflicting evidence, the team encourages the NWS to continue structured research. This research should involve the meteorology and social science communities and explore how changes in the end-to-end warning system would affect public perception and behavior.

4.11.4.3. Altering Behavior

Many respondents said they had been changed by this event, and that seeing the destruction had changed their perceptions. They had gone from perceiving a tornado as unlikely and therefore not requiring action, to being motivated to take action despite tornadoes being low-probability occurrences. Devastation from this event, even for those without personal loss, personalized the risk for survivors. The NWS should consider distributing photos and videos of damage to Websites or to media outlets as a way to help people see the destructive potential of major tornadoes. Interviews with survivors may also be effective.

Finding 18: People impacted by tornadoes acknowledged their future responses would be more proactive as a result of the extreme impacts, despite the low probability of being hit.

Recommendation 18: NWS should revise its pre-season tornado preparedness messages to emphasize tornadoes' low probabilities, even in warning areas, but extremely high impacts.

4.11.4.4. Weather Myths as a Barrier to Personalizing the Threat

Some had preconceived notions based on local, often erroneous, information regarding weather threats, and as a result, they downplayed warning messages. There was a belief that being surrounded by mountains provided protection, that tornadoes did not cross rivers or only came from a certain direction. The NWS and partners should consider identifying and dispelling local myths.

4.11.5. Risk Reduction and Protective Action Behavior

4.11.5.1. Unclear Communication of Protective Action Options

Figure 14: Damage in Smithville, MS (courtesy of WCM Chance Hayes, Wichita, KS)

Particularly during violent tornadoes, there is an increased risk of injury or death if people are not underground or in a reinforced concrete safe room. Recommendation 8c of the Super Tuesday Tornado Outbreak of February 5-6, 2008, and Recommendation 6 of the Tornadoes in Southern Alabama and Georgia - March 2007 also involved "safer" shelter options. After surveying the Smithville, MS damage (**Figure 14**), the WFO MEG WCM stated, "*in the core of the tornado, you had to be underground or in a safe room to survive.*" The NWS has developed a priority list of protective actions. The first choices are a basement, storm shelter, or safe room. Secondary choices include interior bathrooms and closets. The team found, however, that the public did not distinguish between primary and secondary choices. A person from Tuscaloosa, AL was taught to "*get away from windows, to the lowest room in the house, somewhere in the middle*."

After further discussion, she agreed that she had been told to get underground or in a storm shelter. A man from Tuscaloosa remembered hearing to get into a closet or bathroom (small area). After further discussion, he remembered it was best to get to a storm shelter or basement, but said he didn't have time and was not sure where one was located.

Finding 19: NWS hazardous weather products use generalized protective action recommendations such as "go to a safe place," or "take cover now," or do not clearly prioritize specific safety actions.

Recommendation 19: NWS should use specific call-to-action statements and clearly prioritize options for shelter from violent tornadoes. NWS should share these options and priorities with key partners.

4.11.5.2. Lack of Availability of Shelters and Safe Rooms

Although officials could not determine the circumstances surrounding more than half of the fatalities, of the remainder, twice as many died in mobile homes as in conventional homes **(Figure 15).** On-scene evidence suggested that many conventional homes were wood-frame construction and did not have reinforced safe rooms or basements for underground sheltering **(Figure 16).** Unfortunately, in the case of EF4 and EF5 tornadoes, seeking shelter in above ground interior spaces, e.g., bathrooms and closets, often will not be sufficient.

Anecdotal evidence provided to the assessment team indicated people died when they thought they were taking shelter in safe locations when, in fact, there were no safe locations in their home. On-scene evidence from areas where mobile homes were destroyed indicated few of the occupants had access to hardened shelters or safe rooms.

Figure 15: A destroyed mobile home near Louin, MS (courtesy of Gary Woodall, MIC, NWS Phoenix, AZ)

Figure 16: A destroyed wood frame house in Concord, AL (courtesy of Gary Woodall, MIC, NWS Phoenix, AZ)

4.11.5.3. Lack of Awareness of Public Shelter Options

Many interviewees reported they were unaware of nearby community shelters. A resident in Tuscaloosa, AL stated, "*I wish they would have said on the TV, they could have said you could go to an underground shelter. We didn't know where to go. It was too wide and too strong*." Another Tuscaloosa resident said, "*If there are tornado shelters that can handle a lot of people and people have enough time to get there…*" she thought that would be a good option. "*They need a plan in place and we just didn't have a plan*."

4.11.6. Public Response Summary

Conclusions of the social science sub-team validated key findings of previous Service Assessments, specifically, those resulting from the Super Tuesday 2008 and Mother's Day 2008 tornado events. While the sampling and interview techniques prohibit the team from making sweeping recommendations in this area, the team believes that further, structured research is vital to maximizing the societal value of NWS products and services. Programs such as Weather and Society – Integrated Studies, Society Woven into Meteorology, and establishment of the OCWWS Social Scientist position should prove helpful in this process. Local EMs are heavily involved in preparedness and response in their jurisdictions and could also play an important role in these activities.

This research should look into the NWS warning process and philosophy, and should heavily involve input from the public, the people NWS is trying to motivate. Alternative concepts of warning content, format, graphical representations, points of emphasis, and delivery are all topics for investigation. By better understanding how people receive, process, and respond to warning messages with these variations, the NWS will be able to better implement long-term changes.

As stated in Section 4.11.4.2, our current detection capabilities and understanding of the science are one of the causes of the high FAR associated with tornado warnings. The team believes that as our understanding of tornado formation processes evolves, and our detection technology advances, an overall reduction in FAR should naturally result. Projects such as high-density local radar networks and phased-array radar will increase our detection capability. However, programs such as the Hazardous Weather Testbed and the VORTEX series must continue to elevate our scientific knowledge and enable us to properly use the new tools that are developed. The team encourages these activities in concert with the societal research described above.

In the short term, the team found some areas for adjustment to help the public respond more successfully to warning messages:

- During pre-season preparedness activities, have WFO staff emphasize the low-probability but very high-impact nature of tornadoes.
- Post on Internet the survivor interviews and damage pictures from this event.
- Clearly state sheltering options to help the public assess its vulnerability when a tornado threatens.
- Add well-known venues, portions of cities, and landmarks to WFO AWIPS locations databases. When combined with very frequent severe weather statements, this would enhance the geographic specificity of the warnings.
- Adding short but specific safety tips to warnings and statements would serve as a last-minute reminder of proper actions to people in the storm's path.

4.12. Post-Event Activities and Support

4.12.1. WFO Staff

The sheer magnitude of the outbreak left a significant emotional scar on many WFO staff members. Numerous hours spent issuing tornado warnings for killer tornadoes that were destroying the communities in which they lived, and losing contact with family and friends during the event, took a dramatic toll on staff. Employees worked strings of long days in the aftermath, conducting damage surveys, which added to fatigue and stress.

Fact: Staff members at WFOs HUN and BMX were affected personally by the tornadoes; many had their homes damaged or had friends who died or were injured.

WFO personnel conducted storm surveys while search and rescue or recovery operations were ongoing. After the surveys, employees stated they were ill-prepared for interacting with survivors and the impact on themselves. MICs at WFOs HUN and BMX obtained counseling services from the NOAA Employee Assistance Program (EAP). Several employees at WFO HUN mentioned that the EAP counselor was “fantastic” and helped them work through the issues related to the tornado outbreak and subsequent damage surveys.

Best Practice: WFOs HUN and BMX made use of an EAP counselor to address emotional issues.

Finding 20: The process required to secure an EAP counselor was described as "difficult and full of red tape."

Recommendation 20: NWS Regions and NWSHQ should streamline the process for using EAP counselors by expressing requirements to NOAA for inclusion in the next EAP contract.

Finding 21: WFO personnel stated they were ill-prepared to meet with survivors and that such meetings had a negative impact on their own emotional well-being.

Recommendation 21: NWS should provide WFO staff with training on how to handle the emotional trauma of meeting people who have lost loved ones or homes in weather disasters.

4.12.2. Southern Region Operations Center

For more than two decades, NWS Regions have established Regional Operations Centers (ROC) to coordinate resources before, during, and after major weather events. The NWS Southern Region (SR) uses personnel from SR WFOs to staff its ROC.

For the April 27 event, the SR ROC functioned in a manner similar to a hurricane response. Before the event, the SR ROC coordinated with offices that would be affected regarding staffing, operational issues, and systems reliability. With significant river flooding and extreme fire conditions also affecting the region, the SR ROC initiated sectorized operations to address the threats. SR ROC staff prepared a daily Regional Threat Briefing for FEMA Regions IV and VI and the Texas State EMA.

After the outbreak, the SR ROC dispatched multiple staff members from neighboring WFOs to the affected offices. These employees assisted with damage surveys and covered operational forecast shifts so local staff could have time off or perform other duties. The SR ROC helped secure the EAP counselors discussed in Section 4.11.8 and served as primary liaison to NWS Headquarters.

The size and extent of this response meant that the SR ROC also needed supplemental staff. These personnel were drawn from nearby offices. The fluid nature of the staffing may have contributed to some problems in communications between the SR ROC and some WFOs. Additionally, there were some logistical items that the SR ROC was unable to support. By and large, the affected WFOs were appreciative of the SR ROC's support, particularly after the event.

4.12.3. Mapping of Tornado Tracks

A common concern of those interviewed was the inconsistent documentation of tornado damage survey information and its dissemination. For example, some WFOs used a paragraph format to describe survey findings, while others used a bullet format in Public Information Statements (PNS). For storms that crossed from one CWA to another, it was sometimes difficult to connect survey information. There were cases where EF intensity scales abruptly changed at CWA borders and storm tracks from one WFO to another were inconsistent **(Figure 17).** This was especially challenging for media markets that span multiple CWAs, such as Chattanooga, TN. These differences also made it more difficult for the Service Assessment Team to piece together a full picture of the event.

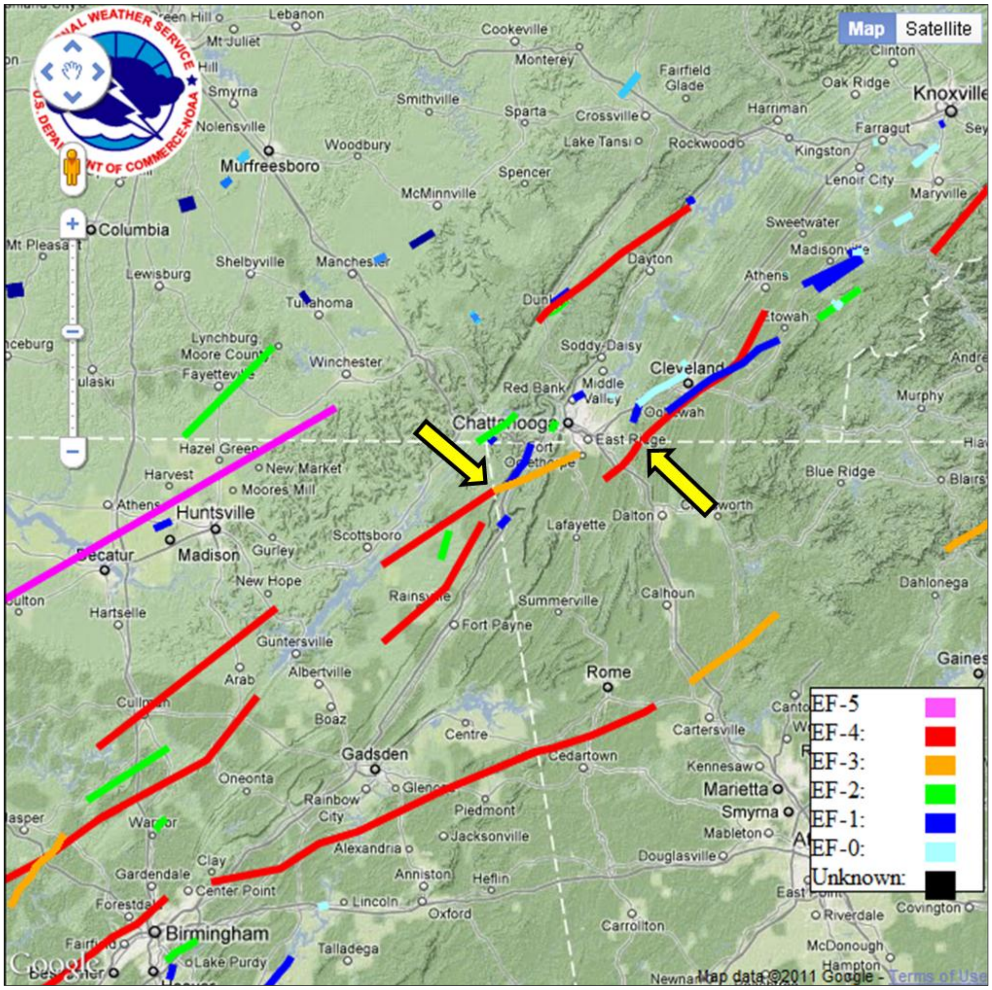


Figure 17: Shown is an example of mapped track inconsistencies as tornadoes crossed CWA boundaries. Yellow arrows mark a change in EF-Scale rating on the track from Alabama to Georgia and the slight break in the track extending from Georgia into Tennessee.

The NWS SR pieced together a tornado track map, which was very useful; however, the map was low resolution and had artificial breaks in tornado paths at some CWA boundaries. Key partners and the Service Assessment Team struggled to link tornado tracks and related information for storms that crossed multiple CWAs.

As an example, one tornado crossing from Pisgah, AL was identified as an EF4 in Alabama, but was then identified as an EF3 in Georgia near Trenton. Another tornado track from Ringgold, GA showed a break at the Tennessee border. It gave the appearance of two tornadoes when, in fact, it was a single storm. This affected post-event media coverage**.**

Finding 22: Many broadcasters stated the variable formats of survey findings made it difficult for them to quickly and accurately compile information about the overall outbreak.

Recommendation 22: OCWWS and the NWS Regions should create a standardized storm survey PNS format, similar to the post-hurricane reports submitted by coastal offices.

Finding 23: Members of the media stated that some of the mapped tornado tracks that crossed CWA borders were inconsistent (e.g., broken tracks, changed EF intensity), causing confusion among media partners and EMs.

Recommendation 23: OCWWS, SPC, and the NWS Regions should collaborate to develop a policy ensuring consistency for mapping tornado tracks that cross CWA boundaries.

As information about the outbreak was released, OCWWS and SPC collaborated to distribute talking points to all offices. The talking points included the number of tornadoes, deaths, damage, and NWS actions.

In preparing its monthly *Storm Data* report, WFO FFC included a locally-developed code at the bottom of each county tornado event. An example is shown below:

[04/27-04/28/11: Tornado #2, County #1-2, EF2, Dade-Walker, 2011:011]

This code contains the episode date, tornado number within the episode, county segment ID, EF-Scale rating, all counties impacted by the tornado, the year, and the tornado number for the year. The code helped WFO FFC staff conduct local tornado climate research and enabled users from outside the area to easily reconstruct the tornado tracks.

Best Practice: WFO FFC developed and implemented a unique code for tracking tornadoes, including multi-county tornado tracks, in its CWA's *Storm Data* entries.

There were numerous requests for tornado track and intensity maps determined from damage swaths in shapefile and KML formats. The NWS was able to provide these formats from surveys in WFOs BMX, HUN, and MRX CWAs. Other WFOs used a variety of methods to plot tornado tracks, but NWS has not set a standard archive method, similar to the above formats, to store these tracks. The "Damage Assessment Toolkit" is an application for smart phones and PDAs that uses the device's GPS capability to geo-reference damage photos and upload the damage track data to a Website in a standard format. Several WFOs used an evaluation version of the toolkit when conducting their storm surveys. Staff commented that the toolkit would be a valuable tool to solve the issue of storm track mapping.

4.12.4. Damage Surveys

Cleanup was well underway in some areas before surveys began, resulting in uncertainty of tornado strength in those areas. The Quick Response Team (QRT) concept specified in NWSI 10-1604 should be re-emphasized; NWS Regions should query affected offices concerning their needs for QRT assistance. The QRT can assist WFOs in evaluating tornado intensity, path length, width and damage intensity swaths before cleanup removes evidence.

Another issue noted in Section 2, "Summary of Tornadoes and Damage," concerns local office expertise. There were 31 tornadoes in the assessment area rated EF3 or stronger. Evaluating this many tornadoes quickly proved to be a challenge to damage surveyors. Some staff used the "EFkit," a PC-based program that enables surveyors to match observed damages with reference photos in the program's database. The user can then estimate the wind speed and resulting EF-Scale rating of the observed damage. The EFkit has proven helpful in evaluation of tornado intensity; however, the number of EF3 and higher examples currently in the EFkit is relatively small, resulting in subjective interpretation. This subjectivity is especially notable regarding damage indicators for trees, vehicles, and unreinforced brick buildings. The EF-Scale Stakeholders Group should provide corrections and updates.

Finding 24: Some surveyors were uncomfortable with their lack of experience differentiating between EF3, EF4, and EF5 damage.

Recommendation 24: NWS should update the EF Scale with input from the EF-Scale Stakeholder's group. NWS should update the accompanying guidance and training to the EF Scale and the EFkit to assist forecasters in discriminating strength of tornadoes with higher EF ratings.

The National Ocean Service flew over several tornado tracks and took geo-referenced photographs. These photos provided excellent documentation of tornado damage for areas where ground surveys had not been completed.

4.12.5. Post-Event Agency Coordination

The Department of Homeland Security (DHS)/FEMA Joint Field Office (JFO) is a temporary coordination center set up in the field to facilitate incident management. The JFO provides a central location for coordination of federal, state, local, tribal, nongovernmental and private-sector organizations with responsibility for threat response and incident support.

DHS/FEMA coordinates the use of remote sensing and reconnaissance operations, activation and deployment of assessment personnel, and GIS support needed for incident management. When activated, DHS/FEMA coordinates all mapping, charting, and geodesy support for the JFO. Activities include incident management, information sharing, law-enforcement criminal investigation, delivery of disaster assistance, and other support as required.

JFO resources and capabilities are effective and should be used for future service assessment activities. The assessment team encourages NWS to collaborate with FEMA to develop agreements and procedures for joint assessment activities.

5. Success Stories Resulting from NWS Products/Services

As noted above, the loss of life from this tornado outbreak was the largest in decades; however, actions taken based on NWS services and products directly resulted in lives being saved. Below are a few examples.

The WFO BMX MIC made a phone call to the EM at the University of Alabama in Tuscaloosa warning that the campus would be struck by a tornado. This StormReady University executed a well-planned response to the approaching storm. The university opened all shelters, displayed warning messages on building signs and on campus buses, and broadcast the warning using police car loudspeakers.

The WFO HUN WCM briefed the Madison County, AL Superintendent of Schools. This gave administrators the time to get students home before the afternoon tornadoes reached the area. This was critical information for the Superintendent's decision making, and he was extraordinarily complimentary of the briefings. In Hackleburg, AL, approximately 34 people squeezed into a county storm shelter designed for 18. The tornado warning provided adequate lead time for residents to leave their homes and reach the shelter. All 34 occupants survived, even though Hackleburg was extensively damaged by an EF5 tornado.

These stories demonstrated that proper planning, personal situational awareness, quick action, and the availability of adequate shelter dramatically increased the odds of survival even in the worst imaginable tornado scenario.

Appendix A: Acronyms

ARRL	American Radio Relay League
AWIPS	Advanced Weather Interactive Processing System
BMX	Weather Forecast Office, Birmingham, AL
CDT	Central Daylight Time
CWA	County Warning Area
DHS	United States Department of Homeland Security
EAP	Employee Assistance Program
EF	Enhanced Fujita (Scale)
EM	Emergency Manager
EMA	Emergency Management Agency
ESA	Electronic Systems Analyst
ET	Electronics Technician
FAR	False Alarm Ratio
FEMA	Federal Emergency Management Agency
FFC	Weather Forecast Office, Atlanta, GA
GPS	Global Positioning System
HPC	Hydrometeorological Prediction Center
HUN	Weather Forecast Office, Huntsville, AL
HWO	Hazardous Weather Outlook
iNWS	Interactive NWS program
ITO	Information Technology Officer
JAN	Weather Forecast Office, Jackson, MS
JFO	Joint Field Office
KBMX	WSR-88D Doppler weather radar, Birmingham, AL
KHTX	WSR-88D Doppler weather radar, Hytop, AL
KML	Keyhole Markup Language
MEG	Weather Forecast Office, Memphis, TN
MIC	Meteorologist in Charge
MRX	Weather Forecast Office, Morristown, TN
NA	Non-baseline AWIPS workstation
NCEP	National Centers for Environmental Prediction
NCF	AWIPS Network Control Facility
nm	Nautical mile
NOAA	National Oceanic and Atmospheric Administration
NWR	NOAA Weather Radio - All Hazards
NWS	National Weather Service
NWSHQ	National Weather Service Headquarters
OCWWS	NWS Office of Climate, Water, and Weather Services
PDA	Personal Digital Assistant
PDS	Particularly Dangerous Situation (tornado watch)
PIO	Public Information Officer
POD	Probability of Detection
QRT	Quick Response Team
RFC	River Forecast Center
ROC	Regional Operations Center

SAD	Situational Awareness Display
SKYWARN	Storm spotter network
SPC	Storm Prediction Center
SVR	Severe Thunderstorm Warning
SVS	Severe Weather Statement
TOR	Tornado Warning
UTC	Coordinated Universal Time
WCM	Warning Coordination Meteorologist
WFO	Weather Forecast Office
WSR-88D	Weather Surveillance Radar, 1988 - Doppler
WWA	Watch/Warning/Advisory

Appendix B: Findings, Recommendations and Best Practices

Definitions

Best Practice—An activity or procedure that has produced outstanding results during a particular situation that 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.

Findings and Recommendations

Finding 1: Several EMs and media representatives stated the growing number of weather awareness weeks (e.g., flood, lightning, fire, etc.) were diluting the messages and causing the events to lose their effectiveness.

Recommendation 1: OCWWS and NWS Regions should collaborate with key local partners to review the number of awareness weeks and determine if they should be consolidated into fewer, higher-impact events.

Finding 2: Several counties in the assessment area had no organized spotter or storm reporting networks and had received no spotter training in at least 2 years.

Recommendation 2: WFOs should arrange to provide storm spotter training classes for each of their counties at least every other year.

Finding 3: WFO MRX was unable to monitor local media broadcasts from Chattanooga. This impacted the staff's situational awareness regarding the violence of the unfolding event. WFO JAN employees faced a similar situation with storms in the Meridian, MS area. At least 20 WFOs have TV markets in their CWAs that cannot be viewed at the WFO.

Recommendation 3: NWS should provide WFOs with the equipment and bandwidth to monitor television outlets in their CWAs but outside of their local media markets.

Finding 4: There was no redundancy along a portion of the fiber-optic communications link between the KHTX radar and WFO HUN. This means when the fiber-optic communications link is down there is no access to these radar data.

Recommendation 4: NWS should ensure alternative methods of data delivery to the WFOs from all remote radars.

Finding 5: Required service backup for WFO BMX was difficult for other WFOs to provide because of equipment issues at the primary backup WFO and weather threats at the secondary backup WFO.

Recommendation 5: NWS should review its current plans for tertiary backup sites. Whenever possible, tertiary sites should be far enough from affected offices so they are not impacted by the same weather event.

Finding 6: As discussed in the *Super Tuesday Tornado Outbreak of February 5-6, 2008*, Service Assessment, the varying number of AWIPS workstations in WFOs resulted in corresponding effectiveness in sectorizing and providing service backup.

Recommendation 6: NWS should re-evaluate the number of baseline/supported workstations at WFOs, to ensure a sufficient number for hazardous weather operations, impact-based decision support, and backup needs.

Finding 7: Destruction of communication lines between WFOs and their NWR sites prevented dissemination of weather information, even at towers where backup power was available.

Recommendation 7: NWS should ensure the Weather Radio Improvement Project includes backup NWR capabilities that do not rely on local or regional power or communications infrastructure.

Finding 8: The text of several tornado and severe thunderstorm warnings did not contain the largest towns within the warning polygon, even if the towns were used as reference points in previous bullets. These omissions made it more difficult for users to locate the most dangerous parts of the storms.

Recommendation 8: WFOs should review their AWIPS location databases and ensure the largest communities in their counties have the highest priority for selection by Warngen.

Finding 9: Forecasters had differing interpretations of the instructions in NWS Directive 10-511 concerning "Tornado Emergency." This inconsistency caused confusion among those media partners whose market areas were covered by multiple WFOs.

Recommendation 9: NWS regional headquarters should ensure that WFOs in their areas of responsibility consistently apply instructions for the application and use of "Tornado Emergency." NWS regional headquarters should inform OCWWS of any requirements to clarify or provide more detail on the use of “Tornado Emergency” in NWS Directive 10-511.

Finding 10: Several WFOs used the generic “Doppler radar indicated” wording in their tornado warnings despite evidence of a tornado in progress.

Recommendation 10: When WFOs have ground truth reports, they should refer to them in severe weather products, rather than “Doppler radar indicated.” OCWWS and the regions should review NWS Directive 10-511 and ensure the directive supports this recommendation.

Finding 11: On occasion, SPC asked WFOs to add a few counties to existing watches so SPC could avoid having to issue a new watch. The speed at which WFOs completed this task varied.

Recommendation 11: OCWWS and the NWS Regions should ensure WFOs can issue watch extensions quickly, and should consider the need for backup procedures when workload prevents the affected WFO from quickly extending watches.

Finding 12: The NWS has limited guidelines about providing information for storms between “watch” and “warning” time frames. More complete guidelines would enable WFOs to provide official NWS guidance to partners who must make preliminary notifications to first responders and high-vulnerability locations.

Recommendation 12: NWS should refine the guidelines in its directives to provide more explicit instructions and examples of pre-warning information on approaching severe storms. These guidelines should also be incorporated into the WFOs’ Weather Event Simulator training curricula.

Finding 13: The public and EMs expressed confusion resulting from the inconsistency between the county-based NWR alarms and polygon-based warnings.

Recommendation 13: NWS should implement an upgrade to NWR allowing the system to broadcast warnings using a polygon-based method.

Finding 14: Despite the popularity of social media and text messaging, the NWS has not taken full advantage of this capability.

Recommendation 14: NWS should formalize an agile, comprehensive policy to promote use of social media and text messaging as standard communication channels.

Finding 15: There were substantial variations in the level of weather-related capabilities from county to county.

Recommendation 15: NWS should partner with FEMA to refine and update the training curriculum, including drills and simulations, for EM hazardous weather competency and NWS decision support services.

Finding 16: Some people needed visual confirmation of the tornadoes before taking protective action. As a result of the rapid forward motion of the storms in this event and the fact that the appearance of many large tornadoes was not familiar, these people typically had a small window of time from when they realized they were seeing a tornado to when they got to a safe shelter.

Recommendation 16: NWS should update awareness and education materials to illustrate the variations in the appearance of large tornadoes.

Finding 17: Most people wanted very specific information about the forecast paths of tornadoes and believe this capability currently exists.

Recommendation 17: WFOs should review their AWIPS location databases to ensure a sufficient density and priority of smaller but known communities, well-known landmarks, and other common locations.

Finding 18: People impacted by tornadoes acknowledged their future responses would be more proactive as a result of the extreme impacts, despite the low probability of being hit.

Recommendation 18: NWS should revise its pre-season tornado preparedness messages to emphasize tornadoes' low probabilities, even in warning areas, but extremely high impacts.

Finding 19: NWS hazardous weather products use generalized protective action recommendations such as "go to a safe place," or "take cover now," or do not clearly prioritize specific safety actions.

Recommendation 19: NWS should use specific call-to-action statements and clearly prioritize options for shelter from violent tornadoes. NWS should share these options and priorities with key partners.

Finding 20: The process required to secure an EAP counselor was described as "difficult and full of red tape."

Recommendation 20: NWS Regions and NWSHQ should streamline the process for using EAP counselors by expressing requirements to NOAA for inclusion in the next EAP contract.

Finding 21: WFO personnel stated they were ill-prepared to meet with survivors and that such meetings had a negative impact on their own emotional well-being.

Recommendation 21: NWS should provide WFO staff with training on how to handle the emotional trauma of meeting people who have lost loved ones or homes in weather disasters.

Finding 22: Many broadcasters stated the variable formats of survey findings made it difficult for them to quickly and accurately compile information about the overall outbreak.

Recommendation 22: OCWWS and the NWS Regions should create a standardized storm survey PNS format, similar to the post-hurricane reports submitted by coastal offices

Finding 23: Members of the media stated that some of the mapped tornado tracks that crossed CWA borders were inconsistent (e.g., broken tracks, changed EF intensity), causing confusion among media partners and EMs.

Recommendation 23: OCWWS, SPC, and the NWS Regions should collaborate to develop a policy ensuring consistency for mapping tornado tracks that cross CWA boundaries.

Finding 24: Some surveyors were uncomfortable with their lack of experience differentiating between EF3, EF4, and EF5 damage.

Recommendation 24: NWS should update the EF Scale with input from the EF-Scale Stakeholder's group. NWS should update the accompanying guidance and training to the EF Scale and the EFkit to assist forecasters in discriminating strength of tornadoes with higher EF ratings.

Best Practices

Best Practice: WFO BMX offered a series of pre-recorded multimedia presentations on a variety of hazardous weather-related topics. The office distributed the presentations to EMs, law enforcement, and fire agencies. Several EMs provided positive feedback on these presentations.

Best Practice: WFO MRX developed a local program to monitor the near-storm convective environment. The program, called "Storm Monitor," is viewable on the Advanced Weather Interactive Processing System (AWIPS) and displays 17 key parameters for more than a dozen selected points within the CWA.

Best Practice: WFOs FFC and JAN used online monitors to verify that warnings were broadcast successfully on NWR.

Best Practice: WFO FFC used a 911 tap to monitor reports coming into the 911 centers, thus receiving real-time notification of emergency dispatches**.**

Best Practice: In the warning immediately prior to the tornado striking Tuscaloosa, WFO BMX added to the list of locations to be impacted the McFarland Mall, Bryant-Denny Stadium, and Deerlick Creek Campgrounds. WFO HUN included the Redstone Arsenal in numerous warnings.

Best Practice: WFO HUN issued short duration (30-45 minutes) tornado warnings for relatively small areas because of fast-moving storms. This enabled the WFO staff to provide focused products and frequent updates.

Best Practice: WFO BMX issued new severe weather statements approximately every 10 minutes during tornado warning valid periods because of the rapidly-evolving situation. While this required considerable work, it resulted in consistent, fresh information for partners and customers.

Best Practice: WFO HUN issued a Special Weather Statement (**Figure 12**) on the early morning storms approximately 1 hour before they approached, giving sufficient time for partners and customers in their CWA to prepare.

Best Practice: While the outbreak was in progress, WFOs JAN and BMX prepared a series of “tactical scale” (focused on the CWA, valid for less than an hour) Web graphics that illustrated storm locations and potential impacts over the next 2-4 hours (**Figure 14**). These images kept their graphical Web presence as fresh as possible during the rapidly-evolving event.

Best Practice: WFO JAN published multimedia briefings in a variety of formats, including Shockwave, for its Web page, MP3 audio, and MP4 and M4V video for smartphones.

Best Practice: WFO JAN has an agreement with the Mississippi Highway Patrol to include a range of Interstate mile markers that are expected to be crossed by tornadoes in WFO warnings and statements.

Best Practice: WFO BMX used a combination of highway mile markers and exit numbers in its warnings.

Best Practice: WFOs HUN and BMX made use of an EAP counselor to address emotional issues.

Best Practice: WFO FFC developed and implemented a unique code for tracking tornadoes, including multi-county tornado tracks, in its CWA’s *Storm Data* entries.

Appendix C: Social Science Methodology and Response Model

The Social Science Sub-team included insights and recommendations in this report that go beyond NWS products and services. Because the agency's mission is to save lives and reduce property damage, the sub-team believes it is vital to recognize that meeting this objective requires changes from a broad group of stakeholders including the media, emergency managers, and the public. All partners must work together to create a truly integrated warning system. In particular, the sub-team focused on how the warning system helped or impeded protective actions.

Data Collection Process

Social science data collection focused primarily on conducting interviews with survivors to understand how the warning system operated and how people responded to different warning cues. A number of tornado survivors along the EF4 and EF5 tracks in Mississippi, Alabama, Tennessee, and northwest Georgia were interviewed 10-13 days after the tornadoes struck. These people ranged from those suffering complete destruction of their homes to those living in close proximity to the impacted zones who experienced minimal or no damage. Interviews were conducted with local residents sifting through debris or working on their homes as well as people living in Red Cross shelters or FEMA relocation trailers because their home were damaged or destroyed, or in restaurants because they no longer had a kitchen. Each person was asked questions, not always in the same sequence, about the warnings and recommended protective action as well as their experience contrasting the April 27 tornadoes with prior events.

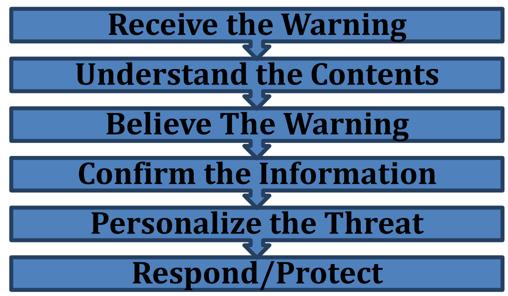
The sampling methodology was limited in several respects. The lack of randomized participant selection may have prevented results that were representative of the area. The sub-team did not visit hospitals to interview more severely injured victims, or obtain records to locate those with minor injuries. The sub-team did not locate direct family members of people who died who could have provided information about protective actions the deceased may or may not have taken. The sub-team's interviewing ability and focus on particular themes improved over time, and may have biased earlier interviews.

As referenced in the 2008 Super Tuesday and the 2010 Nashville Flood Service Assessment reports, the social scientists could not conduct a structured survey in the impact areas. The information those scientists collected was used to identify themes for this report and for further detailed analysis. OCWWS is collaborating with the White House Office of Management and Budget to develop a structured approach to social science data collection for future Service Assessments. This should not be a standard instrument, but rather a standard process that balances repeated use of standardized measures with the ability to focus on unique and important elements of any particular event. Future Service Assessment Teams should have a social science sub-team that operates on an independent but coordinated schedule and includes technical NWS experts.

Analytical Approach

It was important that interpretations of conversations with survivors be compared with prior research about how people respond to disaster threats and warnings because of the limits of the data collection method. This method of comparison provided the ability to determine the degree to which information from this event can be used in the future and the confidence to make recommendations that concurred with prior findings. The method also allowed the sub-team to highlight important new issues and nuances of issues identified in previous Service Assessments that need further exploration. Special attention was given to findings that were relevant to NWS products, policies, and partners.

Table C-1: Phases of Warning Response (Mileti and Sorenson, 1990)

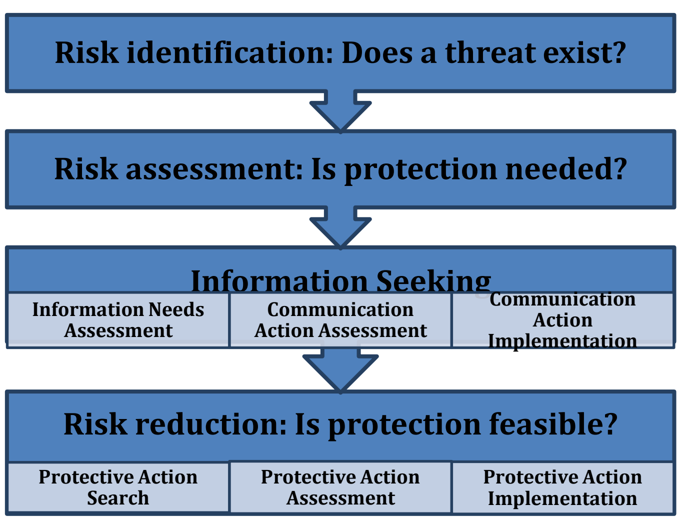


The sub-team looked for issues explaining how people were processing formal and informal messages about the tornado risks and how they used that information to develop perceptions of danger. The sub-team also focused on how these perceptions combined with other factors to influence protective action choices.

The first model we relied on to frame our data collection was Mileti and Sorenson's (1990). This model is based on the assumption that human decision making associated with warnings resembles an ordered choice and that people go through a series of cognitive steps that more or less explain how they process warning information. While the authors are careful to note that not every person will go through every step and that the sequence will not be the same for every person, there is a common pattern to the issues most people consider (**Table C-1).**

The second model we referenced was the Protective Action Decision Model (PADM) of Lindell and Perry. This model illustrates important steps in warning decision making and action. In contrast to Mileti and Sorensen, Lindell and Perry focus more directly on protective action decisions rather than the cognitive. This model is particularly valuable in that it is more comprehensive in its identification of facilitator and impediments to protective actions and the role of information needs/seeking (**Table C-2).**

Table C-2: Phases of Warning Response (Lindell and Perry, 2004)



Appendix D: April 22, 2011, St. Louis Metropolitan Area Tornado Event

Event Summary

On April 22, 2011, two supercell thunderstorms crossed the St. Louis metropolitan area bringing large hail, strong winds, and five tornadoes, including an EF4, which is the primary focus of this report. The EF4 tornado scoured a 21.3 mile path across St. Louis County, MS, and then crossed the Mississippi River into Madison County, IL, where it dissipated. The worst damage occurred when the tornado hit the Lambert St. Louis International Airport in the northwestern part of St. Louis. Many windows were blown out of the airport's terminal buildings and large pieces of the roof were blown off. The St. Louis metropolitan area tornadoes were part of a band of tornadoes and severe thunderstorms that extended from Oklahoma northeast through the Middle Mississippi and Ohio Valleys (**Figure 1)**.

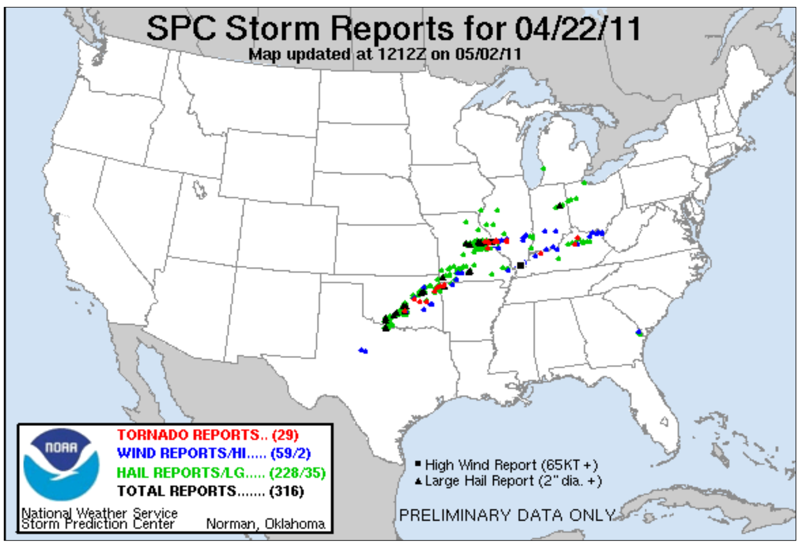


Figure 1: Severe Weather Reports, April 22, 2011. Tornado reports are shown in red, damaging wind reports in blue, and hail reports in green. (*Courtesy of SPC*)

Pre-Event Meteorological Conditions

On Friday, April 22, 2011, a surface cold front was moving across Missouri (**Figure 2**). Unstable air was present over much of Missouri and central Illinois ahead of the cold front. Surface dew points were in the mid to upper 60s over east central Missouri and into central Illinois. This abundant low level moisture combined with strong and veering winds in the upper atmosphere and an approaching cold front to provide the ingredients for severe thunderstorms, including tornadoes in the St. Louis metropolitan area, during the evening of Friday, April 22.

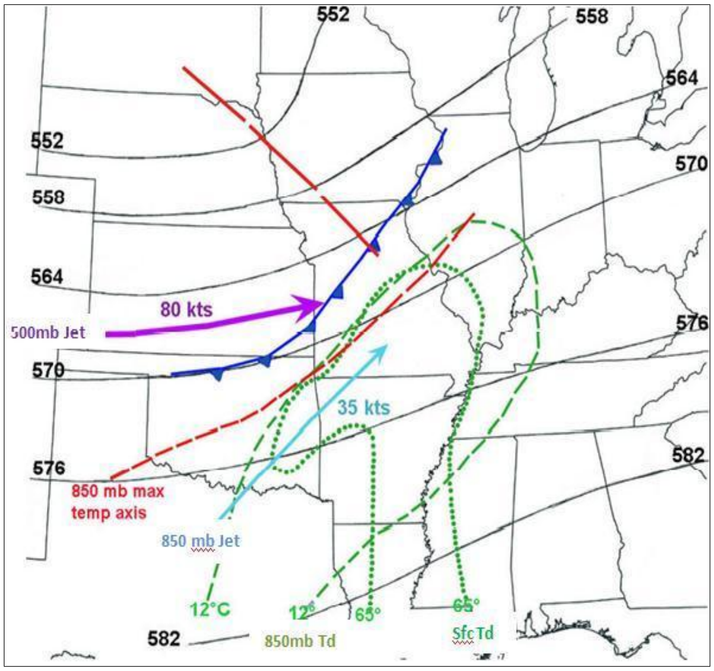


Figure 2: Composite chart of observed upper air parameters valid at 7:00 p.m. CDT, April 22, 2011

Pre-Event Products

Forecast atmospheric conditions became increasingly favorable for severe thunderstorms including tornadoes. The St. Louis metropolitan area was included in a Slight Risk for severe thunderstorms with the issuance of the 0600 UTC (1:00 a.m. CDT) Day 1 Convective Outlook. The 1630 UTC (11:30 a.m. CDT) Day 1 Convective Outlook depicted a Moderate Risk of severe thunderstorms from east central Oklahoma to just southwest of the St. Louis metropolitan area. The threat became increasingly apparent during the afternoon. At 3:35 p.m. CDT, a Tornado Watch was issued for west central Illinois and central and southwest Missouri. All five of the tornadoes in the St. Louis CWA occurred within this Watch (#179), which expired at 10 p.m. CDT, and Tornado Watch #181, issued at 5:50 p.m. CDT, and expired at 1:00 a.m. CDT, Saturday, April 23.

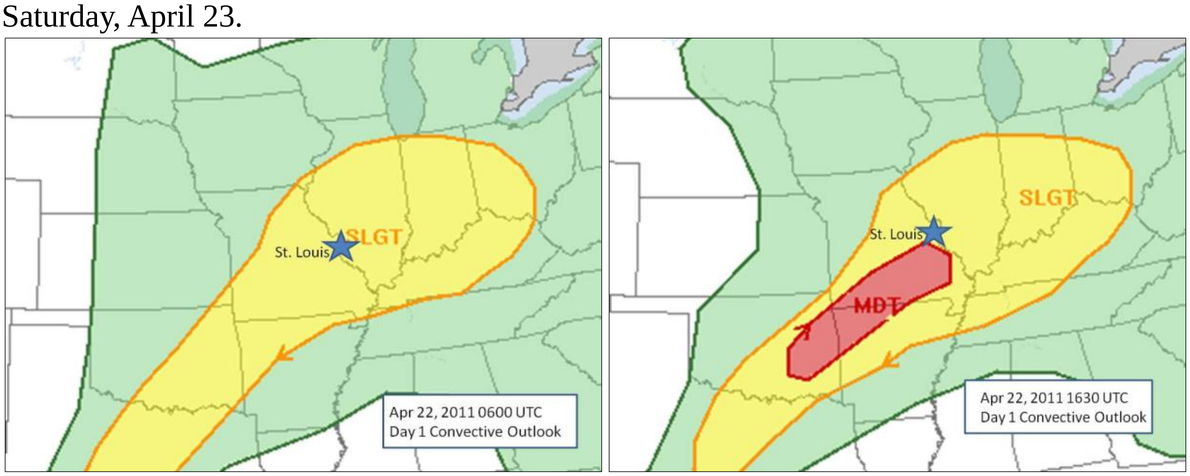


Figure 3: Day 1 Convective Outlooks from SPC, valid 0600 UTC, April 22, 2011, until 1200UTC, April 23, 2011, (left) and 1630 UTC, April 22, 2011, until 1200 UTC, April 23, 2011

(right).

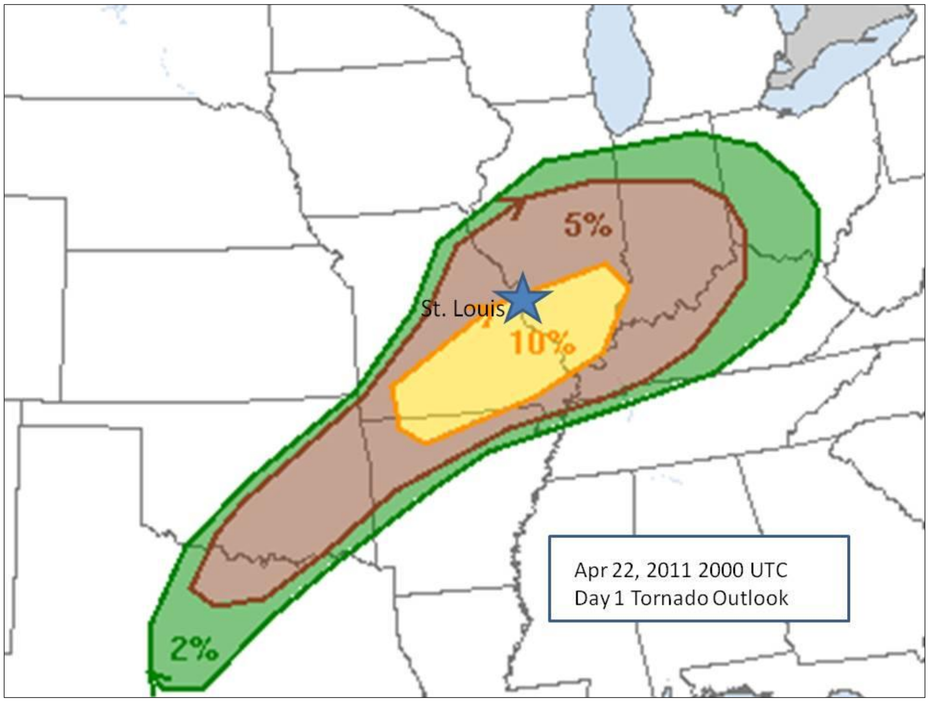


Figure 4: Day 1 Tornado Outlook from SPC, valid 2000 UTC, April 22, 2011, until 1200 UTC, April 23, 2011.

SPC provided further focus on the tornado threat for the St. Louis area in its 5:21 p.m. CDT, Mesoscale Discussion 0520 (**Figure 5**). This discussion read "*Conditions remain favorable for tornadoes across Tornado Watch 179…especially over cntrl and ern portions from the Columbia/Jefferson City/Vichy area east toward St. Louis.* "The discussion continued "*Supercells just s of the Columbia area have shown strong rotation…and this trend is expected to continue as these cells encounter greater low level shear to the east. Isolated strong tornadoes may occur*."

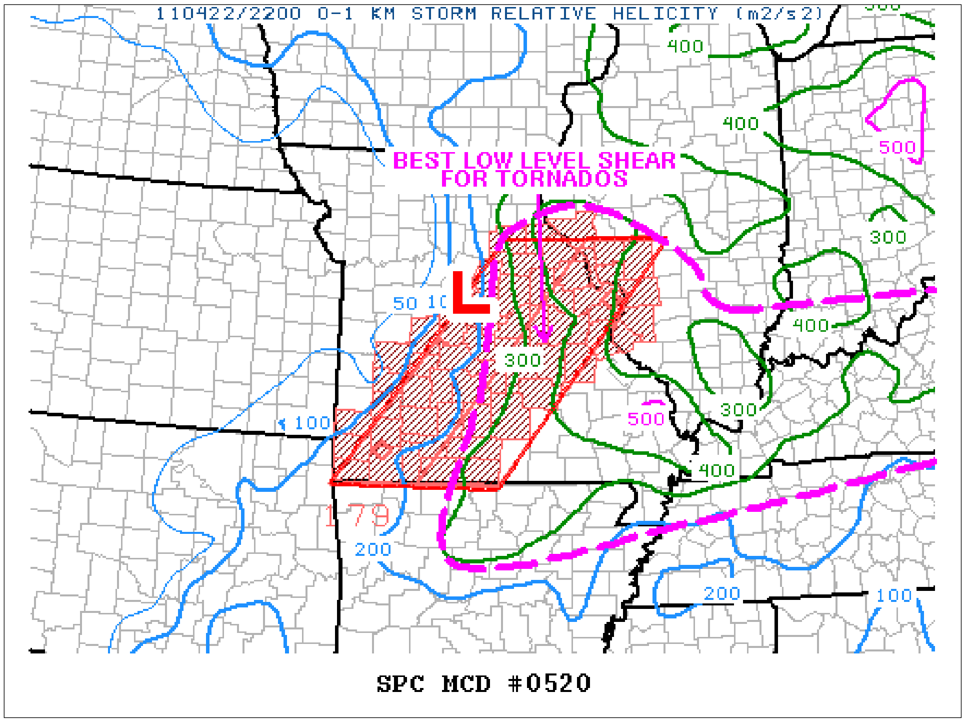


Figure 5: Storm Prediction Center Mesoscale Discussion #0520.

The St. Louis EF4

The EF4 tornado moved across St. Louis County in Missouri and into Madison County, Illinois **(Figure 6)**. The tornado tore a path of destruction from west to east across northern portions of the St. Louis Metropolitan Area. The tornado reached a maximum intensity of EF4 as it tracked through the community of Bridgeton, just west of Lambert St. Louis International Airport. The total path was 21.3 miles long, and up to 1/2 mile wide.

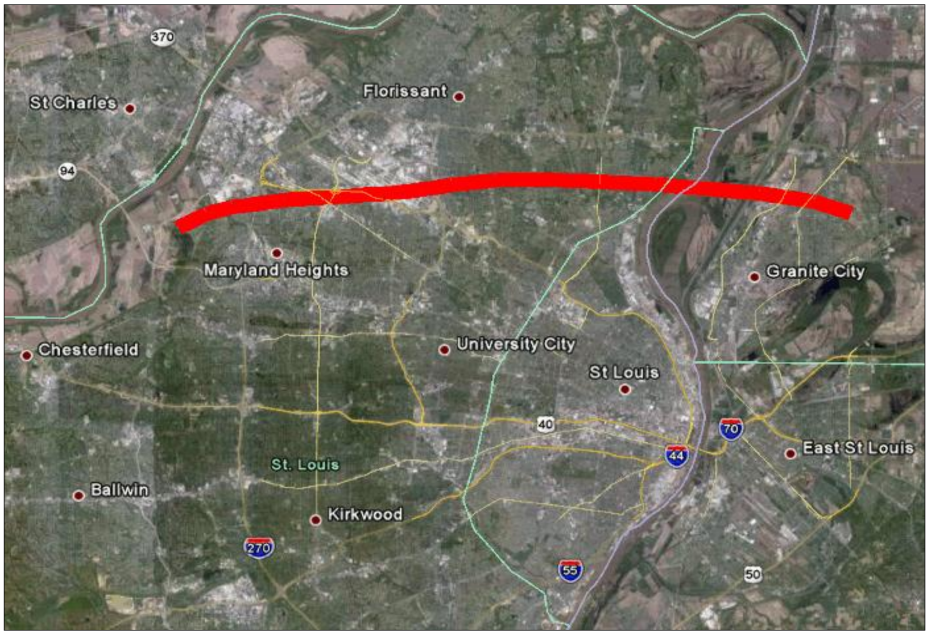


Figure 6: Track of the April 22, 2011, St. Louis tornado. The tornado reached a peak intensity of EF4. It was on the ground for 36 minutes and covered 21.3 miles. (*Courtesy of WFO St. Louis, MO.*)

The tornado progressed as follows:

- Initially touched down along the northern edge of Creve Coeur Lake at approximately 7:59 p.m. CDT.
- Tracked nearly due east at about 40 mph, and intensified as it entered Maryland Heights. In Maryland Heights, it produced up to EF3 damage to many homes and businesses with a damage swath of 200 to 400 yards wide.
- Moved eastward resulting in damage in an unbroken track, crossing I-270 about 1 mile south of I-70.
- Reached peak intensity of EF4 as it devastated the community of Bridgeton along Old St. Charles Road.
- From there, paralleled Interstate 70 through the community of St. Ann.
- Moved directly toward Lambert St. Louis International Airport where many of the large windows in the main terminal building were blown out or damaged by flying debris and a large section of roof was peeled from Concourse C. Five people were treated and released from area hospitals for injuries caused by flying debris. The airport was closed temporarily due to extensive damage. **Figure 7** depicts a debris ball in the radar base reflectivity just east of the airport.

As summarized in **Table 1**, five tornadoes occurred in the St. Louis CWA. An EF4 was produced by the northern of two supercells. This northern supercell spawned two additional tornadoes— an EF1 near New Melle and a long track EF2 that affected Madison, Clinton, and Bond counties in Illinois. The southern supercell produced two short-track tornadoes. The first was rated EF2 in Monroe County, IL and the second was rated EF1 in St. Clair County, IL.

Table 1. Composite tornado statistics for all tornado warnings and tornadoes in the St. Louis CWA on April 22, 2011

Tornadoes	Warnings Issued	POD	FAR	Initial Lead Time (minutes)	Mean Lead Time (minutes)
5	18	1.00	0.61	27.4	37.2

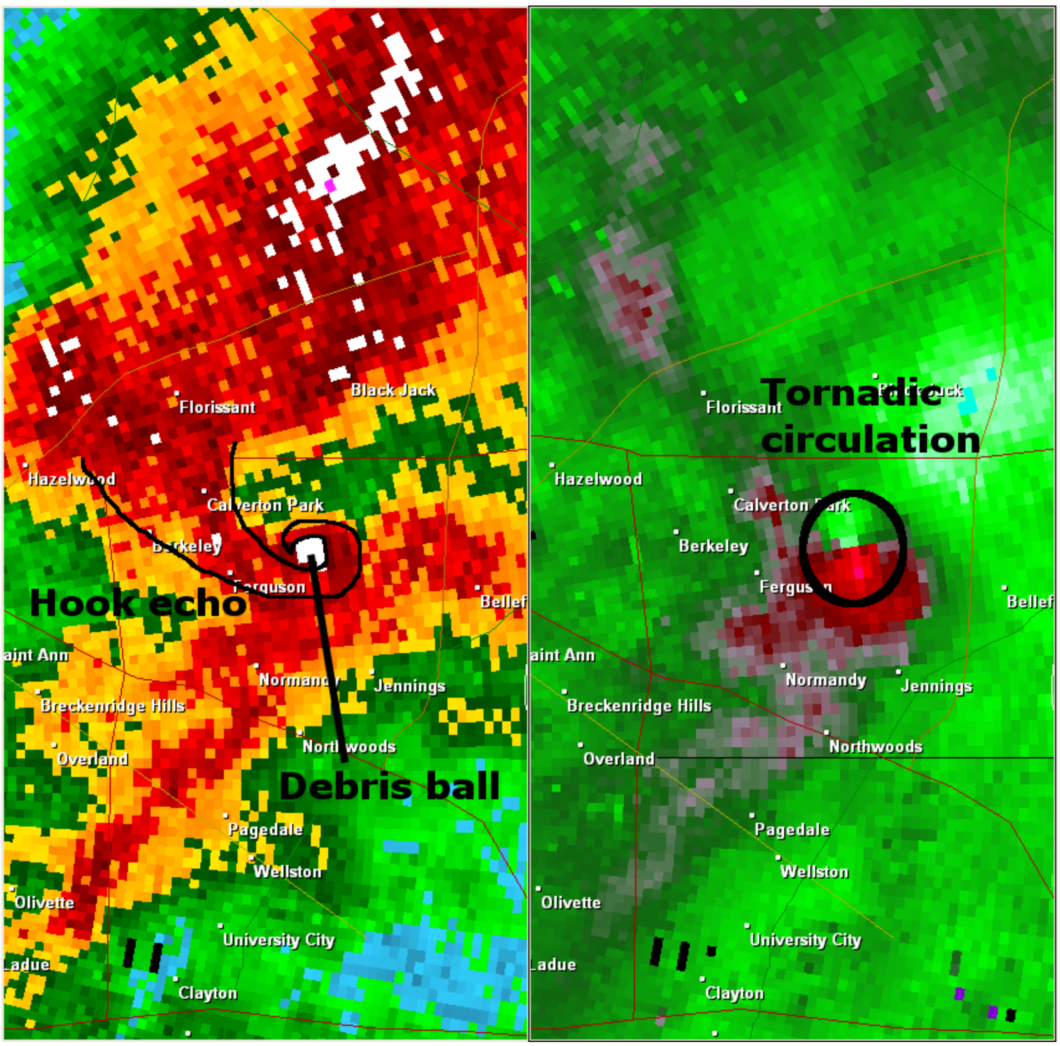


Figure 7: WFO St. Louis, MO Weather Surveillance Radar (WSR-88D), Base Reflectivity and Storm Relative Velocity at 0.5 degree elevation at 8:16 p.m.

Facts, Findings, Recommendations, and Best Practices

Facts

Fact: Five tornadoes occurred across the WFO St. Louis CWA on April 22, 2011. One of these tornadoes was rated an EF4 with a 21.3 mile path length across the St. Louis metropolitan area. The tornado reached its peak EF4 intensity as it struck the community of Bridgeton, just northwest of Lambert St. Louis International Airport.

Fact: No fatalities or serious injuries resulted from the April 22 St. Louis Metropolitan EF4.

Fact: **S**PC outlooks, watches, and mesoscale discussions provided invaluable guidance toward the increasing threat of tornadoes for the St. Louis metropolitan area on April 22, 2011.

Fact: The lead time was 23 minutes for the warning that encompassed the touchdown location of the EF4. The lead time for the Lambert St. Louis International Airport was approximately 34 minutes. The mean lead time along the entire path was 39 minutes.

Findings and Recommendations

Finding D-1: Two employees serving as communicators were trying to access external communication programs at the only available AWIPS workstation. This restricted information dissemination.

Recommendation D-1: WFOs should ensure their workstation configuration and severe weather operating plans accommodate communication requirements for high-impact events with large volumes of information exchange.

Finding D-2: Several storm reports sent out using Electronic Call Log and Image Recording System contained the wrong event time.

Recommendation D-2: Storm report event times should always be checked and, if necessary, corrected before dissemination.

Finding D-3: Reception of storm damage reports from some dispatchers was limited because of the high volume of 911 calls.

Recommendation D-3: WFOs should search for backup means of attaining storm reports from 911, such as scanners and online audio feeds of emergency services. Reference the Best Practice in Section 4.2.

Finding D-4a: Preparedness activities and action plan procedures for the Lambert St. Louis International Airport were minimal and ineffective for this event.

Finding D-4b: People in the concourses of the Lambert St. Louis International Airport did not take cover until they observed winds increasing significantly outside the concourse windows. While airport procedures were to announce warnings in the airport terminal per airport policy, each airline had its own emergency plan for the concourses; however, many airport patrons commented they received no information on the storm whether they were in the main terminal or in a concourse.

Finding D-4c: FAA personnel did not evacuate the Lambert Field tower until 8:08 p.m., when their manager called to convey the warning she saw on television. This was 32 minutes after the warning issuance and 2 minutes before the tornado struck the airport.

Recommendation D-4: WFOs should work closely with airport personnel in their CWA to encourage timely and comprehensive severe weather operating procedures, including a solid means for receiving, disseminating, and responding to warnings. Periodic drills and simulations should be conducted to ensure procedures are adequate.

Best Practices

Best Practice: WFO St. Louis provided excellent information via NWSChat with an obvious effort to "tell what they knew," including the evidence of a debris ball and enhanced radar operator confidence levels.

Best Practice: SPC provided excellent pre-event services, including a pointed mesoscale discussion more than 2.5 hours before the St. Louis EF4.

Best Practice: WFO St. Louis issued a Special Weather Statement at 6:35 p.m. with the headline "*DANGEROUS THUNDERSTORM HEADING INTO THE ST. LOUIS METRO AREA…*"

Best Practice: WFO St. Louis issued frequent severe weather statements, averaging more than three severe weather statements per warning. Four warnings were each followed with five or six severe weather statements.

Best Practice: WFO St. Louis aggressively included ground truth information in warnings and severe weather statements. For example, severe weather statement wording included "*...DESTRUCTIVE TORNADO MOVING THROUGH SOUTHERN ST. CHARLES COUNTY...*" and "*...A LARGE...EXTREMELY DANGEROUS AND POTENTIALLY DEADLY TORNADO IS ON THE GROUND.*" Warnings included wording such as "TRACKING A CONFIRMED DAMAGING TORNADO" and "THIS STORM HAS A HISTORY OF DAMAGING TORNADOES."

Appendix E: NWS Eastern Region Event Review North Carolina/South Carolina/Virginia U.S. Tornado Outbreak

Introduction

On Saturday, April 16, 2011, a deepening low pressure system moving into the Great Lakes region produced 30 tornadoes across portions of North Carolina, South Carolina, and Virginia. Of these, four were rated as EF3 intensity on the Enhanced Fujita (EF) Scale for Tornado Damage. A total of 26 fatalities and 371 injuries have been attributed to these tornadoes; 24 of the fatalities occurred in North Carolina. This tornado outbreak was the most deadly in North Carolina since 1984 when 42 fatalities were recorded.

NWS Forecast and Warning Services

A total of 249 severe weather events were reported during this outbreak, which stretched from southeast Pennsylvania to central South Carolina (**Figure 1)**. NWS Eastern Region Weather Forecast Offices (WFOs) issued 96 tornado warnings during this outbreak with a Probability of Detection (POD) of 87.1 percent, a False Alarm Ratio (FAR) of 51 percent, and a mean lead time of 16.4 minutes. The POD, FAR and lead time exceed the Fiscal Year 2011 NWS Government Performance Requirements Act performance measure goals. **Figure 2** shows the tracks of the tornadoes across portions of North Carolina, eastern South Carolina, and eastern Virginia with the associated EF ratings, and shows the location of injuries and fatalities, where available.

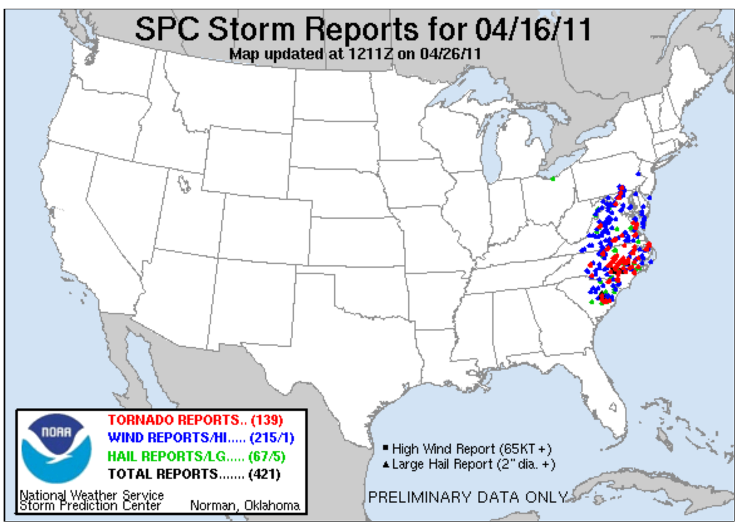


Figure 1: Severe weather reports received by National Centers for Environmental Prediction Storm Prediction Center (SPC) in near real-time via Local Storm Reports on April 16, 2011. Tornado reports are indicated in red, damaging wind reports in blue, and hail reports in green. *Graphic courtesy of SPC*

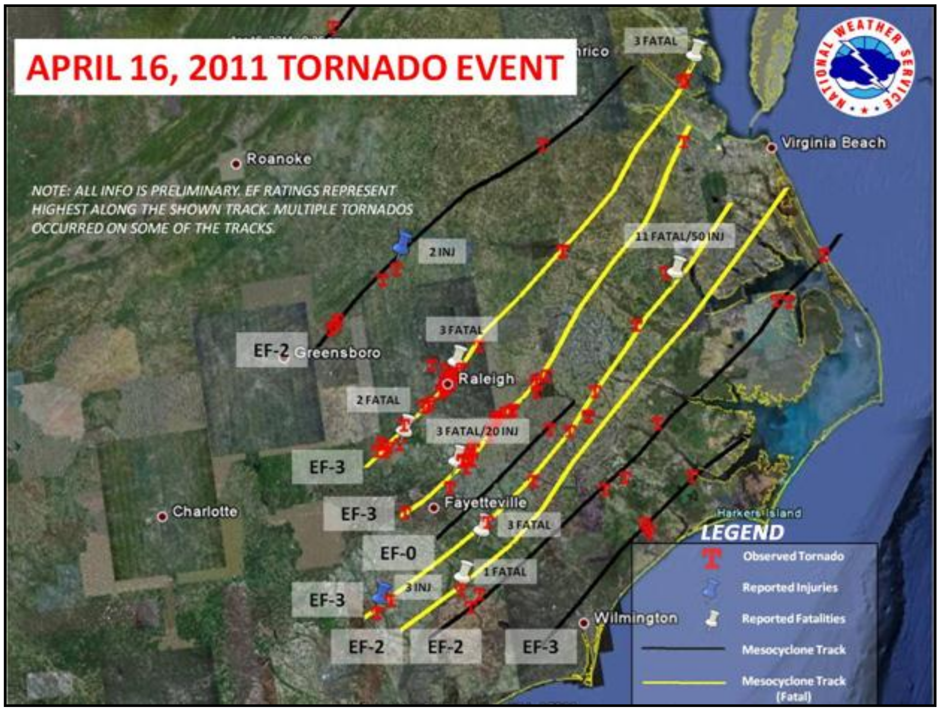


Figure 2: April 16, 2011, tornado tracks with associated EF Scale rating and location of injuries and fatalities, where available

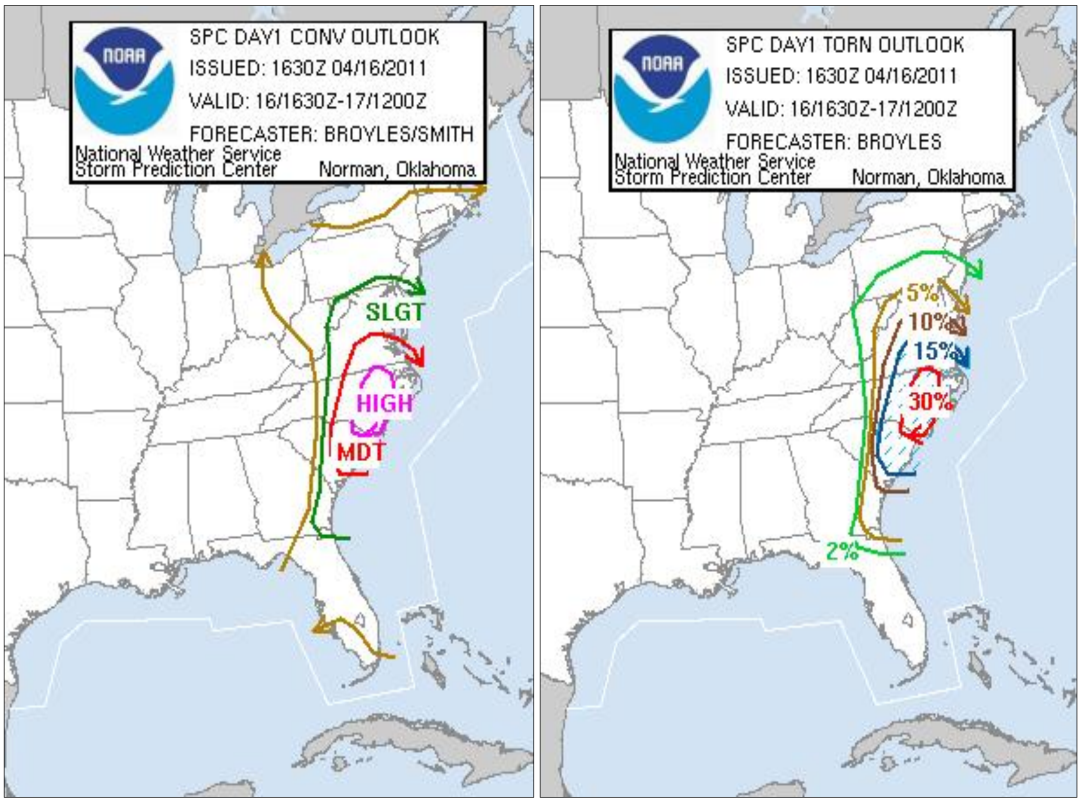
Overall, WFOs provided excellent service during this event. All 26 fatalities during this event occurred where tornado watches and warnings were in effect. The phrase “TORNADO EMERGENCY” was included in warnings and statements prior to the fatalities in Raleigh, Linden, and Dunn, NC. WFOs began highlighting the threat for strong or severe thunderstorms in Hazardous Weather Outlooks as early as Tuesday morning, April 12. WFOs initiated decision support services for emergency management and other state, county, and local officials on April 15, highlighting the severe weather threat for portions of North Carolina, South Carolina, and eastern Virginia.

The SPC included the potential for severe weather across the Southeast and Mid-Atlantic region in the SPC Day 3 Convective Outlook, issued early Thursday, April 14. The following day, SPC’s Day 2 Convective Outlook indicated a moderate risk of severe thunderstorms across eastern portions of North and South Carolina. On Saturday, April 16, SPC’s Day 1 Convective Outlook, issued at 12:30 p.m. EDT, upgraded the moderate risk area to a high risk. This outlook included a relatively high, 30 percent probability, of EF2 or stronger tornadoes across parts of eastern North Carolina. **Figure 3** depicts the SPC Day 1 Convective Outlook and Probabilistic Tornado Graphic issued at 1630z on Saturday, April 16.

Impacts

The tornadoes resulted in 26 fatalities and 371 injuries in Virginia, North Carolina, and South Carolina, with 24 of the fatalities in North Carolina. This tornado outbreak is the most deadly in North Carolina since 1984, when 42 fatalities were recorded.

North Carolina sustained the most significant and widespread damage from the tornadoes. According to state officials, the tornadoes destroyed 440 homes and 21 businesses, and damaged over 6200 homes and 92 businesses across the central and eastern portion of the state. **Figure 4** shows the damage sustained at the Lowes Home Improvement store in Sanford, NC. Following the outbreak, President Obama issued a disaster declaration for 20 counties in central and eastern North Carolina. Damage estimates reported via media from local, county, and state emergency management directors as of May 2011 indicate that the tornadoes caused about $208 million in insured losses in North Carolina. A preliminary estimate of the total damage cost of the tornadoes is assumed to be about twice the insured losses, or approximately $416 million.



(a) (b)

Figure 3: SPC Day 1 Convective Outlook (a) issued at 1630z, April 16, 2011, showing high risk area over portions of North Carolina and South Carolina, and Probabilistic Tornado Graphic (b) depicting a 30 percent probability of EF2-EF5 tornadoes across portions of North Carolina and South Carolina. (*Graphics courtesy of SPC*)

Figure 4: Lowes Home Improvement store after it was hit by a tornado in Sanford, NC, Saturday, April 16, 2011.
(*Courtesy of AP*)

Customer/Partner Feedback

WFOs received positive feedback on their services and performance during this event from both partners and customers. The examples below are typical of the comments received by the offices:

I really appreciated the phone call I received from Steve Pfaff [WCM, WFO Wilmington, NC] to let us know that we could expect a possible tornado. The call was timely and allowed us to initiate a Reverse 9-1-1 call to our residents. I also was able to maintain contact with the NWS and let them know the progress of the storm as I followed it into Bladen County. – ***Bradley Kinlaw, Emergency Management Director, Bladen County, NC***

The NWS chat has been extremely helpful during the severe events of the past few months. The ability to receive instant ground truth really helps improve our coverage on-air. – ***Jerry Jackson, Chief Meteorologist, WWAY, Wilmington, NC***

I have friends in NC that a NOAA Weather Radio (NWR) LITERALLY saved their lives this weekend!! They called me this morning and told me about the tornado that destroyed their house and that it was an experience that they would NEVER forget! They said they heard their NWR go off announcing there was a "tornado warning" and to take cover. They went to their basement and no sooner than they got settled in the basement the tornado came over head and ripped up trees and debris flying and when all the noise stopped they came out to find all they had left was a basement.
They are originally from Austin and told me the reason the originally bought the NWR was they had heard you on the news talking about it and got one and now they are VERY grateful they did! – ***NWR public testimonial, Austin, TX, Courtesy of Jim Spencer, WXAN, Austin, TX***.

Facts, Findings, Recommendations, and Best Practices

Facts, Findings, and Recommendations

Fact: Text noting SPC's issuance of a Particularly Dangerous Situation (PDS) Watch was not included in the baseline Watch County Notification (WCN) or Watch Outline Update (WOU) product and subsequently not included on NWR broadcasts, despite being included in the SPC Severe Local Storm product.

Finding E-1: The omission of text in WCNs and WOUs noting the PDS Watch resulted in a lost opportunity to amplify the importance of this high threat convective event.

Recommendation E-1: When SPC issues a PDS Statement, WFOs should include enhanced wording to emphasize the potential seriousness of the event in the WCN/WOU.

Fact: One WFO did not request onsite amateur radio support prior to or during this tornado event.

Finding E-2: The office's situational awareness and timely knowledge that tornadoes were on the ground within their CWA was reduced by the lack of onsite amateur radio support during the event.

Recommendation E-2: WFOs should request onsite amateur radio support for potentially major severe weather events.

Fact: During this event, WFOs used all AWIPS workstations, including E-AWIPS in some instances, to support operations.

Finding E-3: The available baselined AWIPS workstations were overwhelmed by the need to sectorize WFO warning operations during this event, coupled with the demands of Enhanced Short-Term Forecasting (ESTF) operations, aviation, verification, data acquisition, and provision of support statements.

Recommendation E-3a: WFOs should explore the feasibility of transitioning E-AWIPS workstations to full operational status.

Recommendation E-3b: WFOs should use E-AWIPS workstations to release non-critical, hydrometeorological products and manipulate data (e.g., GFE) to augment warning operations.

Fact: Several WFOs noted issues with range folding of WSR-88D velocity data during this outbreak. A few offices applied range folding mitigation techniques including switching to VCP 212.

Finding E-4: Several WFOs applied WSR-88D range folding mitigation techniques as part of their severe weather plan while others required radar operators to adjust the Pulse Repetition Frequency sectors in real-time to get a more unobstructed view of the velocity data.

Recommendation E-4: WFOs should periodically review WSR-88D range folding mitigation techniques, in coordination with their Unit Radar Committee, for application during convective events to reduce range-obscured velocity data.

Fact: In several cases, aerial damage surveys by Civil Air Patrols (CAP) were necessary to determine the extent of tornado tracks and damage especially over sparsely populated areas.

Finding E-5: In at least one instance, the office Station Duty Manual (SDM) had no information or guidance on how to initiate CAP flights for aerial damage surveys.

Recommendation E-5: WFOs should include instructions on how to initiate CAP flights for aerial damage surveys in their SDMs to support damage surveys activities.

Fact: WFOs received numerous phone calls within the first 24 hours after this outbreak asking for more information about the tornadoes; e.g., fatalities, injuries, intensity. These calls came from the public, media, and emergency managers, among others. In many instances, WFO damage survey teams were still in the field gathering and documenting information on the tornadoes.

Finding E-6: WFO personnel at the office often had limited information about ongoing damage surveys. This resulted in inconsistent, and sometimes incomplete, information provided to the media and the public.

Recommendation E-6: WFOs should develop a standard set of talking points for significant, high-impact convective events to allow personnel at the office to respond to public and media inquiries prior to the completion of storm damage surveys.

Best Practices

Best Practice: Several WFOs provided storm damage survey training to all staff members. This training was especially beneficial when a large number of damage surveys were needed in a short period of time.

Best Practice: During the event, many WFOs effectively managed their staff resources to minimize fatigue and optimize warning performance by periodically rotating staff through various operational assignments; e.g., radar, event coordinator, verification.

Best Practice: Disk space on archival systems was checked prior to this significant event to ensure adequate storage was available for critical data used during post-event reviews.

Best Practice: Several WFOs involved in this event had at least of two “grab and go” storm damage survey kits available at all times. These kits included GPS units, photographic capability, a laptop computer, fully charged batteries, and the EFkit.

Best Practice: When issuing polygon warnings, WFOs should maintain a balance between warning polygon size and duration. When issuing a warning for a storm that will exit a polygon, the two polygons were overlapped slightly to avoid gaps between warnings.

Best Practice: When SPC issued a moderate or high risk outlook for severe storms, the WFOs issued a Special Weather Statement in addition to the Hazardous Weather Outlook, to highlight the threat and increase public awareness of a potentially significant severe weather event.

Best Practice: The WFOs created a link on their homepage where appropriate decision support services PowerPoint briefings could be viewed by the media and the public.

Best Practice: WFO Raleigh used the Top News of the Day portion of its Web page to highlight critical severe weather products, including warnings and radar, and the public severe weather phone number for reports.