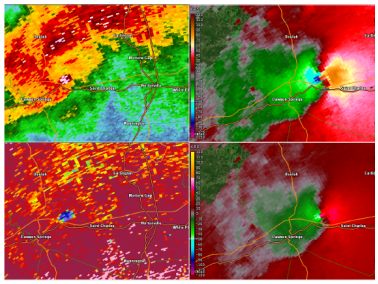
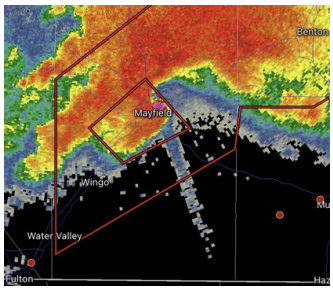
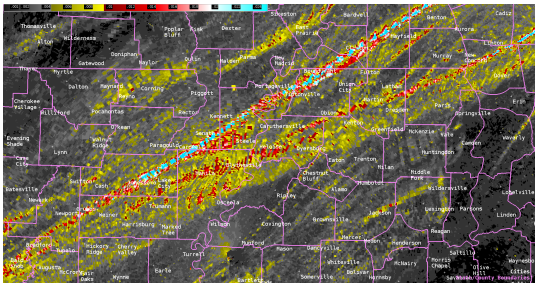
NWS Regional Service Assessment
Central / Southern Region
December 10-11, 2021 Tornadoes


U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration

National Weather Service, Central Region Headquarters, Kansas City, MO
National Weather Service, Southern Region Headquarters, Fort Worth, TX

June 01, 2023

Cover Photos

Upper Left:
4 panel composite KHPX radar at 0436 UTC, 12/11/2021 near Dawson Spring, Kentucky

Upper Center:
KPAH reflectivity image at 0327 UTC, 12/11/2021 over Mayfield, Kentucky

Upper Right:
Damaged car in Mayfield, Kentucky. Photo by WFO Paducah

Lower Left:
NSSL MRMS rotation track overlay - 12/10/2021 and 12/11/2021

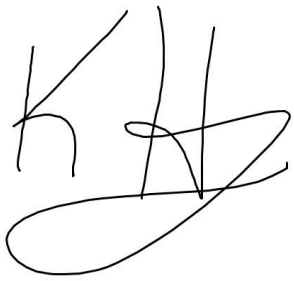
Lower Right:
Aerial shot of Amazon Warehouse damage, Edwardsville, IL. Courtesy KTVI Fox 2, St. Louis Missouri

Preface

During the evening of December 10th and 11th, 2021, a potent storm system brought widespread severe weather to the Ohio and Tennessee River Valleys. Numerous severe thunderstorms and tornadoes occurred, including a significant long-track tornado that devastated Mayfield, Kentucky, and several other cities and towns in its path. This tornado began near Woodland Mills, Tennessee, at 8:49 P.M. CST, and had a continuous track of 165.6 miles that ended in Falls of Rough, Kentucky, at 11:47 P.M. CST.

Due to the rarity and significant impact of this tornadic and severe weather outbreak from December 10-11, 2021, a joint regional Service Assessment team was formed to examine the warning and forecast services provided by the National Weather Service (NWS) before, during, and after this event. This joint regional assessment is a partnership between the Central Region and Southern Region of the NWS.

Findings and recommendations from Service Assessments provide a valuable contribution to ongoing efforts by the NWS to improve the quality, timeliness, and value of our products and services to our partners and the American public. Subsequently, these improvements will help the NWS carry out its mission of protecting life and property, while advancing the Weather-Ready Nation initiative.



Ken Harding
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National Weather Service

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June 01, 2023

Executive Summary

On the evening of December 10-11, 2021, a deadly and historic tornado outbreak occurred over portions of the central and southern United States. The economic impact of the tornadoes and associated severe weather was estimated at over $4.3 Billion[1]. One tornado had a path length of 165.6 miles, which became the longest tracked December tornado on record.

Two of the more devastating impacts from the tornadoes occurred in the towns of Mayfield, Kentucky, and near Edwardsville, Illinois. The Mayfield tornado was rated an EF-4, with 190 mph winds. The Edwardsville tornado was rated an EF-3 with 150 mph winds. In all, the NWS confirmed 71 tornadoes across eight states, which resulted in 89 direct tornado fatalities. This makes the event the deadliest December tornado event on record since 1950, surpassing the Vicksburg, Mississippi tornado of December 5, 1953, with 38 fatalities. Aside from tornadoes, there were over 230 reports of high wind gusts across the Midwest, including a peak wind gust of 107 mph that was recorded at a mesonet site in Graves County, Kentucky.

The outlooks, forecasts and warnings issued for this historic event by the NWS Storm Prediction Center (SPC) and the local Weather Forecast Offices (WFOs) were excellent. Further, there was an average lead time of over 19 minutes for all tornado warnings issued during this outbreak. NWS employees performed exceptionally well throughout the event. The joint regional Service Assessment team found that employees went above and beyond to fulfill the mission, as events demanded quick decision-making to solve immediate problems. Several WFOs provided mutual aid to help meet the workload demand of the event. Tornado warnings and tornado emergencies were issued as needed by backup offices, in some cases without radar data from the primary office location coming into the Advanced Weather Interactive Processing System (AWIPS). NWS staff collaborated to provide exceptional services to maximize the protection of life and property.

Extreme weather events also highlight the importance of a consistent and repeatable approach to severe weather operations. This report points out several best practices, findings and recommendations from the offices interviewed and the after action reports they provided to the Service Assessment team. While some recommendations are highlighted in this report, the assessment team found many instances of offices doing an exceptional job in a highly stressful situation. The team found that Critical Incident Stress Management (CISM) became very important to office managers after this event. Finding and maintaining a positive environment for employees' mental health and wellbeing is also highlighted within this report.

[1] U.S. Billion-Dollar Disaster Events Summary | National Centers for Environmental Information (NCEI) (noaa.gov)

Table of Contents

Methodology

The NWS Central and Southern Region Headquarters formed a joint Service Assessment team on February 11, 2022. This 11 member team consisted of employees from WFOs, NWS Regional Headquarters, and the SPC. The team completed the following activities:

- Evaluated after action reviews (AARs) from and conducted remote interviews with the following WFOs and Regional Operation Centers (ROCs):
    - WFO Paducah, KY (PAH)
    - WFO Louisville, KY (LMK)
    - WFO Memphis, TN (MEG)
    - WFO St Louis, MO (LSX)
    - WFO Nashville, TN (OHX)
    - WFO Little Rock, AR (LZK)
    - WFO Lincoln, IL (ILX)
    - WFO Springfield, MO (SGF)
    - Central Region ROC (CR ROC)
    - Southern Region ROC (SR ROC)
- Conducted additional remote interviews with
    - Staff from the Storm Prediction Center (SPC)
    - Kathy O'Nan, Mayor of Mayfield, KY
- Evaluated the generation and provision of operational products and services
- Identified best practices and findings
- Made recommendations to address any service deficiencies

Facts, Findings, Recommendations, and Best Practices

The historic outbreak of December 10-11, 2021 brought forth the challenge of forecasting, warning for and messaging a tornado outbreak at a time of year when many in the public, and even our partners, do not normally associate with a threat for tornadic activity. The challenge of messaging the potential dangerous weather was further complicated by the fact that much of the severe weather was forecast to occur after sunset during some of the days with the shortest amount of daylight during the year. Dedication to the mission, and an exceptional level of performance in a high-stress and time-critical environment were fully displayed by those who served at affected WFOs, ROCs, and the SPC during all phases of the outbreak.

Storm Prediction Center

The potential for severe thunderstorms on Friday, December 10th, was first mentioned on Day 8 in the Day 4 - 8 Convective Outlook text issued on Friday, December 3rd, at 3:20 A.M. CST. Subsequent forecasts continued to discuss the potential for severe storms in the Day 4 - 8 Outlook text. The first graphical depiction of a risk area occurred with the Day 3 Convective Outlook issued at 2:15 A.M. CST on Wednesday, December 8th, approximately 60 hours prior to initial storm reports from the event. This graphical outlook placed an area from northern Louisiana northeast through western Kentucky and southern Indiana under a Slight Risk for severe thunderstorms. Primary uncertainties expressed in the Day 3 Convective Outlook related to the quality of boundary-layer moisture within the northward-advancing warm sector and variability in model guidance related to convective initiation.

At 12:58 A.M. CST on Thursday, December 9th, approximately 38 hours prior to the initial storm reports, the SPC upgraded the severe weather threat to an Enhanced Risk in the Day 2 Convective Outlook. The Enhanced Risk level was driven by a 10 percent tornado risk with a significant tornado hatched area, and a 30 percent severe wind probability area. At 10:49 P.M. CST on December 9th, the SPC collaborated with WFOs St. Louis, Central Illinois, and Springfield to issue an upgrade from a Marginal to an Enhanced Risk, for portions of their areas. The risk level was further increased to a Moderate Risk at the Day 1 Convective Outlook issued at 10:18 A.M. CST on December 10th. For this update (approximately 5 hours prior to the initial storm reports), the Moderate Risk featured a 15 percent tornado probability and a significant tornado hatched area. This upgraded outlook was collaborated with WFOs Paducah, St. Louis, Memphis, and Little Rock via AWIPS Collaboration chats. The issuing Lead Forecaster transmitted the outlook 12 minutes early in order to get the word out to public safety officials and the Weather, Water, and Climate Enterprise as quickly as possible. In addition, two Public Severe Weather Outlooks (PWOs) were issued on December 10th to further highlight the high-end tornado potential. The first PWO was issued at 10:27 A.M. CST, and the second at 2:01 P.M. CST.

A Convective Outlook progression graphic is presented in **Figure 1**, and all available SPC products issued from 1200 UTC on the 10th through 1200 UTC on the 11th are available online at: https://www.spc.noaa.gov/products/archive/index.php?date=20211210

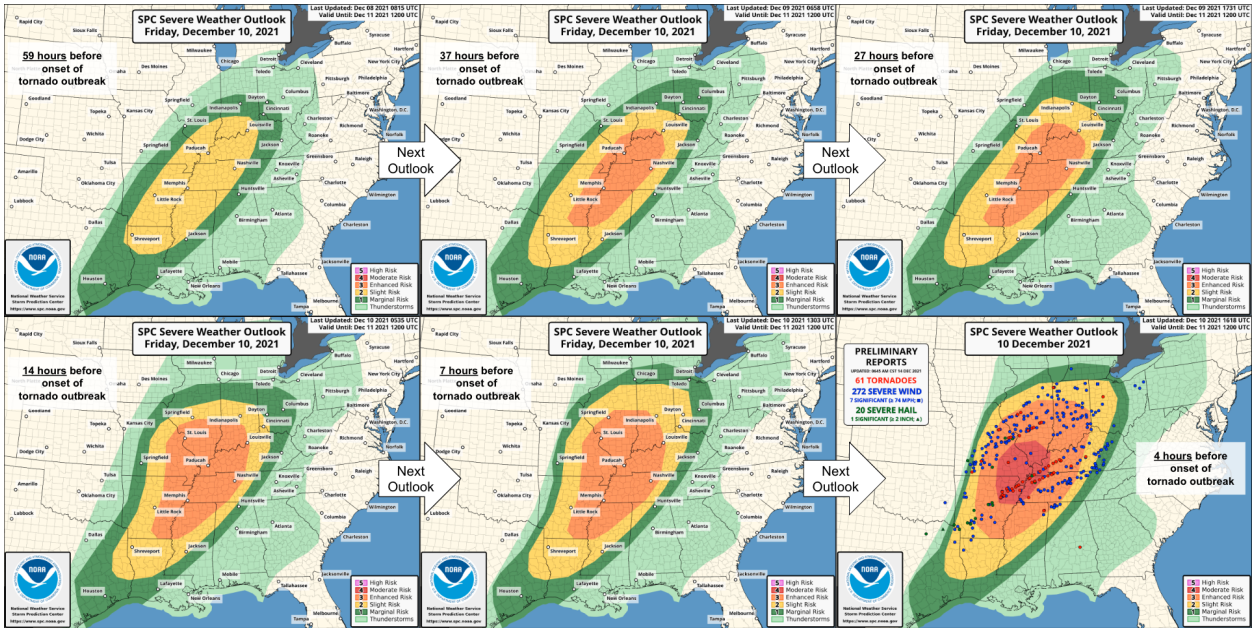

Figure 1. Progression of SPC Convective Outlooks, from 59 hours to 4 hours prior to the December 10th, 2021 tornado outbreak. Preliminary reports are included with the 1630z Convective Outlook (bottom right).

A forecast challenge for SPC forecasters preparing a Day 4-8 Convective Outlook is balancing the potential impacts of an approaching event with inherent uncertainties when assessing whether to introduce a 15 or 30 percent risk area. In a follow-up discussion after the December 10th outbreak, many of the affected WFOs met with the SPC Operations Chief and Warning Coordination Meteorologist (WCM) to discuss how best to resolve these challenges, and to encourage the depiction of graphical risk areas in SPC extended-range convective outlooks when confidence allows. SPC forecasters have learned over time that events with significant severe potential often fail to verify at higher severe probabilities due to any one of a number of potential failure modes, and this has led to an incremental approach in ramping up severe probabilities with time as an event approaches. To address this challenge, SPC forecasters had been evaluating machine-learning extended-range severe guidance during much of 2021. Evaluation of this emerging guidance suggests considerable value in highlighting risk areas prior to certain higher-end potential severe situations, especially when combined with expert forecaster assessment. This is especially true during the cool season since these events are often more strongly forced, and can have lesser convective contamination from prior days leading up to the forecast event. Operational use of this guidance in extended-range outlooks in early 2022 has resulted in very positive feedback.

Finding 1: The use of emerging medium range probabilistic, statistical and machine learning datasets allowed for a spectrum of severe convective scenarios/patterns to be identified at longer lead times to inform NWS internal operations planning and coordination, and earlier messaging and Impact Decision Support Services (IDSS) delivery.

Recommendation 1: SPC should continue to explore the use of emerging guidance to effectively balance potential impacts with forecast uncertainty when introducing or modifying risk areas in Day 4-8 Convective Outlooks.

As the severe potential evolved from December 6th through December 11th, the on-site SPC Liaison to the Federal Emergency Management Agency (FEMA) was routinely briefed. During these briefings, the SPC Liaison provided senior levels of national and regional FEMA leadership with timely updates to ensure an optimal readiness posture both prior to and during the event.

As thunderstorm development within a very favorable environment became increasingly likely, Mesoscale Convective Discussion (MCD) #1978 was issued at 1:35 P.M. CST on December 10th, stating that discrete supercell storms were expected to develop between 4:00 P.M. and 6:00 P.M. CST, and there was a 95 percent chance of watch issuance. The first of eleven Tornado Watches (**Figure 2**) issued for this event, Tornado Watch #552, was issued at 3:00 P.M. CST, valid until 11:00 P.M. CST, for an area from central Arkansas northeast through extreme northwest Mississippi, northwest Tennessee, western Kentucky, southeast Missouri, southern Illinois and southwest Indiana. The Tornado Watch mentioned the potential for intense tornadoes in the watch hazard language. This language can be configured by the issuing forecaster based on the probabilities contained in the Watch Probabilities product.

As the severe weather threat evolved, Tornado Watch #553 was issued at 5:20 P.M. CST for portions of central Missouri and west-central Illinois. This tornado watch was valid through 11:00 P.M. CST and highlighted the potential for intense tornadoes. Lead time from the issuance of Tornado Watch #552 to the initial EF-4 tornado touchdown in northeast Arkansas was approximately 3 hours 40 minutes, with approximately 6 hours 25 minutes of lead time prior to the tornado that severely impacted the town of Mayfield, Kentucky. Lead time from the issuance of Tornado Watch #553 to the EF-3 tornado touchdown at the Amazon Facility in Edwardsville, Illinois was approximately 3 hours.

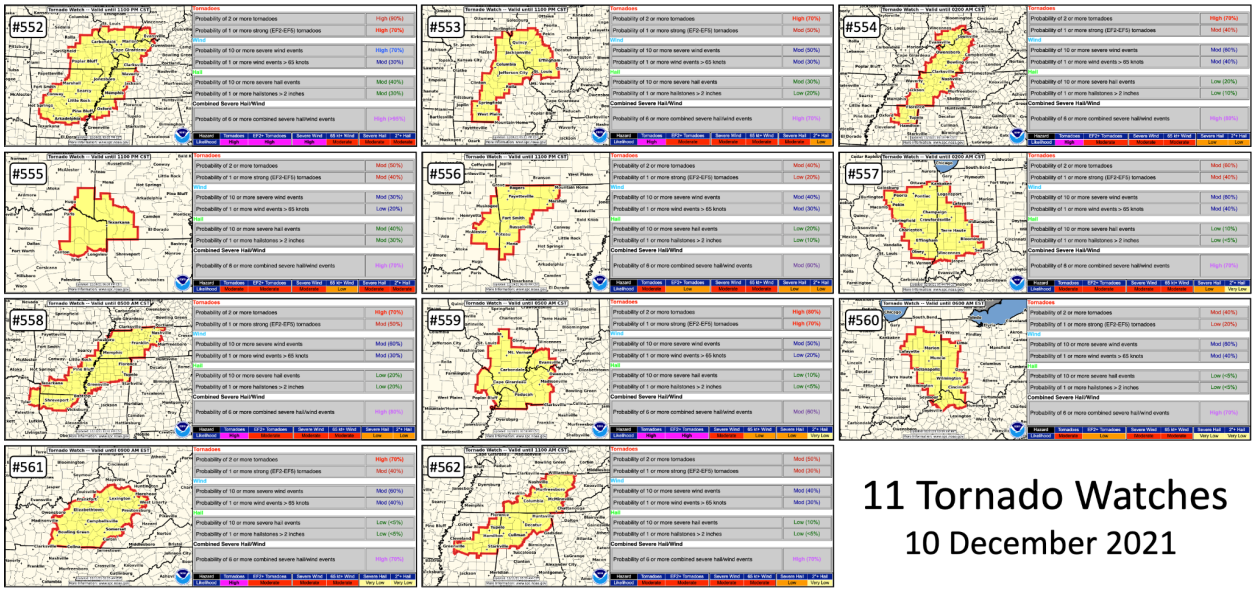

Figure 2: Social media graphics displaying all SPC Watches issued on December 10th and 11th. Full Watches from Dec 10th and Dec 11th.

An SPC strategic priority over the past few years has been to increase the flow of actionable information across the watch-to-warning continuum. This increase of actionable information is intended to aid WFOs in their planning and IDSS operations, and to benefit the Weather, Water, and Climate Enterprise as a whole. Dissemination of this information can take place in several arenas, such as the AWIPS Collaboration Chat, phone calls, and MCDs for areas that are smaller than those typically depicted in SPC mesoscale discussions (i.e., "sub-watch scale" or meso-beta scale). A summary of meso-beta scale MCDs issued during the outbreak is shown in **Figure 3**.

Finding 2: Some WFOs interviewed indicated that meso-beta scale MCDs with frequent updates were found to be exceptionally useful in supporting WFO operations.

Recommendation 2: SPC should ensure a consistent meso-beta scale MCD service from event to event, with clear expectations of when this service will be provided.

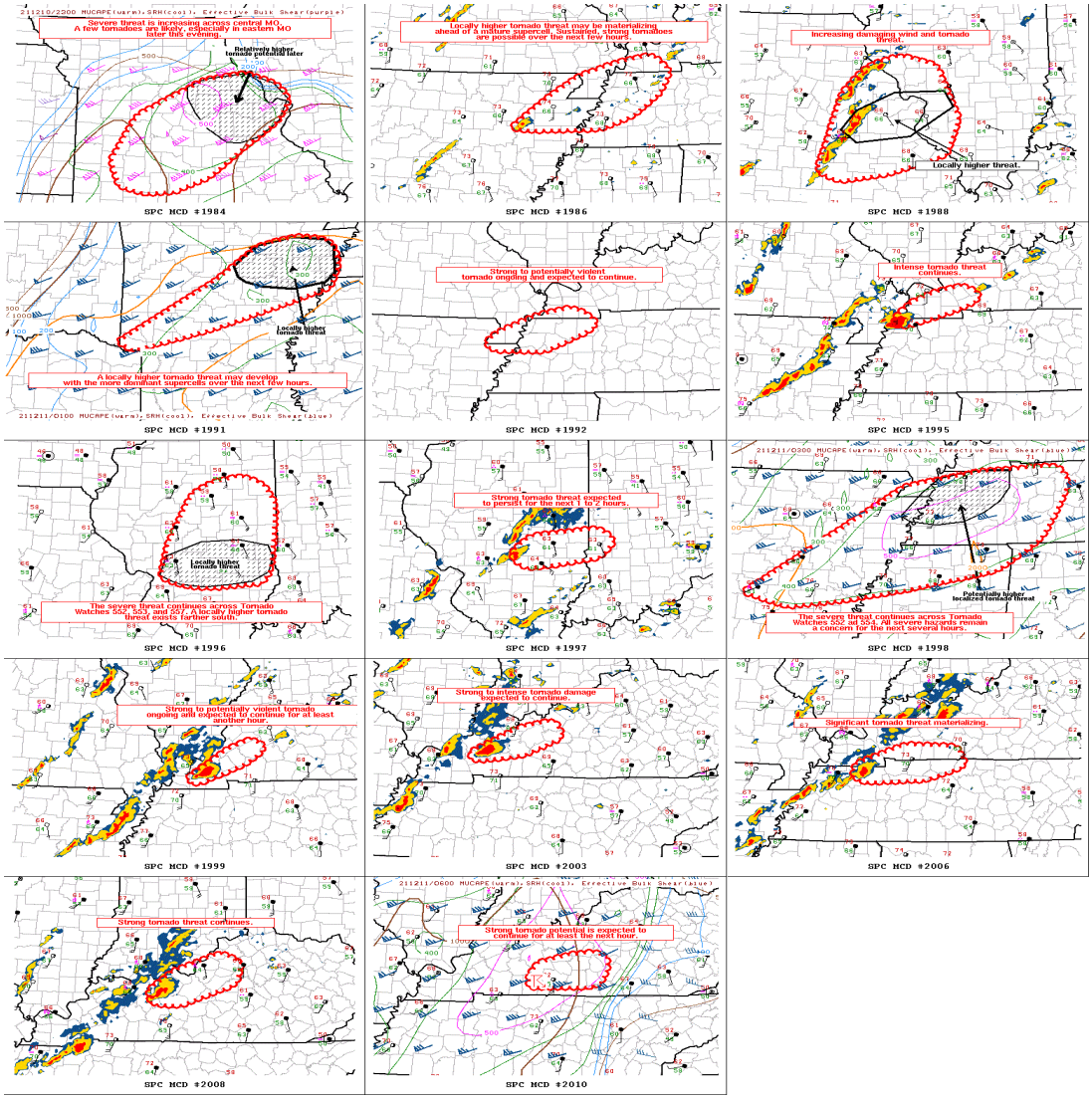

Figure 3: Highlighted meso-beta corridors of strong to violent tornado potential or a higher tornado threat.

During the December 10-11 outbreak, AWIPS Collaboration chat was used to convey likely expected tornadic wind speeds to WFOs based on the intensity and duration of observed rotational velocity couplets. Additional information communicated to WFOs via chat included the existing and downstream near-storm environment and the potential for storm-scale interactions to influence storm morphology. SPC Shift Log Entries of tornado-damage estimated wind speed information communicated to WFOs prior to and during initial tornado emergencies issued for the pair of long-track, violent EF-4 tornadoes are presented in **Table 1**.

Collaboration	Chatted MEG at 0125Z. "Based on Vrot and STP built from Smith et. al. 2021, that storm damage wind speed range is currently 135 to 180 mph in Craighead county." They replied "Thanks...it's insane right now..."
Collaboration	Chatted MEG at 0147Z. Based on longevity of the circulation, estimated damage is now 150 to 190 mph with that storm. They replied "Thanks"
Collaboration	Chatted Paducah at 0326Z. "Graves county storm has most likely tornadic winds of 135 to 180 mph based on the last 15 minutes of radar data based on Smith et al. 2021 dataset. If vRot stays above 70 knots for another 5 minutes, estimated wind speeds will increase to 150 to 190 mph.

Table 1: SPC Shift Log Entries of tornado-damage estimated wind speed information communicated to WFOs prior to and during initial tornado emergencies issued for the pair of long-track, violent EF-4 tornadoes.

During the afternoon and evening of December 10th and the early morning of the 11th, diversified methods were employed to communicate information regarding the favorability of the evolving near-storm environment, and the anticipation of the likelihood of a significant severe weather event to continue downstream. In particular, during the 8-hour evening shift of December 10, 2021, SPC mesoscale meteorologists issued an unprecedented 28 MCDs containing expert assessment of environmental conditions during the outbreak. This far exceeded the previous record for the most discussions issued within a single shift of 20, which previously occurred during the tornado outbreaks of April 27, 2011; May 19, 2013; and April 27, 2014. A chronology of all MCDs issued during the evening of December 10th is presented in **Figure 4**, and along with a detailed breakdown of their content in **Table 2**.

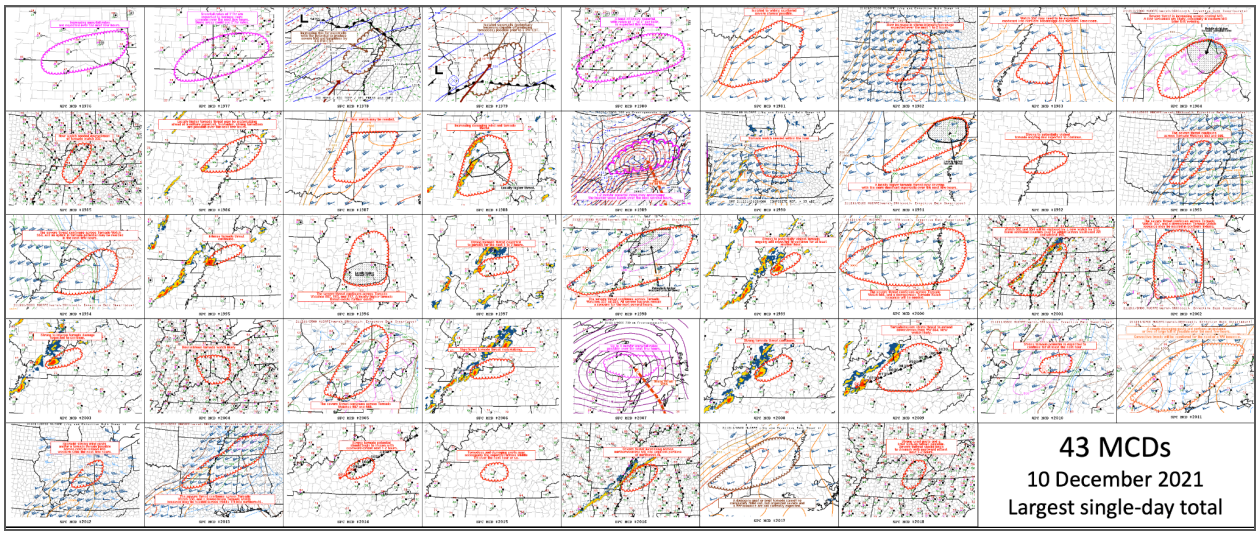

Figure 4: Social media graphics displaying all MCDs issued on December 10th. Full MCDs from Dec 10th and Dec 11th.

County	Peak rating	Start of EF-3 damage	End of EF-3 damage	MCD Number	MCD Issuance	Lead Time to Start of EF-3	Lead Time to End of EF-3	MCD tornado potential verbiage
Craighead AR - Lake TN	EF-4	0123Z	0232Z	1986	0022Z	**1:01**	**2:10**	Strong
				1992	0141Z	-	0:51	Strong to Violent
St. Charles MO	EF-3	0141Z	0141Z	1984	2327Z	**2:08**	**2:08**	Higher
				1988	0102Z	0:39	0:39	Higher
Madison IL	EF-3	0229Z	0229Z	1992	0102Z	**1:27**	**1:27**	Higher
Fulton - Ohio KY	EF-4	0301Z	0529Z	1986	0022Z	**2:39**	-	Strong
				1992	0141Z	1:20	-	Strong to Violent
				1995	0248Z	0:14	**2:41**	Intense

				1999	0348Z	-	1:41	Strong to Violent
				2003	0444Z	-	0:45	Strong to Intense
Gibson - Henry TN	EF-3	0448Z	0521Z	1998	0340Z	**1:08**	**1:33**	Higher
Logan KY	EF-3	0648Z	0709Z	2006	0536Z	**1:12**	**1:33**	Strong
Warren KY	EF-3	0716Z	0727Z	2006	0536Z	**1:40**	**1:51**	Strong
Marion KY	EF-3	0824Z	0824Z	2010	0705Z	**1:19**	**1:19**	Strong

Table 2: Lead time for MCDs that highlighted a tornado threat of ≥ EF-3 or higher during the outbreak (initial lead time bolded).

Weather Forecast Office Services and Findings

WFO Memphis included the first mention of the potential for severe weather in their Area Forecast Discussion (AFD) on Monday, December 6th:

"Friday we should be well into the 70s with some warm air advection showers possible. Guidance points to a front moving through the region sometime in the Friday/Saturday time frame. This looks like it could be another severe weather threat. We will have to watch this over the next several days to monitor the trends and evolution of this system."

Due to recent severe weather that affected portions of Kentucky, Tennessee, Missouri, Arkansas and Illinois days prior, WFO Paducah held its first conference call on Monday Dec 6th for the possibility of strong to severe storms to again affect the same areas. WFO Louisville, utilizing probabilistic datasets that will be further discussed in this report, also messaged the following headline in their AFD on Monday, December 6th:

"STRONG TO POSSIBLY SEVERE STORMS POSSIBLE FRIDAY AND SATURDAY WITH HEAVY RAINFALL AND POSSIBLE FLOODING CONCERNS".

With the issuance of the Day 3 Slight Risk outlook by SPC on Wednesday, December 8th, and the subsequent upgrade to an Enhanced Risk in the Day 2 outlook issued on Thursday, December 9th, multiple WFOs held conference calls with partners on both of these days.

Finding 3a: While some offices took a more proactive approach, others waited until Day 1 or 2 to ramp up services in part due to established playbooks.

Finding 3b: As probabilistic, statistical, and machine learning datasets and techniques continue to mature, high impact events can be identified at longer lead times with higher confidence compared to legacy thresholds/approaches.

Recommendation 3: WFOs should use probabilistic, statistical, and machine learning datasets and techniques to drive a "say what you know when you know it" services mindset, and provide as much lead time as is technically feasible.

Messaging began to accelerate with stronger wording of severe thunderstorms included in the Hazardous Weather Outlooks (HWOs), AFDs, and social media at all affected offices (**Figures 5 to 7**). The WFO Louisville AFD on December 10th at 3:34 P.M. EST[2] mentioned a "Significant Nighttime Severe Weather Event". WFO Louisville's discussion also recommended having multiple ways to receive warnings while asleep and suggested those in vulnerable housing consider alternate lodging. WFO Paducah included "a couple long-track tornadoes are possible" wording within their HWO[3] at 2:42 P.M. CST on Thursday, December 9th. Additionally, DSS Packets and/or partner emails highlighting the severe weather potential were sent. By this time, WFOs also began finalizing staffing plans for the upcoming event.

[2] https://www.weather.gov/media/crh/publications/AAR/20211210/20211210_LMK_AFD.txt
[3] https://www.weather.gov/media/crh/publications/AAR/20211210/20211210_PAH_HWO.txt

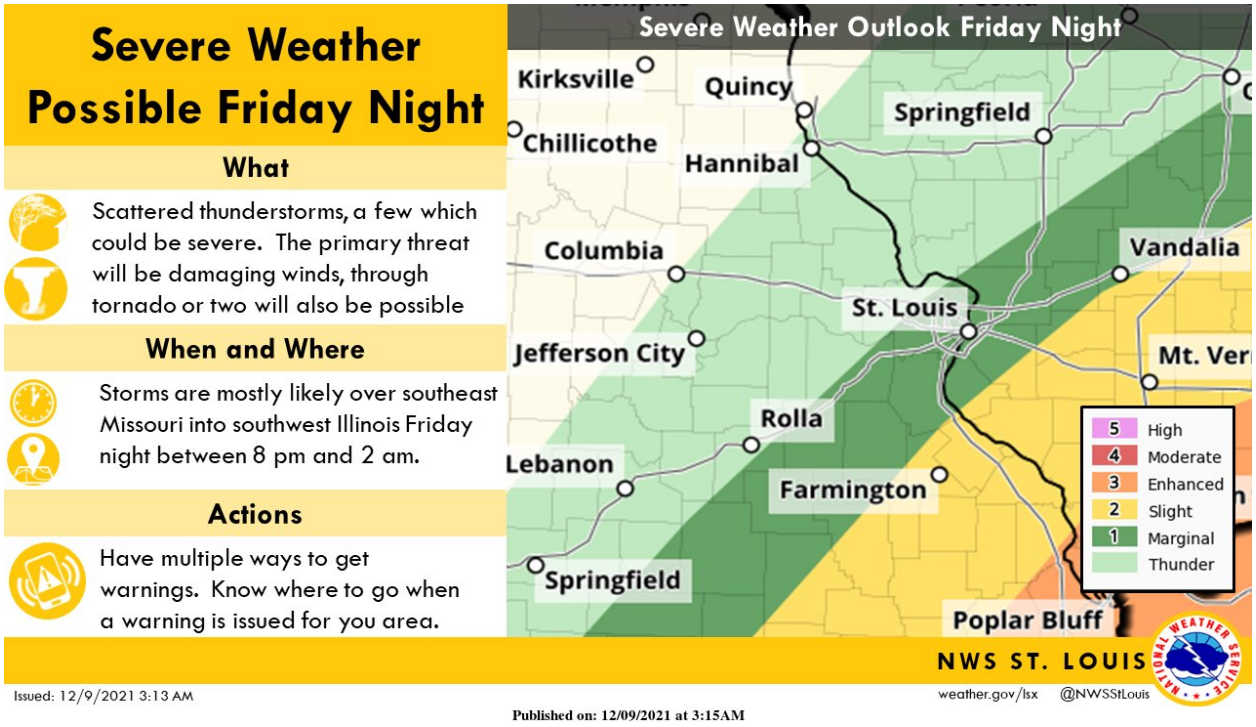

Figure 5: Forecast graphic from WFO St. Louis depicts the expected severe weather on Friday night, December 10th. Issued at 3:13 a.m CST. on Thursday, December 9th

WFO Memphis received positive comments on proactive messaging, which began in the morning AFD on Monday, December 6th. WFO messaging was proactive and hit on the conditional threat for early supercells and then the greater confidence in widespread overnight convection. WFO Memphis utilized Facebook Live in advance of the severe weather on Friday afternoon.

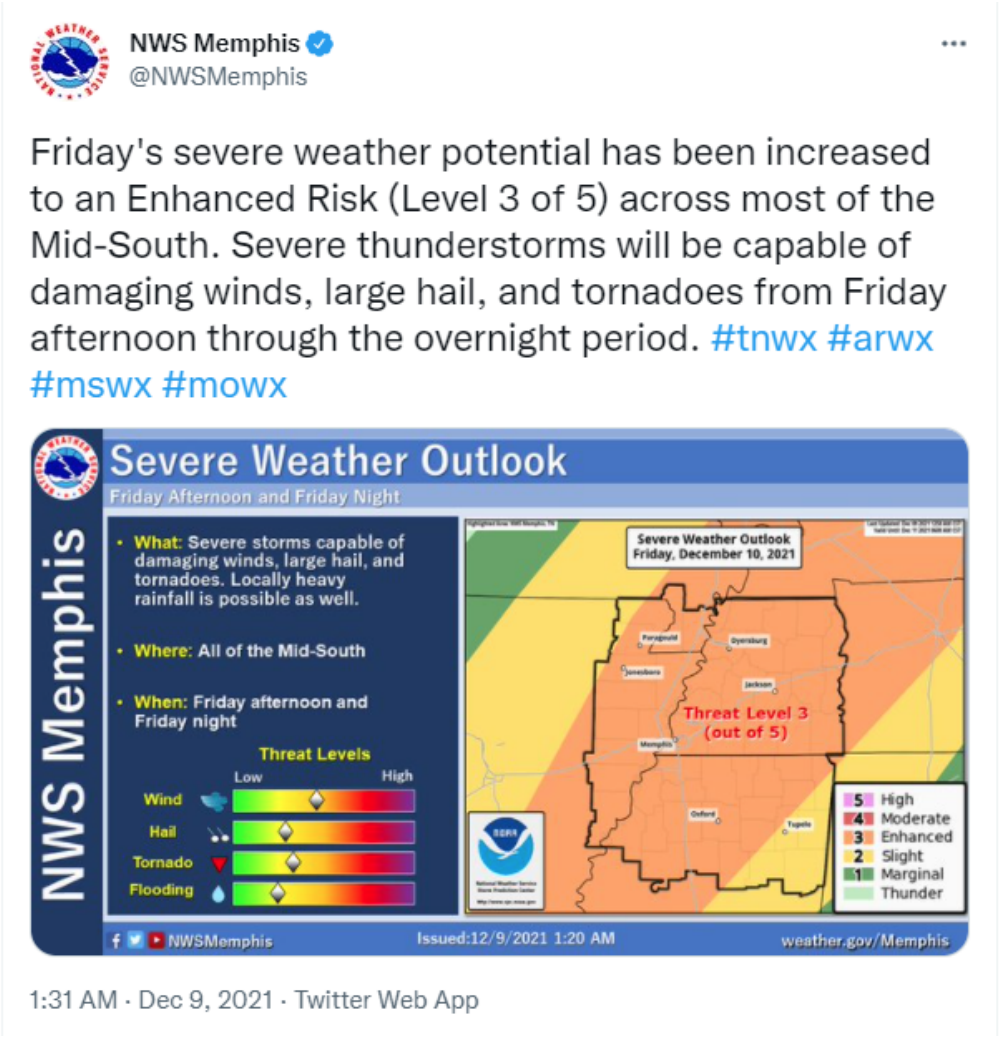

Figure 6: Forecast graphic from WFO Memphis depicts the expected severe weather Friday night, December 10th. Issued at 1:20 A.M. CST on Thursday, December 9th

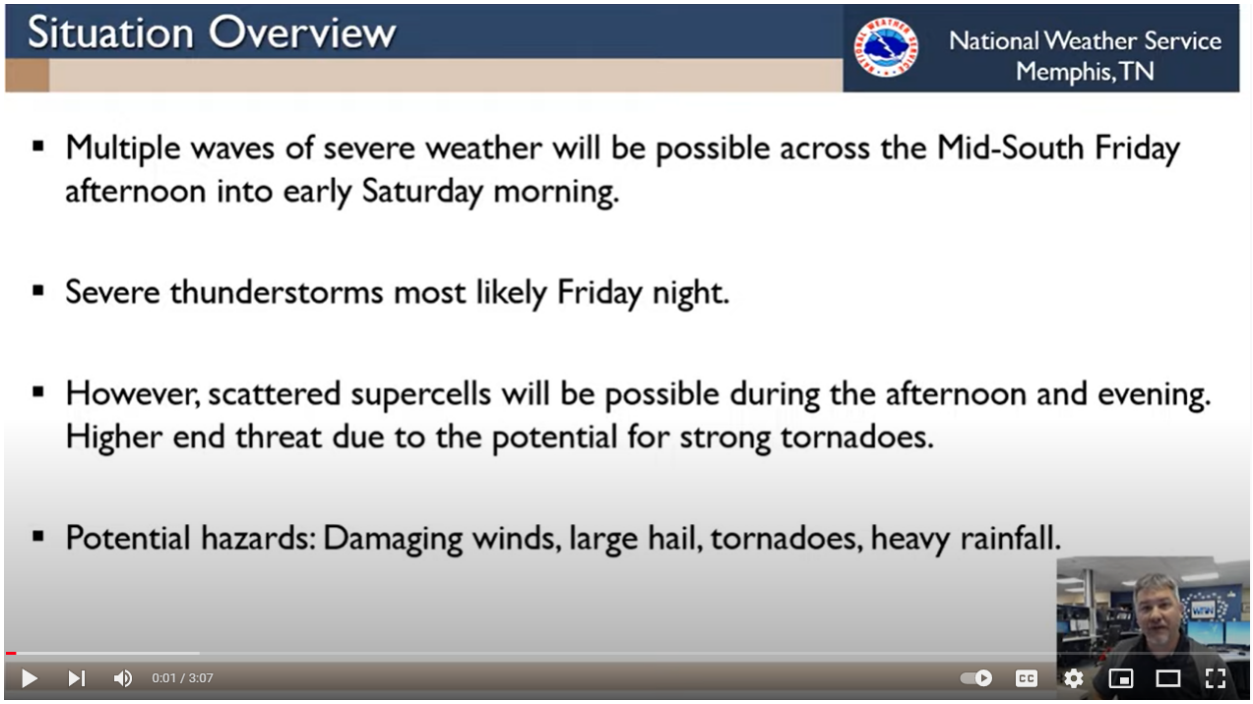

Figure 7: Slide from WFO Memphis video briefing for the event on Thursday, Dec 9th, with the mention of strong tornadoes.

Conference calls with partners continued through the morning of December 10th. The SPC upgraded the outlook area to a Moderate Risk with the 1630Z Day 1 Convective Outlook on December 10th. The messaging to the public increased through the day on December 10th with WFO Louisville including an "Important Messaging" section to their AFD as shown in **Figure 8**.

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Important Messaging
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As we have mentioned over the past 24 hours, we want to stress the
danger in the overnight severe weather potential.  Historically,
tornadic and widespread severe weather events in the month of
December are rare, although we've had a couple of events in the last
10 years (12/2013 and 12/2015).  We would like to emphasize the
following topics:

1. Have multiple ways to get warnings overnight.  Leave your cell
phone on and have WEA alerts turned on.  Check the status of your
weather radio and make sure it is functioning.  Charge/replace
batteries in your alert devices.

2. Review your severe weather plans for your household.  Review
where your lowest level interior rooms in your home are and have
space ready in there to shelter. Put as many walls as you can
between you and the outside of your home.  If you have a basement,
make sure a shelter space in an interior room or under substantial
framing is available and ready in the event of a warning.  Stay away
from exterior windows and doors.

3. If you live in a mobile home, consider finding a more substantial
shelter this evening with friends and/or family.  Even in non-
tornadic winds, gusts of 60+ MPH can easily flip mobile homes
whether they are tied or bolted down.

4. These storms will be moving quickly with speeds of 55 to 60 MPH.
Warning lead time on these storms could be a challenge especially
involving mesoscale vortices within the anticipated squall line.
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Figure 8: Important Messaging section in the WFO Louisville AFD on December 10th 3:34 P.M. EST issuance

WFO Paducah sent a tweet at 10:19 A.M. CST on December 10th that stated:

"No graphics with this post. Just straight from the office. From late afternoon on through tonight, be ready. This could be a significant severe event with a strong tornado or two across our region. Think about what you would do now. Better to err on the safe side."

A couple of offices also used Facebook Live as a platform to interactively discuss the situation and provide information on what people could do to help keep themselves and their loved ones safe.

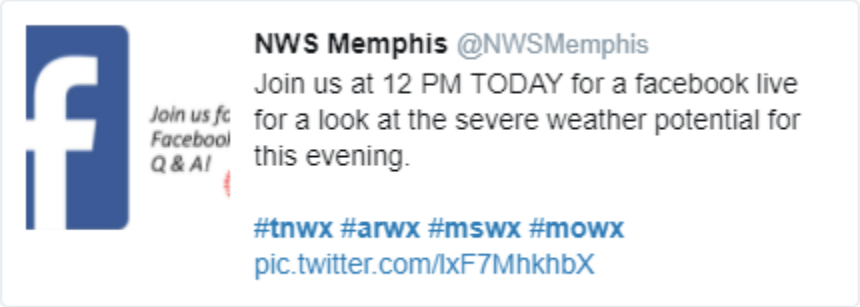


Figure 8: Tweet from WFO Memphis announcing the Facebook Live severe weather briefing.

WFO Louisville stressed within their social media posts the importance of having multiple ways to receive a warning, and included instructions on how to ensure a smartphone had WEA alerting turned on especially given the nocturnal threat as shown in **Figure 9**.

Figure 9: Graphics from WFO Louisville stressing the importance of receiving warnings.

WFO St. Louis also ramped up public messaging further, discussing the potential for potentially strong, long-track tornadoes while WFO Memphis highlighted the increased tornado potential (**Figures 10 and 11**).

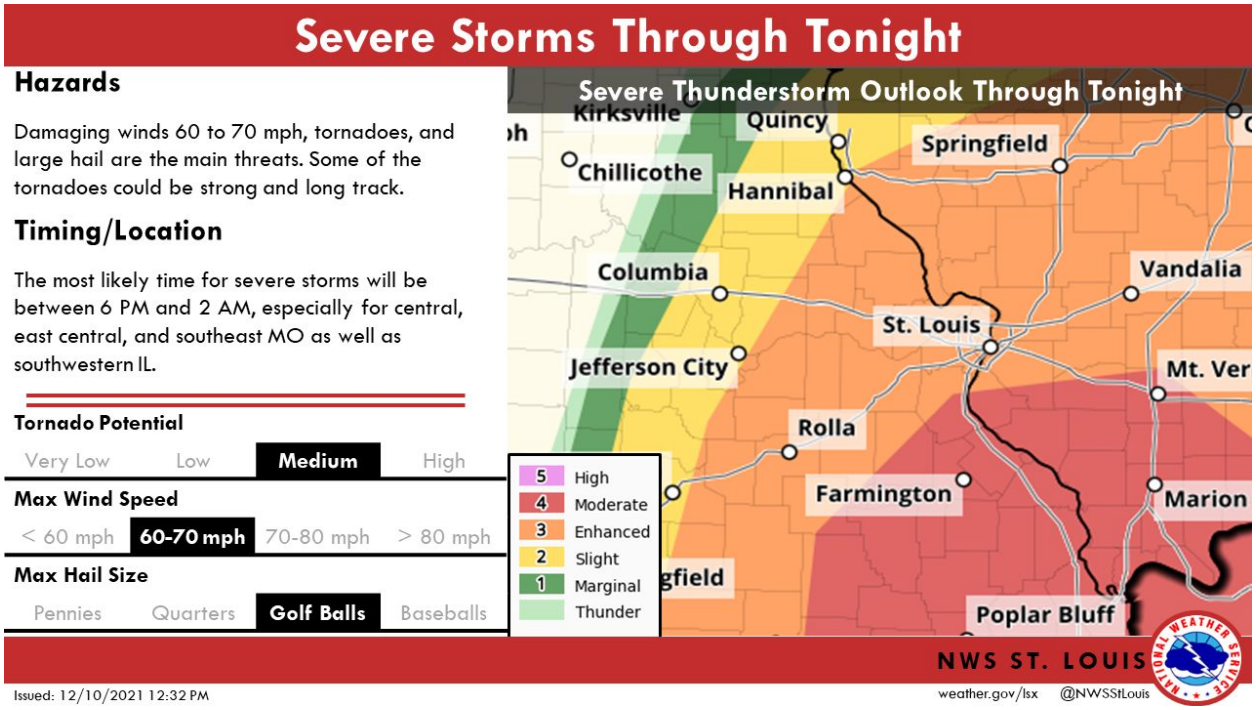


Figure 10: Graphics from WFO St. Louis highlighting the increased risk of severe thunderstorms.

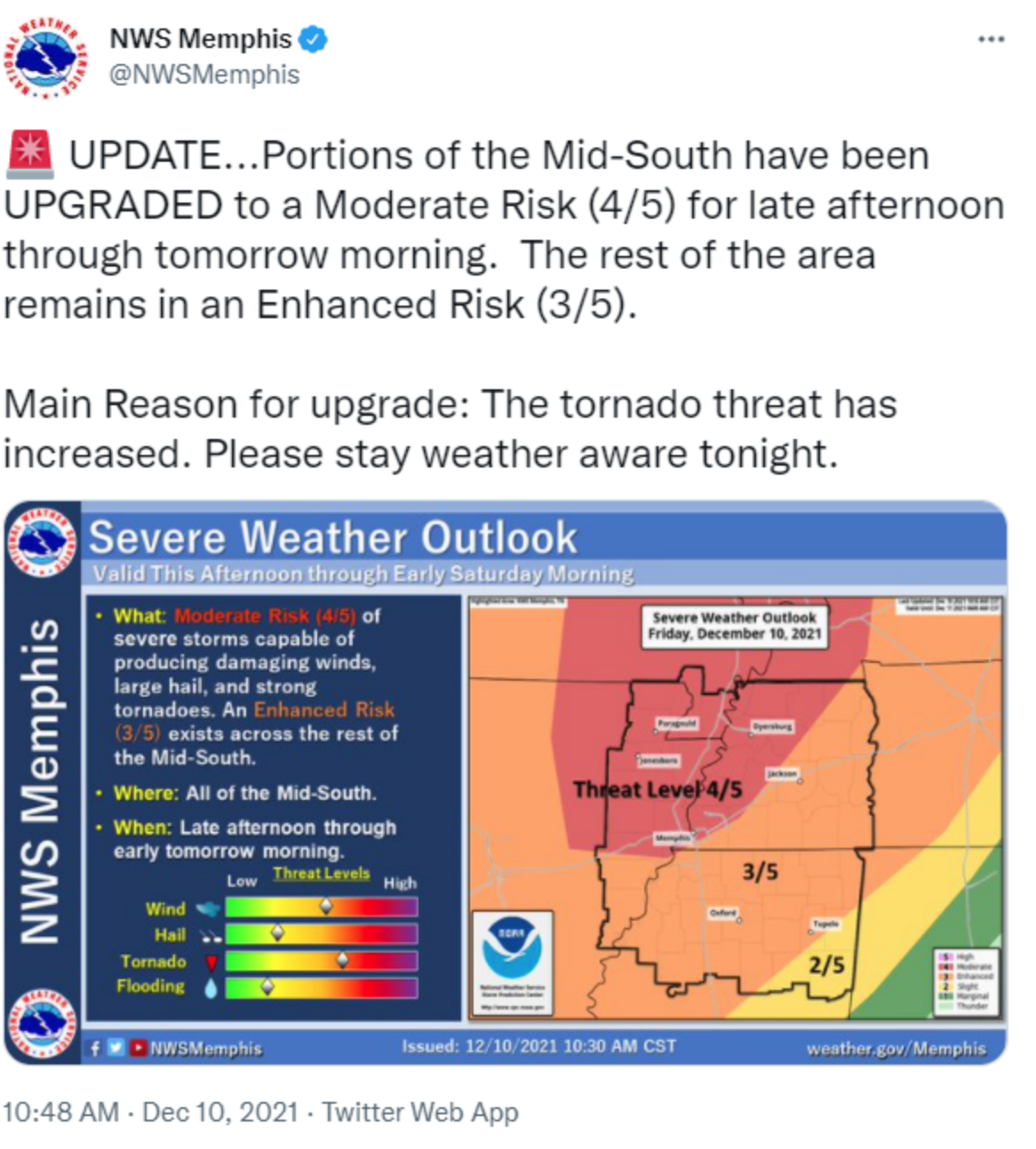


Figure 11: Graphic from WFO Memphis highlighting the increased risk of severe thunderstorms.

As the risk area expanded northward, WFO Lincoln included enhanced messaging within two Mesoscale AFDs during the evening of Friday, December 10th, highlighting the favorable tornado environment across central Illinois.

.MESOSCALE DISCUSSION...
Issued at 643 PM CST Fri Dec 10 2021

Deep low pressure is analyzed over NW MO this hour with a warm front draped to the east to near/north of Peoria to Bloomington. Within the warm sector, dew points have increased into the upper 50s to lower 60s which is contributing to seasonably strong instability moving into the region. Latest RAP indicates that 500-1000 J/kg overspreading most of central Illinois in the next few hours. Currently monitoring a broken line of storms moving across the Mississippi River. Strong winds aloft will result in bulk shear in excess of 60kt much of which is falling in the lowest 2-3 km. Backed surface flow, very strong effective SRH, and low LCLs of 500-750m all point to a favorable tornado environment over central Illinois. Do anticipate that additional weather watches will be needed downstream of Tornado Watch 553 which remains in effect until 11 pm this evening.

Figure 12: Portion of AFD from WFO Lincoln

.MESOSCALE DISCUSSION...
Issued at 923 PM CST Fri Dec 10 2021

As of around 915 PM this evening, severe threat continues but is shifting east of the I-55 corridor. Ahead of the main line of storms, the environment remains favorable for strong to severe storms including a few tornadoes. Latest SPC mesoanalysis shows seasonably strong 500-1000 J/kg MLCAPE up to roughly the I-74 corridor in central and east central Illinois. KILX VWP indicate 45- 55 kt winds as low as 2000 feet which is contributing to extremely strong shear values. In advance of the line of storms, effective wind shear values well in excess of 60kt is in place, much of this located in the lowest 2-3 km. Storms have evolved into more QLCS mode an a number of transient, northward migrating mesovortices have resulted in sporadic wind and tornado damage across the area and this threat continues into east central Illinois. Will need to monitor a particularly strong storm currently in Fayette County that will be passing into southern Shelby County and possibly northern Effingham County. Be sure to have a means to receive updated warning information late this evening and take shelter if severe storms approach your area.

Figure 13: Portion of AFD from WFO Lincoln

All WFOs discussed staffing plans and strategies well in advance of the storms. While each office had recommended staffing plans or levels in place, each office took the extra step to review their plans and adjusted accordingly. WFO Paducah stated in their AAR: “Staffing was planned well in advance with personnel sliding their hours or planning on coming in for the event. Just before the event started with the first supercell and knowing how the evening might progress, people were in roles where they would excel/where they had the most experience.”

WFO St. Louis produced a video that was tweeted right as the Tornado Watch was issued highlighting the dangers of nighttime tornadoes, using the recent Jefferson City tornado for reference. The first tornado warning of the event was issued by WFO Paducah at 5:28 P.M. CST on December 10th. While the storms were ongoing, Twitter was utilized effectively in highlighting the dangerous storms, particularly the fact that they were occuring at night. Radar updates were utilized to highlight areas of concern including radar-confirmed tornadoes. The mesoanalyst at WFO Paducah sent numerous messages on NWSChat between 4:30 P.M. and 7:30 P.M. including:

- “Models are really keying in on 6 to 9 P.M. for New Madrid/Mississippi in SEMO, far west KY and the southern tip of IL. Could be a cell or two in this area before then when the shear may be just slightly less. This will be an area to watch closely.”
- “Small cells continue to form near I-55 Sikeston, east in west KY. Through 6 P.M. severe is possible as we start to ramp up. From 6 or 7 P.M. to 11 P.M. latest data is concerning from New Madrid and Mississippi Co. northeast across west KY toward Henderson, KY. Tornadic potential increases…”
- “Seems the surface, boundary layer conditions are marginally favorable based on the lastest wind profiles from the radar and lingering weak capping. This should change rapidly through 9 P.M. increasing our tornado potential further. Surface flow still below 20 kts in gusts. Definitely showing the potential for what's to come.”
- “Update for those across west KY. The guidance has been focused on west KY by 8 or 9 P.M., and there's a Supercell near Jonesboro AR. This activity could be long-tracked as it moves into west KY. This storm will encounter an increasingly favorable environment for Tornadoes. There could be more than one Supercell storm.”

Between 7:30 P.M. and 8:45 P.M. CST, direct text messages were exchanged between WFO Paducah and the Emergency Managers (EM’s) of Hickman, Fulton, Graves, and Marshall counties in western Kentucky about the approaching supercell and strong confirmed tornado. This transitioned to verbal coordination with the EM’s in Hickman

and Graves counties. WFO Paducah indicated that they were becoming very concerned about the supercell storm over the Missouri Bootheel region and northeast Arkansas.

Finding 4: WFO Paducah used direct text messaging to communicate threats with partners.

Recommendation 4: WFOs should use all means to communicate higher end threats and life threatening situations. Clearly defined policies and procedures for direct text messaging of partners for short fused convective threats should be established.

WFO St. Louis contacted WFO Kansas City shortly before 7:45 P.M. CST to transfer warning operations as a tornado looked to potentially pass close to the office. The staff sheltered in the office safe room from 7:45 P.M. to 7:53 P.M. CST. A tweet was sent out showing the office taking shelter with the goal to convey that the tornado threat was real, and it was even impacting the staff at the WFO **(Figure 13)**.

Figure 13: Tweet from WFO St. Louis about the office taking shelter.

At 7:28 P.M. CST, two chats were sent from WFO Paducah, "Graves, Fulton, part of Hickman in the path of the Supercell approaching the MO Bootheel. Concern very high with this storm." and "845 to 9 pm arrival time." At 733 pm CST, a Special Weather Statement (SPS) was issued by WFO Paducah to highlight the high degree of concern regarding the long-track supercell over the Missouri Bootheel.

Finding 5: WFO Paducah issued an SPS well in advance of any severe storms entering their CWA.

Recommendation 5: Policy should be developed for consistent application of the legacy SPS, or other messaging approaches, as a tool to message threats in the "Watch to Warning Gap" as well as downstream of ongoing warnings.

Shortly after returning from sheltering, WFO St. Louis continued warning operations and issued a new tornado warning at 8:06 P.M. CST which included portions of the eastern St. Louis metropolitan area and portions of Madison County, Illinois. While a separate warning, this was in essence a continuation of the evolution of a supercell moving through the western side of the St. Louis metropolitan area. As the storm moved near the Mississippi River, the tornado appeared to be making its way towards Edwardsville, Illinois. WFO meteorologists saw evidence of debris on radar imagery at 8:29 P.M. CST, and communicated to partners in NWSChat.

02:32 <Jim Sieveking (NWS St. Louis)> TORNADO north/northwest of Glen Carbon moving toward Edwardsville!!! Issuing CONSIDERABLE tag given strength of the rotation and debris evident on radar (TDS)

Figure 14: NWSChat message from WFO St. Louis at 8:32 P.M. CST (02:32 UTC).

As the debris and additional evidence that Edwardsville was in the path of this storm, WFO St. Louis increased the number of NWSChat messages concerning the threat.

02:34 <Jim Sieveking (NWS St. Louis)> LARGE TDS (DEBRIS) between Glen Carbon and Edwardsville - TORNADO ON THE GROUND

02:35 <Jim Sieveking (NWS St. Louis)> TORNADO MOVING INTO EDWARDSVILLE

02:37 <nwsbot> LSX issues Tornado Warning [tornado: RADAR INDICATED, hail: 1.00 IN] for Macoupin, Madison [IL] till 9:15 PM CST ...AT 836 PM CST, A SEVERE THUNDERSTORM CAPABLE OF PRODUCING A TORNADO WAS LOCATED OVER PRAIRIETOWN, MOVING NORTHEAST AT 60 MPH.
Link: https://nwschat.weather.gov/vtec/#2021-O-NEW-KLSX-TO-W-0053

02:37 <nwsbot> LSX expires Severe Thunderstorm Warning for Franklin [MO]
Link: https://nwschat.weather.gov/vtec/#2021-O-EXP-KLSX-SV-W-0187

02:37 <Jim Sieveking (NWS St. Louis)> Tornado now east of Edwardsville moving toward I-55

02:40 <nwsbot> Local Storm Report by NWS LSX: 5 N Rush Hill [Audrain Co, MO] law enforcement reports TSTM WND DMG at 06:35 PM CST -- audrain county dispatch reported a tree down on hwy j near the hwy b intersection. time estimated from radar.
Link: https://nwschat.weather.gov/lsr/#LSX/202112110035/202112110035

02:41 <Jim Sieveking (NWS St. Louis)> Tornado has appeared to dissipate east of Edwardsville

Figure 15: NWSChat message from WFO St. Louis from 8:34 P.M. CST (02:34 UTC).

An Amazon warehouse suffered extensive damage from this tornado at approximately 8:27 P.M. CST. The tornado warning and additional information was provided approximately 25 minutes prior to the warehouse being hit.

At 8:29 P.M. CST, the initial tornado warning for Fulton County, Kentucky was issued with the confirmed Tornado and considerable Impact Based Warning (IBW) tags. At 9:05 P.M. CST, the initial tornado warning for Graves County, Kentucky, including the town of Mayfield, was issued. At 9:10 P.M. CST, the following Tweet was sent:

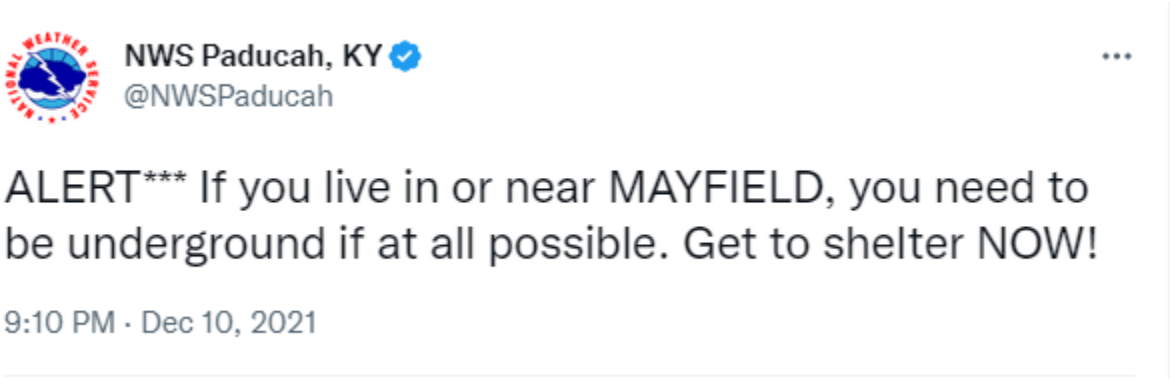


Figure 16: Tweet from WFO Paducah about the Mayfield tornado.

At 9:26 P.M., a Tornado Emergency was issued for Mayfield, Kentucky, and the EM for Graves County was contacted directly. A tweet was also sent messaging the situation.

Figure 17: Tweet from WFO Paducah about the Mayfield tornado emergency.

At approximately 9:25 P.M. CST, commercial power was lost at WFO Paducah and the backup generator failed. A call was made at 9:30 P.M. to coordinate with WFO Louisville about assuming backup operations. WFO Louisville confirmed that they could take over operations, but would need more staff. A follow up call 5 minutes later revealed that WFO Louisville was not able to get extra staff in time to handle backup operations. Secondary service backup was then initiated around 9:45 P.M. CST with WFO Springfield, Missouri assuming WFO Paducah's operations at 9:52 P.M. CST. WFO Paducah used cell phones to continue communications with both the CR ROC, to communicate information received about the tornado damage, injuries and fatalities and WFO Springfield, to continue relaying information for Local Storm Reports (LSRs). Additional details on the WFO Paducah backup are included on page 49 within the Information Technology, Network Infrastructure and Systems section.

The following tornado emergencies were subsequently issued between 9:45 P.M. and 10:44 P.M. CST by WFO Springfield while backing up WFO Paducah:

- 09:45 P.M. - A Tornado Emergency was issued for Benton, KY
- 10:17 P.M. - A Tornado Emergency was issued for Princeton, KY
- 10:31 P.M. - A Tornado Emergency was issued for Dawson Springs and St. Charles, KY
- 10:44 P.M. - A Tornado Emergency was issued for Earlington and Anton, KY
- 10:58 P.M. - A Tornado Emergency was issued for Bremen, KY.

In all, 57 fatalities occurred across the Paducah, Kentucky County Warning Area resulting in the highest number of fatalities recorded in the history of WFO Paducah.

As the activity began moving into the WFO Louisville forecast area, the office started sending out social media posts, chats, and calling the Ohio County EM ahead of the tornado warnings. During this time, the main supercell storm that impacted Mayfield, Kentucky began to weaken while a hybrid QLCS with embedded supercells moved across northwest Tennessee. This system briefly weakened before re-strengthening to produce an EF-3 tornado in northern Logan County, Kentucky. Sixteen fatalities occurred in a residential area on the southwest side of Bowling Green, Kentucky. The WBKO television station was on the air as the tornado passed 250 yards north of them. According to chief meteorologist Shane Holinde:

"The studio shook twice-the second time more violently-just before they lost power. A scary moment for everyone here. Once we came back up via a backup generator, my colleague and I resorted to drawing TOR polygons by hand on a blank map since all radar data was lost."

As the storm moved into the downtown Bowling Green area, a Western Kentucky University (WKU) White Squirrel Weather webcam was on the Situation Awareness Display at WFO Louisville. This webcam showed power flashes in real time. A decision was made by the warning team to go to a Considerable Tag in the Tornado Warning at 1:18 A.M. CST.

Figure 18: Power flash (highlighted by red circle) seen in realtime on the WKU White Squirrel Weather webcam in the operations area, occurring at 1:18 A.M. CST. Webcam faced west at the time.

Figure 19: Debris seen on the same webcam flowing toward the south during the Bowling Green tornado.

The storm went on to produce EF-2 tornado damage across south and southeast Bowling Green and EF-3 tornado damage in the vicinity of the Transpark industrial complex. Another EF-3 tornado caused a fatality in Taylor County, Kentucky. Additionally, a family of smaller tornadoes developed out of this cell in Boyle, Garrard, and Madison counties in Kentucky. Moderate to heavy rains were continuing behind the swaths of the supercells tracks, resulting in narrow areas of flash flooding. A fatality occurred in Franklin County, Kentucky, when a 62-year-old male drove his vehicle into high water and got washed downstream into North Benson Creek.

From the evening of Friday, December 10th through the morning hours of Saturday, December 11th, a total of 136 tornado warnings were issued for this event with a probability of detection of 96.4% across the eight offices included in this Service Assessment. Eight Catastrophic Tags were used for Tornado Warnings within the IBW framework, all of which were verified with significant tornadoes rated at EF-3 to EF-4. Specific findings and recommendations related to the software, guidance, policies and procedures of the warning process will be discussed in later sections.

Offices	Tornado Warnings	Probability of Detection	False Alarm Rate	Unwarned Tornadoes	Average Lead Time (minutes)	Initial Lead Time (minutes)
ILX	10	1.0	0.4	0	18.27	18.22
LMK	19	0.985	0.421	0	20.51	19.80
LSX	24	0.894	0.750	1	17.74	16.80
LZK	8	1.0	0.50	0	21.90	20.00
MEG	25	0.999	0.320	0	22.07	20.25
OHX	17	0.951	0.353	0	15.52	15.15
PAH	25	0.889	0.440	1	20.14	15.17
SGF	8	0.875	0.625	0	12.44	10.75
Total	136	0.964	.471	2	19.28	17.91

Table 3: Tornado warning statistics by the offices involved in the December 9-10 tornado outbreak. Official NWS verification data as validated by StormData.

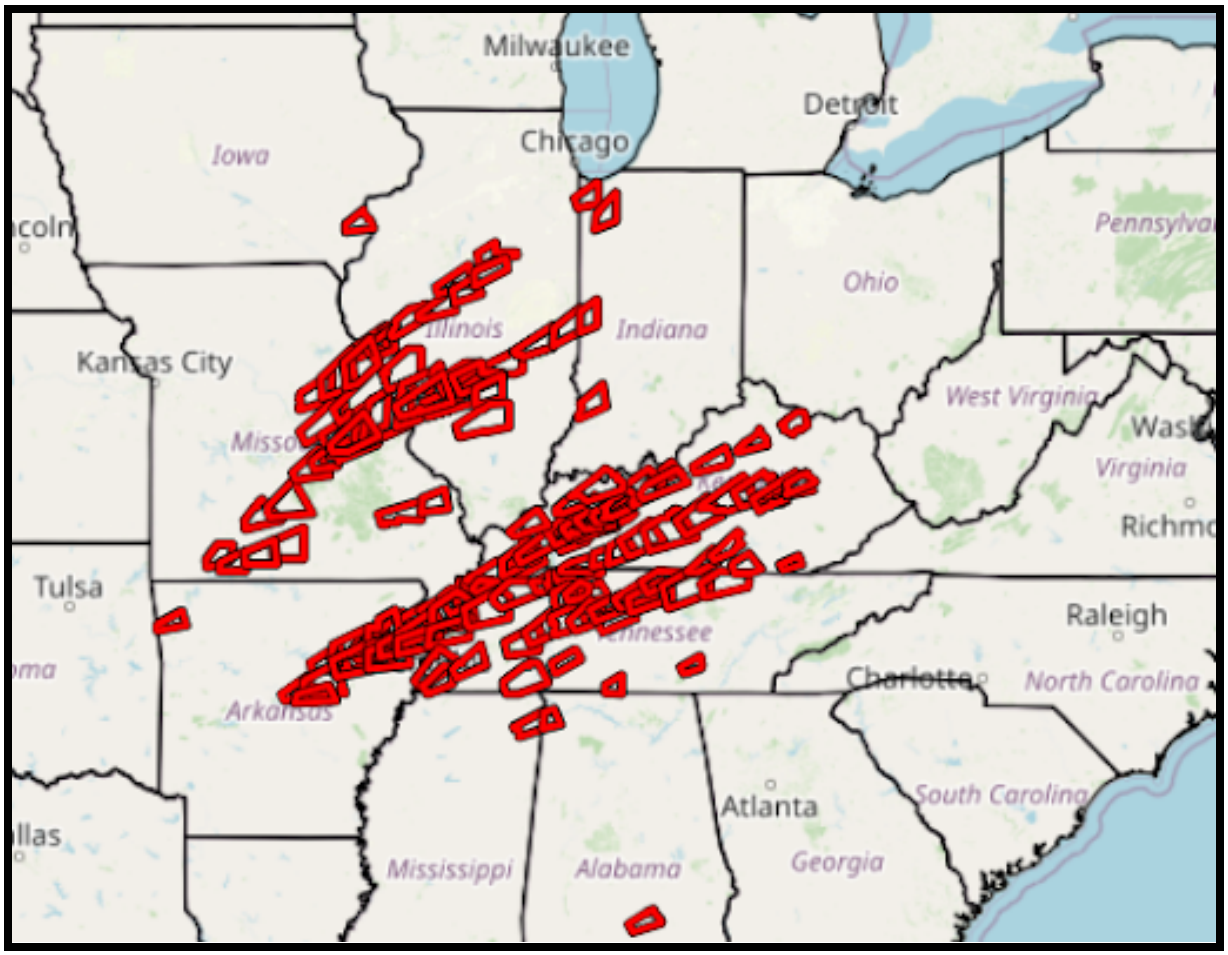


Figure 20: Tornado Warning polygons issued on December 10-11, 2021

The significant WFO post event efforts, including extensive damage surveys, will be discussed in the Mutual Aid section of this report. IDSS to impacted communities and responding agencies was continued by many offices in the days following the outbreak in support of search and rescue and clean up efforts.

It should be noted that a common theme was identified by WFOs in the post event of a gap in NWS safety outreach materials or resources for buildings with large footprints. This was identified as a result of damage and fatalities that occurred at large warehouse buildings during the event. From the WFO St. Louis AAR: *"The tornadoes of December 10th brought to light the need for increased outreach to local businesses, particularly large warehouse buildings where their large footprint and open nature of their buildings leave those working inside more susceptible to injury in severe weather…The NWS has very little outreach material to aid private companies in developing their severe weather plans and educating them on severe weather preparedness. While the Weather-Ready Nation initiative has proven to be an effective program for private industries, there is a lack of resources available to NWS to aid businesses in making their severe weather plans (no official NWS/Occupational Safety & Health Administration*

(OSHA) recommendations for severe weather sheltering guidelines in the workplace, no guidance on what types of warnings to shelter for, no differentiation in shelters for businesses with large warehouse construction, etc.).."

Finding 6: Multiple offices identified a gap in NWS safety outreach and resources related to buildings with large footprints, such as warehouses.

Recommendation 6: The NWS HQ Analyze, Forecast, and Support Office's Severe Weather Program should work with experts to develop materials with basic tornado safety guidelines for large facilities.

Regional Operations Centers

The CR ROC and SR ROC provide briefings to regionally-based Federal partners (e.g., FEMA Regions) as a part of routine IDSS. Per normal event cadence, there was increased contact with FEMA Regional Watch Centers to provide information ahead of and during the event. The ROCs used information primarily from the field offices and SPC to ensure that the FEMA Watch Center was able to anticipate how long the event would continue and how many states may need resources. Preliminary tornado track information was also provided to the FEMA Regions and the SPC FEMA Liaison to assist them with the prepositioning of response resources.

Several offices developed preliminary damage paths for the storms, working with the ROCs to produce damage paths for local, state and federal partners. For the storms on December 10-11th, several offices found the time steps available from Multi-Radar/Multi-Sensor (MRMS) were not sufficient to develop preliminary paths for the extreme length of these tornadoes.

Finding 7: Several offices mentioned that the MRMS time steps were insufficient for these long track tornadoes.

Recommendation 7: NWS should increase MRMS time steps within the tornado track tool, to help with long tornado tracks that are provided to FEMA. NWS should also provide the ability to overlay local storm reports within this tool.

Immediately following the outbreak, FEMA dispatched the National Incident Management Assistance Team (N-IMAT) Blue team to the Kentucky State Emergency Operations Center (EOC). Of note, this was the first dispatch of the N-IMAT within Central Region since the creation of the CR ROC.

Best Practice: The CR ROC divided up duties between the ROC Emergency Response Specialist (ERS) staff after this event, to more efficiently manage FEMA support needs, including Presidential Disaster Declaration (PDD) Summary requests, N-IMAT deployment coordination, and ongoing NWS support functions.

The ROCs and regional headquarters rely heavily on planning for events through the use of Incident Command System (ICS) principles. When a significant event is anticipated, the ROC will increase the operations level and enact the Regional Response Plan to ensure adequate staffing is available. In addition, it was also beneficial to establish in advance an after-hours point of contact for information technology (IT) and regional facilities needs in case such issues arose. The Regional Action Plan is required at an Operations Level 2 or 1 to ensure a reasonable span of control. During this event, Operations Level 2 was enacted by CR ROC, with expanded hours through the weekend and into the following week.

Finding 8: The proactive declaration of Operations Level 2 allowed the CR ROC to get a jump start on assessing potential staffing needs.

Recommendation 8a: The CR ROC should update the Regional Action Plan template to include a "one stop shop" of actions that should be taken or considered before, during, and after a significant weather event. Additionally, updates to the Regional Action Plan should include templates for different types of weather events, which would provide a starting point for common actions that may be unique to certain types of significant weather events.

Recommendation 8b: ERS staff should be as proactive as possible in anticipating future workload and potential requests in order to effectively manage incoming requests with ongoing or routine duties. Examples of proactive work include getting an early start on creating Significant Event Reports, FEMA PDD weather summaries, morning briefing slides, and the daily regional situation reports.

Finding 9: Offices found it difficult to manage travel after these storms, especially as deployments were found to be necessary.

Recommendation 9: ROCs should declare a Finance Section Chief and/or Deployment Unit Leader when expanding the ICS structure to assist with managing the logistics for additional damage survey team deployments if such a request is deemed necessary after a significant weather event.

Beginning in March 2020, the CR ROC had been working remotely under the mandatory evacuation order issued by the Department of Commerce (DOC). Due to rising COVID-19 cases, having multiple on-site personnel for this event was not encouraged unless the event could

simply not be managed remotely. Frequent and deliberate communication was vital as all ERSs were in different locations. Virtual communication methods, benefits, and shortcomings were established and practiced well ahead of the event due to the extended telework operations over the previous 20 months.

One of the benefits of remote operations is that staffing surges can be ordered quickly and staff can be nimble. However, one ERS reported on-site while the event was unfolding to ensure access to the Central Region Headquarters network and to establish a "home base" in the event of further escalation. Additionally, the concern over rising COVID-19 numbers across the entire country introduced hesitation into deployments for an in-person Quick Response Team (QRT) and additional damage survey team travel.

Telework was both a benefit and a challenge, but the Regional Staff was able to manage challenges well. Telework policies and procedures have evolved since this event, with the Regional Headquarters assisting local offices in subsequent events.

The near-simultaneous and relatively recent full stand-up of all of the ROCs has led to the need for routine communication, coordination, and relationship building between all of the ERS staff and ROC MICs over the past few years. Additionally, the ROCs have worked together during previous events to provide mutual aid as needed. During this event, national media interviews and international media requests for information and live interviews were shared among the CR ROC and SR ROC to meet the demand.

Due to the widespread nature of the severe weather impacts, there were numerous requests for information from FEMA regions, national and international media outlets, NWS Headquarters, and NWS Congressional Affairs. Talking Points were developed and shared with the impacted offices as a collecting point for damage survey updates to allow for timely and consistent messaging of the latest information to internal and external partners. A primary action of the ROCs was to maintain situational awareness, facilitate a steady flow of information from the field to NWS leadership, and maintain proactive talking points for national, regional, and local office PIOs. A separate set of talking points were prepared for NWS Congressional Affairs due to the high level of interest from State Officials, FEMA Administration, and the White House.

Finding 10: The proactive drafting of Talking Points and Significant Event Reports helped with effectively documenting critical event information and also prepared staff for formal information requests.

Recommendation 10a: ROCs should start developing a Talking Points document and/or Key Messages document early, after it is apparent significant impacts have occurred from a regional weather event. When there's a chance the significant weather event could garner national or international media attention, it's critical to have such documents ready and available before the increase in media requests occurs.

Recommendation 10b: The ROCs should suggest a strategy to the impacted offices on how to manage national and international news coverage. This could include offering to immediately deploy an Emergency Response Specialist to a Joint Information Center or State EOC to handle Public Information Officer (PIO) duties.

Mutual aid was coordinated from the ROCs and included forming a virtual QRT, which was followed by the deployment of several meteorologists to assist with storm damage surveys and on-site assistance. Additional assistance was provided to organize damage survey teams, develop a webpage to highlight damage survey results, interrogate high-resolution satellite imagery to assist with the damage survey assessment, and coordinate post-event Critical Incident Stress Management (CISM) resources.

Finding 11: The December 10-11, 2021 outbreak overwhelmed local office resources due to the demand for information, numerous damage surveys and local office duties.

Recommendation 11a: ROCs should take the initiative to find additional survey teams from neighboring offices in the event of a long-track tornado and present mutual aid options to the impacted office(s).

Recommendation 11b: During high impact events, the ROCs along with the Regional WCMs, should consider organizing a QRT ahead of any request should the office need it.

The CR ROC also assisted with the organization of the CR Remote Mesoanalysis chatroom (which will be discussed in the Mutual Aid section of this report) and other instances of remote mutual aid as requested by the field. The use of mutual aid during this event highlighted not only the diverse tasks that ultimately can be distributed to other offices, but also how willing staff members from other offices are to assist WFOs who are managing all aspects of a significant weather event.

Finding 12: Some offices stated that they would like for the ROCs to take a more proactive role in setting up the Remote Mesoanalysis process with the expectation that it will likely be a part of most severe weather event operations going forward. Several offices relayed their appreciation for the Remote Mesoanalysis initiatives.

Recommendation 12: The remote mesoanalysis process should continue to be grown across the regions.

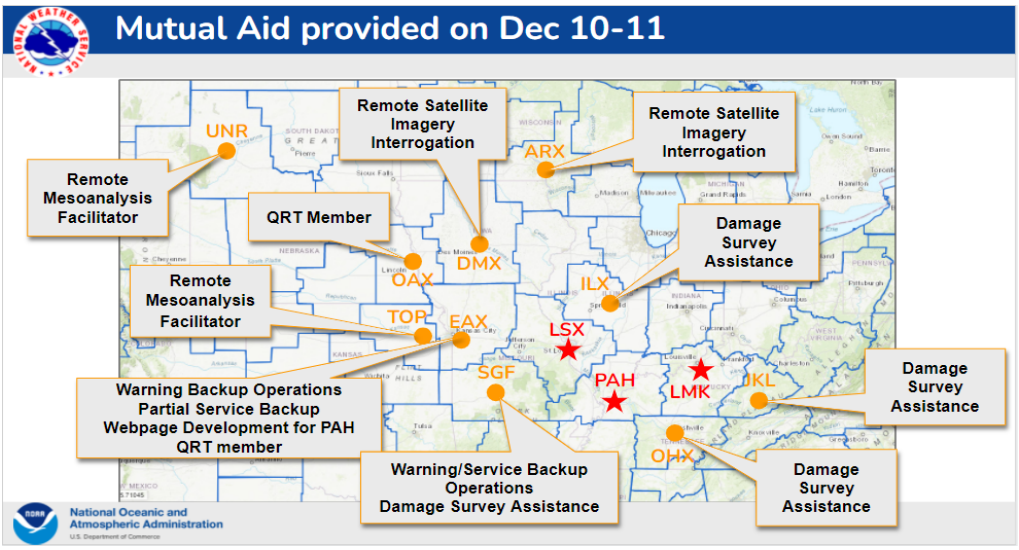


Figure 21: Mutual aid provided on December 10-11, 2021

Finding 13a: The ROCs played a central role in the coordination of various mutual aid requests submitted by the most significantly affected WFOs.

Finding 13b: The other affected offices were unaware of the mutual aid offered to WFO Paducah.

Recommendation 13: The ROCs should hold conference calls with all affected office management teams as soon as practical following the event to coordinate mutual aid.

As found in the 2020 Midwest Derecho Regional Service Assessment, it was identified early that a regional web presence and GIS mutual aid was needed. For events that span multiple CWAs, internal and external partners appreciate having one location to find information on the event. CR hosted a webpage where a summary of the event and links to the individual WFO pages were posted. Additionally through the Field Geospatial Intelligence Workgroup (GIW), a group of field GIS experts was assembled to help with mapping and documenting the event for a Story Map summary. Both efforts were pursued for this event, though there was a lot of improvisation.

Finding 14a: The regional Top News Story and regional coordination of GIS services lacked effective internal processes. The affected WFOs reported that they appreciate assistance with top news stories and social media graphics that take a regional perspective. This was also helpful for national and international media questions. However, manually posting the most current verified casualty numbers, track lengths, peak intensity, and other facts in sync with field office official reports was a full time job.

Finding 14b: Several GIS experts wanted to assist offices with mapping efforts, but procedures and organization were not yet in place to help multiple offices with one Story Map or with tactical mapping assistance.

Recommendation 14a: Future events should have this duty split off and managed by one person, nested under the PIO.

Recommendation 14b: The Field GIW should work with the Geospatial Integrated Work Team (GIWT) to develop a process for fielding requests for assistance.

Additionally, there were two significant IT issues and one significant equipment failure for which the ROCs provided support. NWSChat and ArcGIS® Survey123 (Survey123™) were both overwhelmed during the event. These issues were communicated to developers to ensure operational impacts were understood and needs were being met. The outcome was that additional capacity was added to both national systems to support the high volume. There was also a failure of WFO Paducah's generator as the event was ongoing. WFO Paducah and WFO Springfield worked together to ensure a seamless transition of services. These were also reported to the Region Facilities Branch to help begin troubleshooting. Details on these IT and equipment issues are presented in the Information Technology, Network Infrastructure and Systems section of this report.

Finding 15: The Assessment Team noted that office generators are aging. WFO staff stated that it is becoming increasingly more difficult to source parts needed for repair.

Recommendation 15: Offices should test generators ahead of potential significant weather events that may directly impact the office.

Mutual Aid and Forecast Collaboration

The events of December 10-11, 2021, demanded not just a whole office or whole region response, but rather a whole agency response. Coordinating the forecast and the message leading up to the event, supporting each other during the event, and meeting the demands and healing in the post event are all best done when we bring the collective power of our people to the

challenge. A greater eagerness and openness to asking for and providing mutual aid continues to become more apparent within the NWS. The outbreak of December 10-11, 2021 highlights well examples of what we can do when we support one another beyond our office or regional borders. A culture of accepting and giving mutual aid is the necessary foundation for the evolution of NWS operations.

Mesoanalysis Collaboration and the CR Remote Mesoanalysis Initiative

Mesoscale environment analysis has long been recognized as an important best practice for not only improved warning decision-making, but increasingly to provide actionable information within the gap between the watch and the warning phases of events. However, there can be challenges in locally staffing this role, namely:

- Sufficient mesoanalysis expertise available locally for the event
- The effects of multitasking by combining mesoanalysis with other operational tasks as workload increases during an event
- Over dependence on SPC's mesoanalysis page
- Effective target threat analysis to support targeted threat messaging

In recognizing the above challenges, CR set up a demonstration Remote Mesoanalysis (RMA) initiative in which mesoanalysis experts at offices where the weather was quiet could support offices involved in high-impact operations. This crowd sourced remote mesoanalysis initiative was born out of renewed emphasis on mesoanalysis, namely the Operations Proving Ground (OPG) Mesoanalyst Boot Camp and the Mesoscale Environmental Assessment (MEA) Course. The RMA is ultimately the culmination of a CR SOO group suggestion of enhancing operational mutual aid.

The RMA also fosters the growth of mesoanalysis knowledge and experience across CR, provides an avenue for peer-to-peer learning, provides critical storm environment information to offices who cannot staff an experienced mesoanalyst, and/or provides “second opinion” storm environment information to offices that are able to staff that position locally.

The RMA consists of an often facilitated chatroom to directly support severe weather operations and IDSS at requesting offices through remote mesoanalysis. The RMA’s program and infrastructure was developed in the summer of 2020, with a test run in support of five CR WFOs in November 2020. The RMA was officially launched across all of CR in March 2021.

During the December 10-11, 2021 outbreak, the RMA was active for a total of 13 hours and 45 minutes, officially supporting WFOs Springfield, St. Louis, Paducah, and Louisville. While SR

did not not operate a remote mesoanalysis effort during this event, SR is looking into expanding into this type of mutual aid.

There were several examples of the impact of the RMA on warning operations during the event including:

- Per WFO St. Louis, the RMA and SPC mesoscale updates helped increase confidence to issue longer than usual tornado warnings.
- Per WFO Springfield , the RMA support was valuable as the expertise of virtual mesoscale forecasters allowed WFO Springfield to utilize valuable staffing resources elsewhere.
- During the WFO Louisville office interview, it was stated that the RMA bridged the gap between the tornado warned storm in WFO Paducah's area while it moved into Louisville's area. The RMA gave the warning forecaster great confidence to put out longer length Tornado Warnings to increase lead time.

While the RMA was a clear success story of mutual aid in this event, facilitation of large events supporting multiple offices brings a challenge of potentially overwhelming a single facilitator and not being able to provide equitable service to all participating offices.

Finding 16: The CR RMA effort proved to be a mutual aid success story during this event in supporting local office efforts to provide better mesoscale threat recognition.

Recommendation 16: Ongoing coordination between SR, CR, national STI, and SPC should continue to merge various streams of remote mesoanalysis initiatives to provide a consistent and supported program that cross cuts regional and national center boundaries. Since facilitators can generally only participate when their local workload is low, having the regional entities work together will yield a larger pool of individuals to provide continuous mutual aid availability.

Finding 17: On site and remote mesoanalysis was found to be valuable for increasing confidence of WFO warning forecasters.

Recommendation 17: WFOs should ensure they incorporate a mesoanalyst role, and the regions should incorporate a mutual aid approach to mesoanalysis, such that participating staff are fully trained through the MEA Course and/or local office/region focused mesoanalysis training.

Forecast Collaboration

It is clear from discussions with the WFOs impacted by this event that state liaison offices have established robust partnerships with their state government emergency management and response partners. In most cases, the state liaison office has collaborated with all the WFOs serving the state to ensure they are providing one clear, consistent message to the state, while also giving

each WFO a voice in the process. While there does not seem to be a one size fits all approach to providing briefings or products to meet our state government partners needs, each state liaison office has found a solution that works for them and for the other WFOs in the state.

For example, WFO Nashville reported that a state level briefing is triggered whenever two or more CWA's in Tennessee will be impacted by severe weather. Briefings were then provided every two hours to the state level government partners. Similar collaboration efforts have taken place with the ROCs. One example is the service provided to the FEMA regions. While Kentucky falls within FEMA Region 4, FEMA Region 4's headquarters are located in Southern Region's domain. Therefore, the SR ROC is their primary NWS partner. However, the CR ROC provides briefings and information for the state of Kentucky. Another example of collaboration during this event was that both the CR and SR ROCs served as facilitators for collaboration with the SPC.

Office to office collaboration is widely accepted and utilized to ensure a consistent message to our core partners and to the public. One critical use of office to office collaboration was exercised during the time WFO Springfield was backing up WFO Paducah. WFO Paducah used cell phones during the service backup to maintain contact with WFO Springfield and with the CR ROC. The WFO Paducah communications outage and resulting service backup during critical warning operations will be discussed later in the Information Technology, Network Infrastructure, and Systems section, beginning on page 49.

Post-Event Long Duration Storm Survey Efforts and Mutual Aid

The extensive areas impacted by damaging tornadoes, including multiple population centers, demanded storm survey efforts that spanned days to even weeks. At least one of the affected offices noted that the expansive area of catastrophic damage stretched the resources of the local office beyond their capacity. Short daylight hours in December, cold weather, internet connectivity challenges, and the weight of critical incident stress all compounded the strain of the survey workload and other post event support.

In order to survey damaged areas more efficiently, a mutual aid approach was utilized in the post event to help affected offices. Additionally, a QRT was activated to aid in surveying suspected damage that could be in excess of an EF-3 rating. WFO Kansas City called WFO St. Louis and provided partial service backup on the day after the outbreak. This allowed the WFO St. Louis staff to focus on post-event duties by deploying two storm damage survey teams, instead of just one, which helped expedite the publishing of survey findings by the end of December 12th. WFOs Lincoln, Springfield, Jackson (Kentucky) and Nashville provided additional staffing to WFOs Paducah and Louisville for storm damage surveys. On Sunday, December 12th, the Paducah office requested the activation of the QRT. WFOs Omaha and Kansas City provided staffing to the QRT. While initially working remotely, it was requested during the evening of

December 12th that the QRT be in person. It was noted that the QRT chat room was essential during and after the damage assessments.

Finding 18a: Extensive storm survey campaigns that spanned multiple days placed a significant strain on staffing, and took a large emotional toll on those who witnessed days of human suffering and damage. Events of this magnitude can quickly overwhelm the resources of even the most experienced and fully staffed offices. For some of the impacted offices, the demands for information on storm damage survey results from the media and public challenged the ability to provide social media updates on the progress of the surveys.

Finding 18b: Post-event mutual aid was a necessity for offices to respond and support the post-event. However, complexities still remain regarding proactive coordination of mutual aid resources between the field and regional levels.

Recommendation 18: Comprehensive pre, during, and post-event mutual aid plans should be established with clear and consistent coordination procedures between the field and regional levels with an emphasis on proactive, not reactive, mutual aid mobilization.

Finding 19: Damage surveys were conducted by NWS personnel that were inexperienced with surveys. This was done out of necessity to ensure enough personnel were available.

Recommendation 19: Coaching and clear expectations should be provided to staff that are inexperienced in conducting damage surveys.

Finding 20: WFO Kansas City office called the St. Louis office the day after the tornadoes and offered partial backup services for routine forecasts. This enabled WFO St. Louis to maximize employees on damage surveys.

Recommendation 20: Service backup should be used after larger-scale events to mitigate the strain on staff performing post-event assessments.

Science, Guidance, and Training

Central Region Tornado Warning Improvement Project (TWIP) and the Southern Region Severe Weather Operations Team (SWOT)

CR began the Tornado Warning Improvement Project (TWIP) as early as 2017, highlighting best practices to improve tornado warnings. SR chartered the Severe Weather Operations

Team (SWOT) in 2020. The CR TWIP became the Convective Warning Improvement Project (CWIP) in 2021 to holistically address all convective hazards. Several similarities between the two projects were found. Several instances of the efforts and initiatives of these teams were noted for their positive impacts to warning operations during the December 10-11, 2021 outbreak.

Finding 21a: The application of advanced dual pol signatures and tornadogenesis concepts from the CR CWIP Supercell Tornadogenesis guide led to proactive tornado warning issuance. There was specific discussion on the WFO Springfield operations floor regarding uninterrupted Zdr arcs giving the warning forecasters high enough confidence to proactively issue new tornado warnings in a high storm relative helicity environment versus waiting for strong rotational velocities.

Finding 21b: The recommended training and concepts from the TWIP and SWOT were found to be effective in operations during this event.

Recommendation 21: WFOs should make full use of SWOT and CWIP training and tools to infuse the latest science and technology into warning operations**.**

The vast amounts of data and the required analysis and decision points in modern warning operations demands a team approach. This includes increased low level scan frequency with Supplemental Adaptive Intra-Volume Low Level Scans and Mid-Volume Rescan of Low-Level Elevations, advanced dual pol tornadogenesis techniques,the Quasi-Linear Convective System Three Ingredients Method, local and even remote mesoanalysis information, one-minute Geostationary Operational Environmental Satellite imagery, proper application of Impact Based Warnings, reports via social media and spotters, and simply keeping track of warning issuance and update times.

Finding 22a: Radar teams (also known as warning teams), consisting of a primary radar operator and an assistant, were used at many offices to navigate the complexities of the modern warning environment to provide high levels of service with a team approach at its foundation.

Finding 22b: The amount of information available to and decision points required of the warning forecaster necessitates the use of warning teams to the greatest extent possible.

Recommendation 22: WFOs should outline within their Severe Weather Operations Plans (or their equivalent Station Duy Manual chapters or Operations Playbooks) the use of warning teams to the greatest extent possible.

Probabilistic Datasets and Tools

At a Joint Winter Weather Workshop held by the CR Southeast Community's Science and Operations Officers (SOOs), a new forecast process approach was presented, with examples using available tools to highlight medium to long range threats. This workshop was held on November 30, 2021, and each of the Kentucky offices participated. The ensemble tools presented during that workshop included the Ensemble Situational Awareness Tool (ESAT), the ECMWF Extreme Forecast Index (EFI) and Shift of Tails (SoT), and WPC Cluster Analysis.

Many of these tools were immediately useful in highlighting the very anomalous nature of the December 10-11, 2021 storm system. The EFI in its Day 7 forecast (**Figure 22**) highlighted a very anomalous CAPE and CAPE-Shear (CAPES) environment along with very unusually warm temperatures. In addition to the high CAPE EFI values, the SoT had contours of 2 over western and central Kentucky, again indicating how far above model climatology this event could be.

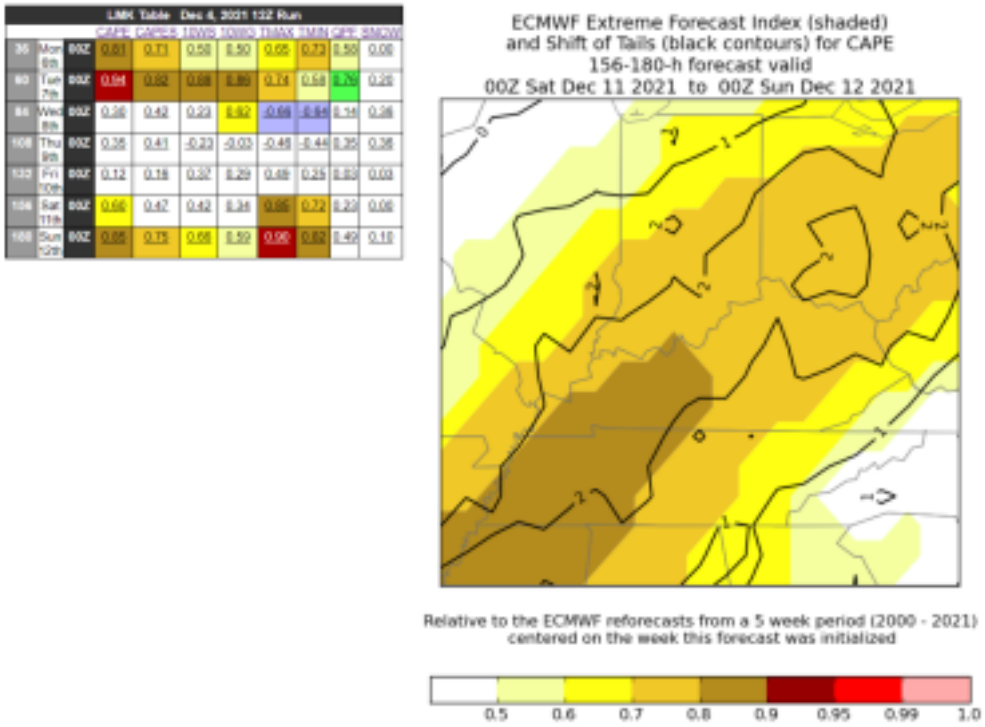


Figure 22: *The EFI for the 156-180 hour forecast with high values in the matrix (left image) and also a SoT contour of 2 (right image) for CAPE, indicating how far above climatology this event could be.*

The high EFI and SoT signal remained consistent as the event approached. Based on these signals, by December 8th, the WFO Louisville 5:40 A.M. AFD[4] mentioned,

"Compared to the previous event [12/6], there will be more instability to work with, higher Td, and stronger shear. Confidence continues to grow as there has been run to run model consistency…as well as indications in our ensemble awareness tools that an anomalous event could occur." At this point, we started sending out partner briefing emails.

Finding 23: Marrying probabilistic datasets with foundational conceptual models and pattern recognition in a modern forecast process allowed these offices to achieve high impact, scenario based threat recognition and messaging at longer lead times.

Recommendation 23: Training on Medium range (Days 3-8) convective forecasting with an emphasis on existing and emerging probabilistic, statistical, and machine learning approaches married to pattern recognition should be delivered to ensure consistent competency and application of medium range convective hazard recognition to inform longer lead IDSS.

Tornado Warning IBW Methodology, Philosophy, and Mechanics

Eight Catastrophic IBW Tornado Warning Tags, or Tornado Emergencies, were issued during the event. All verified with EF-3 and EF-4 tornadoes. When considering both Considerable and Catastrophic IBW Tornado Warning tags together, 71% were verified with EF-2 to EF-5 tornadoes, with 93% verifying with EF-1 to EF-5 tornadoes. 48% of EF2-5 Tornadoes and 76% of EF-3 to EF-5 tornadoes occurred within a Considerable or Catastrophic tag. There were no unwarned EF-3 to EF-5 tornado events.

However, inefficiencies and inconsistencies were noted across offices regarding the IBW methodology, philosophy, and mechanics for using the Catastrophic Tag within a Tornado Warning. In their after action review, WFO Springfield wrote about issues while backing up WFO Paducah: "Cities downstream of the Mayfield warning were often not part of the WarnGen warning template output or pathcast lists. GR2 was used to determine the Tornado Emergency threat. Further, while locations in the Tornado Emergency headline are manually entered, these cities/towns failed to be designated in the Pathcast bullet causing the statement to read 'rural areas'."

[4] https://www.weather.gov/media/crh/publications/AAR/20211210/20211208_LMK_AFD.txt

Finding 24a: Inconsistencies in cities mentioned in the Pathcast, and those mentioned specifically in the Tornado Emergency headline remain. WarnGen Pathcast will not list a city if the "Drag me to Storm" is calculated to be already past the city due to interpolation of the storm motion between volume scans. Thus, in very near time scenarios even if a forecaster places the drag me to storm upstream of the city on the latest radar scan being used, that city may not get a Pathcast mention if the drag me to storm is interpolated past the city (i.e. placing the drag me to storm using a scan that is three or four minutes old, and thus the drag me to storm is being interpolated further downstream based on the current time). This issue is made worse with rapid storm motions.

Finding 24b: WarnGen does not give arrival times within the Pathcast for Tier 3 cities/towns. This is often the case when warnings occupy mostly rural areas, and the smaller Tier 3 cities/towns make up the majority, if not all, of the locations in the Pathcast of the storm.

Recommendation 24: While Hazard Services for convective warnings remains to be deployed, critical WarnGen issues must continue to be addressed, and efforts made to mitigate similar issues in HazardServices. For equitable rural services, Pathcasts within WarnGen and follow on HazardServices for the Tornado Warning and Severe Thunderstorm Warning formatter should include arrival times for Tier 3 cities/towns when those locations are the predominant locations in a warning.

WFO Paducah issued an initial Tornado Warning at 9:05 P.M. CST for an ongoing tornado[5]. In the body of this warning, the text mentioned the tornado would be near Mayfield around 9:30 P.M. CST. WFO Paducah then issued another Tornado Warning at 9:26 P.M. CST, upgrading the message to a Tornado Emergency[6]. In the twenty-one minutes between these tornado warnings, the WFO Paducah staff discussed the possibility as to whether or not a Tornado Emergency would be needed. The operations staff agreed the tornado emergency was appropriate and issued the product, while also noting some complications with the process. The WFO Paducah AAR and office interview reinforced this difficulty when the Paducah SOO said, (it is…) *" very difficult to get this product out when you have two edit areas to worry about, plus getting rid of the syntax."*

Finding 25: The mechanics of issuing a Tornado Emergency after the text product has been created in WarnGen, but before the product is issued, required several manual text edits. This led to inefficiency in issuing the product, especially in a high stress environment.

[5] https://verification.nws.noaa.gov/warnings/2021/Dec/11/WFUS53KPaducah.89133796121121.TXT
[6] https://verification.nws.noaa.gov/warnings/2021/Dec/11/WFUS53KPAH.89191377121121.TXT

Recommendation 25: Each WFO warning meteorologist should routinely train on the issuance of a Tornado Emergency to maintain competency on one of the most rare to be issued, but most urgent and potentially life saving, of warnings sent by the NWS.

For Mayfield, Kentucky, the decision to issue a Tornado Emergency was relatively straightforward. However, several of the interviewed offices mentioned having difficult conversations about whether or not to upgrade to a Tornado Emergency at other decision points in the event. The service assessment team had findings and recommendations to better clarify training on what constitutes a population center to be used for a possible tornado emergency. However, Warning Decision Training Division (WDTD) has published new work and guidance[7] that addresses this need, namely that the first criteria for a Catastrophic tag is an "imminent threat to human life" without the inclusion of "population center" language which was a source of confusion for forecasters.

Critical Incident Stress Management (CISM)

Several offices talked about the impacts of critical incident stress (CIS) on their staffs, not only during and immediately after the tornadoes, but in the days and weeks that followed. According to OSHA, CIS can become an issue when workers responding to emergency events and/or disasters see or experience events that strain their ability to function.

While no NWS offices were directly impacted by tornadoes, CIS was still noted at multiple phases in the event. The emotional weight associated with the forecast and warning process of a tornadic outbreak, the prolonged exposure to human suffering while conducting multi-day damage surveys, and reliving the event through media interviews and post-event analysis all yielded psychological trauma at some of the affected offices.

Office management provided support in a variety of ways. WFOs Paducah, Louisville, and Memphis called upon the NWS Behavioral Health/Wellness Officer to visit their offices to spend time with the office and offer information and support for the impacted staff.

Most offices were aware of the availability of the Employee Assistance Program (EAP) as a resource for the staff, both individually and as a group. Many of the staff, however, did not seem to know about the various CIS management training initiatives and resources that have been implemented recently within the NWS. This includes a variety of resources available through the NWS Leadership Academy website, and two CIS training modules available through the NWS WDTD Warning Operations Course. CIS management was also a topic of discussion at the National WCM/SCH meeting in June 2022. Following a presentation on the subject, and after requests from the majority of offices, follow up webinars featuring LCDR Valarie Gardner were

[7] Impact-Based Convective Warnings (weather.gov)

conducted in October 2022 to help address questions and issues that were not covered at the WCM/SCH meeting.

Finding 26a: Several of the impacted WFOs noted that CIS was an issue among some staff members, including forecasters who had been issuing warnings, staff providing IDSS during the event, and staff members who conducted storm damage surveys in the days and weeks following the event.

Finding 26b: Staff at several of the WFOs noted demonstrations of support (food deliveries, etc.) from other NWS offices around the country. Some also mentioned how helpful even a simple phone call or email from peers at other offices who had been through similar events was in helping them deal with the emotions of the event's aftermath. This concept is the basis for a CISM peer support network being developed by the NWS's new CISM and Wellness Team to help lead the effort to promote awareness and develop tools to help manage CIS in the NWS.

Finding 26c: While most offices were aware of the concept of CISM, some were not aware of the information resources and training available to NWS staff to help them prepare for, recognize and deal with CIS.

Recommendation 26: The NWS should continue to raise awareness about the impacts of CIS, the resources available to mitigate its effects, and encourage the use of those resources when they are needed. Careful CISM considerations should be taken for those who will conduct damage surveys, especially if those considered include the event's warning forecaster(s) or other staff members directly or indirectly involved in the event. Personnel who may be asked to perform post-event damage surveys for any type of hazard should be encouraged to complete the "Stress Management for Damage Surveys" training module, available through the WDTD Warning Operations Course online.

Information Technology, Network Infrastructure, and Systems

WFO Paducah Comms Outage

Per the WFO Paducah and Springfield AAR's, at approximately 9:25 P.M. CST on December 10th, commercial power was lost and the backup generator failed at WFO Paducah. A call was made to one of the WFO Paducah Electronics Technicians who attempted to walk one of the onsite staff through the process of manually switching over to backup power. However, this failed to bring the generator online. At 9:30 P.M. CST a call was made to coordinate with WFO

Louisville about assuming backup operations. WFO Louisville confirmed that they could take over operations, but would need additional staff. A followup call 5 minutes later revealed that WFO Louisville was not able to get extra staff in time to handle backup operations. The decision to go to WFO Paducah's backup office of WFO Springfield was made around 9:45 P.M. CST with WFO Springfield assuming WFO Paducah operations around 9:52 P.M. CST. Cell phones were used to continue communications with both the CR ROC and WFO Springfield.

Troubleshooting continued on the generator with all PCs and AWIPs workstations powered off at WFO Paducah. It was finally determined that a controller was damaged, which prevented the generator from being started. Full service backup was then maintained by WFO Springfield until 2:52 A.M. CST on December 11th, when power was restored at WFO Paducah. This period of service backup encompassed the remainder of the severe weather event for the WFO Paducah county warning area (CWA). During the first 75 minutes of service backup, four Tornado Emergencies were issued by WFO Springfield for WFO Paducah. It should be noted that WFO Springfield also lost commercial power while providing service backup for WFO Paducah. Generator power was established at WFO Springfield within approximately one minute with no interruption to service for either office.

From the WFO Springfield AAR regarding their backup of WFO Paducah warning services during the communications outage "Warning forecasters used PC-based software as their main method for radar interrogation due to the lack of radar data in AWIPS. The primary warning forecasters constructed and disseminated warnings within AWIPS utilizing limited MRMS and radar mosaic datasets as well as PC-based software to craft polygons. It should be noted that AWIPS interrogation was again utilized once storms moved into the southeastern Paducah CWA due to the availability of KOHX data within AWIPS."

Finding 27a: WFO Springfield's success in service backup operations was driven in large part by the availability of and ability to use PC-based software which was still receiving Level II data from all radar sites. This was the only way they had to do radar analysis for the storms in the WFO Paducah CWA since data from Paducah's radars were not getting into AWIPS. At times, warning teams used multiple instances of PC based software, each with a different Radar Data Acquisition, as a primary radar interrogation tool to inform warning issuance and updates being made on AWIPS. Attempts to send Radar Multiple Requests (RMRs) from Springfield to Paducah also failed.

Finding 27b: The team found that PC-based software was an essential supplemental radar analysis tool in warning operations.

Finding 27c: WFO Springfield utilized two person radar teams as part of the warning process that optimized the use of PC-based software by the second member of the team as well as other radar warning team duties.

Recommendation 27: NWS should investigate alternatives to radar data dissemination through the AWIPS system, in the event of an AWIPS outage.

Finding 28a: WFO Springfield prioritized warning decisions over social media updates for WFO Paducah while backing them up. Per WFO Springfield: "Our staff that evening deemed warning decisions by the radar team a higher priority than Facebook posts. NWSChat radar and meso trends were also deemed a higher priority than Facebook. It should be noted that the automatic warnings did go out on the NWS Paducah Twitter feed."

Finding 28b: While the Supplemental Assistance Volunteer Initiative (SAVI) is an established social media mutual aid program, SAVI was not used during this event by offices either in CR or SR.

Recommendation 28: A review and rejuvenation of the SAVI program should be conducted in light of a renewed emphasis and openness to mutual aid in the NWS culture, which should emphasize the role of SAVI as a tool in mutual aid operations beyond primary and secondary setups.

Finding 29: The current NWS primary and secondary backup office structure consists of offices located in clusters that are geographically close to each other. This is a vulnerability when an office's primary and secondary backup offices may also be impacted by large scale, high impact weather or infrastructure failures.

Recommendation 29a: Backup structures of primary and secondary offices in close geographic proximity should be re-evaluated to reduce the vulnerabilities from large scale infrastructure failures (power or communications outages, etc.) and limitations of staffing availability during large scale, high impact events that may affect all offices within the cluster.

Recommendation 29b: NWS should develop on-demand, tertiary backup procedures and technology, as a high priority goal to flex mutual aid to the greatest extent possible and ensure the continuity of operations and mission delivery.

Damage Assessment Toolkit in the Cloud

The Damage Assessment Toolkit (DAT) is the main conduit for organizing and categorizing this information so that it may be shared with our core partners and the public. This service assessment found that performance issues with the DAT and/or the Survey123™ application

created challenges for multiple offices, making the work of damage surveyors more complicated and less efficient.

More specifically, several offices noted that their damage surveyors and those at the WFO supporting those surveyors had significant issues in collecting and sending data using Survey123™. These problems were caused by the DAT infrastructure experiencing degradation to the point where it was completely unresponsive and unusable. The inability for Survey123™ to transmit information to the DAT was affected by the quality, or in certain areas the complete lack of, cell phone service coverage. However, there were a few instances when survey teams waited until they got into an area with better cell service to transmit their data from Survey123™ to the DAT, and yet the application still failed.

Along with delaying the organization and eventual release of survey findings to our partners and the public, the noted failures/shortcomings of Survey123™ and the DAT during this event created a compounding effect that amplified the already high stress levels of the situation.

Finding 30: Some offices were unaware of the full range of Survey123™ capabilities. This may have contributed to confusion and frustration among some survey team members.

Recommendation 30: WFOs should ensure that staff who perform damage surveys receive training on the full capabilities and functionalities of the Survey123™ app, including information on how to gather and transmit survey data in areas with little or no cell service.

NWSChat

NWSChat is a critical tool for communication and collaboration between the WFOs and their emergency management, public safety, and media partners. In addition to sharing radar analysis, storm reports, and updates on critical warning decisions, WFOs used NWSChat to inform partners about the initiation of service backup. This included WFO St Louis notifying partners when they invoked service backup to briefly shelter from a potential tornado near the office, and WFOs Paducah and Springfield providing information on the handoff of warning responsibility from Paducah to Springfield.

The December 10-11 outbreak became the first major stability test since the transition from using the NIDS servers to the IDP servers for NWSchat. On December 10th, instability with NWSChat Live was noted as early as 2:22 P.M. CST, with some partners reporting trouble logging in, spontaneous log-outs, and system slowness. A message from NWS NCEP Central Operations at 2:50 P.M. CST on December 10th indicated a fix had restored NWSChat services. Similar issues cropped up again as the event was ramping up, with partners in several of the affected WFOs' chat rooms reporting that they were being kicked out of the room. The AAR from WFO St. Louis noted that, "Once again, NWSChat had issues and led to a degraded service to our partners

at a time when it was needed most (confirmed tornadoes on the ground)." It should be noted that Pidgin, the free IM software that users are encouraged to utilize when possible appeared to work with few, if any, problems during the event.

With NWSChat Live instability being an issue in the past, most of the affected WFOs had developed plans to use either Google Chat or Google Meet as backup platforms in the event of an NWSChat Live outage, and those plans were enacted during this event. This functionality enabled WFO Paducah to share radar imagery in the Paducah Google Meet backup room, and used the chat function to share updates and text-based information with partners.WFO Springfield was able to use the WFO Paducah backup room to maintain communication and share radar updates with WFO Paducah's partners while they were providing service backup.

Having the backup rooms established in advance, and having partners who knew the plan and were able to access the rooms quickly were critical to the success of the backup concept. The AAR from WFO Louisville said, "We were fortunate to migrate our media/EM partners into the backup chat room well ahead of the storms. Had it occurred in the midst of warning decisions, our partners would have missed this vital information and we would miss the reports that came out of it."

Finding 31: NWSChat Live was unstable before and during the event, and became unusable for many partners and impacted WFOs. NWSChat users using Pidgin were able to remain in the chat rooms.

Recommendation 31: Until the transition to Slack is complete, all NWSChat users, including both partners and NWS staff, should be encouraged to use Pidgin™ or other applications instead of NWSChat Live when possible.

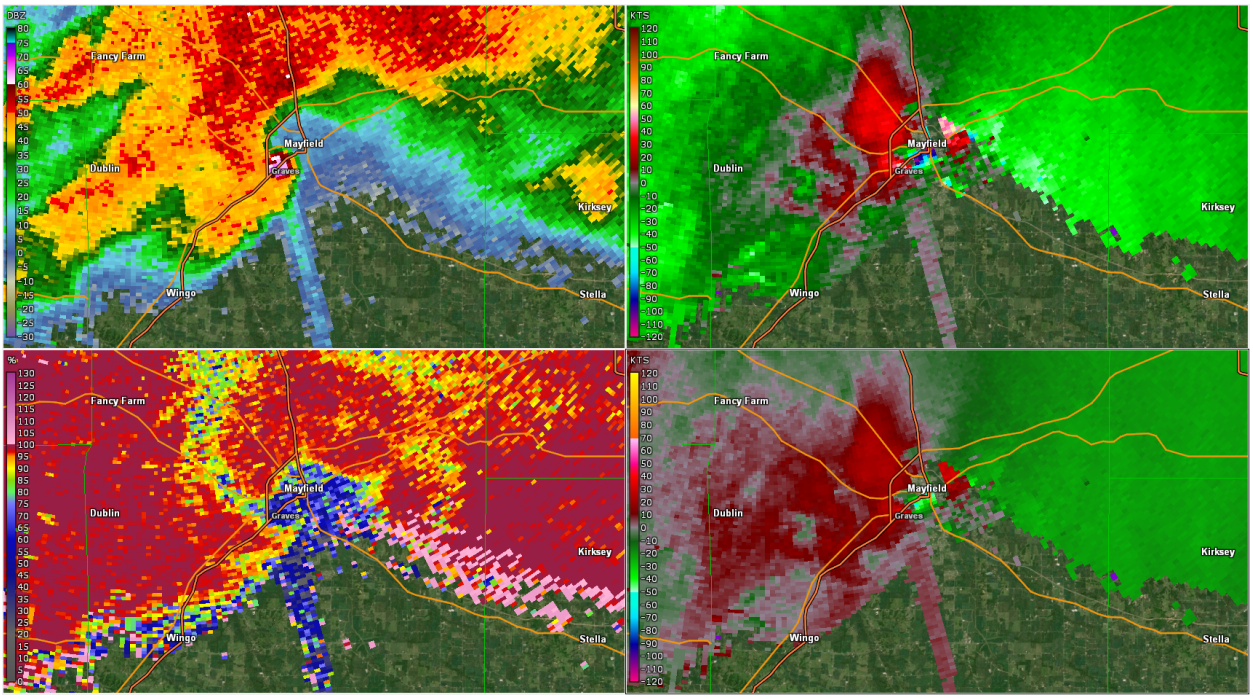
Finding 32: During the NWSChat outage, several offices implemented back-up plans that used Google Meet™ or Google Chat™ to maintain the flow of information between the WFOs and their partners. WFO Springfield was able to use the backup room established by WFO Paducah to maintain communication with WFO Paducah's partners while they were providing service backup.

Recommendation 32a: Offices should be encouraged to establish backup plans that include either Google Meet™ or Google Chat™ to be invoked when NWSChat Live is unstable or goes down. Backup room information should be shared with each WFO's partners and backup offices to allow them to access the rooms, as needed.

Recommendation 32b: Even when using Google platforms for NWSChat backup, offices should maintain a presence and provide the same level of information in NWSChat for those unable to access the backup platform or who are using Pidgin or other programs not impacted by the outage.

Appendices

Appendix A: Radar Imagery



KPAH Radar Imagery at Mayfield, KY. 0327 UTC: Clockwise from top left: Base Reflectivity, Base Velocity, Storm Relative Velocity, Correlation Coefficient

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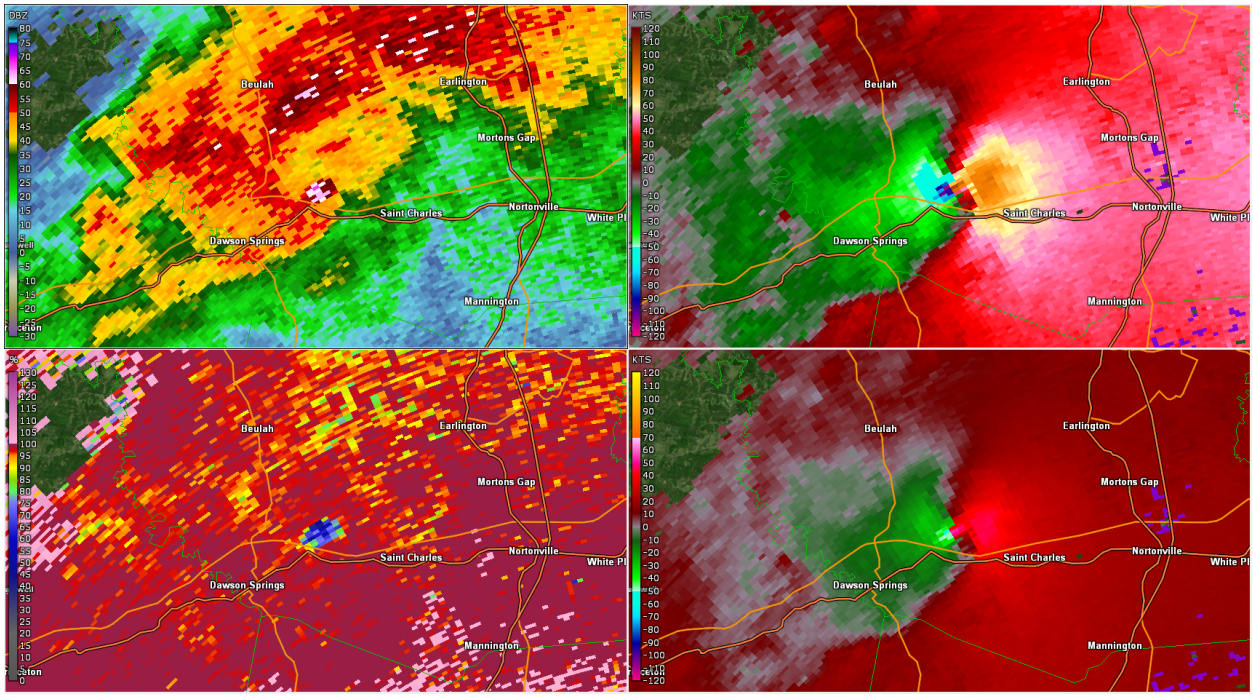
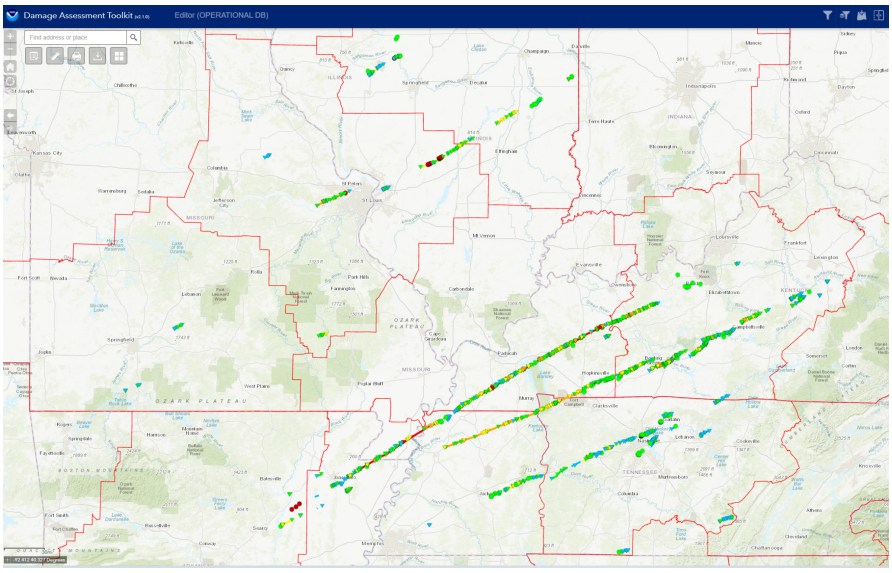


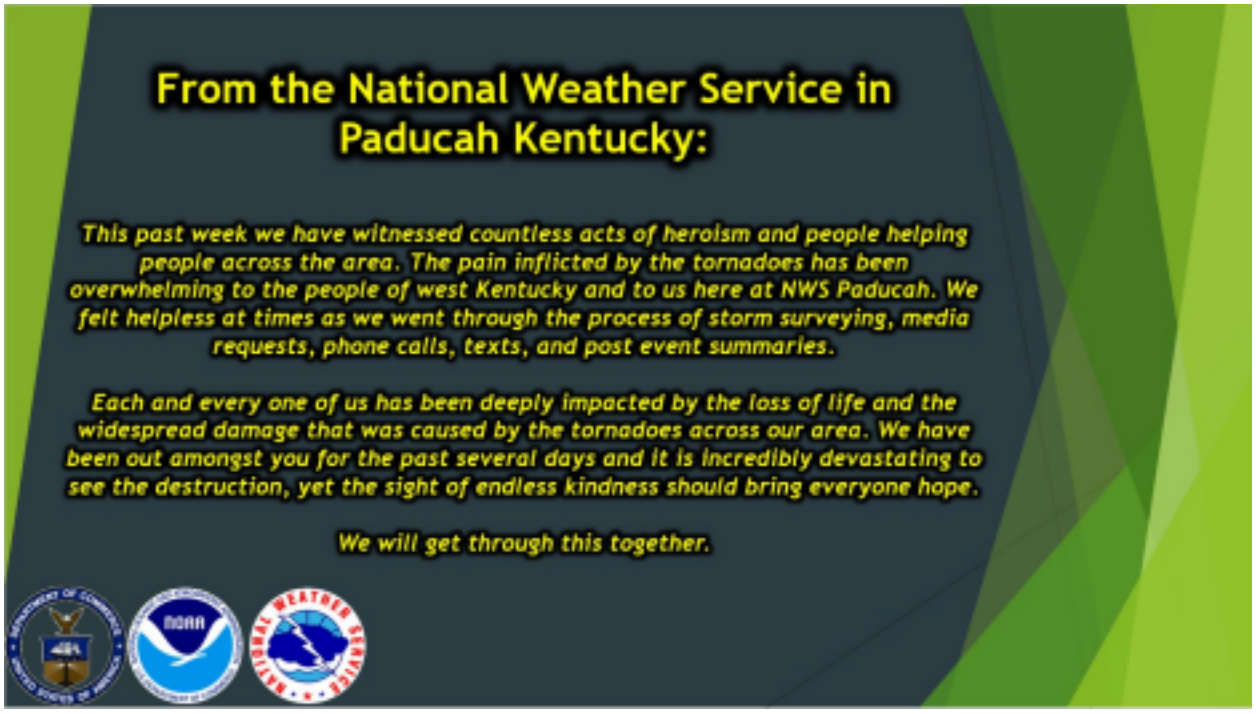
KHPX Radar Imagery near Dawson Springs, KY 0436 UTC : Clockwise from top left: Base Reflectivity, Base Velocity, Storm Relative Velocity, Correlation Coefficient Near Dawson Springs, KY

Appendix B: Other Imagery

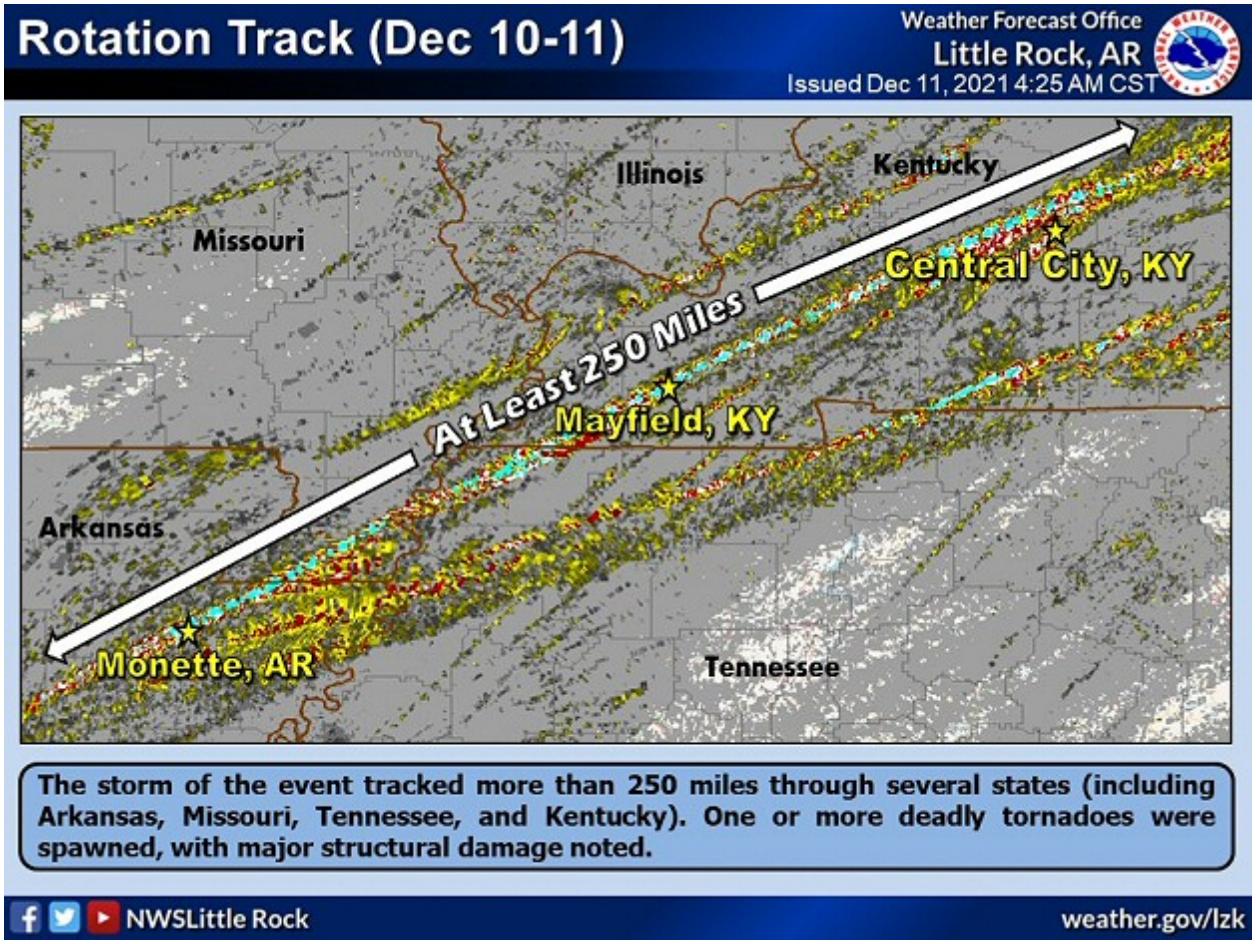


Tornado damage paths and damage assessment points of the December 10-11, 2021 Tornadoes. Screenshot from the Damage Assessment Toolkit.

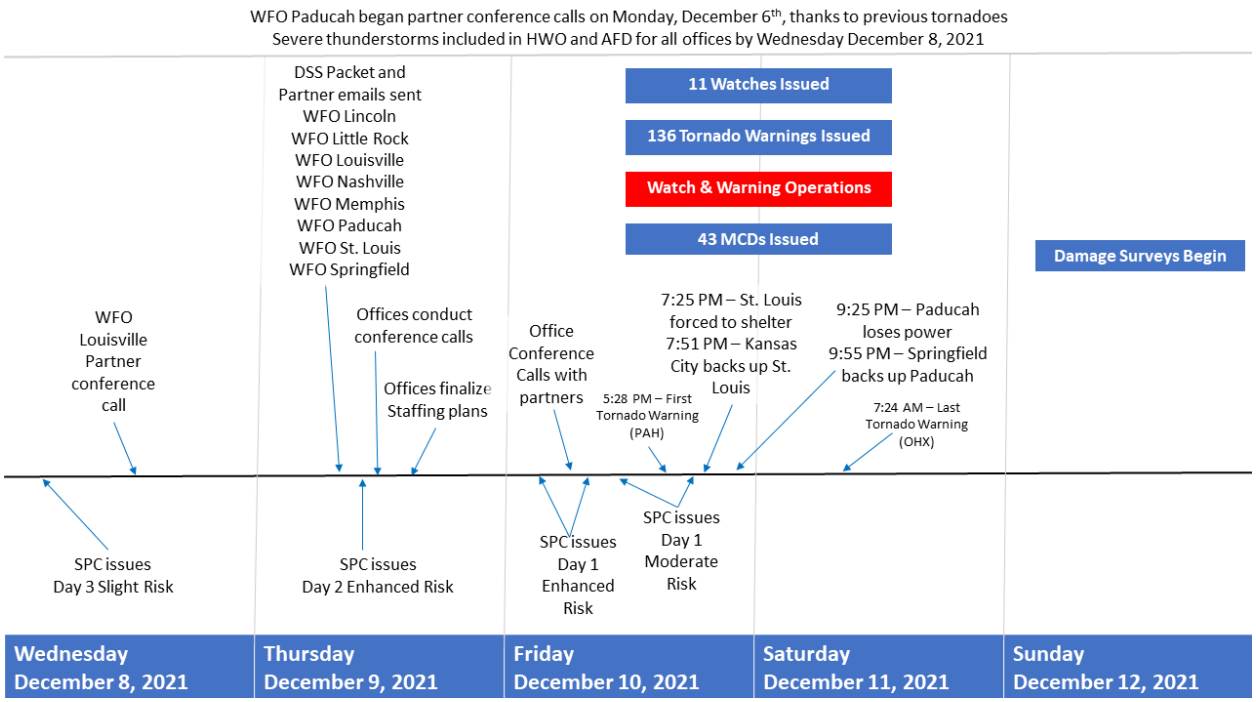
Damage at an Amazon facility in Edwardsville, Illinois. Photo by NWS St. Louis.



NWS Paducah image sent through social media after the tornadoes.



Rotation track of the long-track tornado. Image by NWS Little Rock.



General timeline of events of December 8-12, 2022. Times in CST.

Appendix C: Tornadoes and EF Scale Ratings

EF Scale

Rating	Wind Speed (3 second gust)	Damage Description
EFU	Unknown	No surveyable damage
EF0	65–85 mph	Light damage
EF1	86–110 mph	Moderate damage
EF2	111–135 mph	Considerable damage
EF3	136–165 mph	Severe damage
EF4	166–200 mph	Devastating damage
EF5	>200 mph	Incredible damage

Tornadoes observed on December 10-11, 2022

	City	County	State	EF Rating	Estimated Wind Speed	Path Length (Miles)
1	Mayfield & Dawson Springs	Obion to Breckinridge	KY, TN	EF4	190	165.6
2	Bay to Samburg	Craighead to Obion	AR, TN	EF4	170	80.3
3	Bowling Green	Warren to Edmonson	KY	EF3	165	-
4	Gordonsville, Hadley	Logan, Warren	KY	EF3	140	28
5	Saloma, Bradfordville	Marion, Taylor	KY	EF3	145	14.7
6	Defiance	Saint Charles	MO	EF3	165	21
7	Edwardsville	Madison	IL	EF3	150	3.65
8	Newbern to Elkton	Dyer, TN to Todd, KY	TN, KY	EF3	160	122.7
9	Rock Hill, Horse Cave	Edmonson, Barren, Hart	KY	EF2	130	16.6
10	Horse Cave, Summersville	Hart, Green	KY	EF2	125	24
11	Junction City	Boyle	KY	EF2	135	0.63
12	South Bowling Green	Warren	KY	EF2	115	-
13	Ellington	Reynolds	MO	EF2	130	6.3
14	Ramsey, Herrick	Fayette, Shelby	IL	EF2	118	41.4
15	Virginia	Cass	IL	EF2	125	12.8
16	Windsor, Gays, Mattoon	Shelby, Moultrie, Coles	IL	EF2	125	15.8
17	Atterberry	Menard	IL	EF2	120	4.6
18	Chrisman	Edgar	IL	EF2	115	-
19	Trumann	Poinsett	AR	EF2	130	-

20	Augusta to Overcup	Woodruff to Conway	AR	EF2	135	-
21	Dickson to Burns	Dickson	TN	EF2	135	-
22	White Bluff to Pegram	Dickson to Cheatham	TN	EF2	125	-
23	Lexington	Henderson	TN	EF2	135	-
24	MT Washington	Spencer	KY	EF1	95	1.5
25	Danville	Boyle	KY	EF1	110	3.63
26	Bradfordsville	Eastern Marion	KY	EF1	100	1.9
27	Chrisman Lane	Boyle	KY	EF1	93	0.61
28	Bryantsville	Boyle, Gerrard	KY	EF1	94	2.93
29	Hedgeville	Boyle, Gerrard	KY	EF1	110	1.93
30	Richmond	Madison	KY	EF1	90	-
31	Kirksville	Madison	KY	EF1	90	-
32	SE of Big Spring	Hardin	KY	EF1	-	-
33	NW of Lancaster	Garrard	KY	EF1	-	-
34	Niangua	Webster to Wright	MO	EF1	90	6.3
35	Branson West	Stone	MO	EF1	90	0.67
36	Diaz	Jackson	AR	EF1	100	-
37	Cary	Craighead	AR	EF1	100	-
38	Beedeville	Jackson	AR	EF1	110	-
39	Samburg	Obion	TN	EF1	90	-
40	Jackson	Madison	TN	EF1	100	-
41	Holladay	Benton, Decatur	TN	EF1	90	-
42	Burns to White Bluff	Dickson	TN	EF1	110	-
43	Lobelville	Perry	TN	EF1	100	-
44	Hendersonville	Sumner	TN	EF1	95	-
45	Mount Juliet	Wilson	TN	EF1	105	-
46	Hermitage Springs to Hestand	Clay, TN to Monroe, KY	TN, KY	EF1	105	-

47	Dryden	Craighead	AR	EF1	105	6.1
48	Ada	Hardin	OH	EF1	110	-
49	Marietta	Prentiss	MS	EF1	95	-
50	WNW Walnut Grove	Taney	MO	EF1	-	1.5
51	Rardin	Coles	IL	EF1	-	6.3
52	Wellsville	Montgomery	MO	EF0	80	4.3
53	Cedar Lake to Crown Point	Lake	IN	EF0	80	4.8
54	Bay	Craighead	AR	EF0	65	-
55	7 ENE Fisher	Poinsett	AR	EF0	80	-
56	4 ESE Fisher	Poinsett	AR	EF0	80	-
57	Weiner	Poinsett	AR	EF0	65	-
58	NW of Centerville to SW of Dickson	Hickman to Dickson	TN	EF0	85	-
59	Union City	Obion	TN	EF0	70	-
60	Hornbeak	Obion	TN	EF0	80	-
61	NE of Pegram to NNW of Nashville	Cheatham to Davidson	TN	EF0	85	-
62	Green Hill	Wilson	TN	EF0	85	-
63	Bethpage	Sumner	TN	EF0	85	-
64	Carthage	Smith	TN	EF0	80	-
65	Elkton	Giles	TN	EF0	70	-
66	Emerald Mountain	Elmore	AL	EF0	70	0.2
67	Irwinton	Wilkinson	GA	EF0	70	3.8
68	Lambert	Fayette	TN	EF0	-	0.5
69		Davidson	TN	EF0	-	1.4
70	Coalmont	Grundy	TN	EF0	-	8.9
71	Weldon	Jackson	AR	EF-Unknown	-	-

Appendix D: Findings and Recommendations

Finding 1: The use of emerging medium range probabilistic, statistical and machine learning datasets allowed for a spectrum of severe convective scenarios/patterns to be identified at longer lead times to inform NWS internal operations planning and coordination, and earlier messaging and Impact Decision Support Services (IDSS) delivery.

Recommendation 1: SPC should continue to explore the use of emerging guidance to effectively balance potential impacts with forecast uncertainty when introducing or modifying risk areas in Day 4-8 Convective Outlooks.

Finding 2: Some WFOs interviewed indicated that meso-beta scale MCDs with frequent updates were found to be exceptionally useful in supporting WFO operations.

Recommendation 2: SPC should ensure a consistent meso-beta scale MCD service from event to event, with clear expectations of when this service will be provided.

Finding 3a: While some offices took a more proactive approach, others waited until Day 1 or 2 to ramp up services in part due to established playbooks.

Finding 3b: As probabilistic, statistical, and machine learning datasets and techniques continue to mature, high impact events can be identified at longer lead times with higher confidence compared to legacy thresholds/approaches.

Recommendation 3: WFOs should use probabilistic, statistical, and machine learning datasets and techniques to drive a "say what you know when you know it" services mindset, and provide as much lead time as is technically feasible.

Finding 4: WFO Paducah used direct text messaging to communicate threats with partners.

Recommendation 4: WFOs should use all means to communicate higher end threats and life threatening situations. Clearly defined policies and procedures for direct text messaging of partners for short fused convective threats should be established.

Finding 5: WFO Paducah issued an SPS well in advance of any severe storms entering their CWA.

Recommendation 5: Policy should be developed for consistent application of the legacy SPS, or other messaging approaches, as a tool to message threats in the "Watch to Warning Gap" as well as downstream of ongoing warnings.

Finding 6: Multiple offices identified a gap in NWS safety outreach and resources related to buildings with large footprints, such as warehouses.

Recommendation 6: The NWS HQ Analyze, Forecast, and Support Office's Severe Weather Program should work with experts to develop materials with basic tornado safety guidelines for large facilities.

Finding 7: Several offices mentioned that the MRMS time steps were insufficient for these long track tornadoes.

Recommendation 7: NWS should increase MRMS time steps within the tornado track tool, to help with long tornado tracks that are provided to FEMA. NWS should also provide the ability to overlay local storm reports within this tool.

Best Practice: The CR ROC divided up duties between the ROC Emergency Response Specialist (ERS) staff after this event, to more efficiently manage FEMA support needs, including Presidential Disaster Declaration (PDD) Summary requests, N-IMAT deployment coordination, and ongoing NWS support functions.

Finding 8: The proactive declaration of Operations Level 2 allowed the CR ROC to get a jump start on assessing potential staffing needs.

Recommendation 8a: The CR ROC should update the Regional Action Plan template to include a "one stop shop" of actions that should be taken or considered before, during, and after a significant weather event. Additionally, updates to the Regional Action Plan should include templates for different types of weather events, which would provide a starting point for common actions that may be unique to certain types of significant weather events.

Recommendation 8b: ERS staff should be as proactive as possible in anticipating future workload and potential requests in order to effectively manage incoming requests with ongoing or routine duties. Examples of proactive work include getting an early start on creating Significant Event Reports, FEMA PDD weather summaries, morning briefing slides, and the daily regional situation reports.

Finding 9: Offices found it difficult to manage travel after these storms, especially as deployments were found to be necessary.

Recommendation 9: ROCs should declare a Finance Section Chief and/or Deployment Unit Leader when expanding the ICS structure to assist with managing the logistics for additional damage survey team deployments if such a request is deemed necessary after a significant weather event.

Finding 10: The proactive drafting of Talking Points and Significant Event Reports helped with effectively documenting critical event information and also prepared staff for formal information requests.

Recommendation 10a: ROCs should start developing a Talking Points document and/or Key Messages document early, after it is apparent significant impacts have occurred from a regional weather event. When there's a chance the significant weather event could garner national or international media attention, it's critical to have such documents ready and available before the increase in media requests occurs.

Recommendation 10b: The ROCs should suggest a strategy to the impacted offices on how to manage national and international news coverage. This could include offering to immediately deploy an Emergency Response Specialist to a Joint Information Center or State EOC to handle Public Information Officer (PIO) duties.

Finding 11: The December 10-11, 2021 outbreak overwhelmed local office resources due to the demand for information, numerous damage surveys and local office duties.

Recommendation 11a: ROCs should take the initiative to find additional survey teams from neighboring offices in the event of a long-track tornado and present mutual aid options to the impacted office(s).

Recommendation 11b: During high impact events, the ROCs along with the Regional WCMs, should consider organizing a QRT ahead of any request should the office need it.

Finding 12: Some offices stated that they would like for the ROCs to take a more proactive role in setting up the Remote Mesoanalysis process with the expectation that it will likely be a part of most severe weather event operations going forward. Several offices relayed their appreciation for the Remote Mesoanalysis initiatives.

Recommendation 12: The remote mesoanalysis process should continue to be grown across the regions.

Finding 13a: The ROCs played a central role in the coordination of various mutual aid requests submitted by the most significantly affected WFOs.

Finding 13b: The other affected offices were unaware of the mutual aid offered to WFO Paducah.

Recommendation 13: The ROCs should hold conference calls with all affected office management teams as soon as practical following the event to coordinate mutual aid.

Finding 14a: The regional Top News Story and regional coordination of GIS services lacked effective internal processes. The affected WFOs reported that they appreciate assistance with top news stories and social media graphics that take a regional perspective. This was also helpful for national and international media questions. However, manually posting the most current verified casualty numbers, track lengths, peak intensity, and other facts in sync with field office official reports was a full time job.

Finding 14b: Several GIS experts wanted to assist offices with mapping efforts, but procedures and organization were not yet in place to help multiple offices with one Story Map or with tactical mapping assistance.

Recommendation 14a: Future events should have this duty split off and managed by one person, nested under the PIO.

Recommendation 14b: The Field GIW should work with the Geospatial Integrated Work Team (GIWT) to develop a process for fielding requests for assistance.

Finding 15: The Assessment Team noted that office generators are aging. WFO staff stated that it is becoming increasingly more difficult to source parts needed for repair.

Recommendation 15: Offices should test generators ahead of potential significant weather events that may directly impact the office.

Finding 16: The CR RMA effort proved to be a mutual aid success story during this event in supporting local office efforts to provide better mesoscale threat recognition.

Recommendation 16: Ongoing coordination between SR, CR, national STI, and SPC should continue to merge various streams of remote mesoanalysis initiatives to provide a consistent and supported program that cross cuts regional and national center boundaries. Since facilitators can generally only participate when their local workload is low, having the regional entities work together will yield a larger pool of individuals to provide continuous mutual aid availability.

Finding 17: On site and remote mesoanalysis was found to be valuable for increasing confidence of WFO warning forecasters.

Recommendation 17: WFOs should ensure they incorporate a mesoanalyst role, and the regions should incorporate a mutual aid approach to mesoanalysis, such that participating staff are fully trained through the MEA Course and/or local office/region focused mesoanalysis training.

Finding 18a: Extensive storm survey campaigns that spanned multiple days placed a significant strain on staffing, and took a large emotional toll on those who witnessed days of human suffering and damage. Events of this magnitude can quickly overwhelm the resources of even the most experienced and fully staffed offices. For some of the impacted offices, the demands for information on storm damage survey results from the media and public challenged the ability to provide social media updates on the progress of the surveys.

Finding 18b: Post-event mutual aid was a necessity for offices to respond and support the post-event. However, complexities still remain regarding proactive coordination of mutual aid resources between the field and regional levels.

Recommendation 18: Comprehensive pre, during, and post-event mutual aid plans should be established with clear and consistent coordination procedures between the field and regional levels with an emphasis on proactive, not reactive, mutual aid mobilization.

Finding 19: Damage surveys were conducted by NWS personnel that were inexperienced with surveys. This was done out of necessity to ensure enough personnel were available.

Recommendation 19: Coaching and clear expectations should be provided to staff that are inexperienced in conducting damage surveys.

Finding 20: WFO Kansas City office called the St. Louis office the day after the tornadoes and offered partial backup services for routine forecasts. This enabled WFO St. Louis to maximize employees on damage surveys.

Recommendation 20: Service backup should be used after larger-scale events to mitigate the strain on staff performing post-event assessments.

Finding 21a: The application of advanced dual pol signatures and tornadogenesis concepts from the CR CWIP Supercell Tornadogenesis guide led to proactive tornado warning issuance. There was specific discussion on the WFO Springfield operations floor regarding uninterrupted Zdr arcs giving the warning forecasters high enough confidence to proactively issue new tornado warnings in a high storm relative helicity environment versus waiting for strong rotational velocities.

Finding 21b: The recommended training and concepts from the TWIP and SWOT were found to be effective in operations during this event.

Recommendation 21: WFOs should make full use of SWOT and CWIP training and tools to infuse the latest science and technology into warning operations**.**

Finding 22a: Radar teams (also known as warning teams), consisting of a primary radar operator and an assistant, were used at many offices to navigate the complexities of the modern warning environment to provide high levels of service with a team approach at its foundation.

Finding 22b: The amount of information available to and decision points required of the warning forecaster necessitates the use of warning teams to the greatest extent possible.

Recommendation 22: WFOs should outline within their Severe Weather Operations Plans (or their equivalent Station Duy Manual chapters or Operations Playbooks) the use of warning teams to the greatest extent possible.

Finding 23: Marrying probabilistic datasets with foundational conceptual models and pattern recognition in a modern forecast process allowed these offices to achieve high impact, scenario based threat recognition and messaging at longer lead times.

Recommendation 23: Training on Medium range (Days 3-8) convective forecasting with an emphasis on existing and emerging probabilistic, statistical, and machine learning approaches married to pattern recognition should be delivered to ensure consistent competency and application of medium range convective hazard recognition to inform longer lead IDSS.

Finding 24a: Inconsistencies in cities mentioned in the Pathcast, and those mentioned specifically in the Tornado Emergency headline remain. WarnGen Pathcast will not list a city if the “Drag me to Storm” is calculated to be already past the city due to interpolation of the storm motion between volume scans. Thus, in very near time scenarios even if a forecaster places the drag me to storm upstream of the city on the latest radar scan being used, that city may not get a Pathcast mention if the drag me to storm is interpolated past the city (i.e. placing the drag me to storm using a scan that is three or four minutes old, and thus the drag me to storm is being

interpolated further downstream based on the current time). This issue is made worse with rapid storm motions.

Finding 24b: WarnGen does not give arrival times within the Pathcast for Tier 3 cities/towns. This is often the case when warnings occupy mostly rural areas, and the smaller Tier 3 cities/towns make up the majority, if not all, of the locations in the Pathcast of the storm.

Recommendation 24: While Hazard Services for convective warnings remains to be deployed, critical WarnGen issues must continue to be addressed, and efforts made to mitigate similar issues in HazardServices. For equitable rural services, Pathcasts within WarnGen and follow on HazardServices for the Tornado Warning and Severe Thunderstorm Warning formatter should include arrival times for Tier 3 cities/towns when those locations are the predominant locations in a warning.

Finding 25: The mechanics of issuing a Tornado Emergency after the text product has been created in WarnGen, but before the product is issued, required several manual text edits. This led to inefficiency in issuing the product, especially in a high stress environment.

Recommendation 25: Each WFO warning meteorologist should routinely train on the issuance of a Tornado Emergency to maintain competency on one of the most rare to be issued, but most urgent and potentially life saving, of warnings sent by the NWS.

Finding 26a: Several of the impacted WFOs noted that CIS was an issue among some staff members, including forecasters who had been issuing warnings, staff providing IDSS during the event, and staff members who conducted storm damage surveys in the days and weeks following the event.

Finding 26b: Staff at several of the WFOs noted demonstrations of support (food deliveries, etc.) from other NWS offices around the country. Some also mentioned how helpful even a simple phone call or email from peers at other offices who had been through similar events was in helping them deal with the emotions of the event's aftermath. This concept is the basis for a CISM peer support network being developed by the NWS's new CISM and Wellness Team to help lead the effort to promote awareness and develop tools to help manage CIS in the NWS.

Finding 26c: While most offices were aware of the concept of CISM, some were not aware of the information resources and training available to NWS staff to help them prepare for, recognize and deal with CIS.

Recommendation 26: The NWS should continue to raise awareness about the impacts of CIS, the resources available to mitigate its effects, and encourage the use of those resources when they are needed. Careful CISM considerations should be taken for those who will conduct damage surveys, especially if those considered include the event's warning forecaster(s) or other staff members directly or indirectly involved in the event. Personnel who may be asked to perform post-event damage surveys for any type of hazard should be encouraged to complete the "Stress Management for Damage Surveys" training module, available through the WDTD Warning Operations Course online.

Finding 27b: The team found that PC-based software was an essential supplemental radar analysis tool in warning operations.

Finding 27c: WFO Springfield utilized two person radar teams as part of the warning process that optimized the use of PC-based software by the second member of the team as well as other radar warning team duties.

Recommendation 27: NWS should investigate alternatives to radar data dissemination through the AWIPS system, in the event of an AWIPS outage.

Finding 28a: WFO Springfield prioritized warning decisions over social media updates for WFO Paducah while backing them up. Per WFO Springfield: "Our staff that evening deemed warning decisions by the radar team a higher priority than Facebook posts. NWSChat radar and meso trends were also deemed a higher priority than Facebook. It should be noted that the automatic warnings did go out on the NWS Paducah Twitter feed."

Finding 28b: While the Supplemental Assistance Volunteer Initiative (SAVI) is an established social media mutual aid program, SAVI was not used during this event by offices either in CR or SR.

Recommendation 28: A review and rejuvenation of the SAVI program should be conducted in light of a renewed emphasis and openness to mutual aid in the NWS culture, which should emphasize the role of SAVI as a tool in mutual aid operations beyond primary and secondary setups.

Finding 29: The current NWS primary and secondary backup office structure consists of offices located in clusters that are geographically close to each other. This is a vulnerability when an office's primary and secondary backup offices may also be impacted by large scale, high impact weather or infrastructure failures.

Recommendation 29a: Backup structures of primary and secondary offices in close geographic proximity should be re-evaluated to reduce the vulnerabilities from large scale infrastructure failures (power or communications outages, etc.) and limitations of staffing availability during large scale, high impact events that may affect all offices within the cluster.

Recommendation 29b: NWS should develop on-demand, tertiary backup procedures and technology, as a high priority goal to flex mutual aid to the greatest extent possible and ensure the continuity of operations and mission delivery.

Finding 30: Some offices were unaware of the full range of Survey123™ capabilities. This may have contributed to confusion and frustration among some survey team members.

Recommendation 30: WFOs should ensure that staff who perform damage surveys receive training on the full capabilities and functionalities of the Survey123™ app, including information on how to gather and transmit survey data in areas with little or no cell service.

Finding 31: NWSChat Live was unstable before and during the event, and became unusable for many partners and impacted WFOs. NWSChat users using Pidgin were able to remain in the chat rooms.

Recommendation 31: Until the transition to Slack is complete, all NWSChat users, including both partners and NWS staff, should be encouraged to use Pidgin™ or other applications instead of NWSChat Live when possible.

Finding 32: During the NWSChat outage, several offices implemented back-up plans that used Google Meet™ or Google Chat™ to maintain the flow of information between the WFOs and their partners. WFO Springfield was able to use the backup room established by WFO Paducah to maintain communication with WFO Paducah's partners while they were providing service backup.

Recommendation 32a: Offices should be encouraged to establish backup plans that include either Google Meet™ or Google Chat™ to be invoked when NWSChat Live is unstable or goes down. Backup room information should be shared with each WFO's partners and backup offices to allow them to access the rooms, as needed.

Recommendation 32b: Even when using Google platforms for NWSChat backup, offices should maintain a presence and provide the same level of information in NWSChat for those unable to access the backup platform or who are using Pidgin or other programs not impacted by the outage.

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.
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.

Appendix E: Acronyms

AAR	After Action Review
AFD	Area Forecast Discussion
ARX	Weather Forecast Office La Crosse, Wisconsin
AWIPS	Advanced Weather Interactive Processing System
CAPE	Convective Available Potential Energy
CIS	Critical Incident Stress
CISM	Critical Incident Stress Management
CR	Central Region
CRH	Central Region Headquarters
CST	Central Standard Time
CWA	County Warning Area
DAT	Damage Assessment Toolkit
DMX	Weather Forecast Office Des Moine, Iowa
DOC	Department of Commerce
EAP	Employee Assistance Program
EAX	Weather Forecast Office Kansas City, Missouri

EF	Enhanced Fujita Scale
EFI	Extreme Forecast Index
EM	Emergency Management / Emergency Manager
ERS	Emergency Response Specialist
ESAT	Ensemble Situational Awareness Tool
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System
GIW	Geospatial Intelligence Workgroup
GIWT	Geospatial Integrated Working Team
GOES	Geostationary Operational Environmental Satellite
HWO	Hazardous Weather Outlook
IBW	Impact Based Warnings
ICS	Incident Command Structure
IDP	NWS Integrated Dissemination Program
IDSS	Impact Based Decision Support Service
ILX	Weather Forecast Office Lincoln, Illinois
IM	Instant Messaging
IT	Information Technology
JKL	Weather Forecast Office Jackson, Kentucky
LCDR	Lieutenant Commander
LMK	Weather Forecast Office Louisville, Kentucky
LSX	Weather Forecast Office St. Louis, Missouri
LZK	Weather Forecast Office Little Rock, Arkansas
MCD	Mesoscale Convective Discussion

MEG	Weather Forecast Office Memphis, Tennessee
MIC	Meteorologist-in-Charge
MRLE	Mid-Volume Rescan of Low-Level Elevations
MRMS	Multi-Radar / Multi-Sensor
NCEI	National Center for Environmental Information
NCEP	National Center for Environmental Prediction
NIDS	NWS Internet Dissemination System
N-IMAT	National Incident Management Team
NSSL	National Severe Storms Laboratory
NWS	National Weather Service
OAX	Weather Forecast Office Omaha, Nebraska
OHX	Weather Forecast Office Nashville, Tennessee
OPG	Operations Proving Ground
OSHA	Occupational Health & Safety Administration
PAH	Weather Forecast Office Paducah, Kentucky
PC	Personal Computer
PDD	Presidential Disaster Declaration
PIO	Public Information Officer
QLCS	Quasi-Linear Convective System
QRT	Quick Response Team
RMA	Remote Mesoanalyst
ROC	Regional Operations Center
SAILS	Supplemental Adaptive Intra-Volume Low Level Scan
SCH	Service Coordination Hydrologist

SDM	Station Duty Manual
SGF	Weather Forecast Office Springfield, Missouri
SOO	Science and Operations Officer
SoT	Shift of Tails
SPC	Storm Prediction Center
SR	Southern Region
SRH	Southern Region Headquarters
STI	Science Technology Integration
STP	Significant Tornado Parameter
SVR	Severe Thunderstorm Warning
SWOT	Severe Weather Operations Team
TOP	Weather Forecast Office Topeka, Kansas
TOR	Tornado Warning
TWIP	Tornado Warning Improvement Project
UNR	Weather Forecast Office Rapid City, South Dakota
Vrot	Rotational Velocity
WCM	Warning and Coordination Meteorologist
WDTD	Warning Decision Training Division
WFO	Weather Forecast Office
WPC	Weather PredictionCenter

Appendix F: Assessment Team Members

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