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INVESTIGATING THE IMPACT OF THE INVERSE BULLSEYE EFFECT ON
INTERPRETATIONS OF THE SPC CATEGORICAL CONVECTIVE OUTLOOK

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INVESTIGATING THE IMPACT OF THE INVERSE BULLSEYE EFFECT ON
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Abstract

Risk communication is a vital and growing research area in the field of meteorology. One of the most common graphics for probabilistic risk communication of severe weather is the Storm Prediction Center (SPC) Categorical Convective Outlook, variations of which can be found across local and national news, governmental and commercial websites, and official and unofficial social media pages. The Convective Outlook's widespread use as a tool to communicate to experts and non-experts alike has prompted the implementation of a multitude of studies seeking to understand its effectiveness, including investigations into its color scheme and category names in both English and Spanish. This study adds to the existing body of work by examining the impact of the Inverse Bullseye Effect (IBE), the negative impact that being located outside of the zone of highest risk has on individuals' risk perceptions. Under the influence of the IBE, an individual located in an Enhanced risk area could perceive their risk as lower if a Moderate risk was depicted and higher if a Moderate risk was not depicted (thus making Enhanced the highest risk category on the map).

The first goal of this work was to establish with what frequency tornadic events occur outside of the maximum threshold area (e.g. the Moderate contour area when the Moderate risk was the highest threshold for the day). This was done by intersecting Tornado Report points from the SPC's SVRGIS database with 2000 UTC Categorical Convective Outlooks issued between 2015 and 2023. Results indicate that approximately 50% of weak (EF0 and EF1) tornado reports occurred outside of the maximum threshold area during this period, while the frequency of significant tornado reports occurring outside of the maximum threshold area varied between 15% and 55%, depending on the maximum threshold present. This work also found that tornado

reports occurred outside of the maximum threshold area more frequently when the area was small and when the highest threshold was not driven by the tornado risk.

The second and third goals of this work were to determine if the IBE had an impact on risk perceptions held by members of the public and, if so, whether the addition of a verbal or numeric reminder statement indicating that severe weather can occur outside of the maximum threshold may reduce the impact. These questions were investigated using responses to a set of six questions related to the Convective Outlook that were included in the 2025 edition of the Severe Weather and Society Survey. Participants were randomly assigned one of six mock SPC social media posts with varying combinations of Convective Outlook maps (with either Moderate as the maximum threshold or Enhanced as the maximum threshold) and reminder sentences (No Reminder, Verbal Reminder, or Numeric Reminder), with the same location within the Enhanced region marked on each, and were asked to indicate their estimated probability both verbally and numerically. Results indicate that the IBE did have a slight impact on both the numeric and verbal estimations of likelihood indicated by the participants, and the reminder sentences had little impact on these estimates when included.

Chapter 1: Motivation

Risk communication is a vital and growing research area in the field of meteorology, as even a perfectly forecasted weather event can have devastating, preventable impacts if the risks associated with the weather event are not communicated in a way that is both salient and easily understood by end users. Previous studies have investigated a wide variety of probabilistic risk communication tactics, including verbal, numeric, and visual methods (Ripberger et al. 2022).

1.1 The Categorical Convective Outlook

The Storm Prediction Center (SPC)'s Categorical Convective Outlook is a map-based visualization of the probability of occurrence of severe weather (hail, strong winds, and tornadoes) that is commonly used to communicate risk information to both National Weather Service (NWS) key partners and members of the public. The Convective Outlook first became an operational product in 1955, after two years of development internal to the SPC (then named the Severe Local Storm Warning Service), however, these initial outlooks were closer in style to modern-day tornado watches (Corfidi 1999; Brooks et al. 2019; Edwards and Ostby 2024). The first Day 1 Convective Outlook that differentiated between risk categories was issued in 1973 (Brooks et al. 2019). This version included three risk levels ("Slight", "Moderate", and "High"), which, in 2003, 30 years after the first issuance of the categorical outlook, were aligned with numeric probabilities of tornadoes, wind, and hail (Hitchens and Brooks 2012; Ernst et al. 2021). Eleven years later, in 2014, the "Marginal" and "Enhanced" categories were added into the Days 1, 2, and 3 outlook maps, bringing the total number of severe thresholds to five (Brooks et al. 2019; Edwards and Ostby 2024).

In light of the long history of the SPC Categorical Convective Outlook, multiple studies have been undertaken to determine to what degree forecasters creating these products are able to

accurately capture the presence of severe weather events, in other words, their Type 2 Forecast Goodness (Murphy 1993). This work was spearheaded by Hitchens and Brooks, who, over three papers in 2012, 2014, and 2017, sought to understand the performance of the SPC Categorical Convective Outlook over time. Their 2012 study measured the probability of detection and frequency of hits of the Day 1 slight risk outlook issuances, and found that these forecasts have been improving with time. The 2014 study expanded on this work by including the Day 3 and Day 2 outlooks in the analysis, with similar results. Finally, the 2017 study focused specifically on significant severe events in the Day 3 to Day 1 time period. In 2018, Herman et al. undertook a probabilistic verification of the outlook using the Brier skill score, which found that short lead times and peak storm development times and locations were associated with higher skill verifications. The current study in part seeks to add to the body of work on the Type 2 forecast goodness of the SPC Categorical Convective Outlook by determining the proportion of severe weather events, specifically tornadic storms, that occur outside of the maximum threshold area of a given issuance, as well as identifying potential influencing factors.

The first intentionally public-facing outlooks were issued in 2005, for a few of the Moderate risk days that occurred during that year (Edwards and Ostby 2024). Over the past 21 years, the availability of the Categorical Convective Outlook to the public has increased dramatically. Beyond the SPC Convective Outlook webpage, members of the public may encounter SPC Categorical Convective Outlooks, or edited versions thereof, when they are shared via official sources (SPC or NWS) (Figures 1.1a and 1.1b) or unofficial sources (national and local broadcast media, private weather companies, volunteer organizations, or individuals) (Figures 1.2a-1.2d) via channels such as social media, which may or may not include additional explanation about the outlook or related forecast.

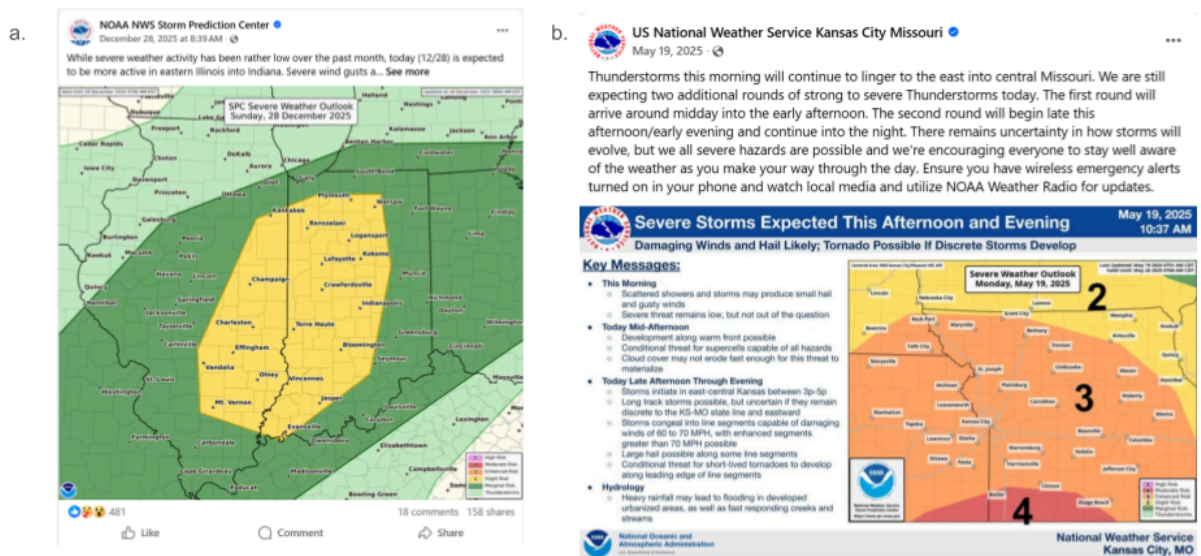


Figure 1.1: Examples of Facebook posts with the SPC Categorical Convective Outlook from (a.) the SPC (courtesy of the SPC 2025) and (b.) NWS Kansas City (courtesy of NWS Kansas City 2025).

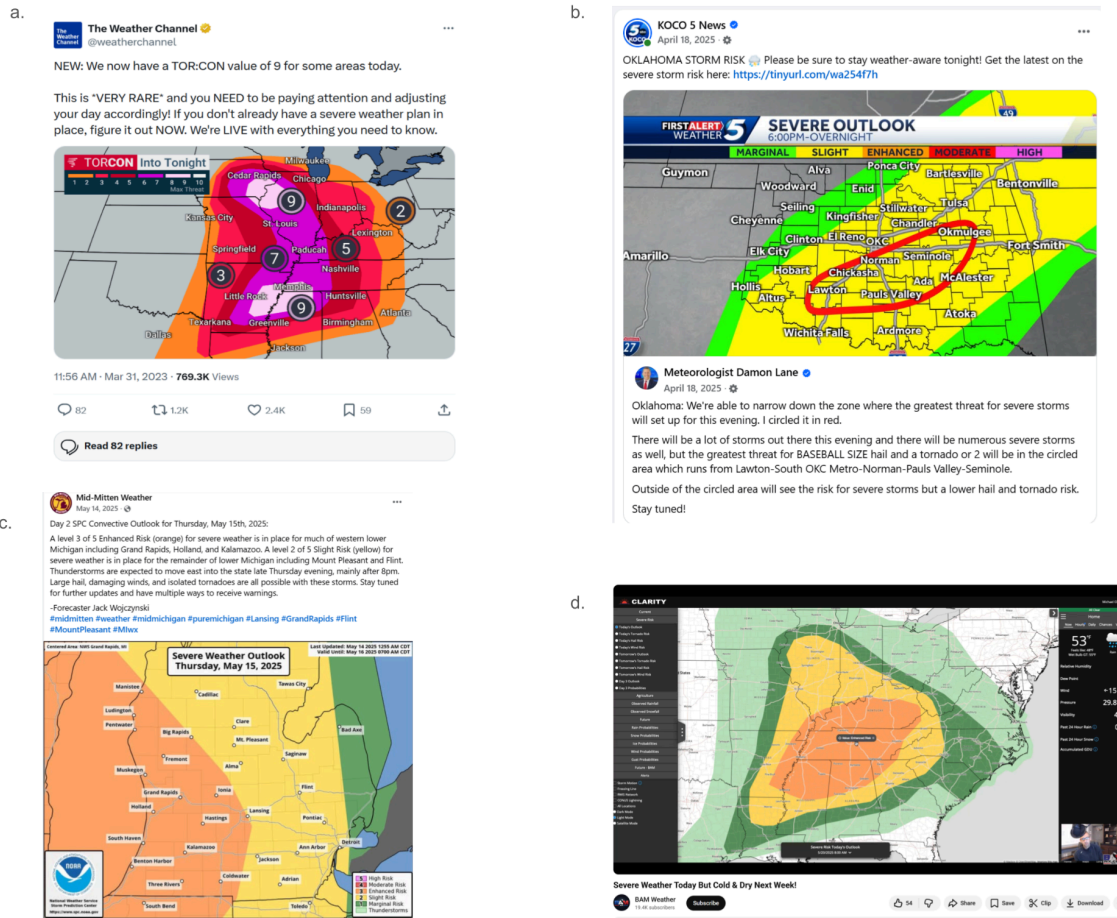


Figure 1.2: Examples of social media posts from The Weather Channel via X (a.) (courtesy of The Weather Channel), a local news station via Facebook (b.) (courtesy of KOCO 5 News), a student forecasting group via Facebook (c.) (courtesy Mid-Mitten Weather), a private weather company via YouTube (d.) (courtesy BAM Weather).

As a result of this widespread distribution, the interpretation and comprehension of the SPC Categorical Convective Outlook has been a much-studied topic at the intersection of

meteorology and social science in recent years. In 2021, Ernst et al. investigated the comprehensibility of current SPC categorical words and colors and found that miscategorizations occurred in relation to both aspects. This was followed in 2022 by Williams et al.'s report on forecasters', NWS partners', and members of the public's understanding of the SPC Categorical Convective Outlook, which resulted in the development of several recommendations on the stylistic aspects of the graphic. Also in 2022, Krocak et al. found that the use of numeric levels, rather than categorical levels, increased correct interpretations of likelihood among members of the public. In a similar vein, Bitterman et al. sought to determine if current Spanish translations of SPC categorical levels were reflective of actual risk levels when presented to a Spanish-speaking audience and suggested an alternative translation scheme to increase understanding (2023). More recently, Ernst et al. found that members of the public may have increased risk perceptions and heightened protective action intentions when conditional intensity contours are added to the Categorical Convective Outlook (2025). While these studies have covered a wide variety of topics, from word choice to color selection, none have explicitly focused on how risk perceptions held by members of the public may change in relation to their location relative to the area of maximum risk, in other words, the impact of the Inverse Bullseye Effect (IBE).

1.2 The Inverse Bullseye Effect

The Inverse Bullseye Effect can be defined as the negative impact that being located outside of the zone of highest risk on a probabilistic risk map has on an individual's risk perceptions. For example, when discerning risk from an SPC Categorical Convective Outlook,

an individual located within an Enhanced threshold area would perceive their risk as lower (higher) when a Moderate risk was (not) depicted on the map.

Some previous work has been conducted to understand how risk perceptions may change as a result of location relative to a threat as well as probabilistic map styling. In 2024, Balžekienė et al.'s findings indicated that distance from a perceived threat is positively correlated with risk perceptions. In other words, people who perceive themselves as being far from the threat generally have lower risk perceptions than those in closer proximity. In this instance, people might interpret the maximum threshold area as being the main or only region in which severe weather is expected to happen and may in turn believe that their risk of severe weather is minimal because they are not as close to the main area of risk. Additionally, work by Mishra and Mishra (2010) has found that participants who saw a location on the opposite side of a state border from a hazard on a map had lowered risk perceptions than those who saw a location within the same state as the hazard, despite the fact that both locations were the same distance from the hazard, thus indicating that the presence of a border between a map user's location and a potential threat may lead to lowered risk perceptions. For the SPC Outlook, specifically the hail probabilities map, Reed (2024) found that the use of continuous color scales (where risk is indicated by a spectrum of colors and/or saturations of color) caused heightened risk perceptions among survey participants who were shown a location of interest just outside of the area of maximum risk compared to the discrete color contours currently in use.

While each of the aforementioned studies has provided insight into how map users are influenced by location relative to the risk as well as the impact of map attributes on risk perceptions, no previous work has been conducted specifically on the IBE. Additionally, while these studies have identified potential pitfalls in map interpretation, aside from Reed (2024),

little work has been done to understand what strategies may be used to mitigate these impacts. Therefore, this study also seeks to explore if the IBE can be mitigated using reminder sentences that could easily be incorporated into current SPC messaging strategies.

In sum, this study seeks to understand the impact of the Inverse Bullseye Effect on interpretations of the SPC Categorical Convective Outlook by addressing three questions:

1. To what extent does the Inverse Bullseye Effect occur in practice?
 - a. What percentage of tornado reports fall outside of the maximum threshold area?
2. Does the Inverse Bullseye Effect empirically influence risk perceptions?
 - a. Does being in a location just outside the maximum threshold area lead to lowered risk perceptions compared to being in the same location without the maximum threshold present?
3. What, if anything, can be done to reduce the Inverse Bullseye Effect?
 - a. Does the inclusion of verbal or numeric reminders that severe weather can happen outside of the area of maximum risk mitigate the Inverse Bullseye Effect?

Chapter 2: SPC Categorical Convective Outlook Climatology

2.1 Analysis of SPC Reports and Outlooks

The data collected for this portion of the study consists of two parts: SPC Convective Outlook contour shapefiles and SPC Storm Reports point shapefiles. Both datasets were limited spatially to the contiguous US and temporally to the period of 1 January 2015 through 31 December 2023. The year 2015 was chosen as the starting point for analysis as it marks the first full year of the inclusion of the Marginal and Enhanced categories in the Days 1-3 Categorical Convective Outlooks, the previous outlooks having only contained Thunderstorm, Slight, Moderate, and High categories (Edwards and Ostby 2024). The year 2023 was chosen as an ending point as it was the last full year of Storm Report data available at the beginning of data analysis.

The SPC Convective Outlook shapefiles were retrieved from the Iowa Environmental Mesonet (IEM) website, which contains repositories of Convective, Excessive Rainfall, and Fire Weather Outlook shapefiles for Days 1-8 (IEM 2026a). Contour shapefiles can be retrieved as either “Cookie Cutters” (only the highest threshold at each location is recorded for that location, see Figure 2.1) or “Cake Layers” (all categories present at a location are recorded for that location). For the purposes of this study, Day 1 Convective Outlook contour shapefiles in the “Cookie Cutter” style were retrieved.

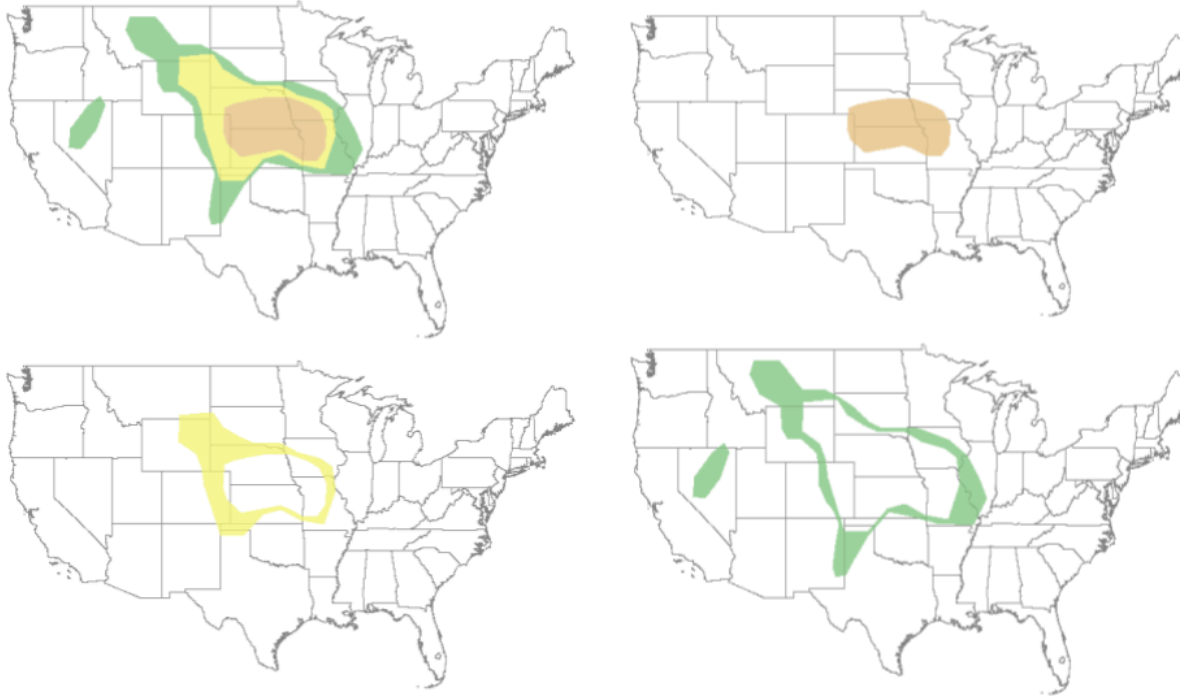


Figure 2.1: Maps showing an example layout of “Cookie Cutter”-style contours.

The SPC Storm Reports data were retrieved from the SPC SVRGIS webpage, which contains finalized tornado, wind, and hail report shapefiles in both path (trajectory of the storms) and initial points (starting points of the storms only) formats (Carbin 2010; Storm Prediction Center 2025). This dataset has been used previously in multiple peer-reviewed studies of tornado spatiotemporality (e.g. Kellner and Niyogi et al. 2014; Market et al. 2019; Johnson et al. 2021). The tornado “initial points” dataset was used in this study.

To conduct a spatiotemporal comparison of the Convective Outlook contours and Storm Reports points, the datasets were first adjusted to maintain the same time zone (UTC) and the same map projection (WGS84). The Storm Reports dataset was limited to the 1 January 2015 through 31 December 2023 time period to match that of the Convective Outlook dataset. For parts of the analysis, the Storm Reports were also filtered to include only tornado reports of a

magnitude of either EF0/EF1 or EF2+ so that any potential correlations between magnitude and the IBE were apparent. The Convective Outlook contour dataset was also limited to only Categorical Outlooks that were issued at 2000 UTC. The Convective Outlook and Storm Reports shapefiles were then spatially intersected and temporally filtered so that only Storm Reports points that fell within the valid period of each 2000 UTC Day 1 SPC Convective Outlook contour were included in the final dataset.

Once the dataset was prepared, the proportion of reports that fell within each specific Categorical contour was calculated and recorded under the variable name “TOR_PROP”. If no Storm Reports occurred during the valid period of the Convective Outlook, the proportion of reports was recorded as “NA,” and the Convective Outlook was dropped from further analysis. Similarly, the “TSTM” or general thunderstorm contour shapefiles were dropped from the dataset, as they are not indicative of severe weather. The proportion of reports that occurred outside of each Categorical contour was also calculated ($TOR_PROP_OUT = 1 - TOR_PROP$) for each Outlook issuance. Finally, as only the proportion of reports that fall outside of the maximum threshold per issuance are of interest to this study, all Outlook contours except for the one representing the highest threshold per issuance were dropped, so that only the maximum threshold contours were retained (e.g. if SLGT was the highest threshold for one issuance, then MRGL was dropped).

First, the average proportion of reports that fell outside of each maximum threshold contour was calculated to understand how this proportion varied based on reported tornado magnitude, size of the maximum threshold contour, by season, regionally, and by whether the maximum threshold was tornado-based. Next, the area of each contour was calculated in square kilometers from the SPC Outlook dataset. These areas were used to determine the impact of

contour size on the proportion of reports that fall outside of the highest contour. This was done by finding the upper, middle, and lower terciles of the maximum contour areas for each Categorical level (e.g. SLGT_SMALL, SLGT_MED, SLGT_LARGE), then calculating the overall proportion of tornado reports that occurred outside of each category.

To ascertain the impact of season on the proportion of reports outside of the maximum threshold contour, the month of outlook issuance was taken from the issuance time included in the SPC Outlook dataset. The months were then organized into meteorological seasons (DJF, MAM, JJA, SON). The average proportion of reports outside of the maximum threshold contour by season and maximum threshold was then calculated

To better understand the variability of the proportion of tornado reports outside of the maximum threshold contour across regions, the dataset was broken down into five regions: West, North Plain, South Plain, Northeast and Southeast (as seen in Figure 2.2). These regions were based on Malloy and Tippet (2025)'s regional breakdown, with the addition of the western region. To assign a region to a convective outlook, the centroid of each maximum threshold contour was found, and the region in which the centroid of the maximum threshold contour fell was then considered the region of the outlook.



Figure 2.2: The regional divisions, West (red), North Plain (yellow), South Plain (blue), Northeast (purple), Southeast (green).

Finally, to determine the role that the primary weather hazard type (tornado, hail, or wind) plays in the proportion of reports outside of the maximum threshold contour, the dataset was separated into “Tornado-Driven” and “Not Tornado-Driven” categories. This was done using the tornado probability contour data from the SPC Convective Outlook dataset. To be included in the “Tornado-Driven” category, the tornado probability for a specific issuance must match the criteria for the highest threshold level present (e.g. a Significant 10% tornado risk with an Enhanced maximum threshold or a 30% tornado risk for a Moderate maximum threshold, see Figure 2.3 below). Note that this only accounts for tornadoes, not wind or hail, so a “Tornado-Driven” issuance could also be a “Hail-Driven” or “Wind-Driven” issuance (e.g. a Slight risk with a 5% tornado risk and a 15% wind and/or hail risk). The average proportion of reports that fell outside of the maximum contour by threshold and by whether or not the issuance was tornado-driven was then calculated.

Day 1 Outlook Probability to Category Conversion

Day 1 Outlook Probability	TORN	WIND	HAIL
2%	MRGL	Not Used	Not Used
5%	SLGT	MRGL	MRGL
10%	ENH	Not Used	Not Used
10% with Significant Severe	ENH	Not Used	Not Used
15%	ENH	SLGT	SLGT
15% with Significant Severe	MDT	SLGT	SLGT
30%	MDT	ENH	ENH
30% with Significant Severe	HIGH	ENH	ENH
45%	HIGH	ENH	ENH
45% with Significant Severe	HIGH	MDT	MDT
60%	HIGH	MDT	MDT
60% with Significant Severe	HIGH	HIGH	MDT

Figure 2.3: SPC probability to category conversion table (courtesy of the Storm Prediction Center).

2.2 Results of Climatological Analysis

Weak vs. Significant Tornadoes

The first stratification of the dataset was between weak (EF0/EF1) and significant (EF2+) tornadoes. Figure 2.4 shows the breakdown of the percent of tornado reports *outside* of the area covered by the maximum threshold by magnitude category. The dashed black line represents the point at which 50% of the reports fall outside of the maximum threshold area, while the dashed gray line represents the point at which 25% of the reports fall outside of the maximum threshold area. The x-axes represent these maximum threshold categories. For example, “(1) MRGL”

represents all issuances in which Marginal was the highest category on the Convective Outlook. The size of each point represents the total number of outlook issuances associated with each combination of variables.

Per Figure 2.4a, for weak (EF0 and EF1) tornadoes, when Marginal is the highest threshold category, 51% of tornado reports fall outside of the Marginal area. Similarly, when Slight is the maximum category, 47% of reports fall outside of the Slight area (into either Marginal or Thunderstorm). The percentage of reports outside of the maximum area is even higher for the higher categories, with 57% of reports outside of the Enhanced area, 57% outside of the Moderate, and 68% outside of the High.

Figure 2.4b depicts the percentage of reports associated with tornadoes of magnitudes EF2 or greater. Generally, the percentage of reports that fall outside of the highest threshold area is much lower for EF2+ tornadoes compared to EF0 and EF1 tornadoes, and increases with increasing threshold category. For example, 17% of reports fall outside of the Marginal area, 28% outside of the Slight, 39% outside of Enhanced, 51% outside of Moderate, and 45% outside of High. Note that there are relatively few reports for EF2+ tornadoes compared to EF0/EF1.

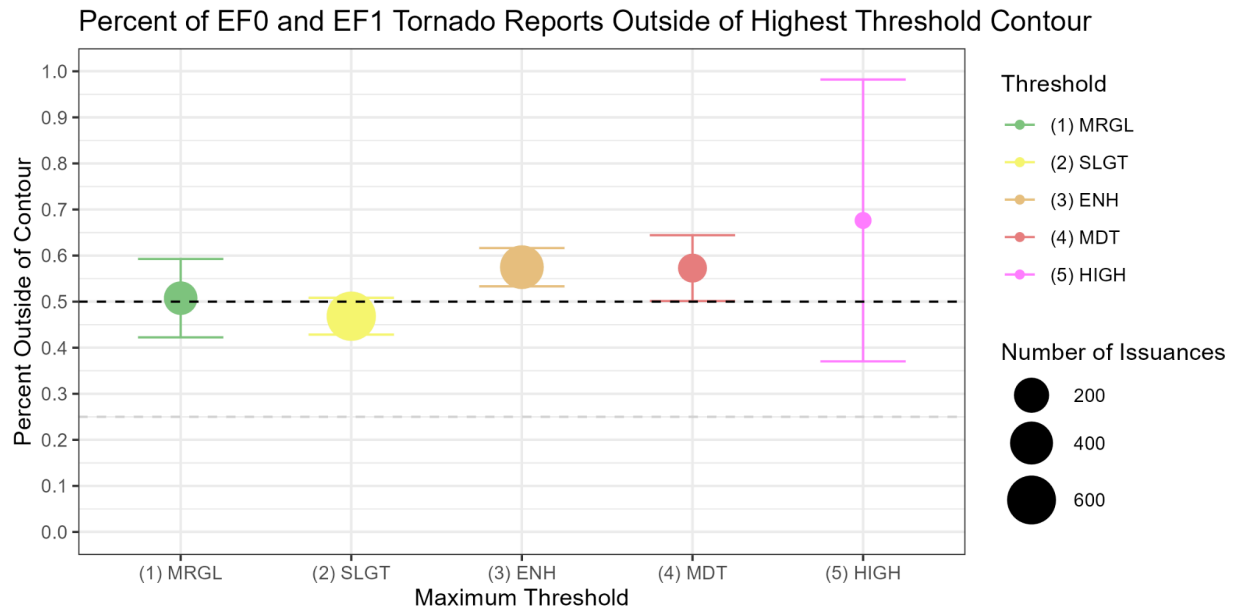


Figure 2.4a: The percent of EF0 and EF1 tornado reports that fall outside of the highest threshold contour by maximum threshold.

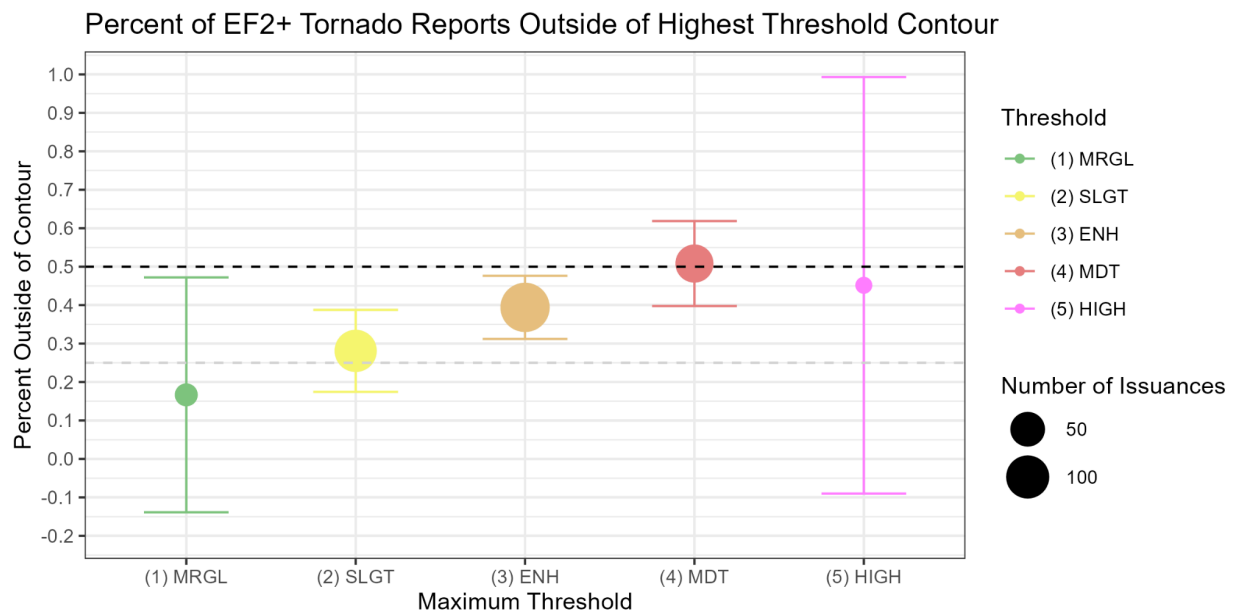


Figure 2.4b: The percent of EF2+ tornado reports that fall outside of the highest threshold contour by maximum threshold.

Regional Stratification

Figure 2.5a depicts the breakdown of EF0 and EF1 reports outside of the maximum threshold area by region. Generally, a higher percentage of reports fell outside of the maximum threshold area for all regions except for the Southeast, where all maximum threshold levels except High had an average of 25-50% of reports fall outside of the maximum threshold area.

Figure 2.5b shows the same regional breakdown as Figure 2.5a, but for EF2+ tornadoes. The percentages of tornado reports outside of the maximum threshold area across regions and maximum thresholds were generally lower for these stronger tornadoes. Similar to the EF0/EF1 breakdown, the Southeast exhibits a generally lower percentage of tornado reports falling outside of the maximum threshold area than the North Plains, Northeast, and South Plains. Note that for both graphs, the Western region had relatively few reports overall, with no High or Moderate threshold days for either breakdown, and only Marginal days for EF2+ tornado reports.

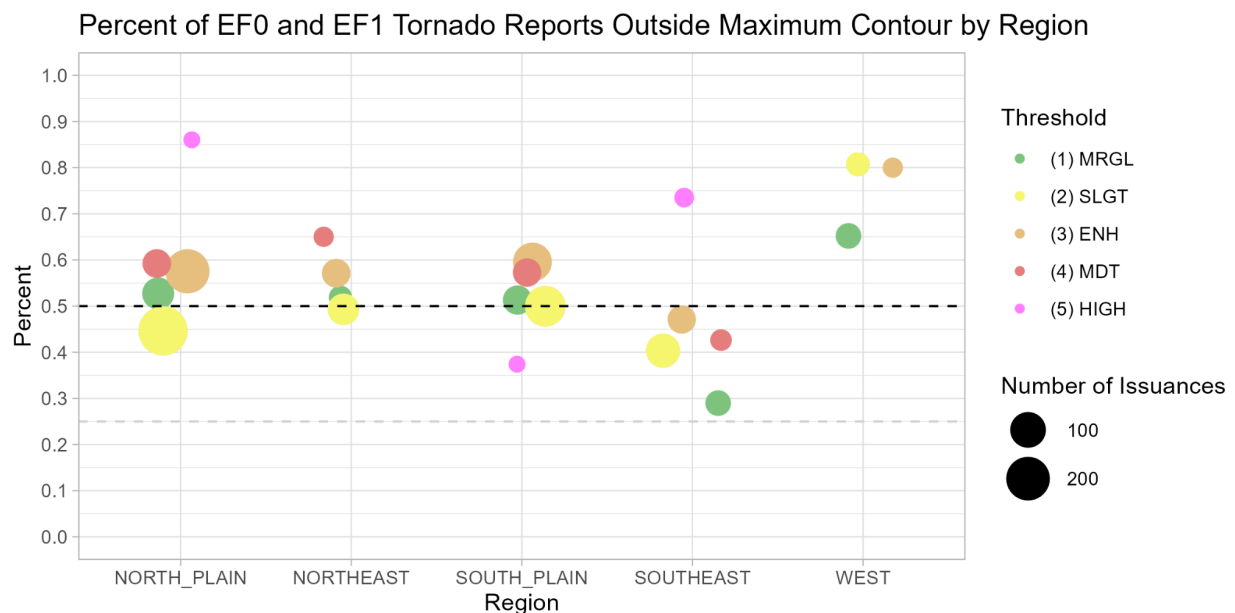


Figure 2.5a: Percent of EF0 and EF1 tornado reports that occurred outside of the maximum threshold stratified by region.

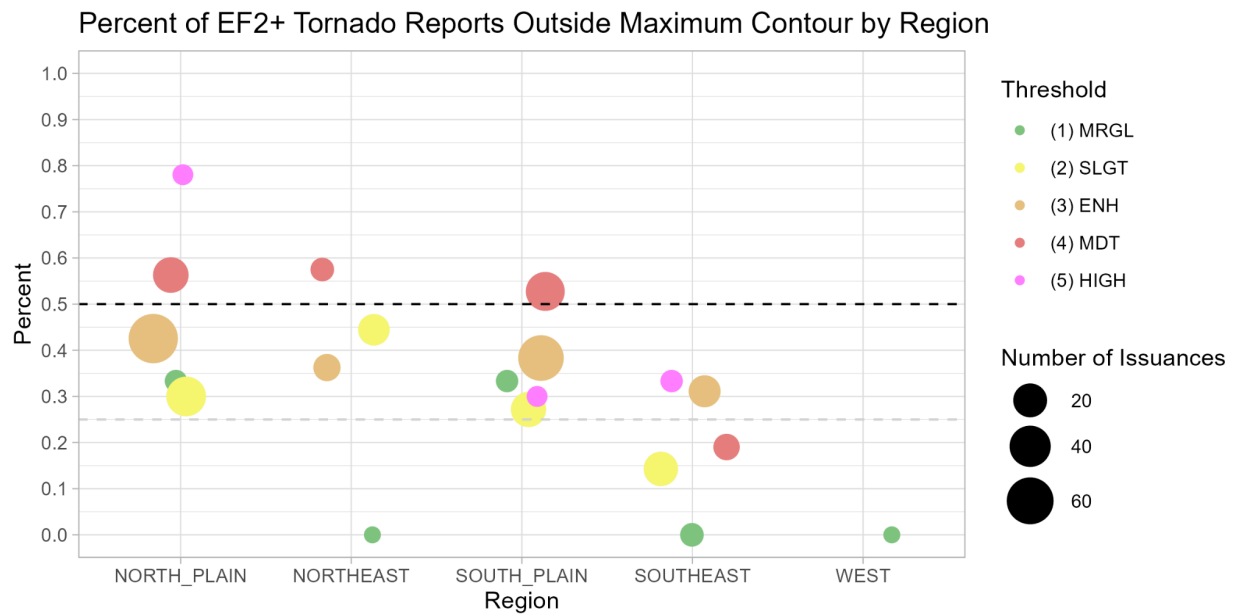


Figure 2.5b: Percent of EF2+ tornado reports that occurred outside of the maximum threshold stratified by region.

Seasonal Stratification

Seasonal stratification reveals a generally increased proportion of tornado reports that occur outside of the maximum threshold area in the summer months (JJA), during which over half of weak tornado reports and 35-75% of significant tornado reports in each maximum threshold category fall outside of their respective maximum threshold areas (Figures 8a and 8b).

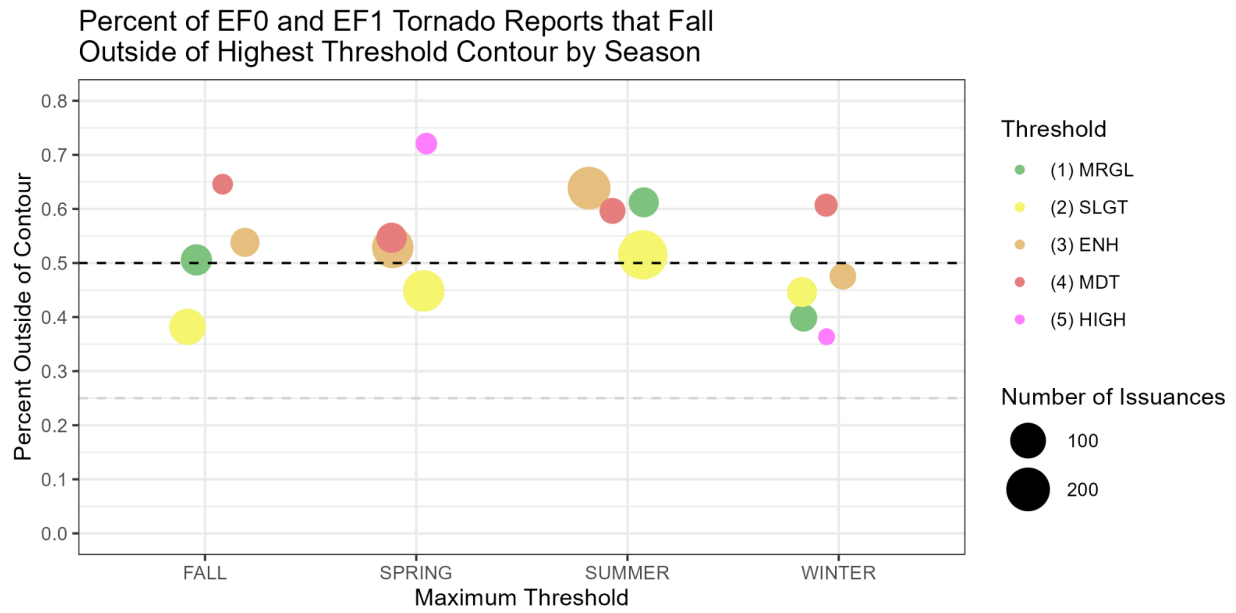


Figure 2.6a: Percent of EF0 and EF1 tornado reports that fall outside of the maximum threshold stratified by season.

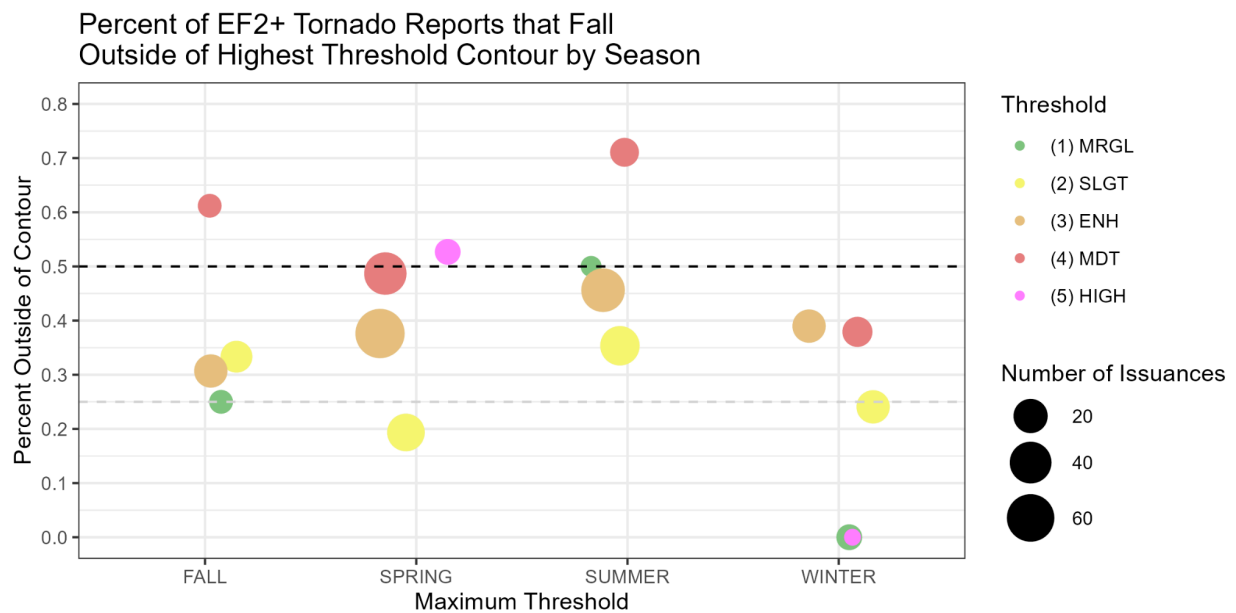


Figure 2.6b: Percent of EF2+ tornado reports that fall outside of the maximum threshold stratified by season.

Area Stratification

Stratification by maximum threshold area reveals a distinct pattern of decreasing proportion of tornado reports outside of the maximum threshold area with increasing area for EF0 and EF1 reports across all levels except for High. At the High threshold level, the Medium threshold area tercile exhibits the highest percent of reports outside of the maximum threshold area at 97%, followed by Small and Large, at 72% and 43%, respectively (Figure 2.7a).

Stratification of EF2+ reports reveals similar patterns across the Enhanced, Moderate, and High thresholds, however, at the Marginal and Slight levels, the Medium terciles had a smaller proportion of outside reports than Small or Large (Figure 2.7b). Across the board, the proportion of reports outside was higher with reports of weak tornadoes than with significant tornado reports.

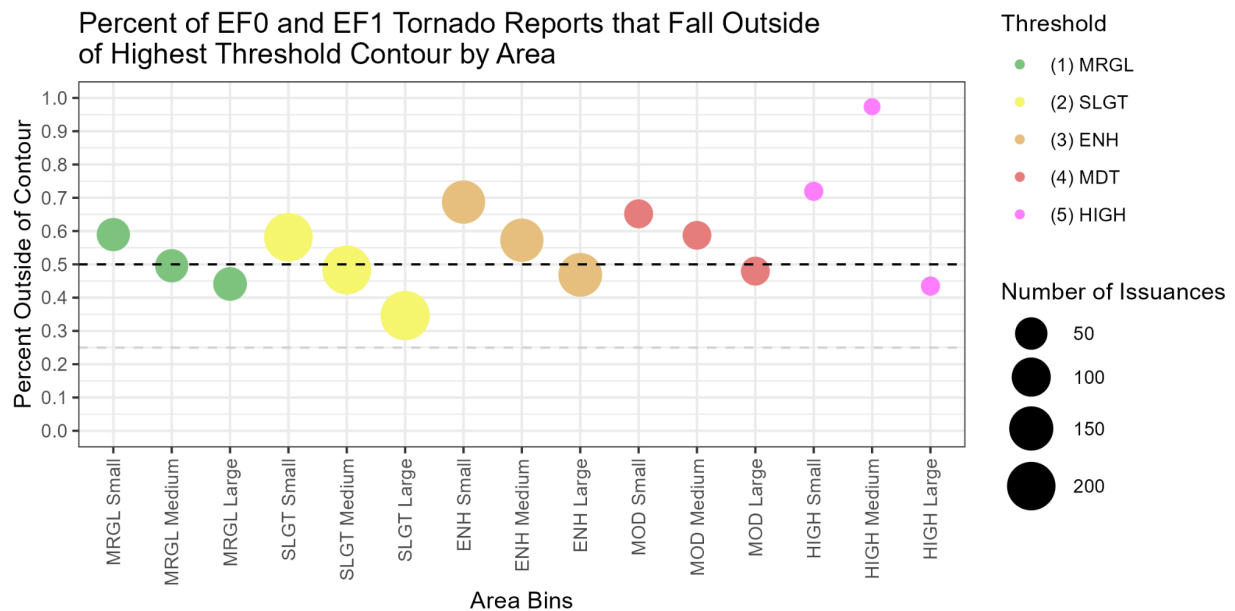


Figure 2.7a: Percent of EF0 and EF1 tornado reports occurring outside of the maximum threshold area stratified by size of maximum threshold area.

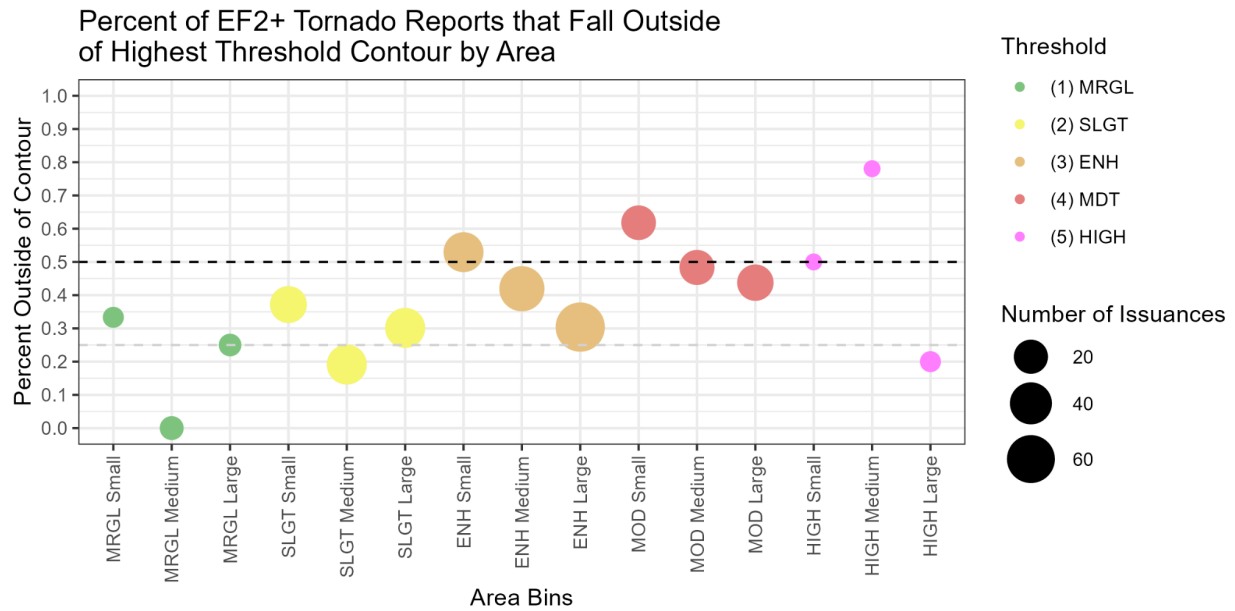


Figure 2.7b: Percent of EF2+ tornado reports occurring outside of the maximum threshold area stratified by size of maximum threshold area.

Tornado-driven Stratification

Finally, the dataset was stratified by whether each Outlook issuance was “tornado-driven” or “not tornado driven.” As discussed above, “tornado-driven” events were those for which the maximum tornado probability met the criteria for the inclusion of the maximum threshold in that issuance (e.g. a 5% tornado chance with Slight as the maximum category). For weak tornadoes in non-tornado-driven events, the percent of tornado reports outside of the maximum threshold area was over 50% for all included maximum thresholds. In contrast, for tornado-driven events, the percentages were more evenly split, with the Moderate and High categories having over 50% of reports outside, while less than 50% of reports in the Enhanced, Slight, and Marginal thresholds fell outside of their respective maximum threshold areas (Figure 2.8a).

The reports for the significant tornadoes exhibited an overall smaller proportion of reports outside of the maximum threshold than those for weak tornadoes, as has generally been the case for each stratification. Between 30% and 55% of reports from non-tornado-driven issuances fell outside of their respective maximum threshold areas, while 15-55% of reports from tornado-driven issuances occurred outside of their respective maximum threshold areas (Figure 2.8b). It is worth noting that, for both weak and significant categories, there were no issuances of Marginal or High maximum thresholds in the non-tornado-driven subset.

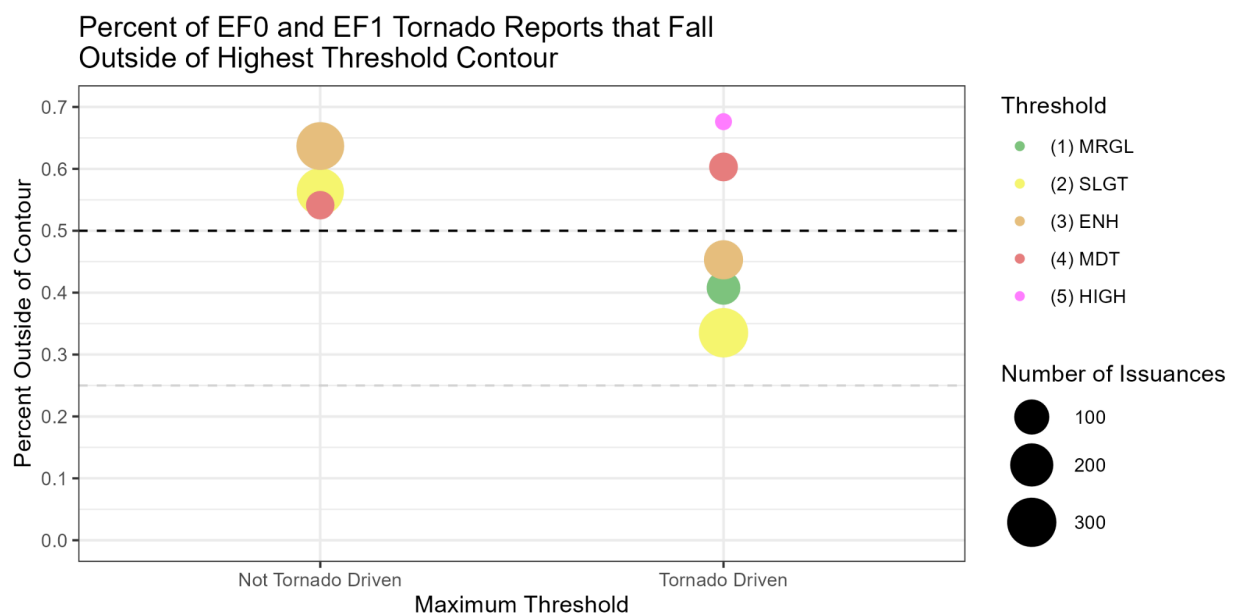


Figure 2.8a: Percent of EF0 and EF1 tornado reports that fall outside of the maximum threshold area stratified by tornado-driven versus non-tornado-driven.

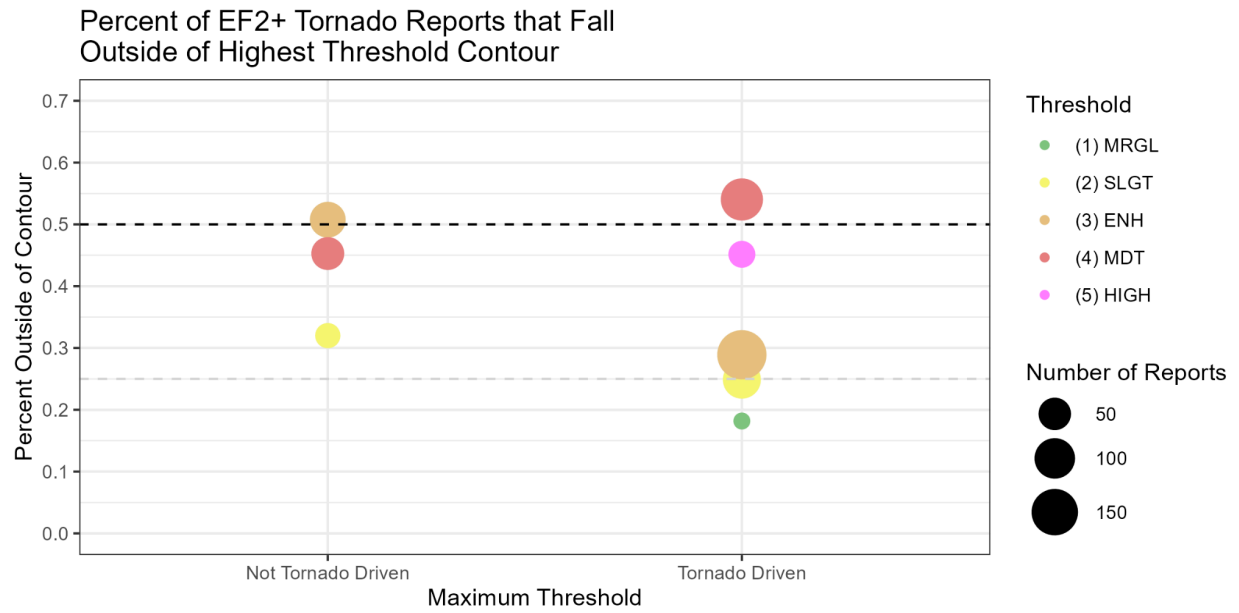


Figure 2.8b: Percent of EF2+ tornado reports that fall outside of the maximum threshold area stratified by tornado-driven versus non-tornado-driven.

Chapter 3: Case Studies

While the climatological analysis indicates that a substantial proportion of tornado reports occur outside of the maximum threshold area, it cannot provide guidance on why this might be happening. In order to gain some insight into the reasons why tornado reports might occur outside of the maximum threshold area, this section highlights four events where 50% or more of the EF2+ tornado reports that occurred during the event fell outside of their respective maximum threshold areas, which occurred in 84 events. From this list, one example event from each meteorological season was selected, each of which included at least one EF3 tornado report that occurred outside of the maximum threshold area. These events were 10 December 2021, 28 March 2020, 4 June 2015, and 29 November 2019. The synoptic-scale set-up, forecast, timeline, and impacts from each event are detailed below. Unless otherwise noted, data and figures are derived from the Storm Prediction Center's Severe Weather Event Archive page (Storm Prediction Center 2026a) for each event.

3.1: Event 1: 10 December 2021, Edwardsville, IL and Defiance, MO

On the 10th of December, 2021 at 7:35pm CST, an EF3 tornado touched down to the southwest of Defiance, MO (NWS St. Louis). Less than an hour later, at 8:27pm CST, another EF3 tornado touched down southwest of Edwardsville, IL (NWS St. Louis). The 2000 UTC SPC Categorical Convective Outlook indicated that both of these events occurred in locations under an Enhanced risk for severe weather, with the highest risk level present on that day (Moderate) located just to the south (Figure 3.1).

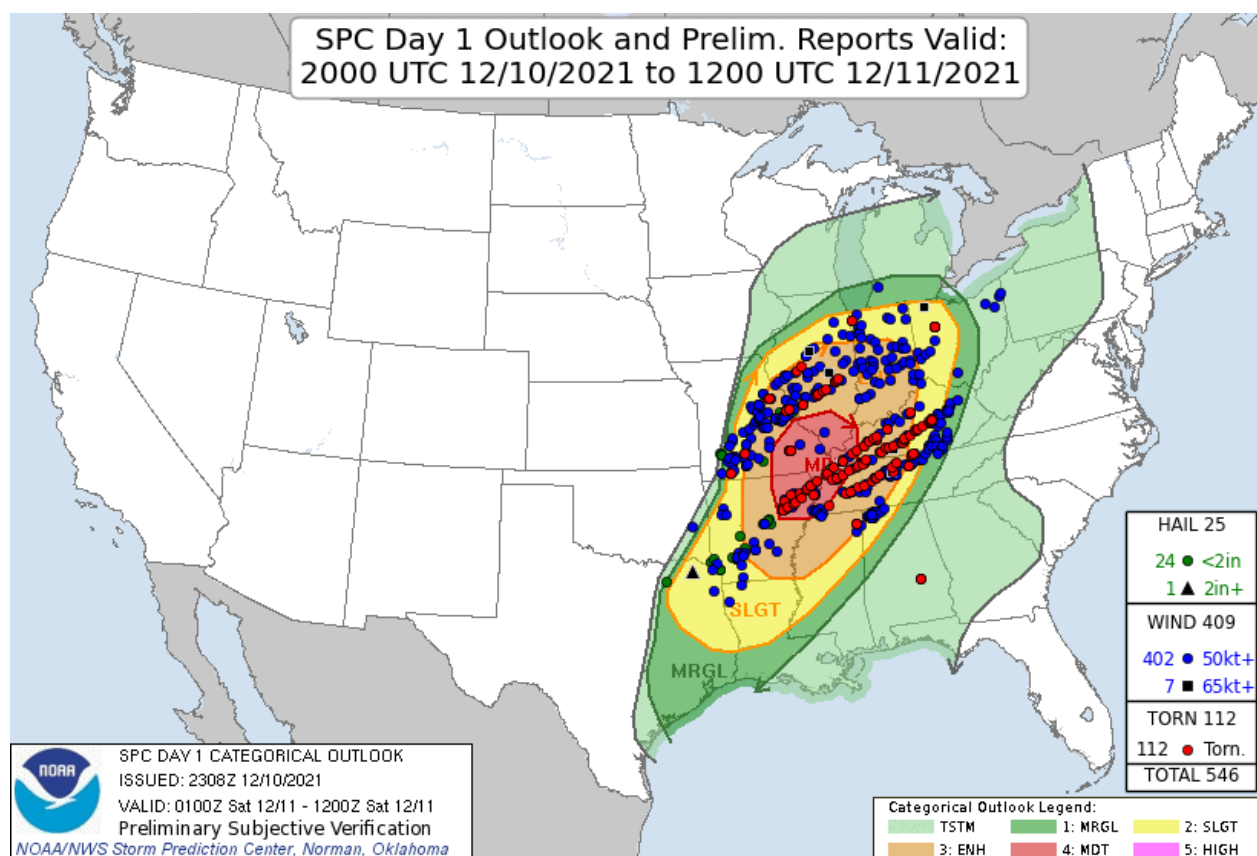


Figure 3.1: 2000 UTC SPC storm report verification for December 10th, 2021.

The first mention of the possibility of severe weather on the 10th appeared on the Day 4-8 Convective Outlook Discussion on the 3rd, in which the SPC cited the potential for trough development and moist air advection, but maintained uncertainty in location and timing. The uncertainty in trough development and moisture advection decreased closer to the events' occurrence, however, difficulty with predicting the exact location of the trough and extent and intensity of any future instability remained uncertain on the 5th. The Day 4-8 Convective Outlook Discussion on the 7th pinpointed the afternoon of the 10th as the most likely time for severe weather and highlighted the Mississippi River Valley as the most likely location, however, the Day 4 Convective Outlook map did not include a 15% contour as the related trough was

positively tilted at the time, there were several potential factors that could have limited the development of severe weather, and the area of interest was fairly large.

The Day 3 Categorical Convective Outlook issued on the 8th was the first outlook to highlight the Mississippi River Valley on the map, with a Slight risk contour stretching from northern Louisiana to southern Indiana. The related discussion indicated that a low-pressure center to the west of the area of interest was expected to progress eastward into a region of warm, moist air moving northwards, creating the potential for severe weather on 10th . Some uncertainty remained as to the strength of instability in the region, as models indicated low mid-level lapse rates. The 1730 UTC Day 2 Categorical Outlook included the addition of an Enhanced risk stretching from southern Arkansas to southern Indiana (Figure 3.2). The associated discussion indicates that instability was expected to increase in this region as upper-level cooling and lower-level moisture advection persisted. The 1630 UTC Day 1 Categorical Outlook was the first to include a Moderate threshold contour, which extended from northeastern Arkansas into extreme southern Illinois. Notably, Edwardsville, IL and Defiance, MO were within the Enhanced threshold contour, not the Moderate contour.

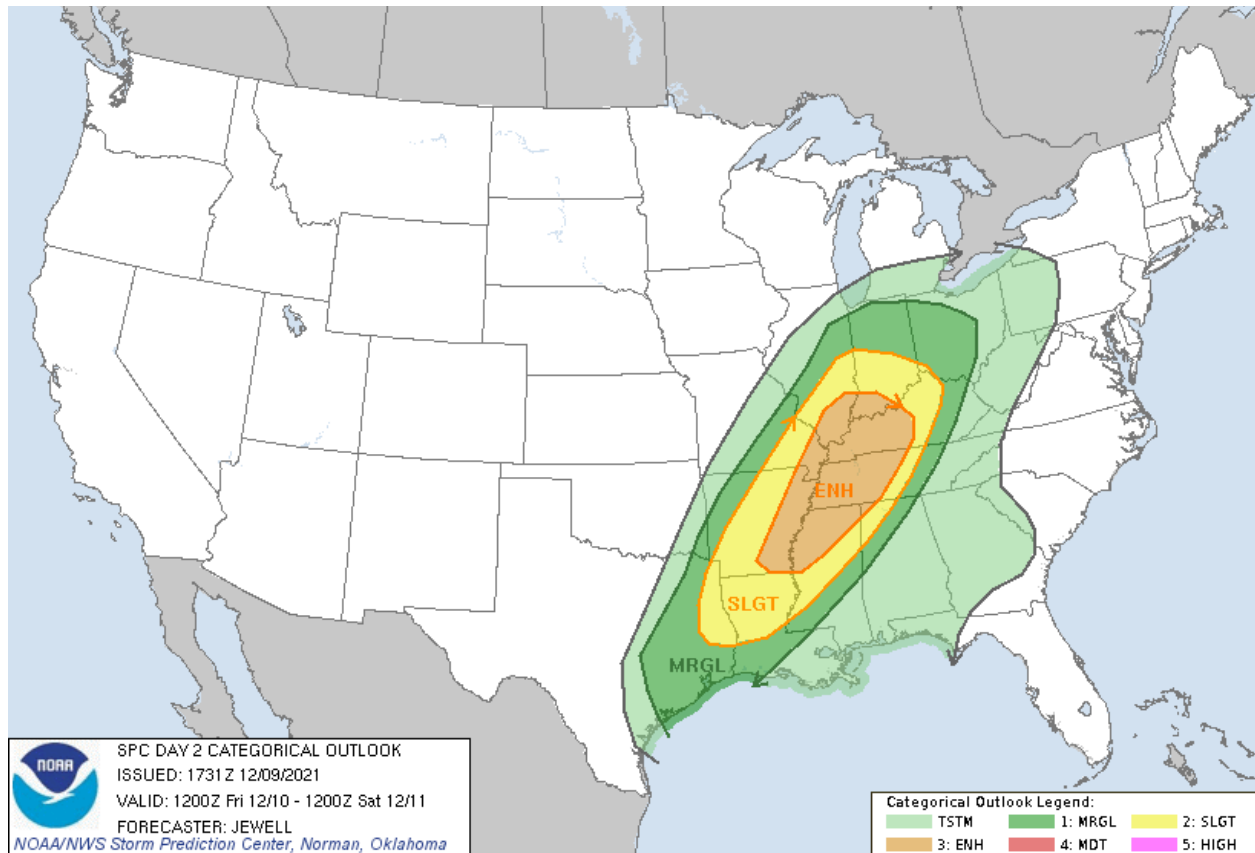


Figure 3.2: The Day 2 Categorical Convective Outlook valid for December 10th, 2021.

The 2000 UTC Day 1 Categorical Outlook was nearly unchanged from the 1630 UTC issuance, except with a minor extension of the Marginal and Slight threshold contours into Texas (Figure 3.3). The 2000 UTC discussion emphasized that the probability of tornadoes is largest in the Ohio and Mississippi River Valleys, with a predicted timing of 0300 UTC on the 11th. As seen in Figures 3.4 and 3.5, the 2000 UTC 300mb map indicated large-scale divergence over much of the Central Plains, including southern Illinois, as well as a deep trough over the Rocky Mountains, which is mirrored in the 500mb map. At 850mb, a mid-level area of low pressure is apparent over northeastern Kansas and southern Nebraska, along with significant moisture in the southeastern US (Figure 3.6). The surface map from 1800 UTC (the closed time available before

2000 UTC) shows a low-pressure center in Nebraska, vertically stacked with the 850mb low pressure center aloft, with a warm front extending across northern Missouri, through southern Indiana, and southward into Georgia, a dryline extending through Oklahoma and into Texas, and a cold front extending into New Mexico (Figure 3.7). At 2000 UTC, the Defiance/Edwardsville area was directly beneath the warm front, with southeasterly winds, 100% relative humidity, and temperatures in the mid-50s.

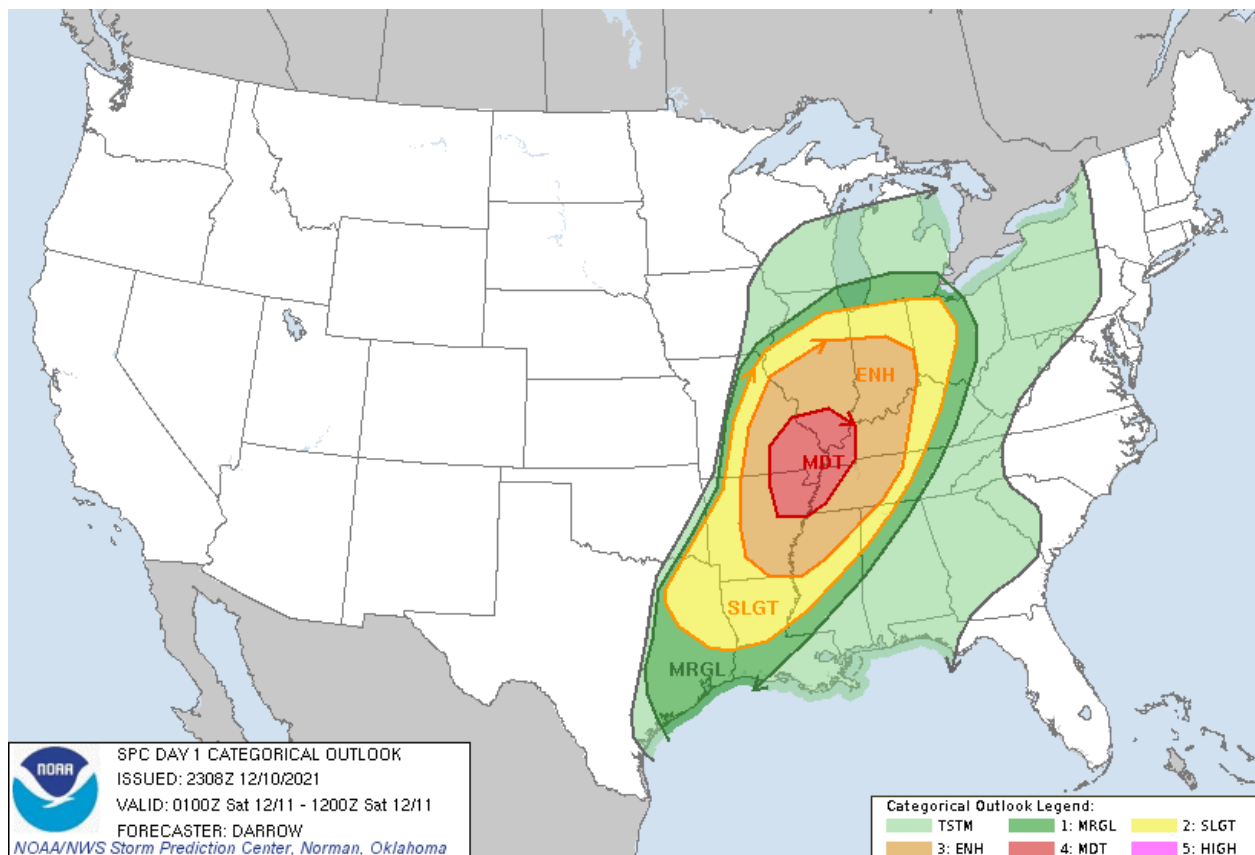


Figure 3.3: The 2000 UTC Day 1 Categorical Convective Outlook for December 10th, 2021.

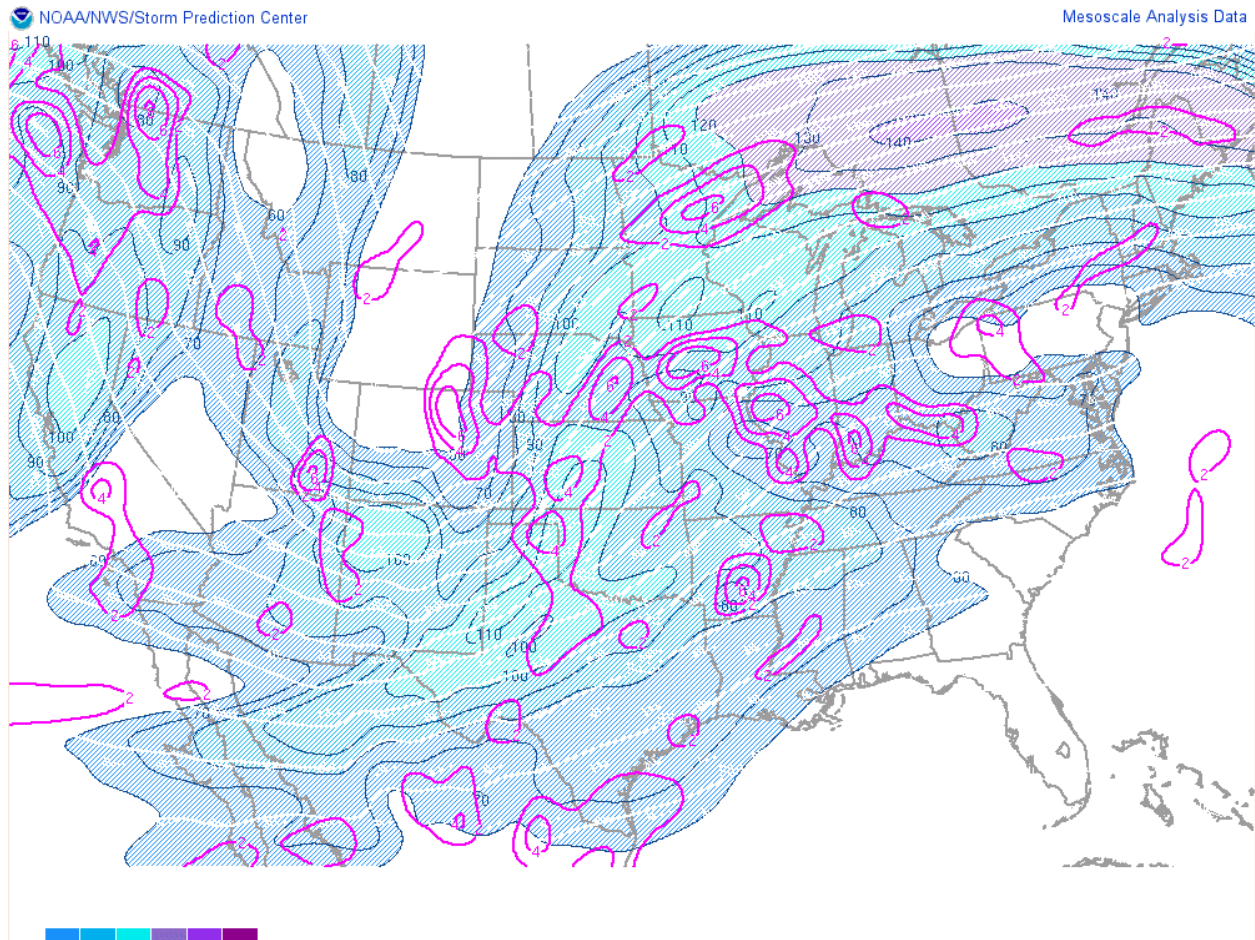


Figure 3.4: The 300mb map for 2000 UTC December 10th, 2021. The white contours represent geopotential heights (m), the shading represents wind speeds (kts), and the purple contours represent divergence (10^{-5}s^{-1}).

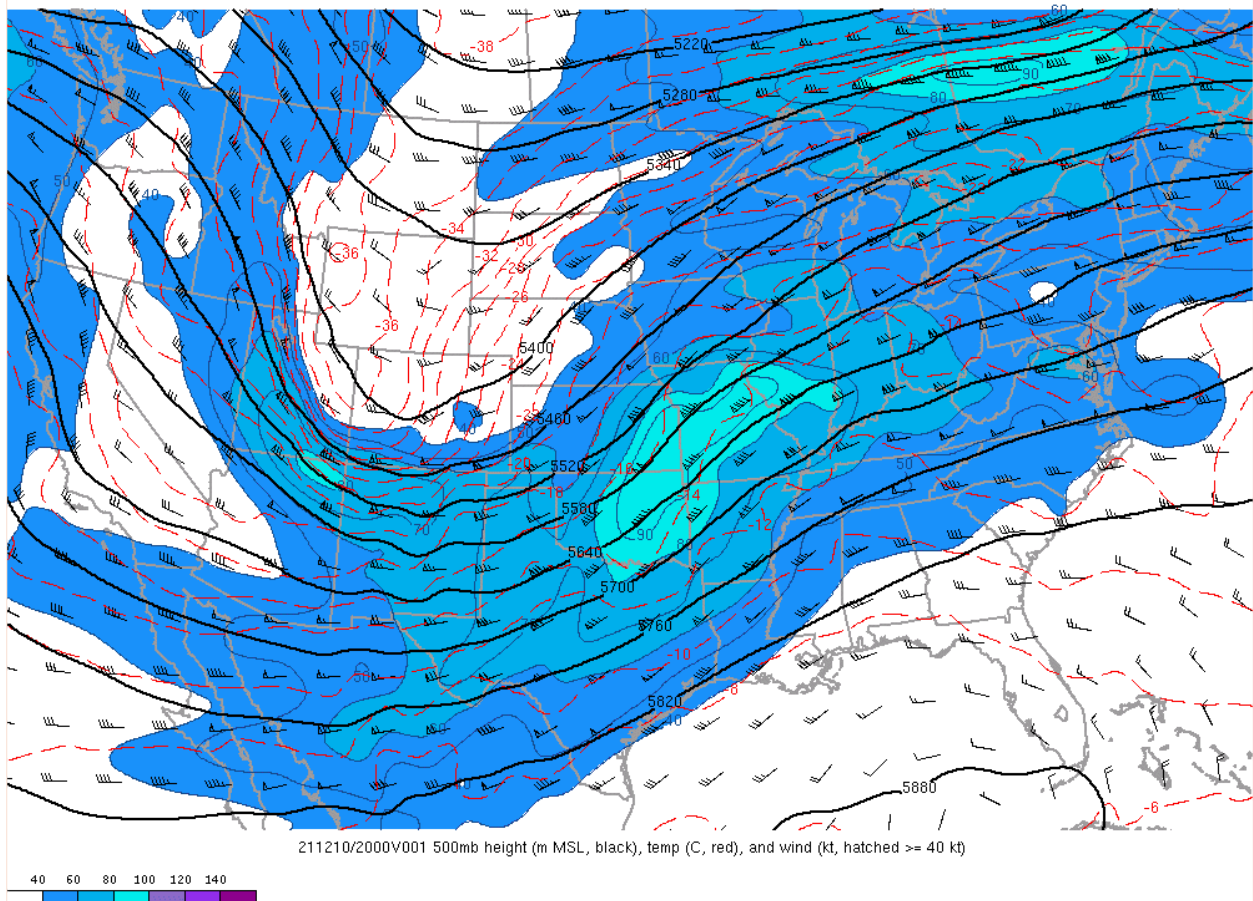


Figure 3.5: The 500mb map for 2000 UTC December 10th, 2021. The black contours represent geopotential heights (m), the red dashed contours represent temperature ($^{\circ}\text{C}$), and the shading and wind barbs represent wind speeds (kts).

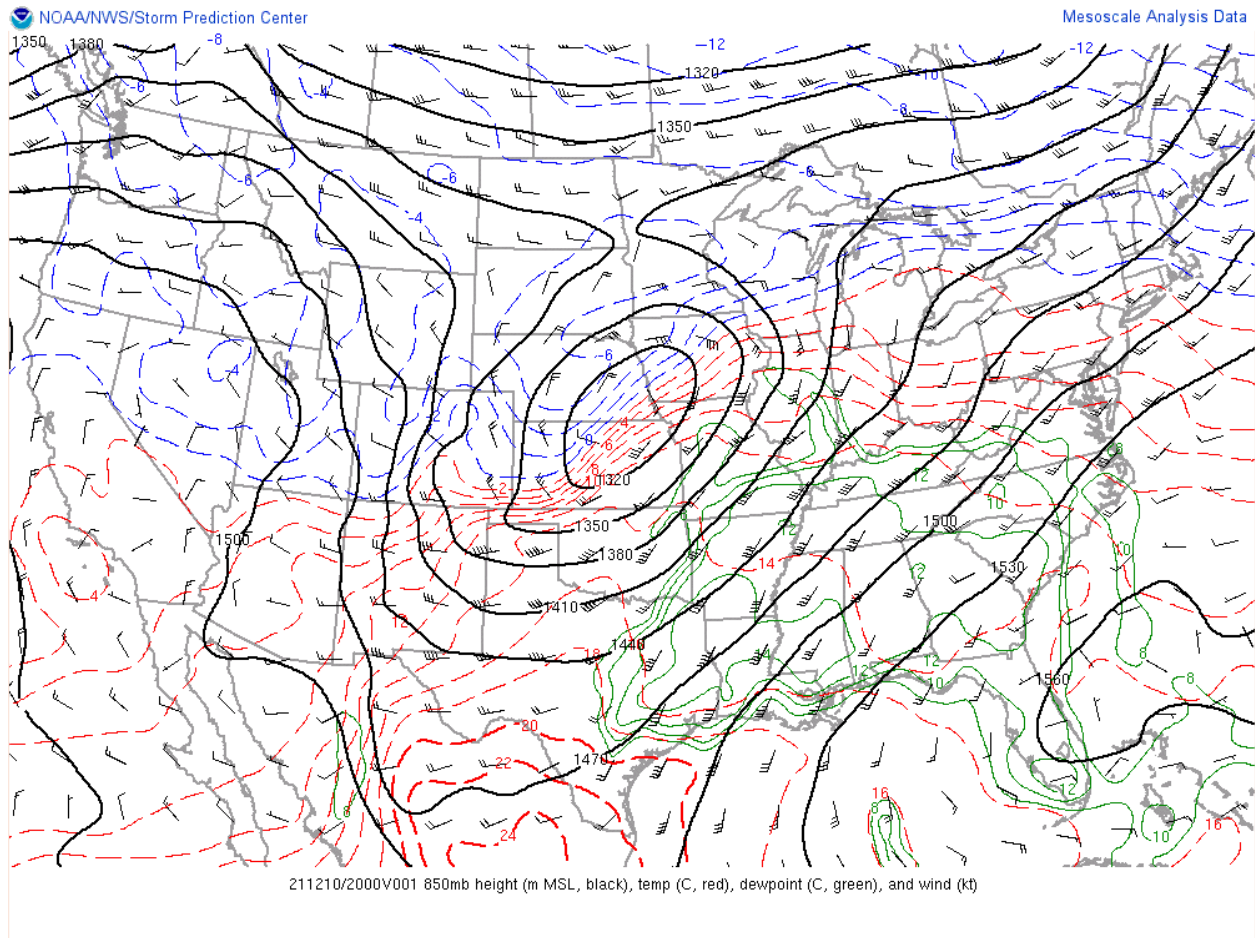


Figure 3.6: The 850mb map for 2000 UTC December 10th, 2021. The black contours represent geopotential heights (m), the dashed red and blue contours represent temperature ($^{\circ}\text{C}$), the wind barbs represent wind velocity (kts), and the green contours represent dew point ($^{\circ}\text{C}$).

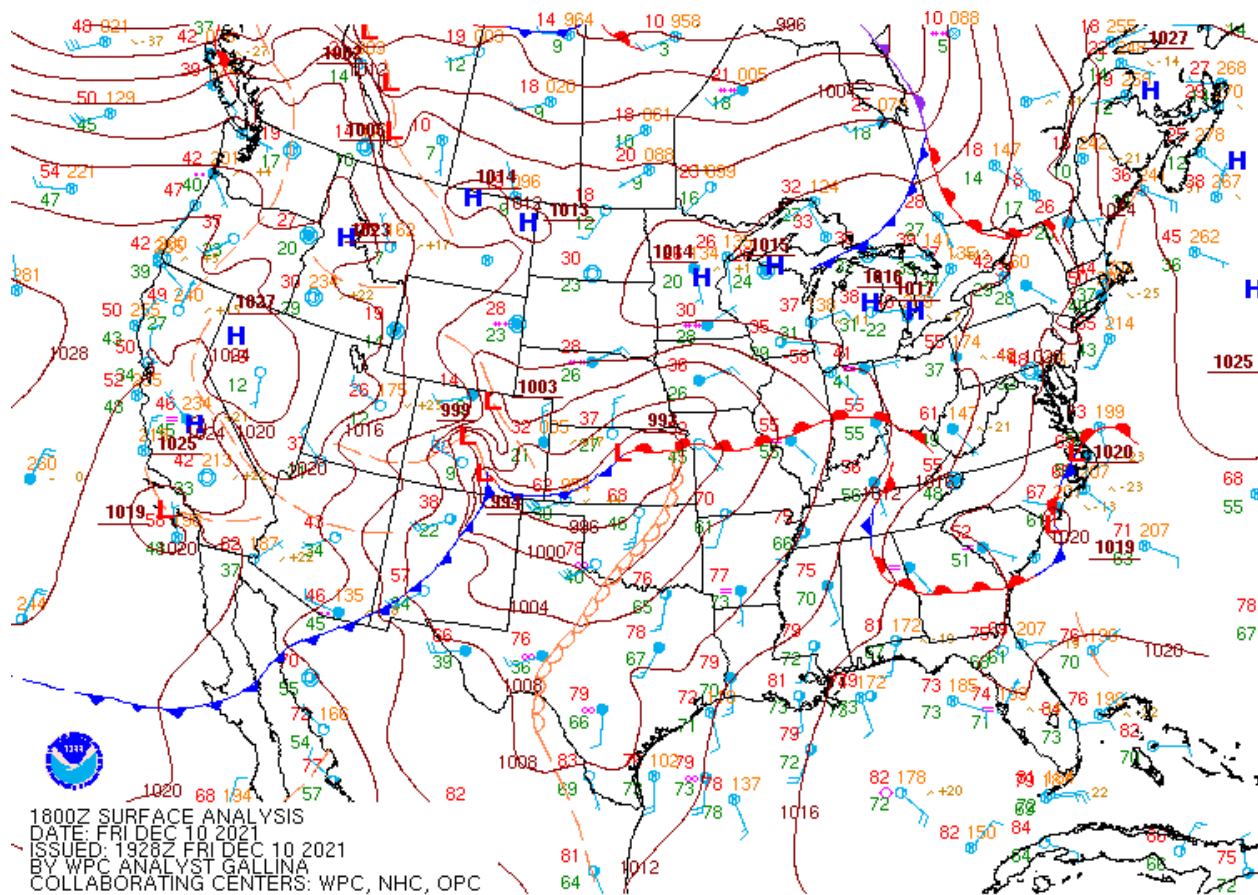


Figure 3.7: The surface map for 1800 UTC December 10th, 2021.

The first and only tornado watch associated with the Defiance/Edwardsville event was issued at 2320 UTC (5:20 pm CST) and covered much of central Missouri and western Illinois (Figure 3.8). Just over an hour and a half later, at 0102 UTC (7:01pm CST), a mesoscale discussion was issued indicating that the Defiance/Edwardsville area was under a threat for strong winds and tornadoes due to the continued development of embedded supercells within a line of storms moving in from central Missouri (Figure 3.9). Around this time, the 0-6 km shear over the Defiance/Edwardsville area was around 80 kts, while the 0-3 km storm relative helicity

was around $400 \text{ m}^2\text{s}^{-2}$, indicating a strong likelihood of supercellular development (Figures 3.10 and 3.11) (Storm Prediction Center 2026a, WFO Louisville).

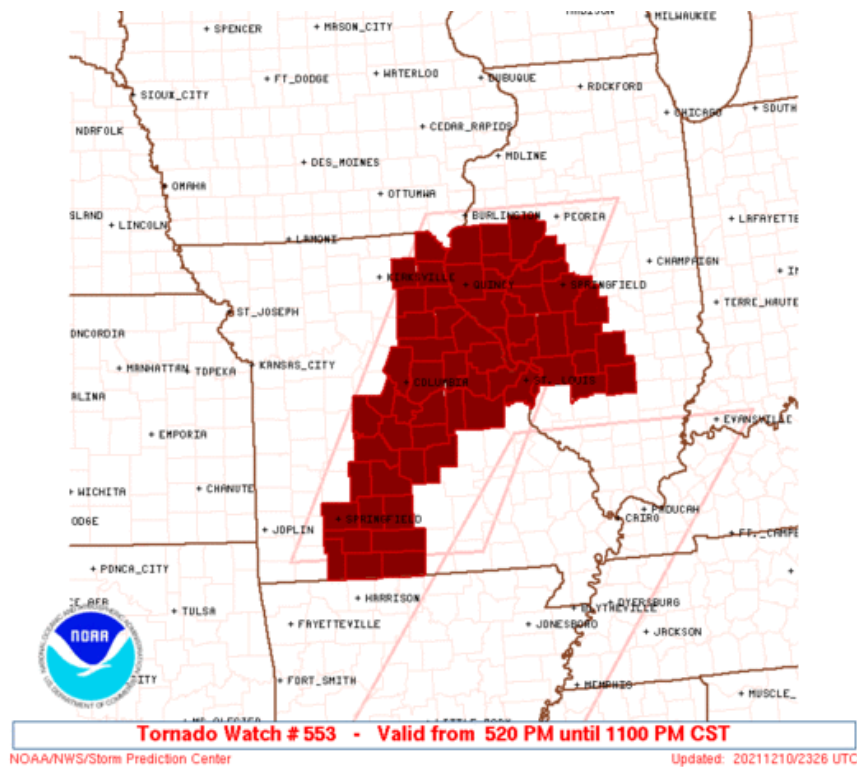


Figure 3.8: The tornado watch associated with the Defiance, MO and Edwardsville, IL tornadoes.

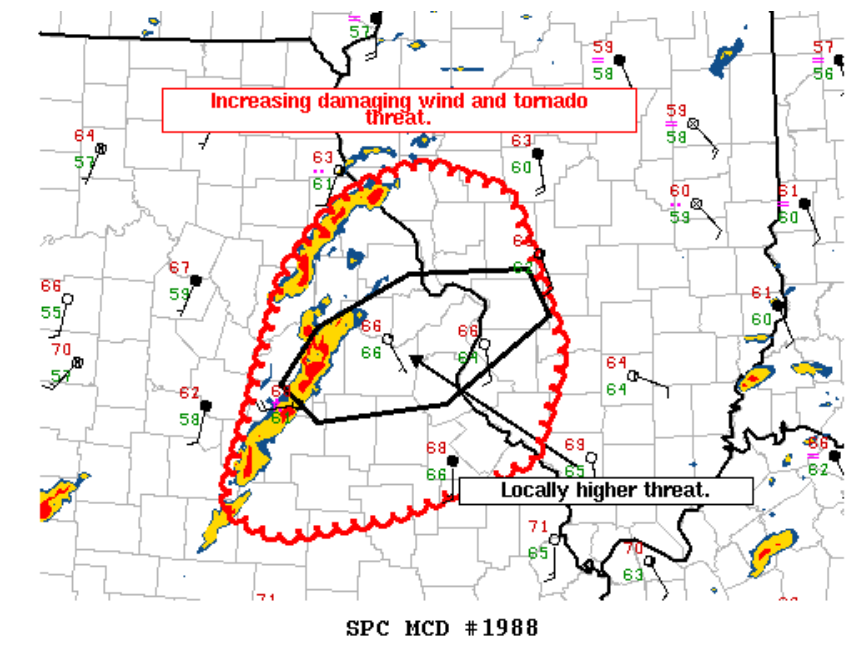


Figure 3.9: The mesoscale discussion associated with the Defiance, MO and Edwardsville, IL tornadoes.

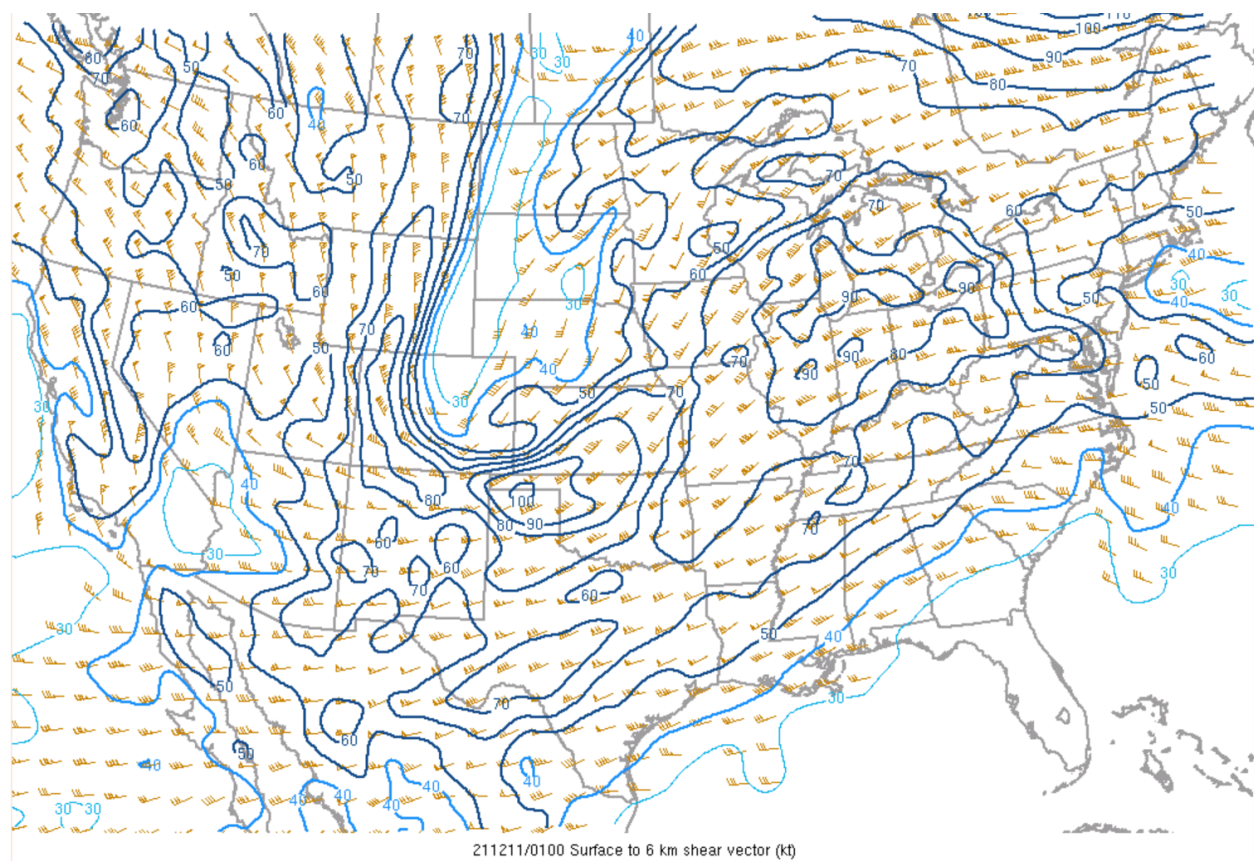


Figure 3.10: Surface to 6km shear (blue contours) for 0100 UTC December 10th, 2021.

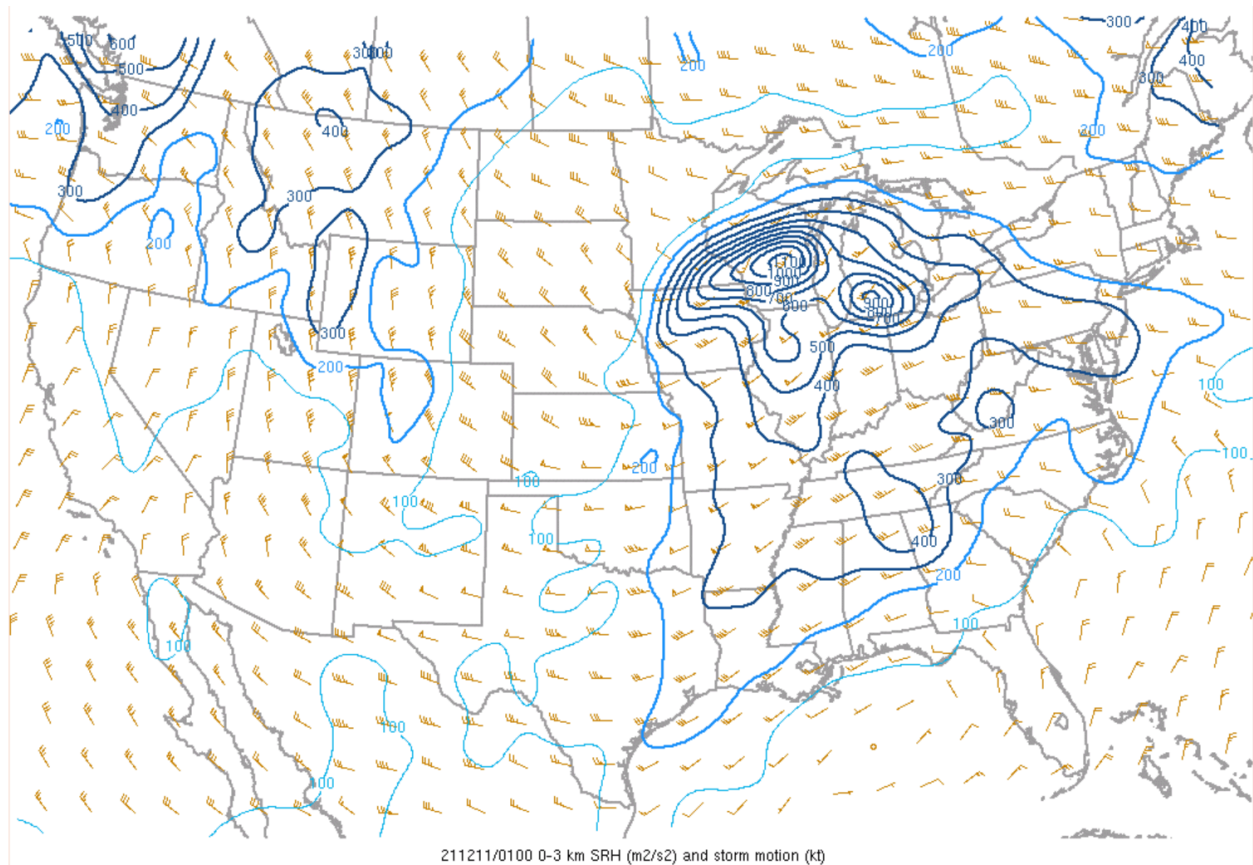


Figure 3.11: Surface to 3km storm relative helicity (m^2s^{-2}) for 0100 UTC December 10th, 2021.

The first tornado warning for Defiance, MO was issued based on radar observations at 0116 UTC (7:16 pm CST) (IEM 2026b). It was followed nine minutes later by an observed tornado warning, which was issued at the same time as the estimated touchdown (IEM 2026b). The first tornado warning over Edwardsville was issued at 0206 UTC (8:06 pm CST), likely in relation to the Defiance storm, which had dissipated at 0201 UTC (8:01pm CST) (IEM 2026b). This was followed 27 minutes later by a Considerable-tagged tornado warning at 0233 UTC

(8:33 pm CST) as the storm re-strengthened (IEM 2026b). The polygons associated with these warnings can be seen in Figure 3.12 below.

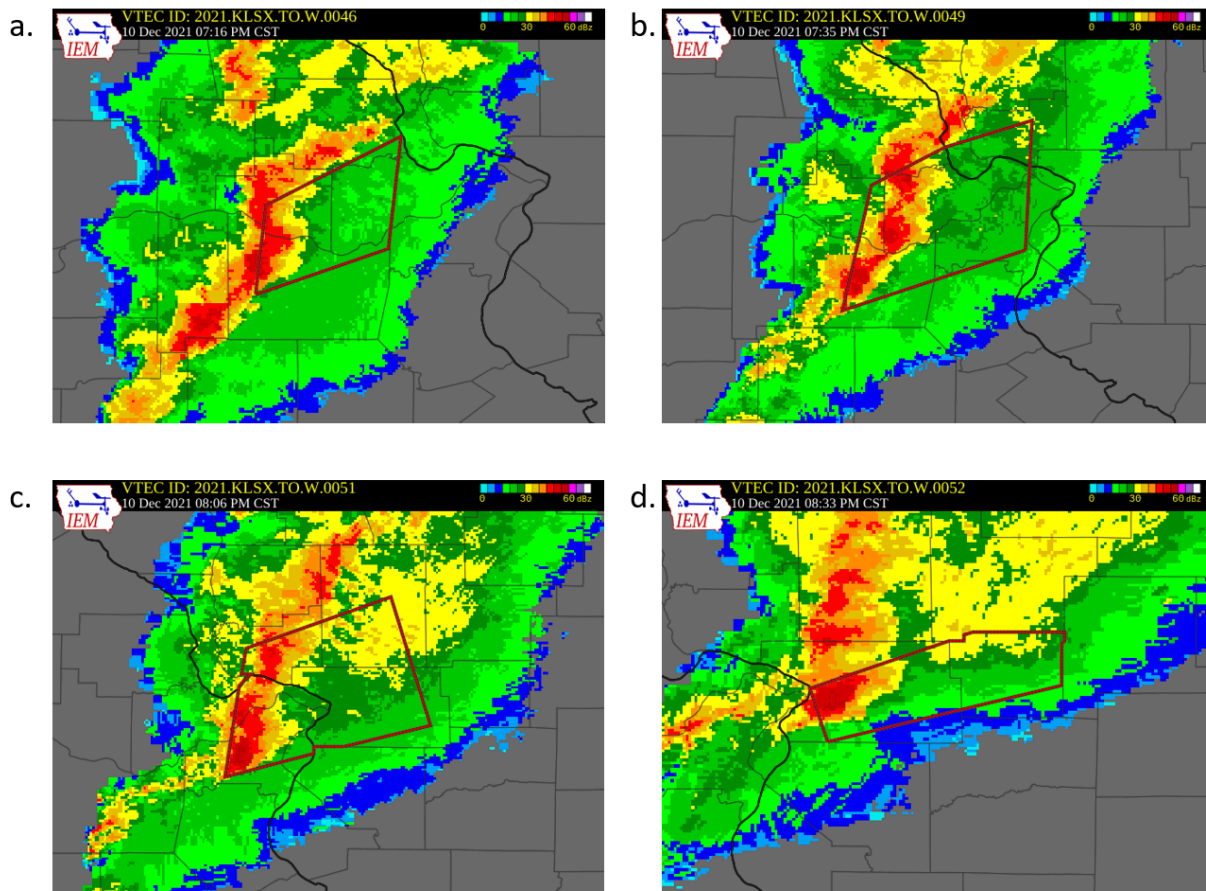


Figure 3.12: Radar imagery and tornado warning polygons for; a. Defiance, MO at 0116 UTC, b. Defiance, MO at 0135 UTC, c. Edwardsville, IL at 0206 UTC, and d. Edwardsville, IL at 0233 UTC. Courtesy of the Iowa Environmental Mesonet.

In this case, the Moderate contour of the 2000 UTC Categorical Convective Outlook was able to capture the beginnings of the strong, long-tracked storms that passed through Missouri, Tennessee, and Kentucky, but did not include the the ends of these storm's tracks, nor the tornadoes that occurred farther to the north in Missouri and Illinois. Within the 1630 UTC

Convective Outlook Discussion, there is mention of potential northward growth of the warm sector into Missouri and Illinois, while the 2000 UTC update also mentions the potential for storms moving into Tennessee and Kentucky after initiation, however, as expected, it appears that the highest confidence in storm occurrence at these times was for the area under the Moderate contour, where there was ample moisture and widespread instability in the warm sector. Defiance and Edwardsville, both north of the Moderate contour, were not yet in the warm sector by 2000 UTC, and therefore it is possible that there was some uncertainty surrounding the amount of time this area would spend in a region conducive to severe weather. The most significant and densely-packed tornadoes occurred within the Moderate region, while the Enhanced region captured the less densely-packed reports as well as the majority of the reports associated with the long-track storms through the Ohio River Valley. Thus, the decision to place the Moderate contour as-is was completely reasonable under the circumstances.

The Defiance tornado resulted in one death, two reported injuries, and significant damage to several homes and businesses along its path (NWS St. Louis). The Edwardsville storm resulted in one injury and 6 deaths, all of which occurred as a result of the collapse of an Amazon warehouse early in the tornado's path, an incident that initiated investigations into workplace safety at the warehouse (NWS St. Louis, Palmer 2021). The tornado also damaged several homes and small businesses in the Edwardsville area (Woods and Genetti 2021).

3.2: Event 2: 28 March 2020, Jonesboro, AR

Just before 5:00pm CDT on March 28th, 2020, a tornado touched down in Jonesboro, Arkansas (Marshall and Woodall 2022). The storm tracked northeastward through southeastern Jonesboro and into the neighboring town of Brookland before dissipating 12.53 miles from its

origin, leaving up to EF3-level damage in its wake (Marshall and Woodall 2022, NCEI 2026). This storm occurred on the very southern edge of the Enhanced region on the 2000 UTC issuance of Categorical Outlook, while the highest threshold for the day, a Moderate risk, was centered over northern Illinois (Figure 3.13).

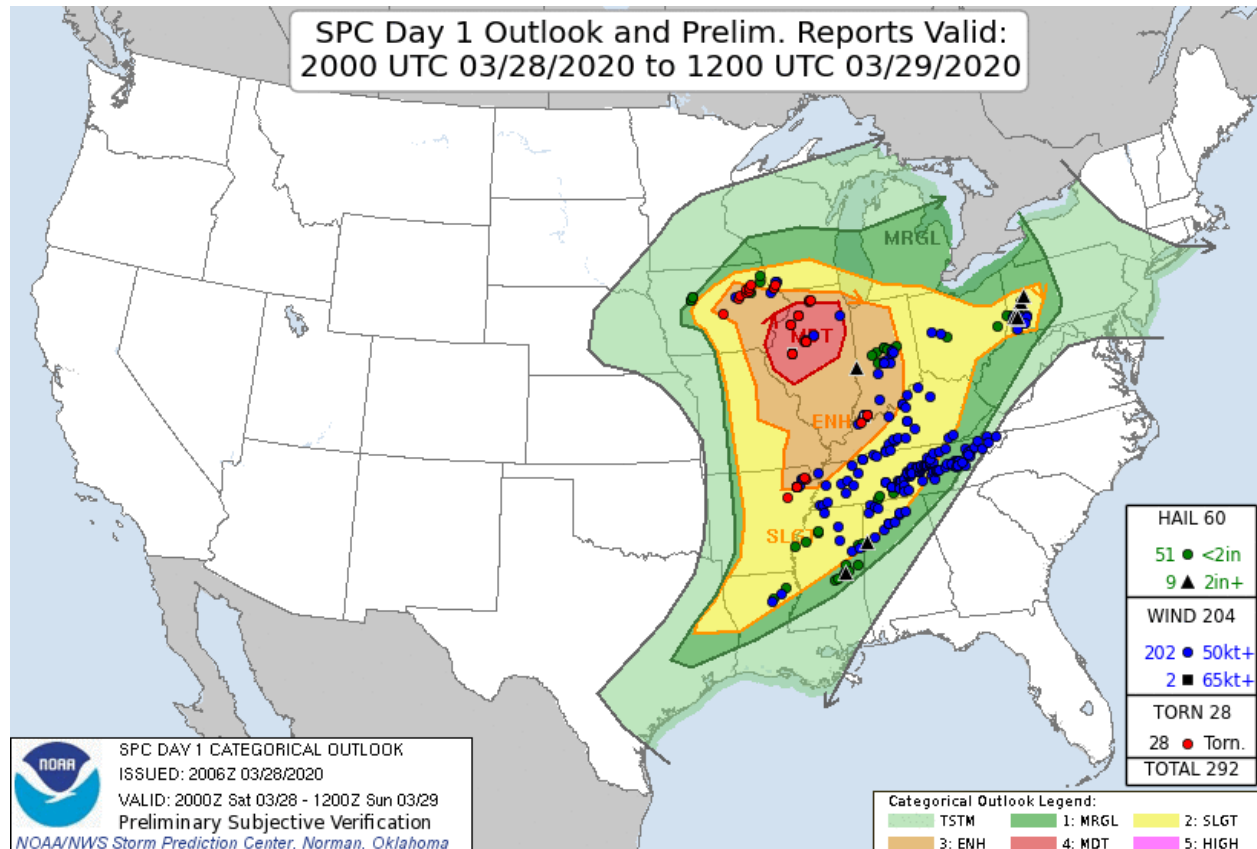


Figure 3.13: 2000 UTC SPC storm report verification for March 28th 2020.

The potential for severe weather in Arkansas associated with this event was first mentioned in the Day 4-8 Outlook Discussion issued on the 21st, in which forecasters indicated the potential for a shortwave trough to come off the Rocky Mountains, creating the possibility for severe thunderstorms occurring in Arkansas and the surrounding region on Friday the 27th,

with the potential for additional storms along the Gulf on the 28th. By the 24th, the model agreement had increased enough for forecasters to place a 15% probability contour over northern Mississippi, northern Alabama, and central Tennessee, citing a cold front moving in from the west and northward moisture advection into the region. On the March 25th Day 4-8 Outlook, the 15% probability contour was shifted slightly westward, over extreme eastern Arkansas, western Tennessee, and Mississippi. The concurrent discussion indicated that wind and hail were the expected primary threats, as well as the possibility that the severe weather threat could reach southern Illinois.

The Day 3 Categorical Convective Outlook highlighted one Slight risk over Illinois and another over southern Arkansas, northern Louisiana, and Mississippi. The associated discussion highlighted the threat of hail due to warm and moist air advection as the reason behind the northern Slight region, and the potential adequate shear and instability for the development of tornadoes, wind, and hail as the reason for the southern Slight risk. For the Day 2 1730 UTC Outlook, the forecasters added Moderate and Enhanced risk contours over northern Illinois, and expanded the Slight risk contour from eastern Iowa to Ohio and from southern Wisconsin to northern Mississippi. Notably, Arkansas was only under a Marginal risk in this issuance). The 1730 UTC Day 2 discussion highlighted the potential for a “significant severe weather outbreak” in the Moderate risk region with all hazards possible due the expectation for very strong shear and high levels of instability. The potential for severe weather in the south was less emphasized as the low-level shear was not expected to be as strong and thus the tornado risk was lower. The 0600 UTC, 1300 UTC, and 1630 UTC Day 1 Categorical Convective Outlooks saw the expansion of the Slight risk contour into Arkansas and surrounding states, largely due to sufficient shear despite smaller lapse rates.

At 1610 UTC on the 28th, a tornado watch was issued for a large portion of northeast Arkansas, including Jonesboro that was valid until 0100 UTC on the 29th (Figure 3.14). The watch text cited the passage of a cold front through the area as a catalyst for severe thunderstorms with all hazards possible. The associated Mesoscale Discussion, valid from 2159 UTC to 2300 UTC, specifically highlighted northeastern Arkansas and the surrounding area as being under a threat of supercells as 500 mb wind speeds increased (Figure 3.15).

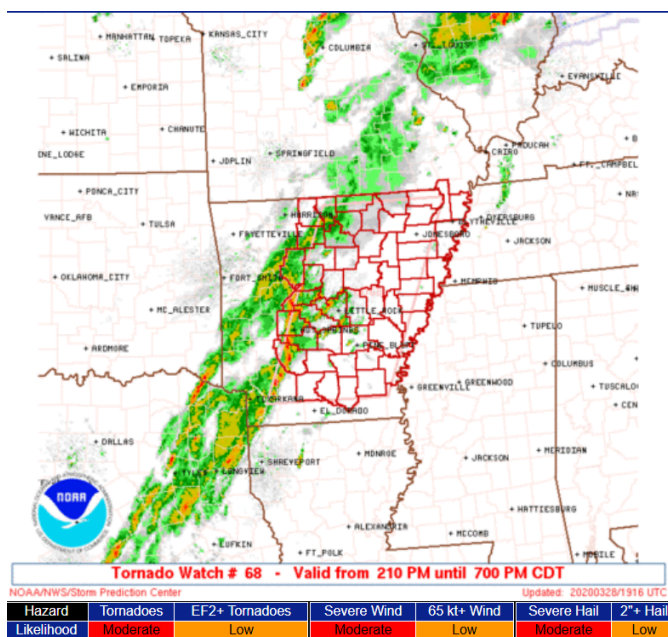


Figure 3.14: The tornado watch associated with the Jonesboro tornado.

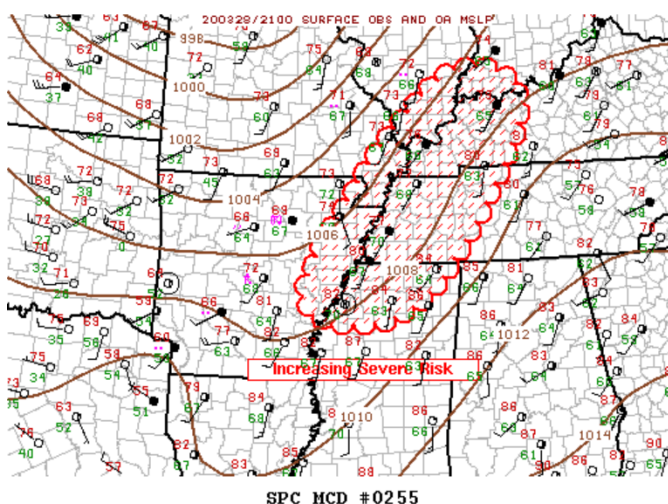


Figure 3.15: The mesoscale discussion image associated with the Jonesboro tornado.

The Day 1 2000 UTC Outlook was the only outlook to include Arkansas in the Enhanced risk contour along with a 30% chance of damaging winds due to the expectation for a linear set-up with the potential for embedded supercells (Figure 3.16).

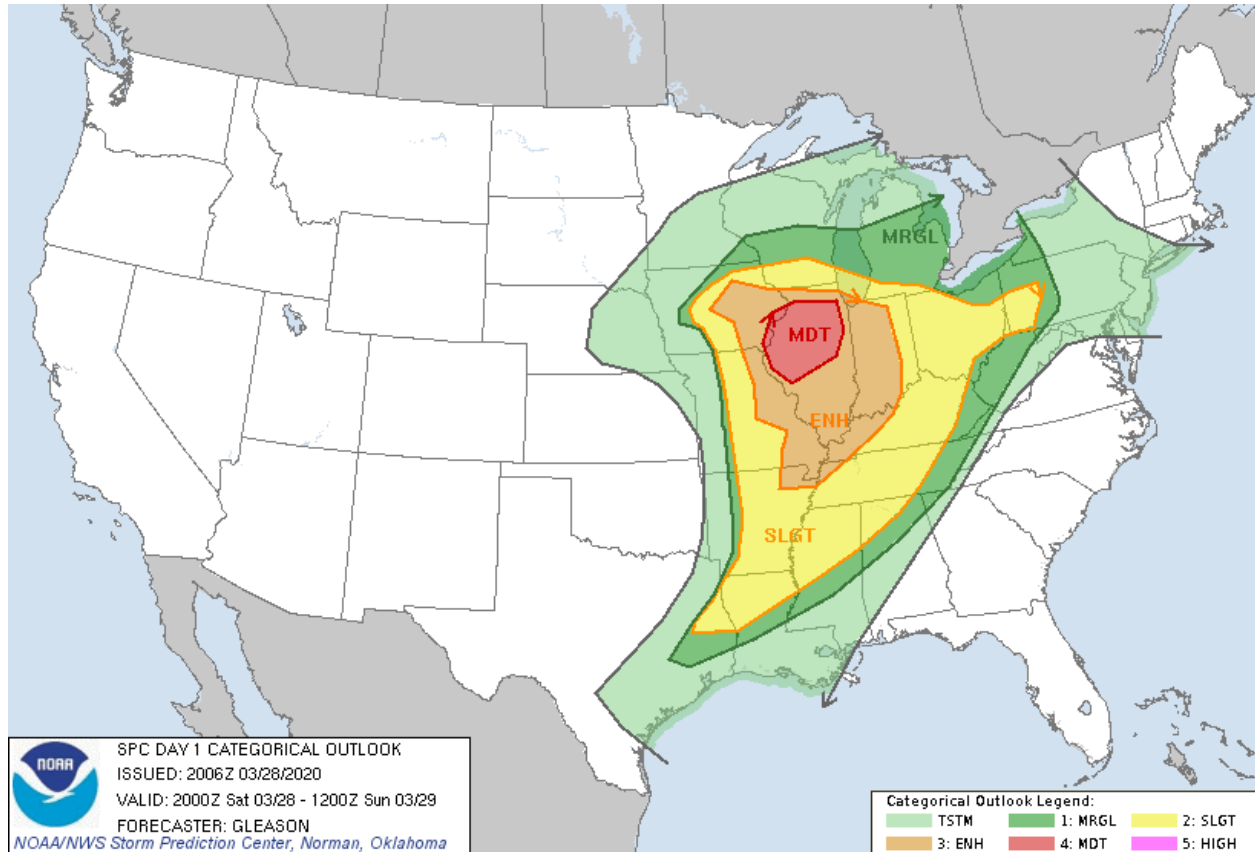


Figure 3.16: The 2000 UTC SPC Categorical Convective Outlook.

The 300mb map at 2000 UTC showed a very strong upper-level jet along the eastern side of the upper-level trough sitting over the northern plains, along with very strong divergence over northeastern Arkansas (Figure 3.17). Further below, at the 500mb level, a closed upper-level low was present over Nebraska (Figure 3.18). The same area of low pressure was present over

Nebraska and Iowa at 850 mb, along with high dewpoints throughout the eastern US (Figure 3.19). At the surface at 1800 UTC, the low pressure system was centered over southern Nebraska, meaning that it was nearly vertically stacked with those at the 850 mb and 500 mb level (Figure 3.20). This vertical stacking, along with the small occluded front extending to the east of the surface indicates a mature surface cyclone. At 2000 UTC, Jonesboro was deep within the warm sector, with a temperature around 79°F, dewpoint around 68°F, and southwesterly winds around 10 knots. A cold front extended to the west of the region across extreme western Missouri and Arkansas (Figure 3.20),

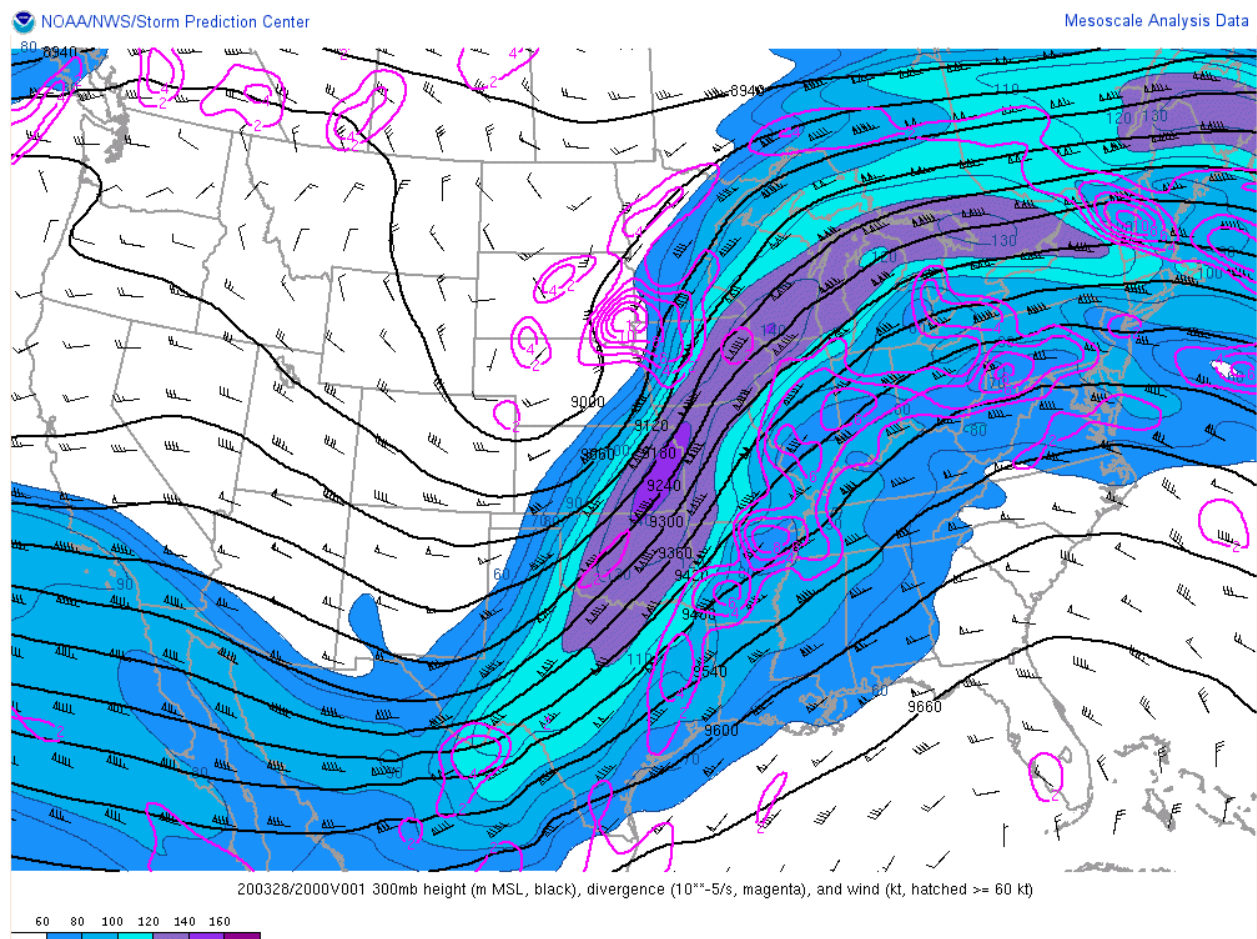
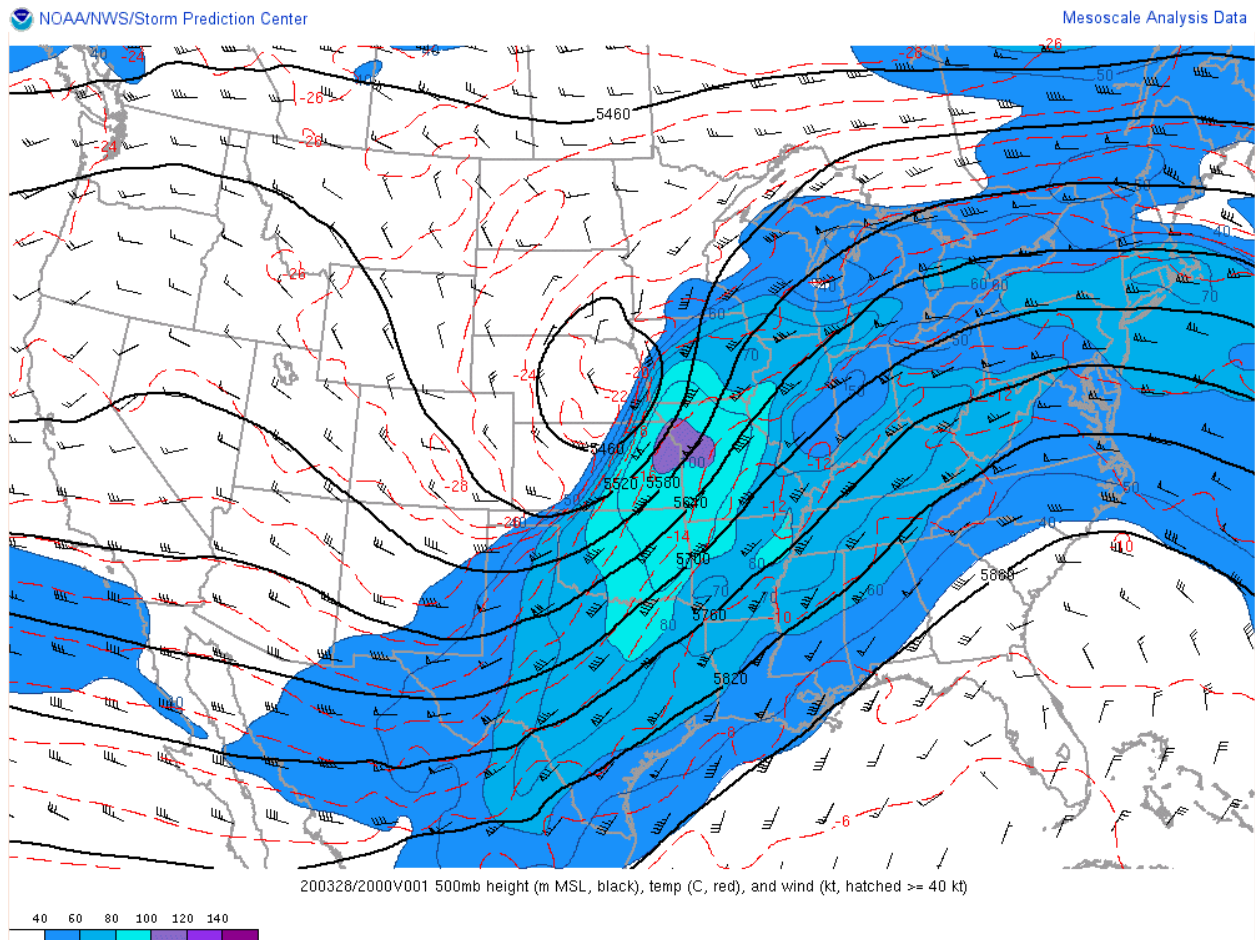


Figure 3.17: The 300mb map for 2000 UTC March 28th 2020. The black contours represent geopotential heights (m), the shading represents wind speeds (kts), and the purple contours represent divergence (10^{-5}s^{-1}).



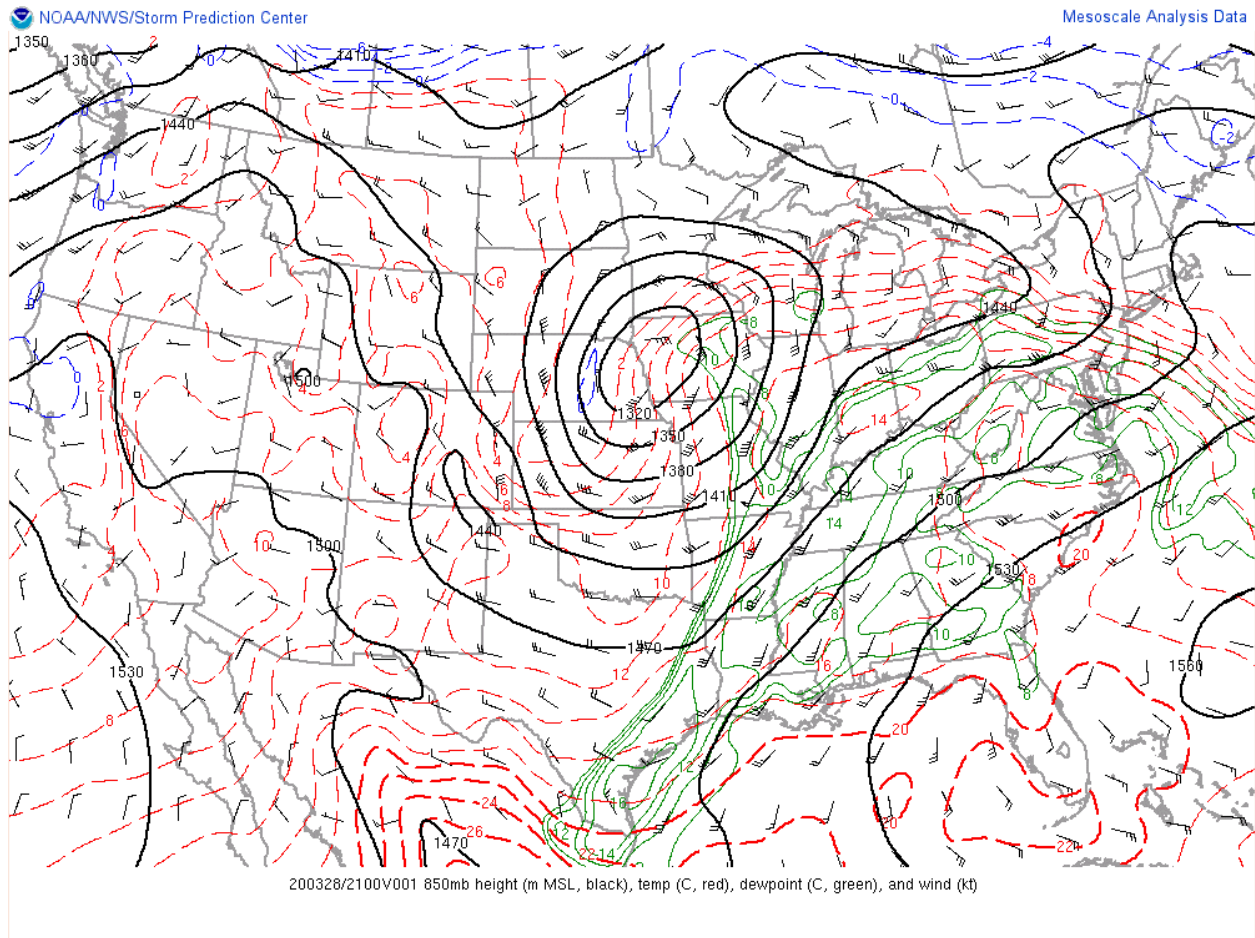


Figure 3.19: The 850mb map for 2000 UTC March 28th, 2020. The black contours represent geopotential heights (m), the dashed red and blue contours represent temperature ($^{\circ}\text{C}$), the wind

barbs represent wind velocity (kts), and the green contours represent dew point ($^{\circ}\text{C}$).

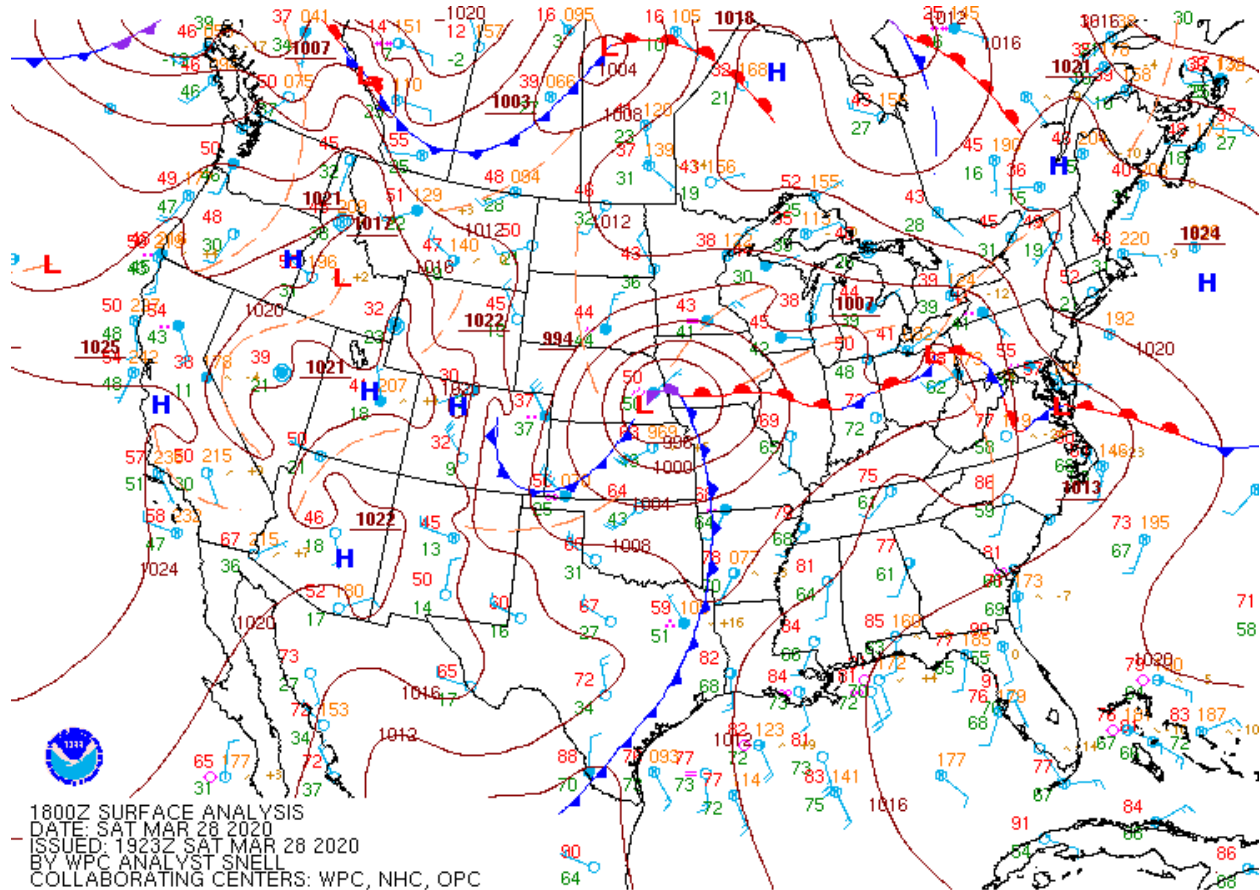


Figure 3.20: The surface map for 1800 UTC March 28th, 2020.

By 2200 UTC (4:00 pm CDT) on the 28th, the 0-6 km shear had reached up to 70 knots in the Jonesboro area, indicating sufficient shear for supercellular development (Figure 3.21) (WFO Louisville, Storm Prediction Center 2026a). At the same time, the 0-3 km storm relative

helicity was around $200 \text{ m}^2\text{s}^{-2}$ in the Jonesboro area (Figure 3.22).

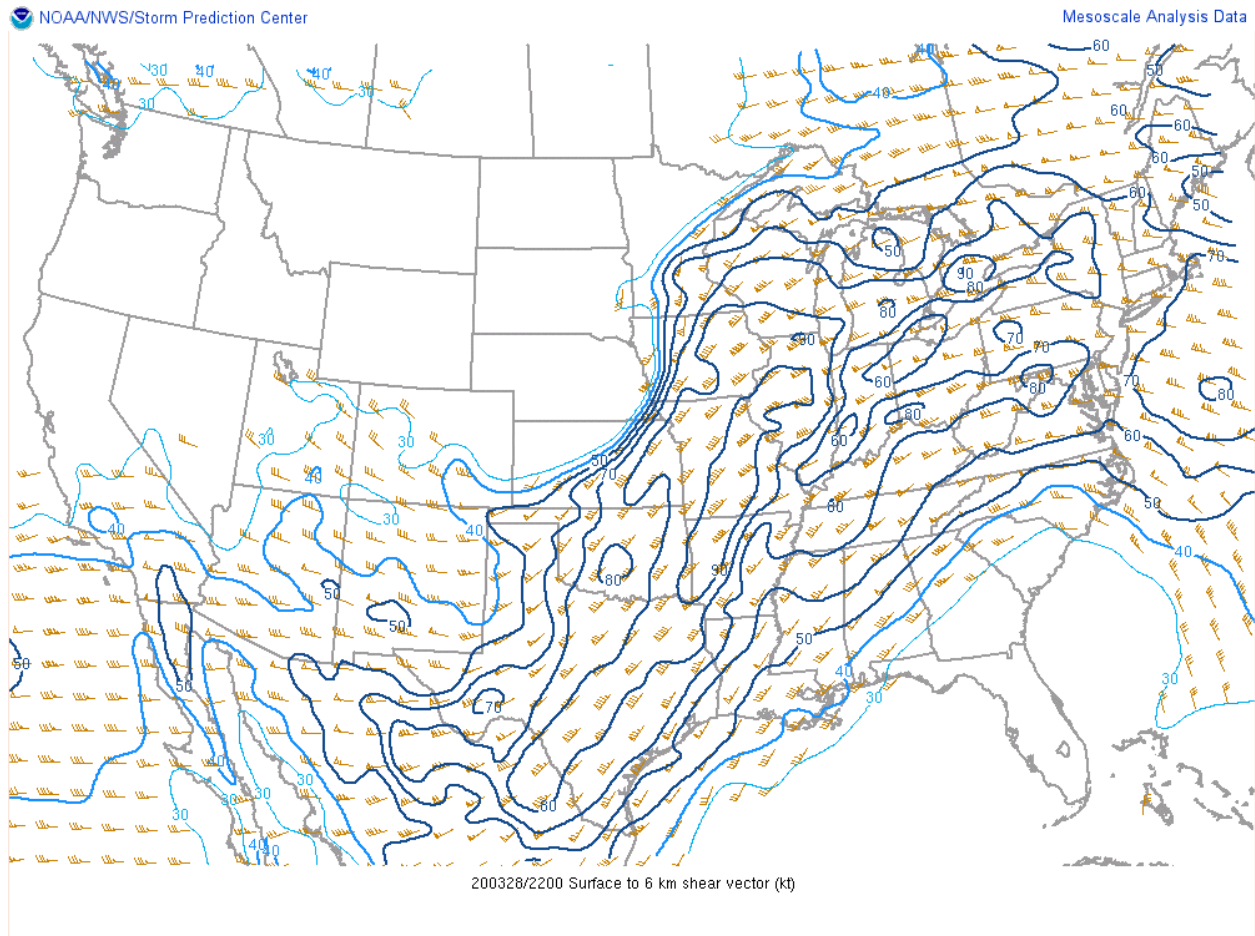


Figure 3.21: Surface to 6km shear (blue contours) for 2200 UTC March 28th, 2020.

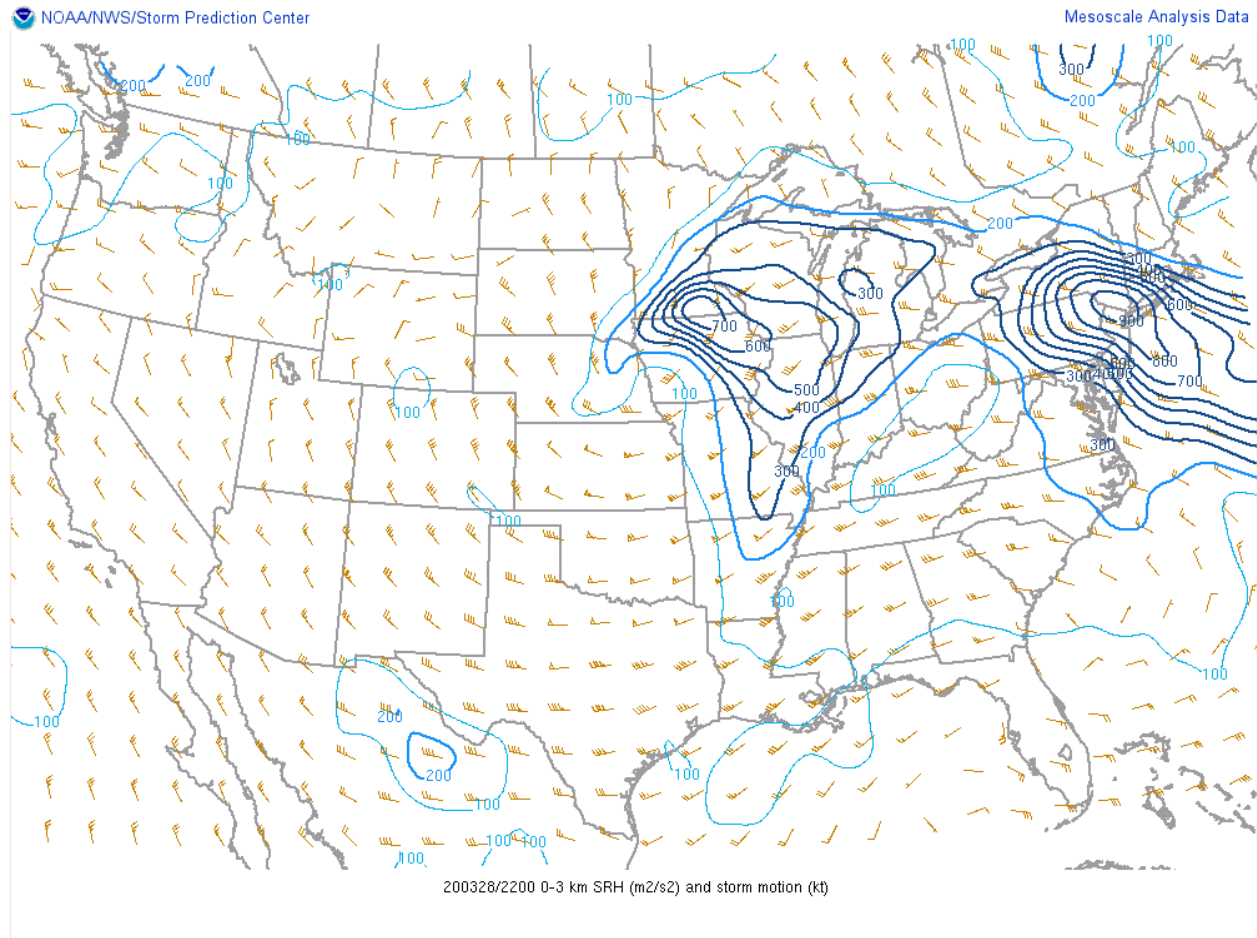


Figure 3.22: Surface to 3km storm relative helicity (m^2s^{-2}) for 2200 UTC March 28th, 2020.

At 2247 UTC, radar-indicated tornado warning was issued for a storm just to the southwest of Jonesboro, moving northeastward (Figure 3.23) (IEM 2026b). The tornado touched down directly south of Arkansas State University on the southeastern side of Jonesboro, tracked directly through the Jonesboro Municipal Airport, where it caused EF-3-level damage, then continued northeastward into the surrounding suburbs (Figure 3.24) (NOAA 2026).

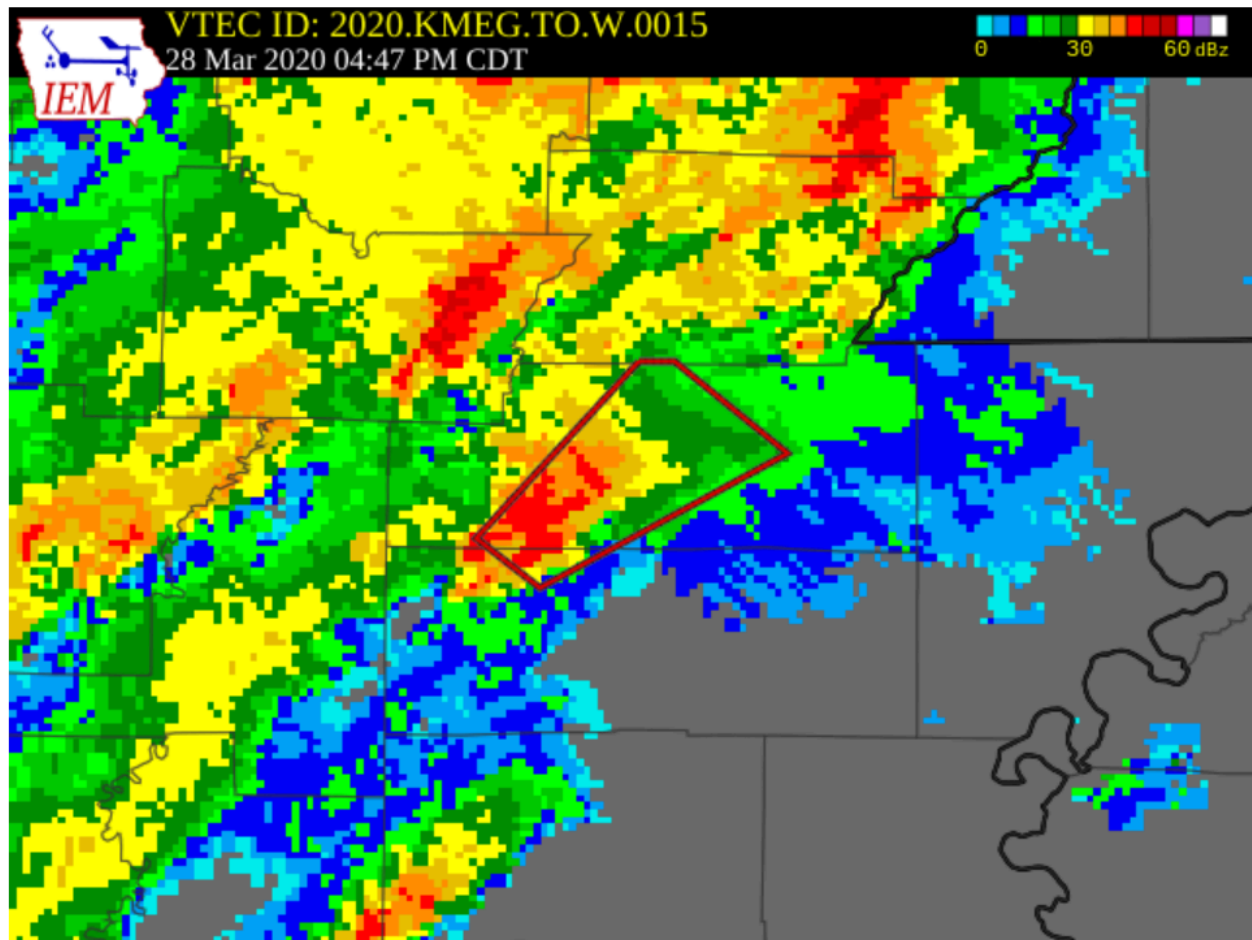


Figure 3.23: The tornado warning associated with the Jonesboro tornado. Courtesy of the Iowa Environmental Mesonet.

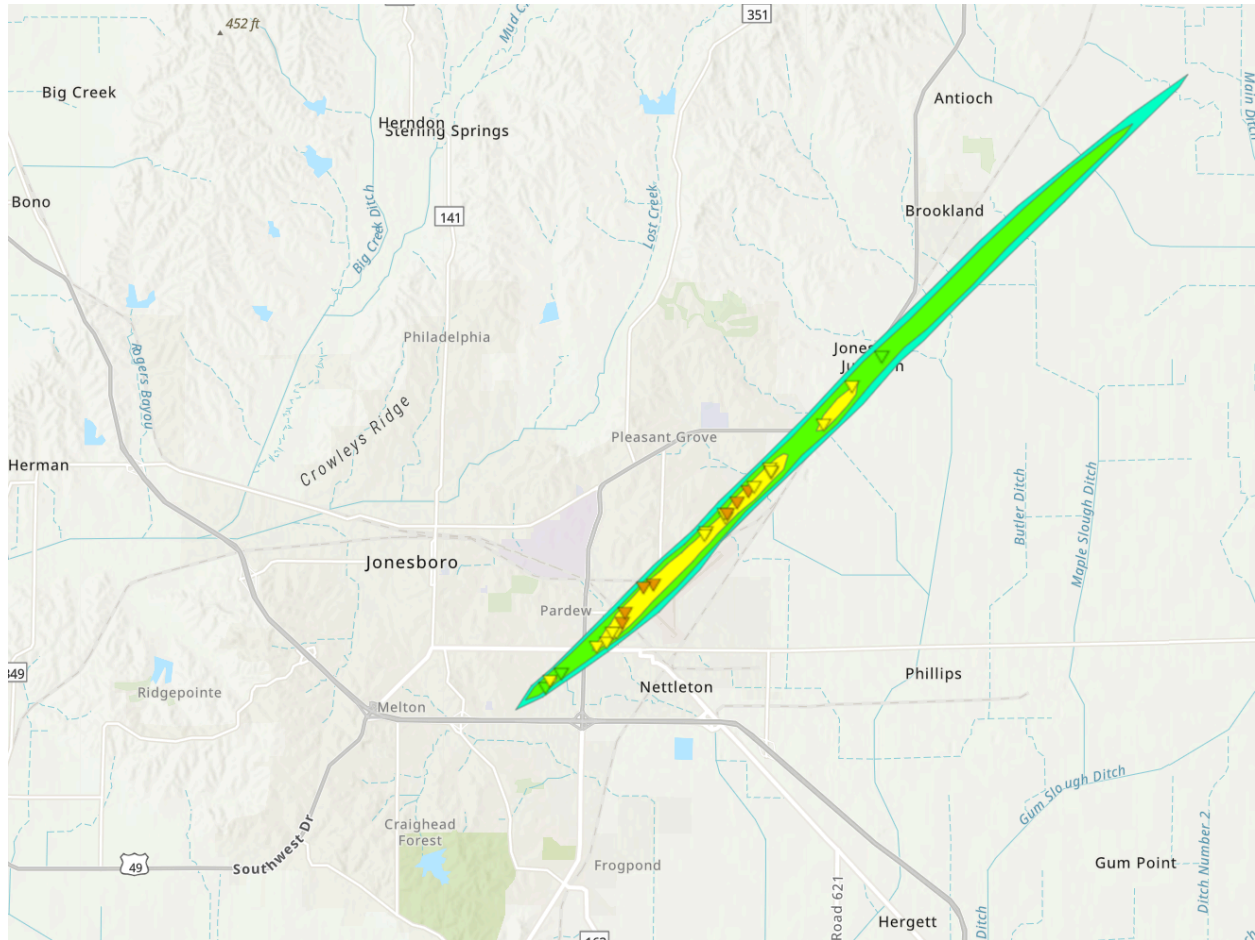


Figure 3.24: The track of the Jonesboro tornado. Courtesy of NOAA.

In this instance, it appears that there was a significant amount of uncertainty about the presence and strength of instability and shear across the risk area. In the earlier convective outlook discussions, low-level shear over Arkansas was predicted to be relatively low during the forecast period, indicating that, while supercells could form, strong tornadic activity was relatively unlikely compared to the more northern risk area. The 1300 UTC Day 1 outlook discussion mentioned the potential for tornadoes in the mid-South, however, the Enhanced contour was not expanded into Arkansas until the 2000 UTC outlook, while the Moderate risk area remained the same size and in the same place throughout the day. Overall, from the outlook

discussions, it appears as though the main focus of the event was northern Illinois and Missouri, as storms were expected to develop in Iowa and strengthen as they moved eastward. Instead, the occurrence of tornadic storms began farther west than expected, over eastern Iowa, before progressing into Illinois. Additionally, and importantly for this case study, the QLCS associated with the cold front passing Arkansas was able to generate a few slightly more discrete cells, one of which became particularly strong and formed the Jonesboro tornado. Overall, it appears that, with the main focus on northern Illinois, the formation and intensification of storms along the warm front in Iowa in particular, as well as the QLCS tornado in Arkansas were not as well captured.

The March 2020 Jonesboro tornado caused 22 reported injuries, with no reported fatalities (NCEI 2026). Multiple neighborhoods and commercial buildings were impacted, along with the Jonesboro Municipal Airport, which saw damage consistent with an EF-3 event, as well as a freight train, which was blown over on its tracks (Marshall and Woodall 2022). Overall, the reported damage caused by this storm totaled \$300 million (NCEI 2026).

3.3: Event 3: 7 July 2016, Eureka, KS

Eureka, Kansas was impacted by two strong tornadoes on July 7th, 2016 (NWS Wichita). The first, later rated an EF-3 at its peak severity toward the end of its track, touched down at 9:10 pm CDT several miles to the northwest of Eureka, tracked southeast for just over four miles, then dissipated 7 miles to the northwest of the Eureka Municipal Airport (NWS Wichita, NCEI 2026). The second tornado formed just to the northwest of Eureka at 9:41 pm CDT, around the time that the first storm ended, and tracked southeastward, across the northern part of the town, leaving EF-2-level damage in the middle of its track (NWS Wichita). These storms were located in the

Marginal threshold on the 2000 UTC Categorical Convective Outlook, just to the southwest of one of the areas under the Enhanced risk, the highest risk level of the day (Figure 3.25).

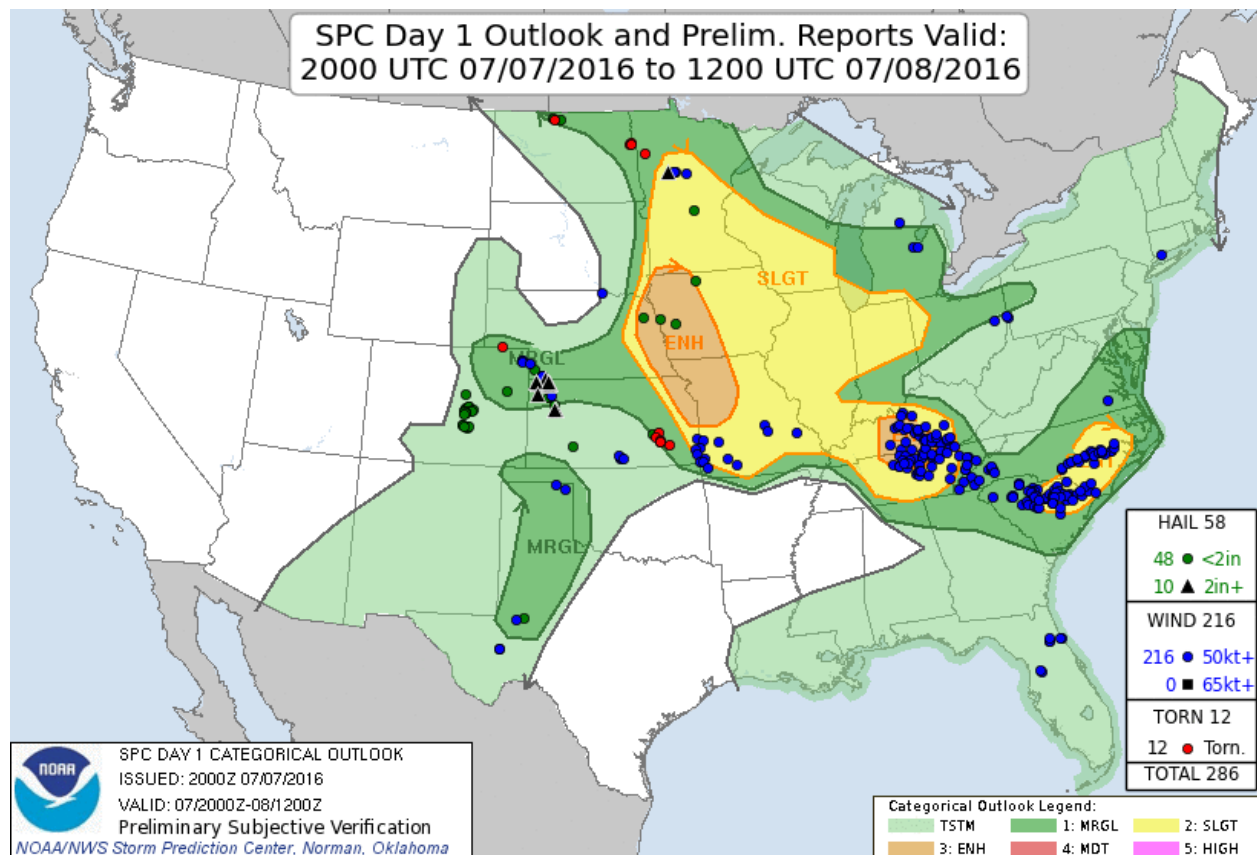


Figure 3.25: 2000 UTC SPC storm report verification for July 7th 2016.

The potential for severe weather was first mentioned eight days out from July 7th, in the June 30th Day 4-8 outlook discussion, where forecasters predicted that moist, unstable air would be present over the Plains, along with a shortwave trough across the northern Plains states, however, large model uncertainties precluded forecasters from even mentioning the possibility of severe weather on the 7th in the remaining relevant Day 4-8 outlook discussions (July 1st through the 4th).

Similar to Event 1, the Day 3 Categorical Convective Outlook for the 7th was the first to include a contour indicating severe weather potential, with a Slight risk contour positioned over Iowa and the surrounding states. In the accompanying discussion, a shortwave trough was forecast to pass across the Northern Plains, along with a surface front, however, the potential for, and location and timing of severe weather was still highly uncertain due to diverging model solutions.

The Day 2 0600 UTC Day 2 Categorical Outlook introduced an Enhanced risk contour over Iowa, which was expanded into Minnesota and Illinois for the 1730 UTC Outlook (Figures 3.26 and 3.27). The 1730 UTC discussion predicted the potential for the development of a mesoscale convective system in Iowa with increasing moisture, heat, and instability potentially leading to further development to the east. The Carolinas were also pointed out as a region with the potential for damaging winds. It should be noted that Kansas remained largely in the Thunderstorm/Marginal contours for both of these outlooks.

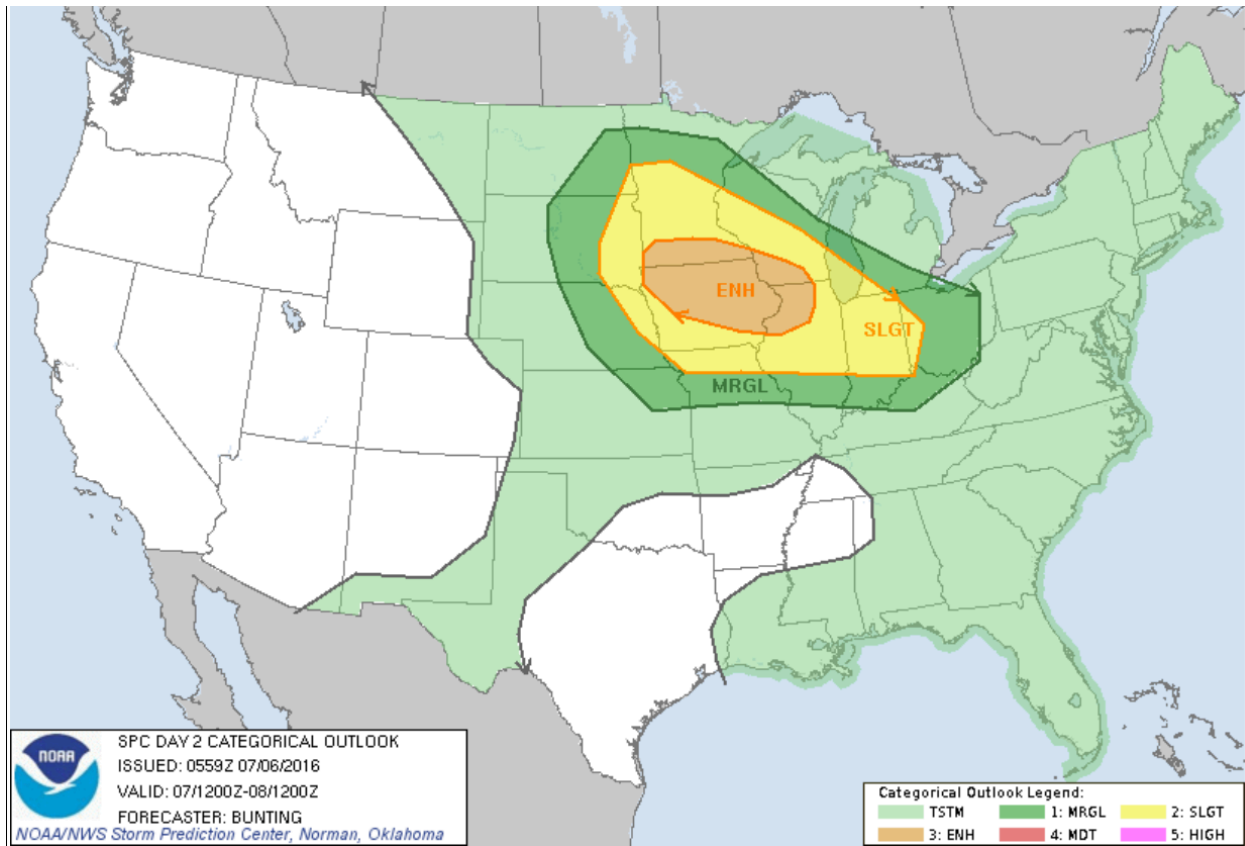


Figure 3.26: The Day 2 0600 UTC SPC Categorical Convective Outlook.

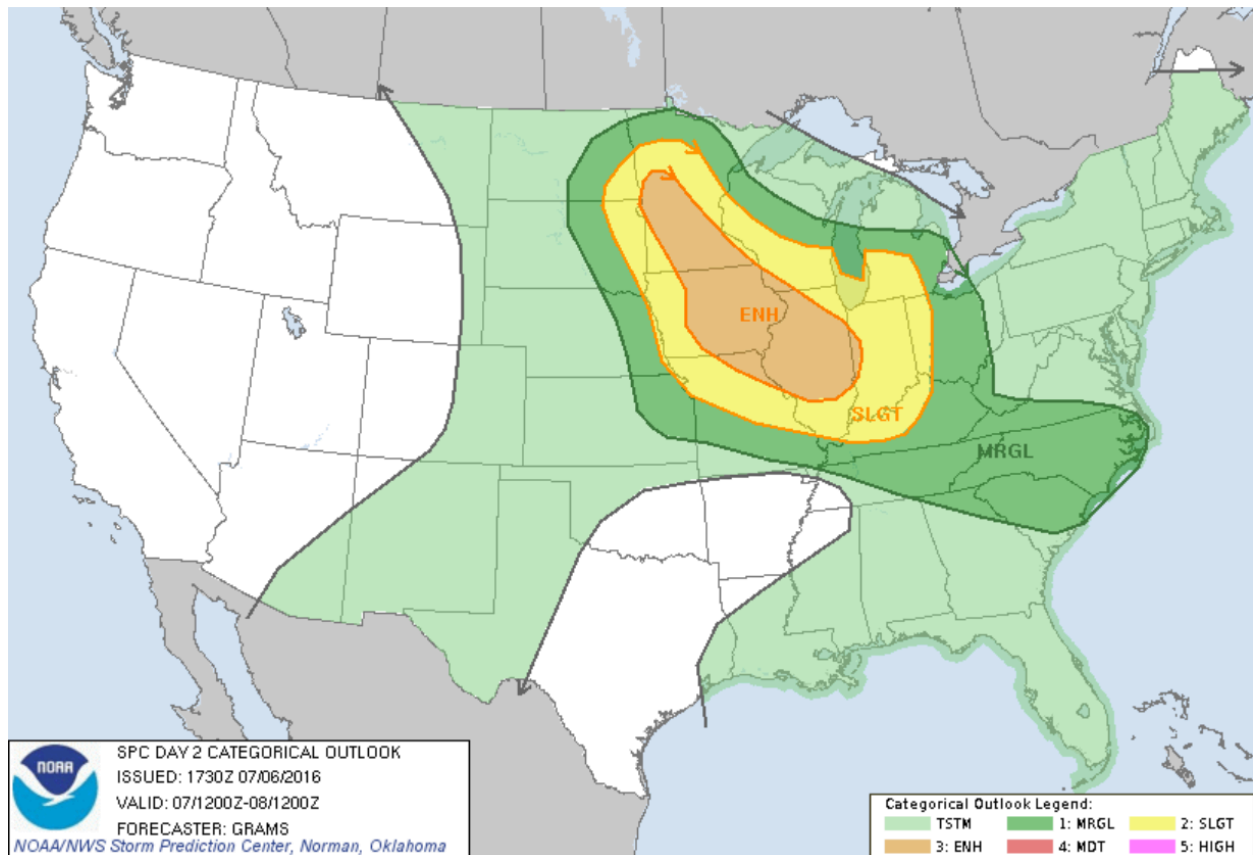


Figure 3.27: The Day 2 1730 UTC SPC Categorical Convective Outlook.

The largely varying placement of the Enhanced contours on the Day 1 Categorical Outlooks indicated the large degree of uncertainty that remained in the forecast even in the hours leading up to the event. The 0600 UTC update removed the Enhanced risk from most of Minnesota, while the 1300 UTC update placed the Enhanced contour over southern Illinois, eastern Missouri, and western Tennessee and Kentucky, removing Iowa from the Enhanced area entirely (Figures 3.28 and 3.29). The 1630 UTC update split the Enhanced region into two, with one contour over western Iowa, Western Missouri, and extreme northeastern Kansas, and another

over central Tennessee and Kentucky.

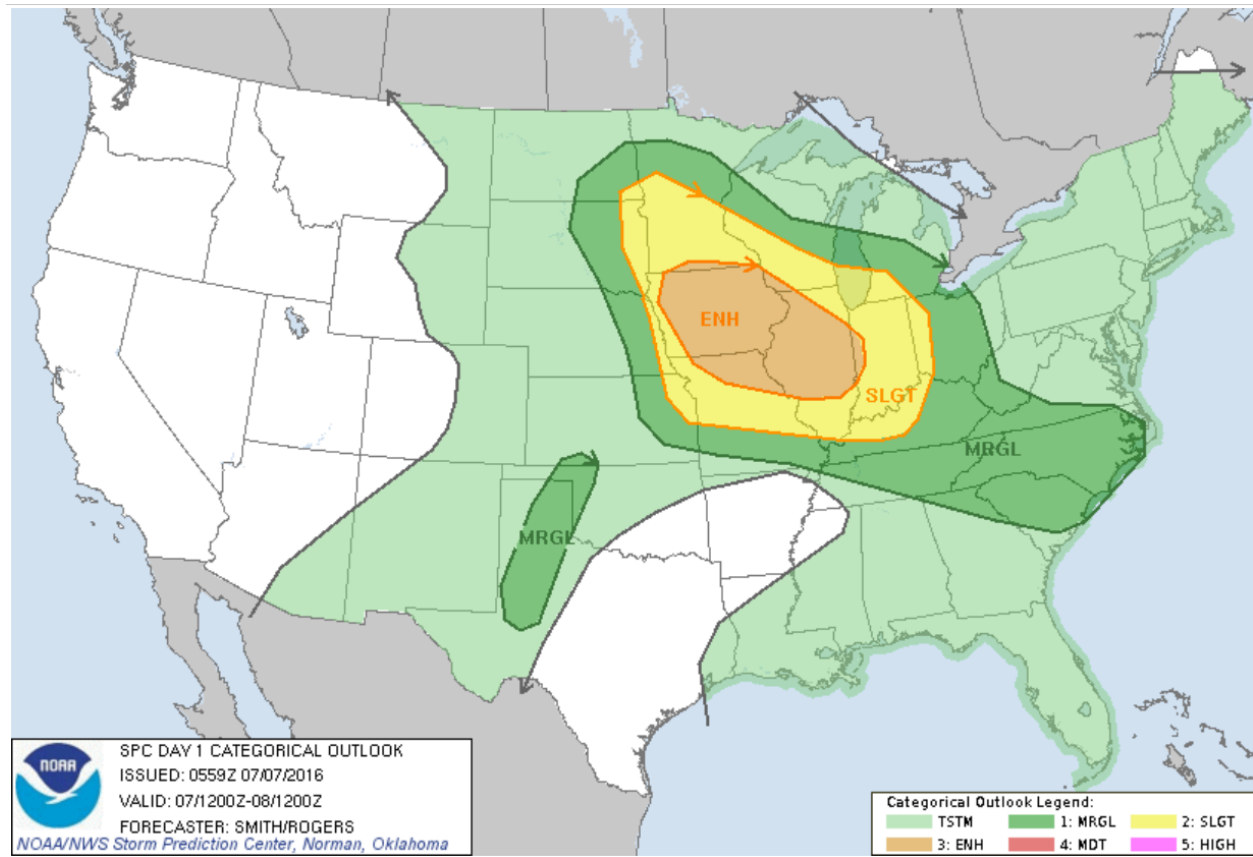


Figure 3.28: The Day 1 0600 UTC SPC Categorical Convective Outlook.

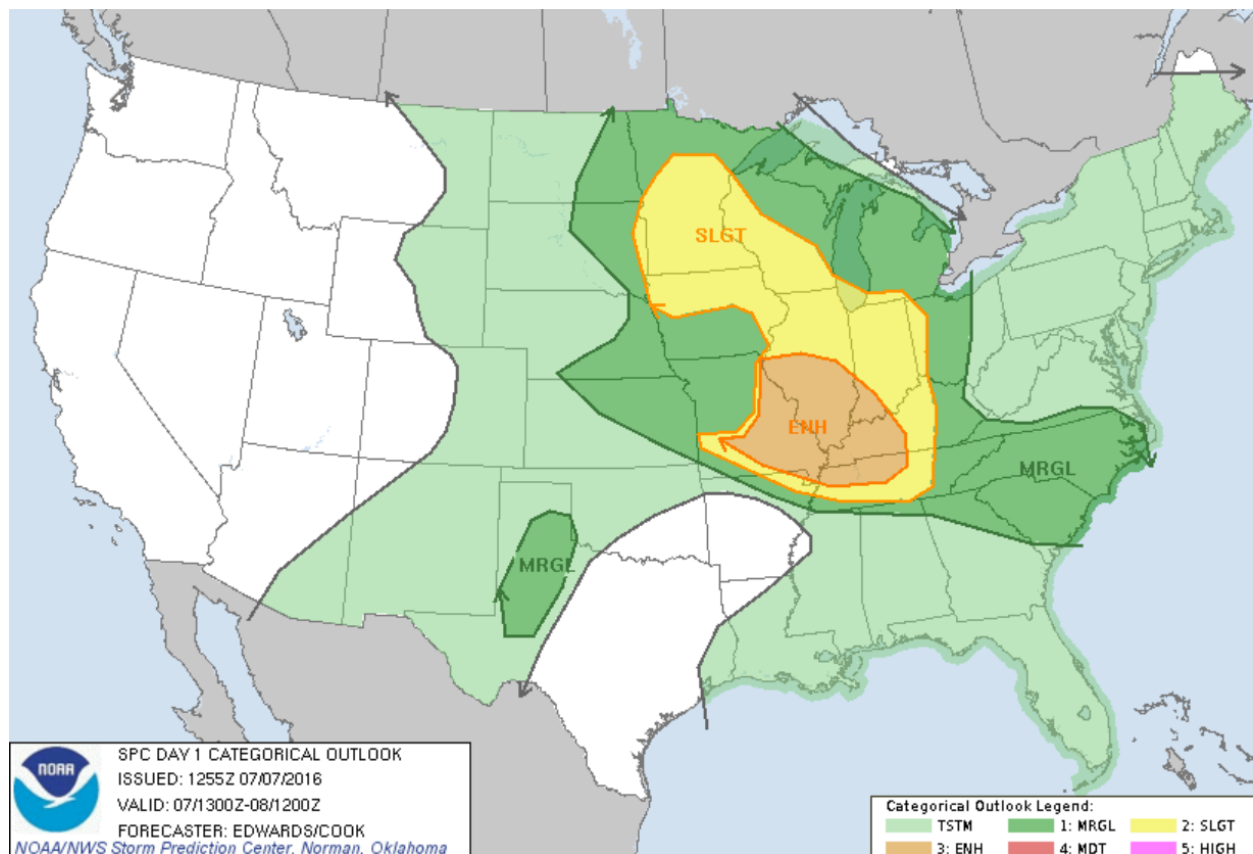


Figure 3.29: The Day 1 1300 UTC SPC Categorical Convective Outlook.

This split was maintained in the 2000 UTC update, with the addition of a Slight region over the Carolinas to capture the wind risk in that region (Figure 3.30). Due to generally unfavorable conditions, the forecasters continued to express uncertainty in where and whether severe weather would occur in the Plains, including only a statement that they believed that a mesoscale convective system may develop along the Kansas-Missouri border overnight.

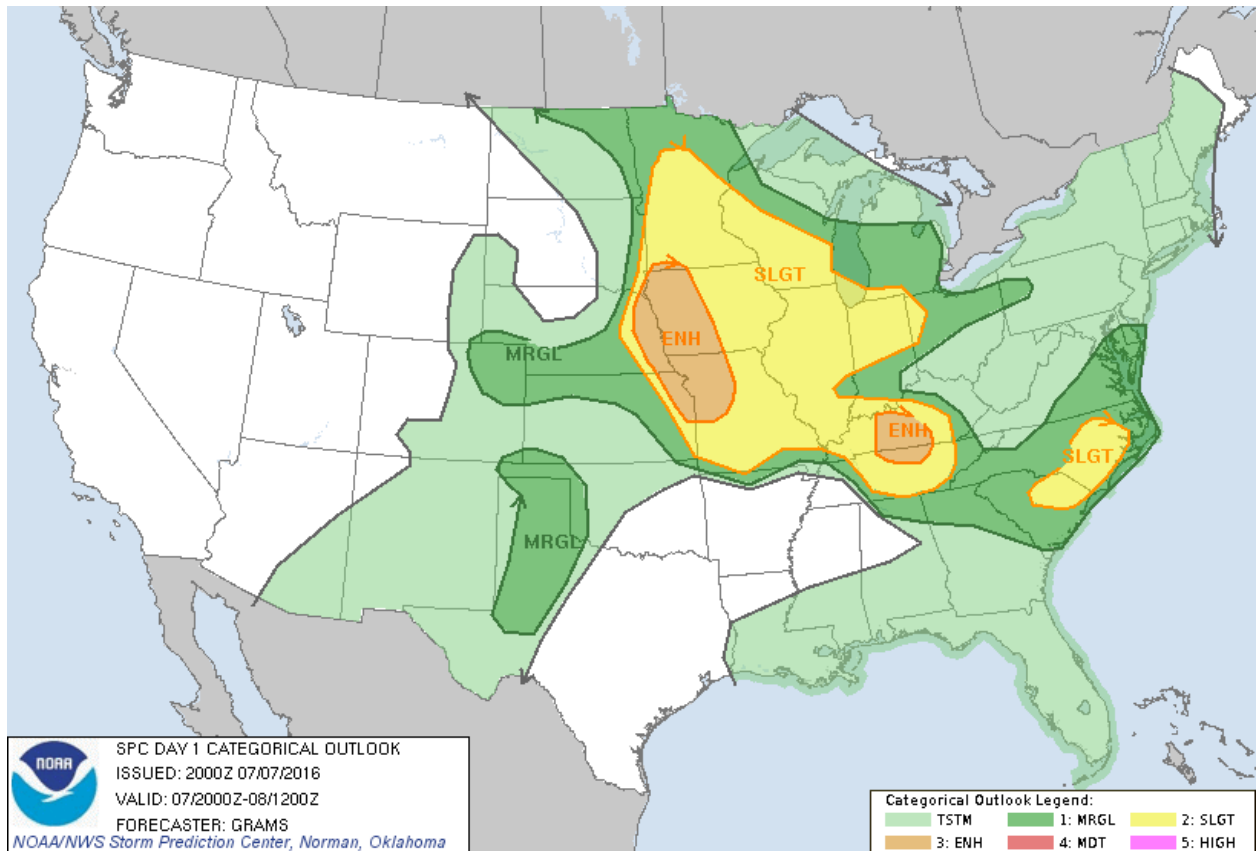


Figure 3.30: The Day 1 2000 UTC SPC Categorical Convective Outlook.

A look at the 2000 UTC upper-level maps gives a good depiction of the rather disorganized conditions at this time. While a shortwave trough was present over the Dakotas at the 300 mb level, upper-level divergence remained minimal (Figure 3.31). The most notable feature in the area at this time was the upper-level jet streak situated over South Dakota and Nebraska, which is mirrored at the 500 mb level (Figures 3.31 and 3.32). An additional short wave trough was present over Illinois at this time, with an attendant jet streak over Missouri and Illinois (Figure 3.32). At the 850 mb level, there is evidence of moist air aloft, along with some warm air advection, particularly across Oklahoma (Figure 3.33). However, at the surface at 1800

UTC, the dewpoint depression near Eureka was around 15°F, with temperatures in the mid-80s and dew points around 70°F (Figure 3.34).

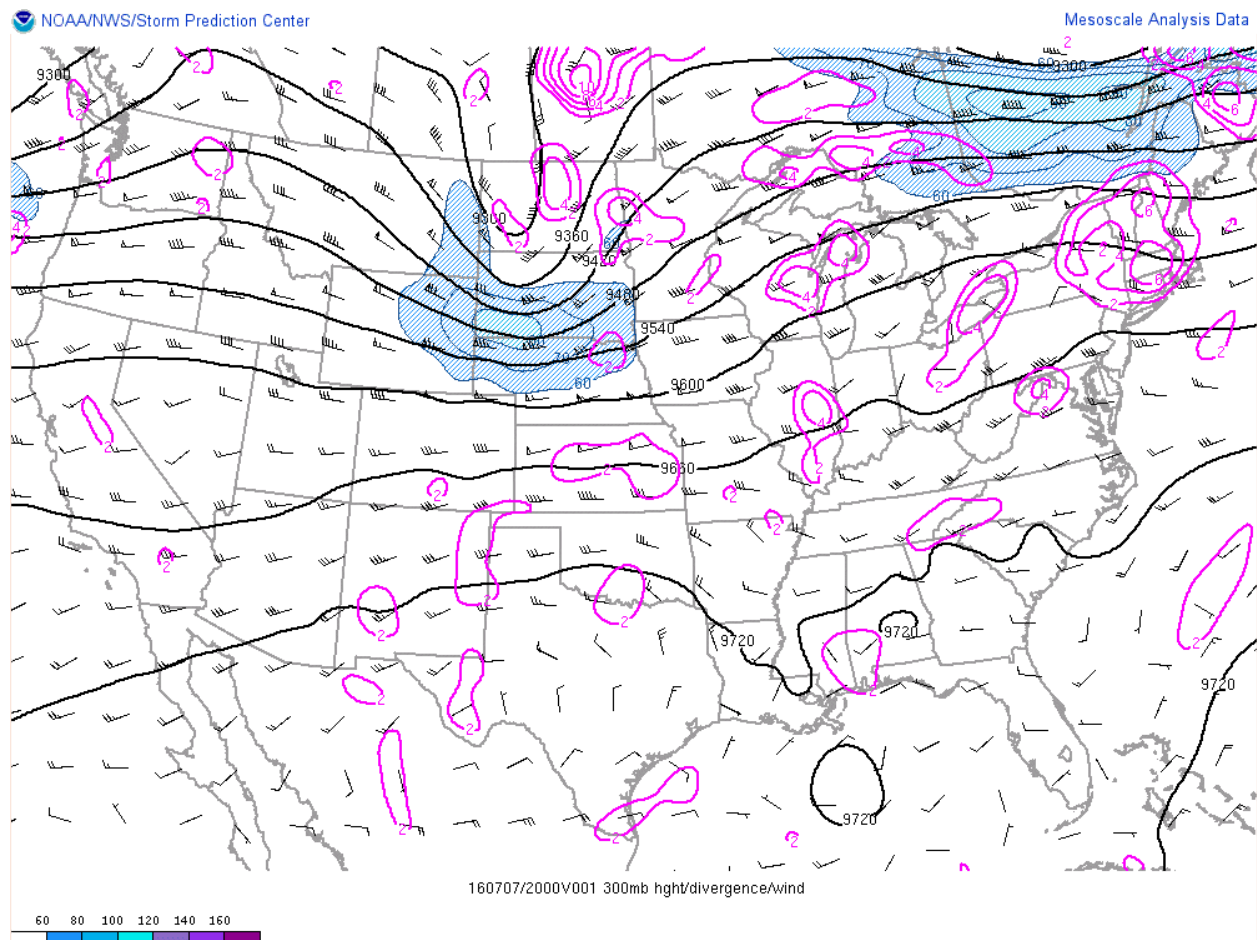


Figure 3.31: The 300mb map for 2000 UTC July 7th, 2016. The black contours represent geopotential heights (m), the shading represents wind speeds (kts), and the purple contours represent divergence (10^{-5}s^{-1}).

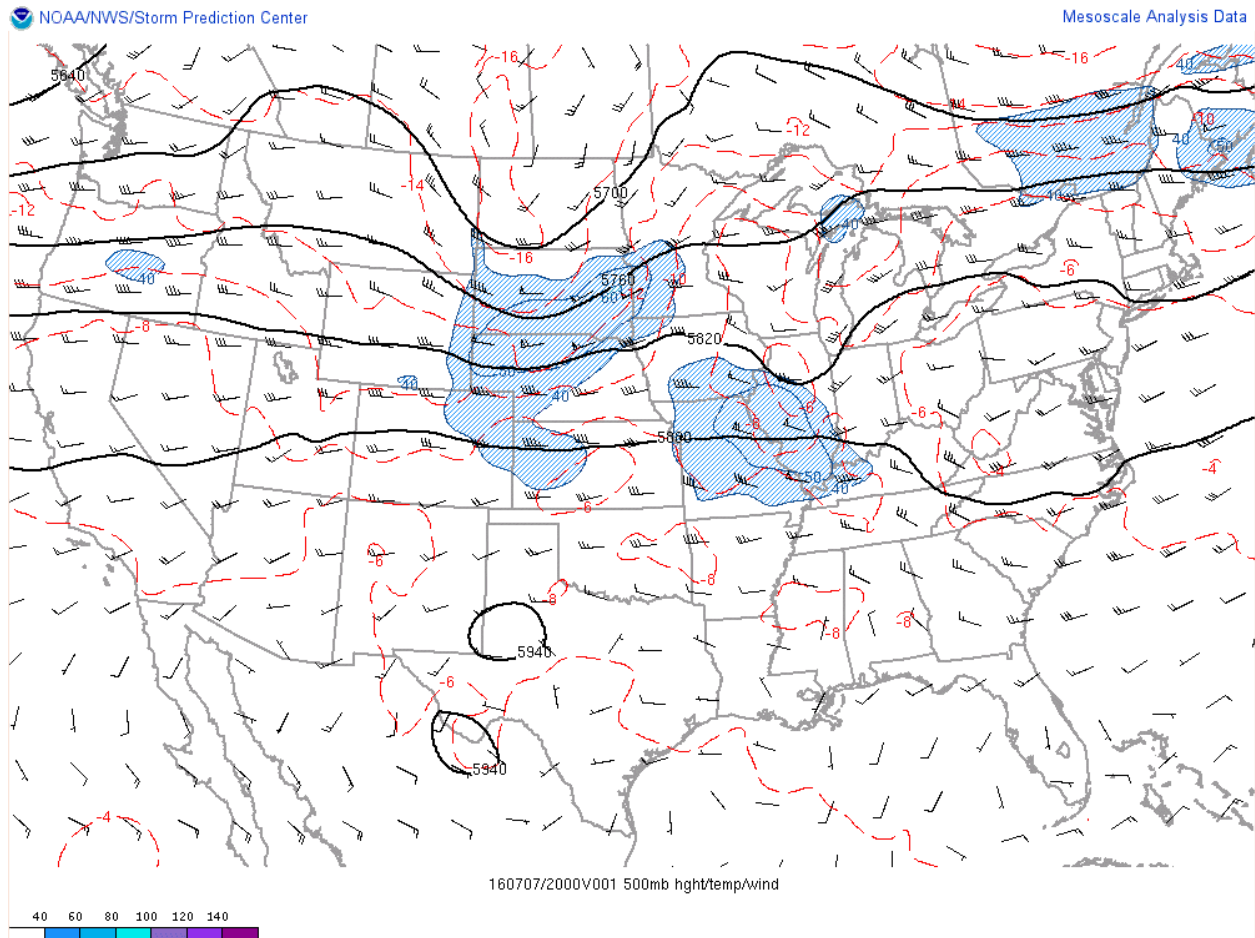


Figure 3.32: The 500mb map for 2000 UTC July 7th, 2016. The black contours represent geopotential heights (m), the red dashed contours represent temperature ($^{\circ}\text{C}$), and the shading and wind barbs represent wind speeds (kts).

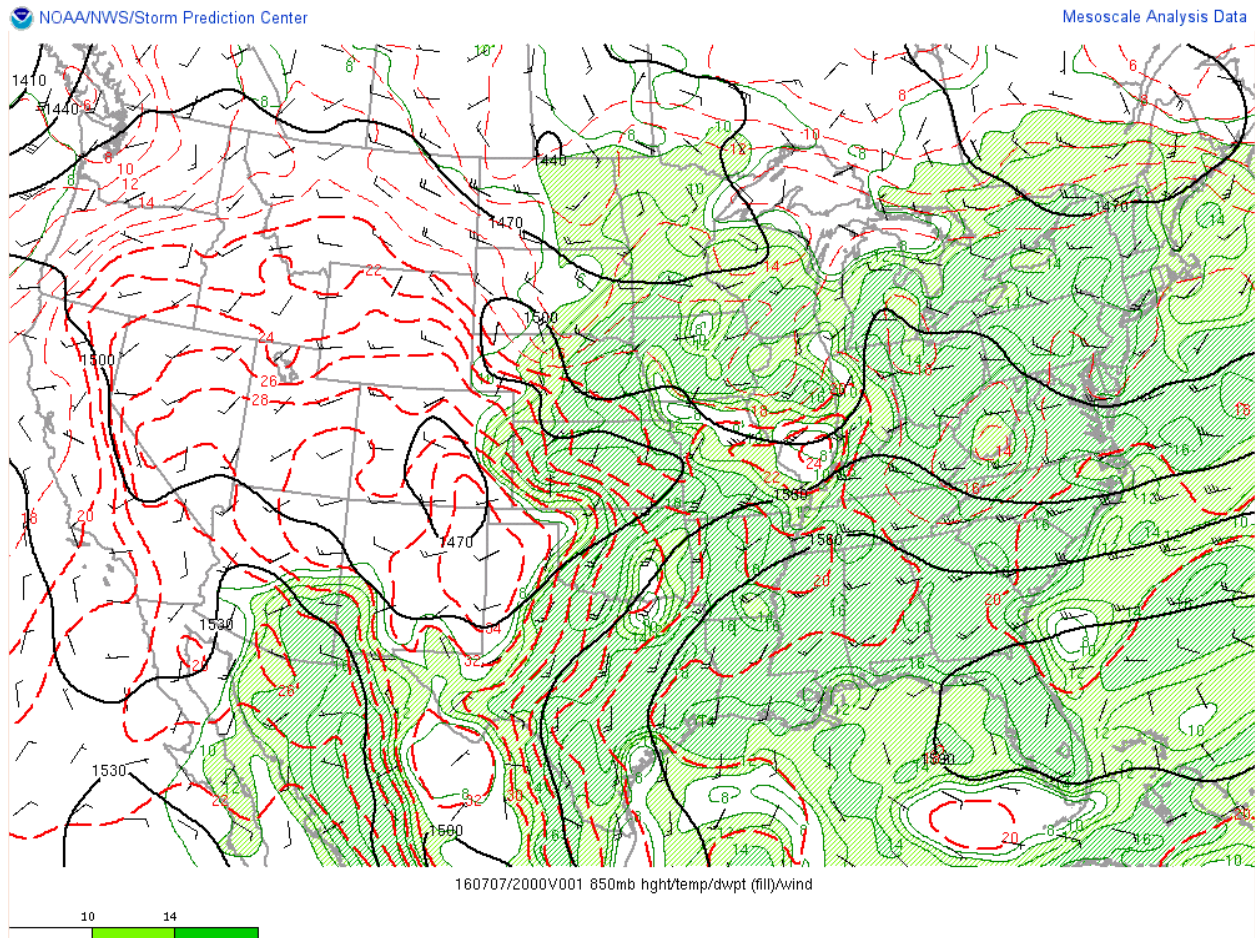


Figure 3.33: The 850mb map for 2000 UTC July 7th, 2016. The black contours represent geopotential heights (m), the dashed red contours represent temperature ($^{\circ}\text{C}$), the wind barbs

represent wind velocity (kts), and the green filled contours represent dew point ($^{\circ}\text{C}$).

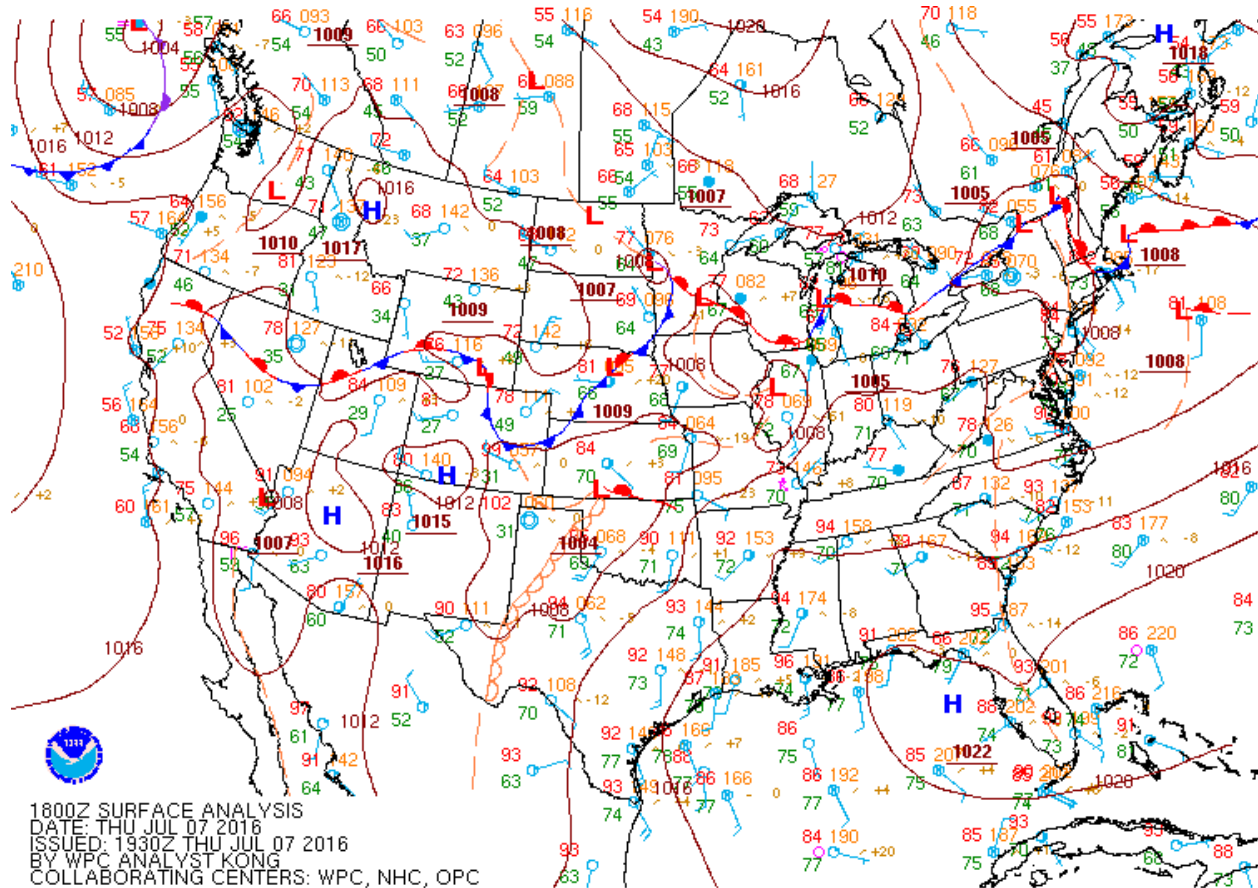


Figure 3.34: The surface map for 1800 UTC July 7th, 2016.

No tornado watch was issued in advance of this event, however, a severe thunderstorm watch was issued for east-central Kansas and central Missouri at 0120 UTC (8:20 pm CDT) to last until 0700 UTC (2:00 am CDT) (Figure 3.35). The accompanying discussion indicates a threat of strong winds and large hail, but does not mention tornadoes, except for the indication of a “low” threat for any tornadoes and a “very low” threat for EF2+ tornadoes. A Mesoscale Discussion issued 19 minutes before at 0101 UTC (8:01 pm CDT), to last until 0300 UTC (10:00

pm CDT) (Figure 3.36). Again, only wind and hail were mentioned, with wind shear specifically being pointed out as a limiting factor to increasing severity.

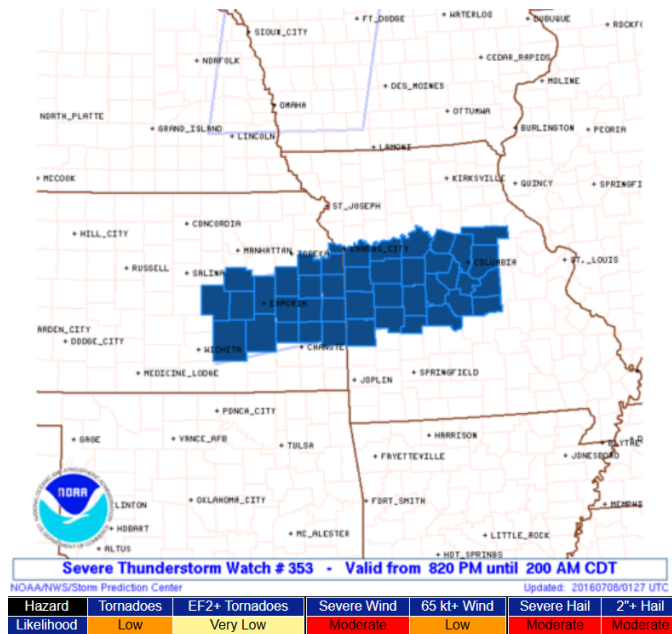


Figure 3.35: The severe thunderstorm watch associated with the Eureka tornadoes.

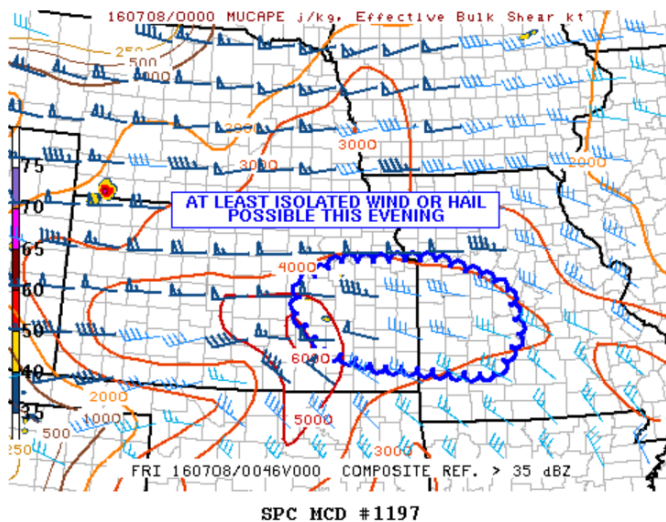


Figure 3.36: The mesoscale discussion image associated with the Eureka tornadoes.

By 0000 UTC, the cold front that was previously over the northwestern corner of Kansas had progressed further into the state, while temperatures near Eureka remained in the upper 80s with dewpoints in the low 70s (Figure 3.37). The 0-6 km wind shear in the region was between 30-40 knots, putting it right on the edge of supercellular conditions (Figure 3.38) (WFO Louisville). Similarly, the 0-3 km storm relative helicity fell between 100-200 m^2s^{-2} , meaning that conditions just met the criteria needed to expect supercells to develop (Figure 3.39) (WFO Louisville).

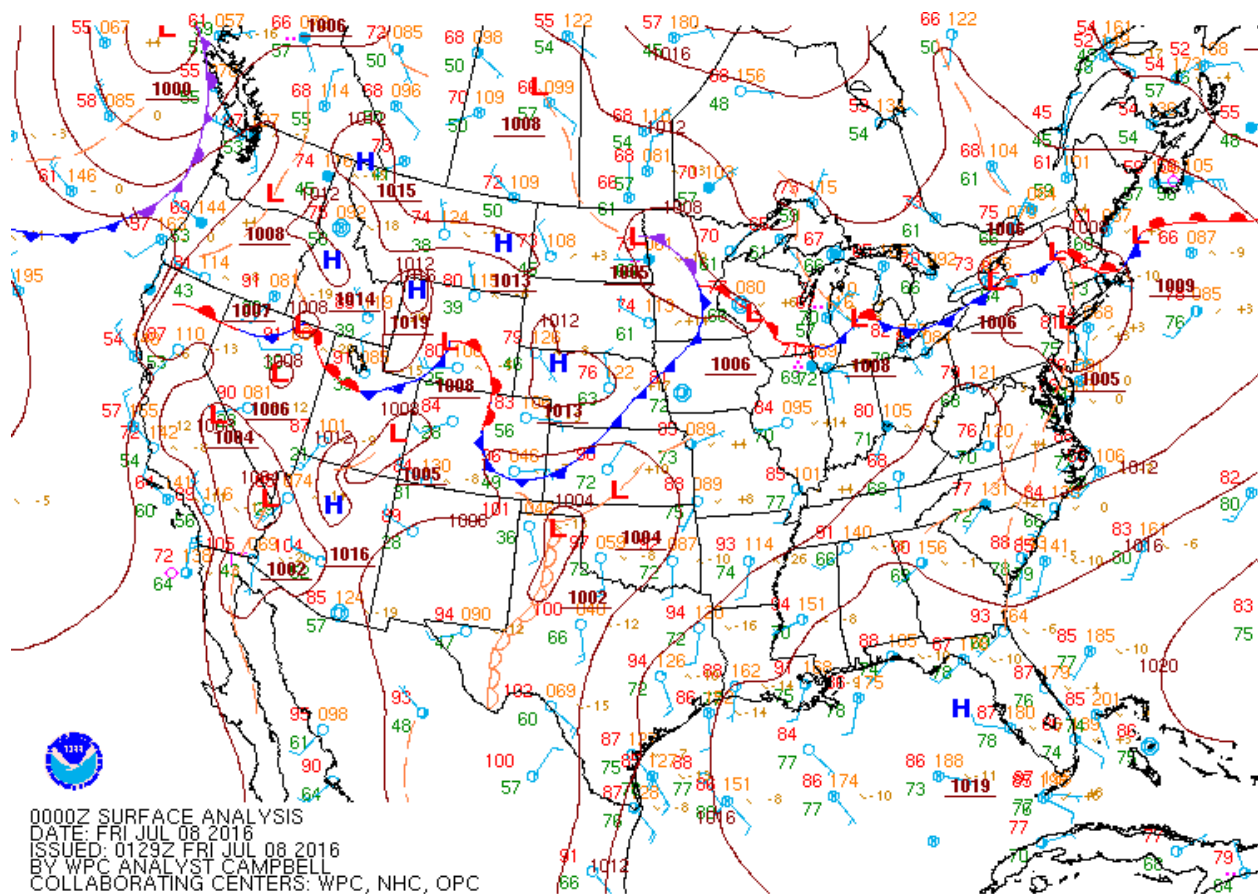


Figure 3.37: The surface map for 0000 UTC July 8th, 2016.

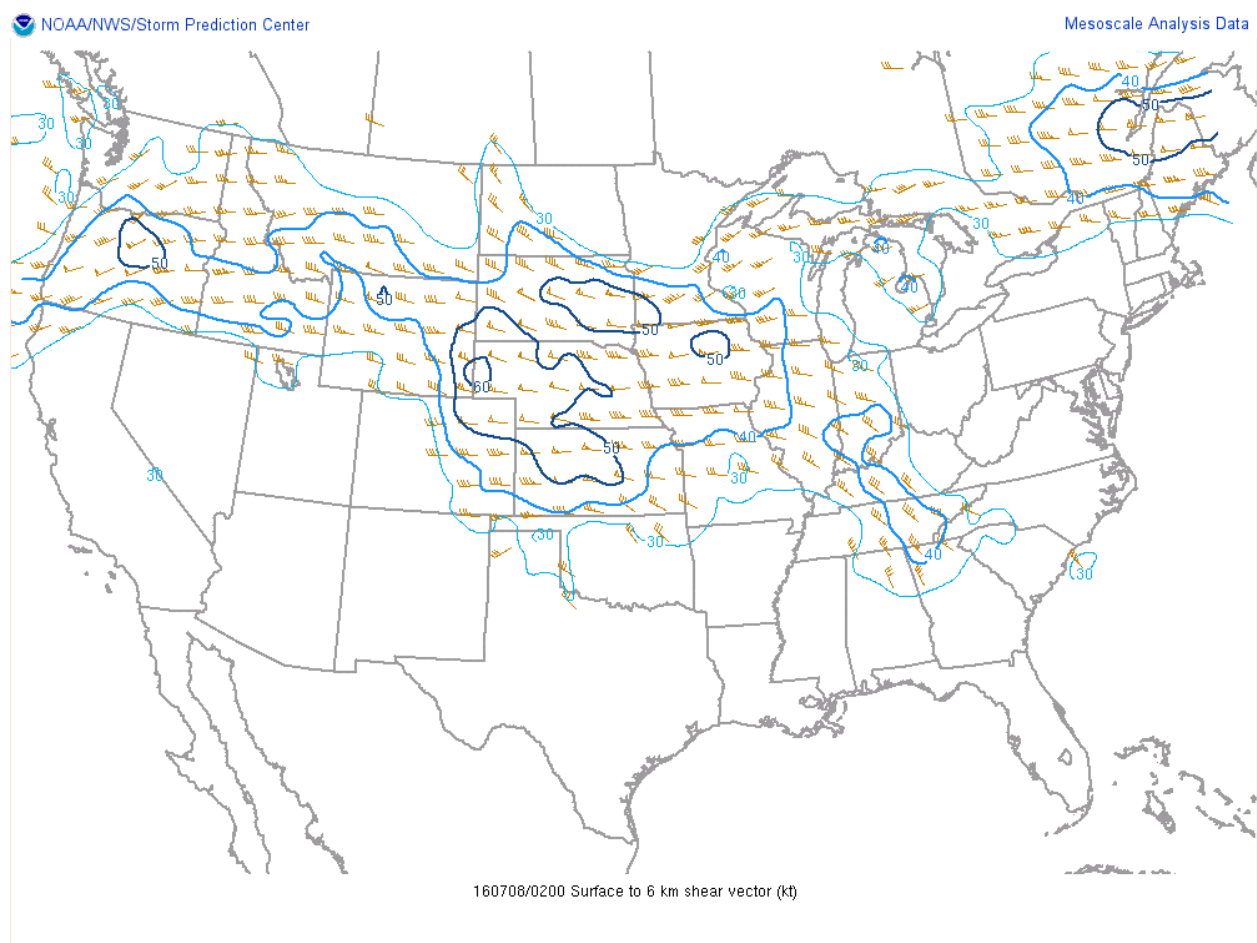


Figure 3.38: Surface to 6km shear (blue contours) for 0200 UTC July 8th, 2016.

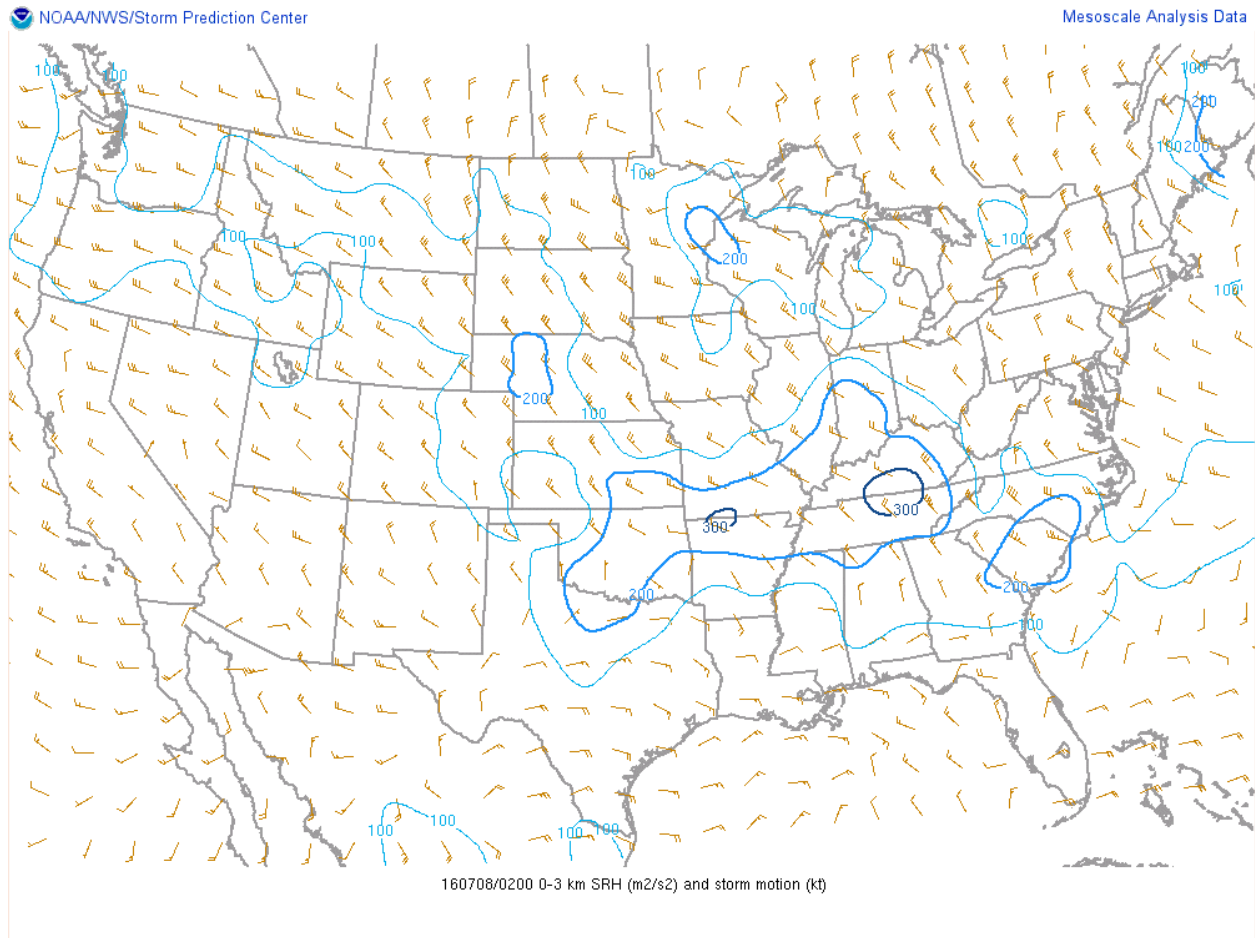


Figure 3.39: Surface to 3km storm relative helicity (m^2s^{-2}) for 0200 UTC July 8th, 2016.

At 0206 UTC (9:06 pm CDT), the first tornado warning associated with this event was issued for the Eureka, KS area (Figure 3.40) (IEM 2026b). Four minutes later, the first tornado touched down just to the northwest of Eureka, tracking a path 4 miles to the southeast (Figure

3.41) (NCEI 2026).

RADAR Composite at Issuance Time

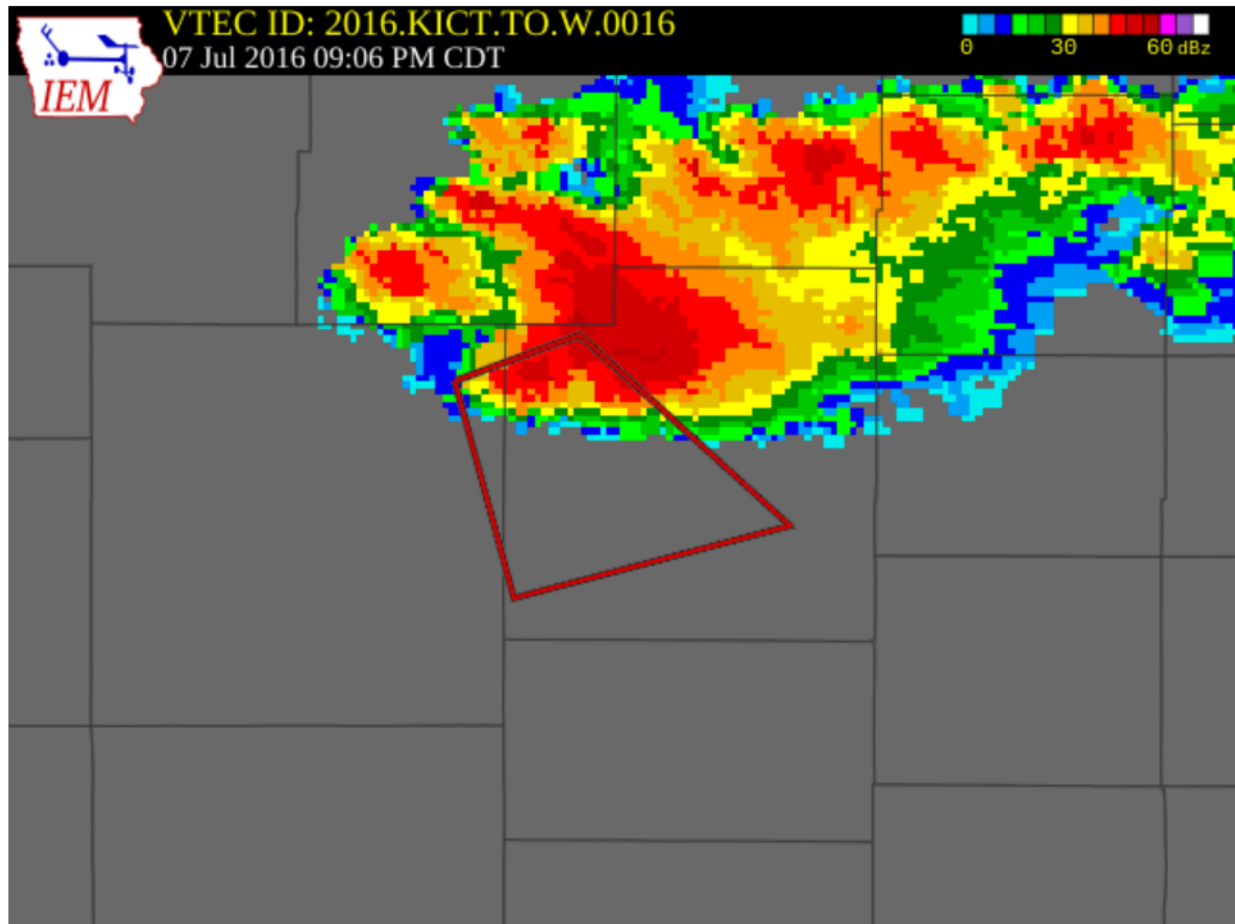


Figure 3.40: The tornado warning associated with the first Eureka tornado. Courtesy of the Iowa Environmental Mesonet.

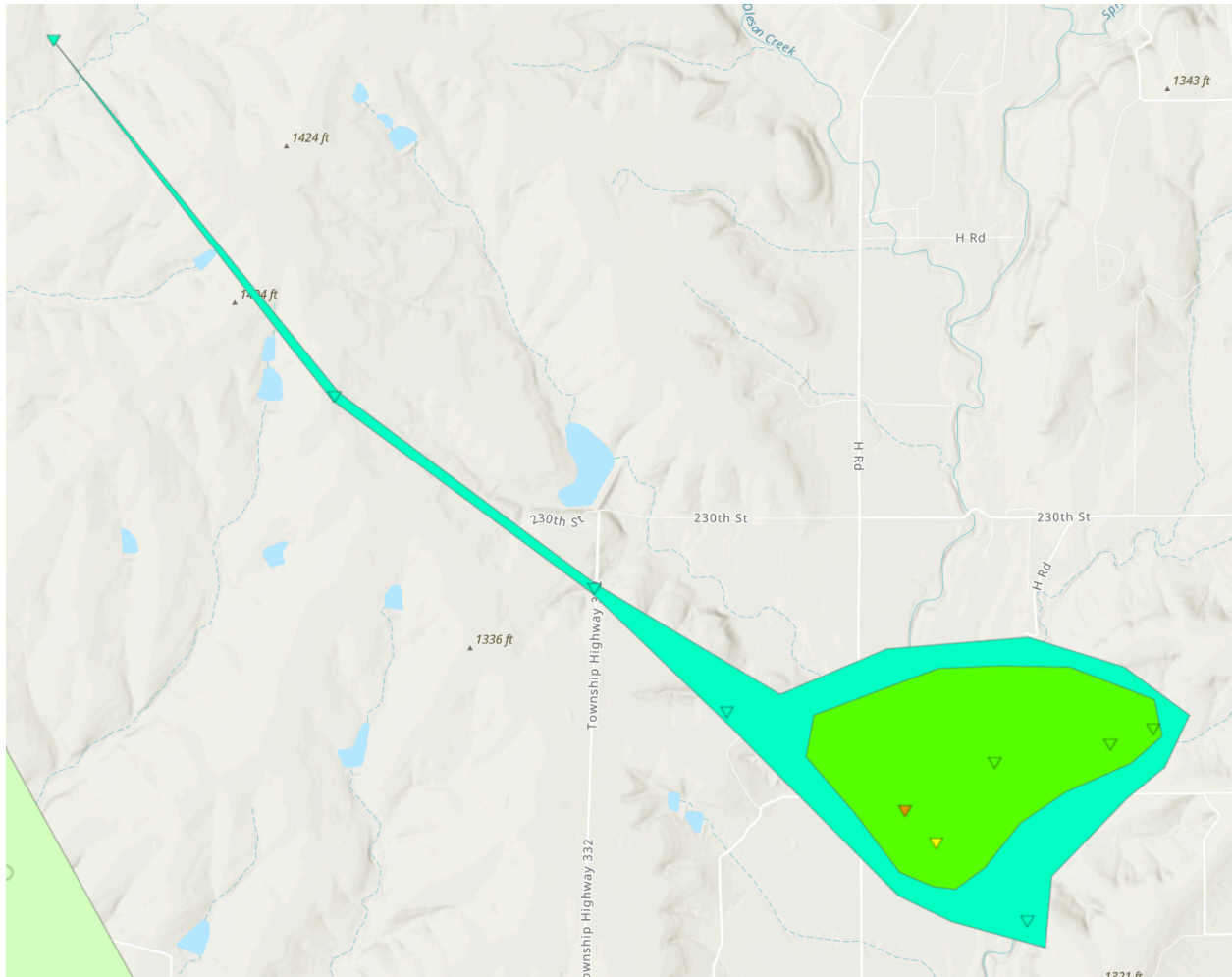


Figure 3.41: The track of the first Eureka tornado. Courtesy of NOAA.

As the storm continued southeast towards Eureka, a second tornado warning was issued at 0244 UTC (9:44 pm CDT), which, unlike the first, was visually confirmed instead of radar-indicated (Figure 3.42) (IEM 2026b). The associated tornado carved a path through the northern part of Eureka (Figure 3.43).

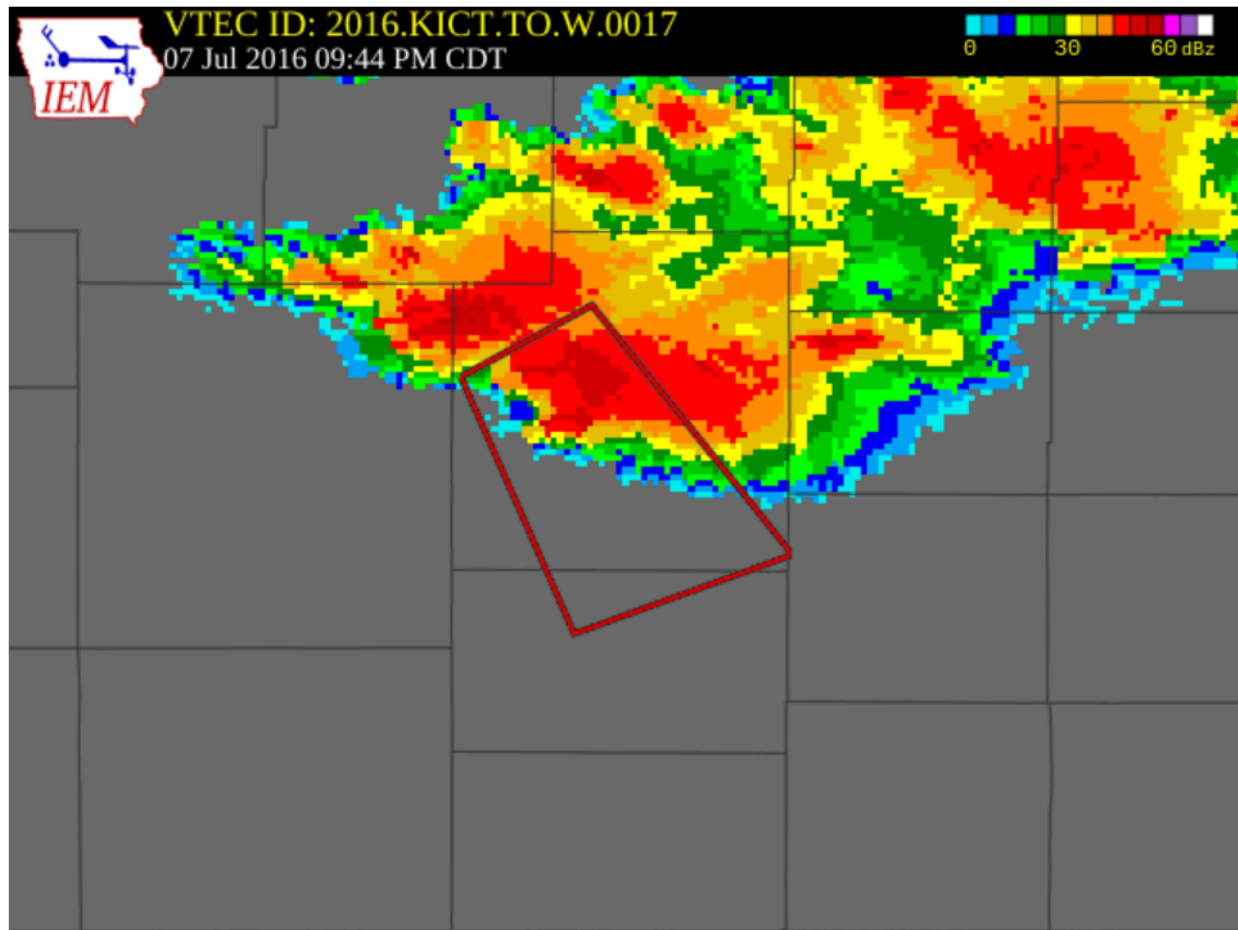


Figure 3.42: The tornado warning associated with the second Eureka tornado. Courtesy of the Iowa Environmental Mesonet.

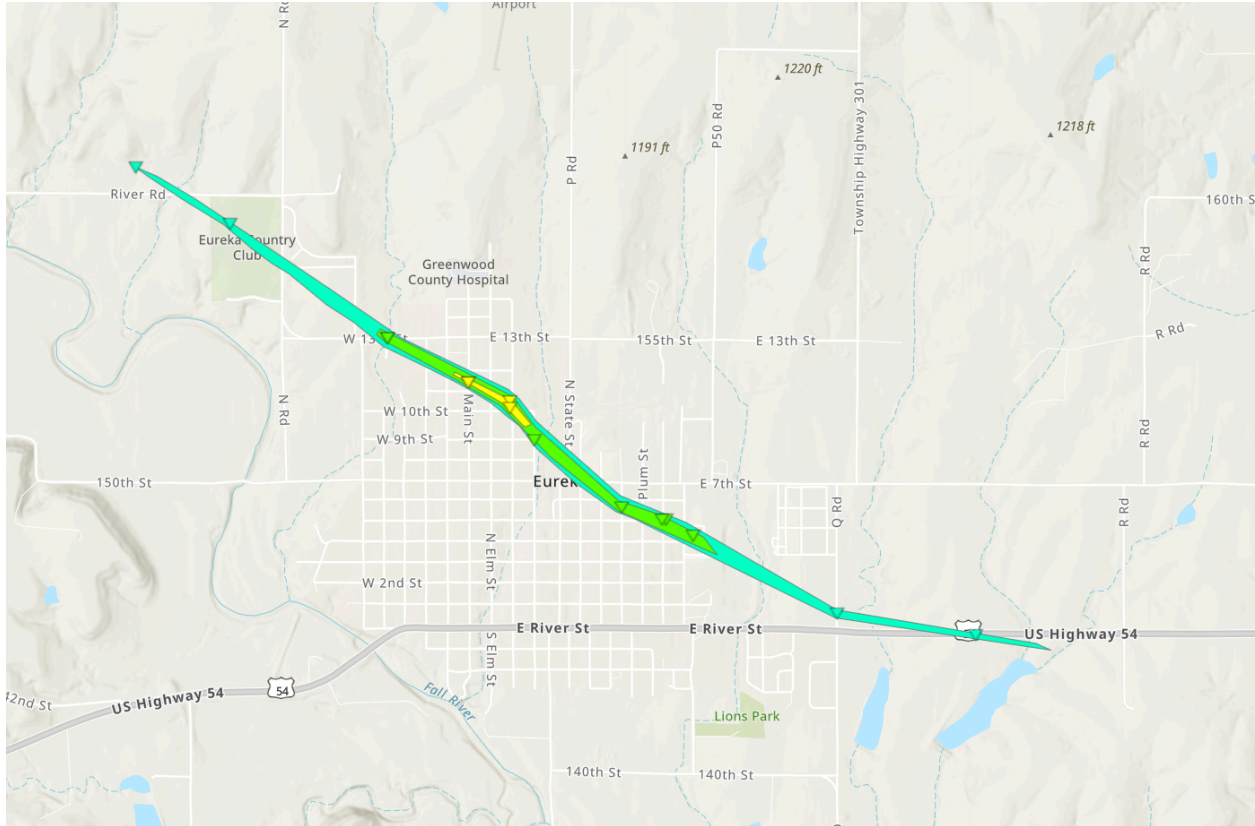


Figure 3.43: The track of the second Eureka tornado. Courtesy of NOAA.

As previously discussed, there appears to have been a large degree of uncertainty leading up to this shortwave-based event, with major changes to the outlook contour locations and aerial coverages. For example, between the 0600 UTC, the 1300 UTC, and the 2000 UTC Day 1 Categorical Outlook issuances, western Iowa went from being under an Enhanced risk to being under a Marginal risk, to then being under an Enhanced risk once again. It also appears that model guidance was widely divergent, with the 1300 UTC Outlook discussion describing the output from the convection-allowing models as “nearly clueless about behavior.” This uncertainty was likely a result of two factors: the relatively “messy” environment left over from multiple previous days of widespread storm activity and the relatively small and non-textbook impetus from the shortwave trough over the Dakotas. Interestingly, by the definition put forth in

Chapter 2, this event was wind and hail driven, both with probabilities of 30% at 2000 UTC, while the tornado probability forecast was only 2% at this time. As noted in Chapter 2, these “non-tornado-driven” situations tend to have a larger proportion of tornado reports occur outside of their maximum threshold areas. Overall, the Eureka, KS tornado appears to have been a “low-probability, high-intensity”-type event, in which the chances of such an event are relatively low, but the effects of the event are large.

The first tornado largely remained in uninhabited areas, however, one house in its path was swept off of its foundation and destroyed, resulting in \$100,000 worth of damage and the designation of EF-3 storm (NWS Wichita, NCEI 2026). The second storm’s track through northern Eureka resulted in damage to 152 houses and other structures for a total of \$3.08 million worth of damage (NCEI 2026). Fortunately, due to the first tornado occurring over a largely unpopulated area and the second tornado having sufficient warning, no reported injuries or fatalities occurred as a result of these storms (NCEI 2026).

3.4: Event 4: 29-30 November 2016, Ider and Rosalie, AL

Just after midnight local time (CST) on the 30th of November 2016, a tornado touched down just to the south of Rosalie, Alabama (NCEI 2026). Over the course of 18 minutes, the storm strengthened to an EF-3 tornado and tracked 13.7 miles west-northwestward through northern Ider, AL before lifting at the Alabama/Georgia state line (NWS Huntsville). This storm was originally recorded as two tornadoes, one an EF-2 tornado beginning near Rosalie and ending just west of Ider and the other an EF-3 beginning west of Ider and continuing to the state line, however, further assessment led to the judgement that the track was continuous (NCEI

2026). While the highest risk threshold on the 2000 UTC Categorical Outlook map was a Moderate risk, Rosalie and Ider were only under a Slight risk at this time (Figure 3.44) .

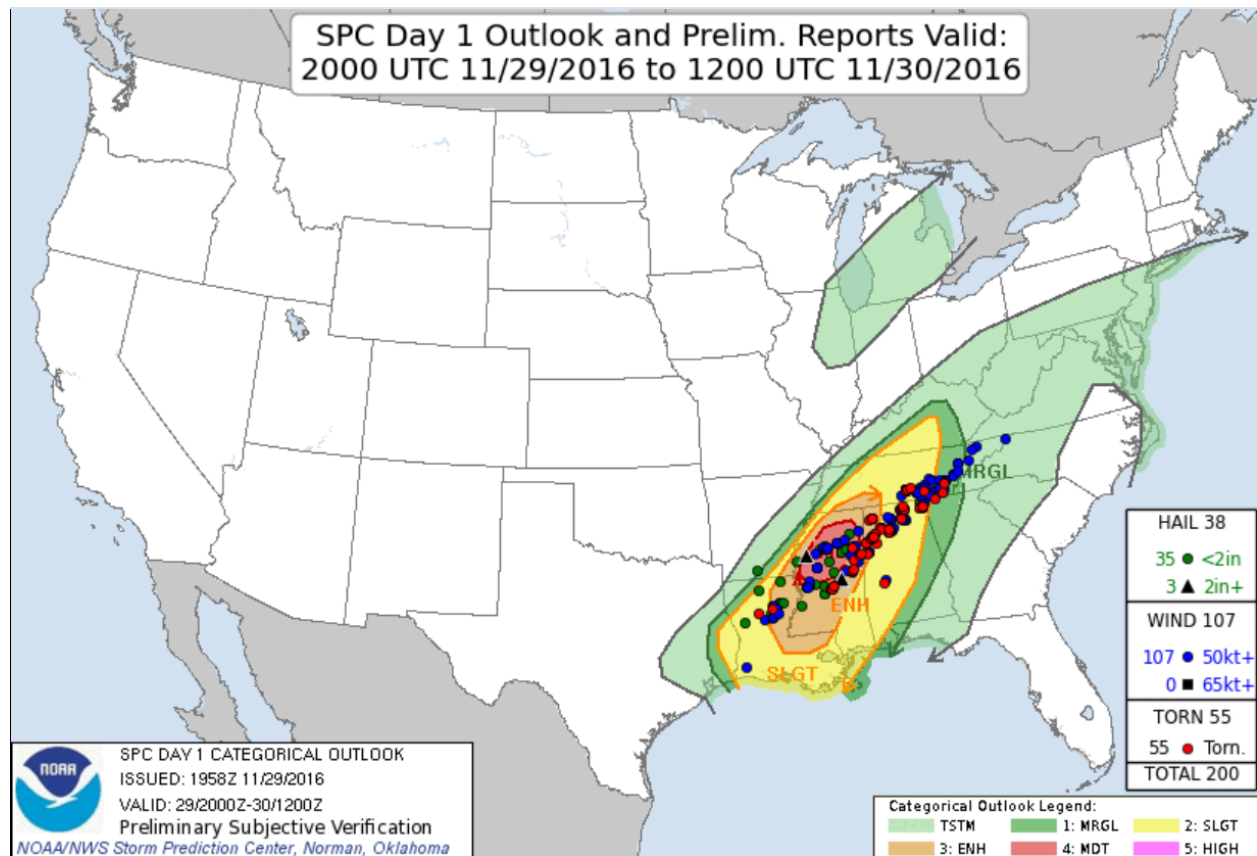


Figure 3.44: 2000 UTC SPC storm report verification for November 29, 2016.

The first indication that severe weather was possible around the 29th was in the Day 4-8 forecast discussion on the 22nd, in which forecasters predicted that a shortwave trough would develop and move into the Southern Plains and Southeast, along with moisture advection from the Gulf. The Day 4-8 forecast discussion issued on the 23rd included a mention of severe weather potential in the Southeast, but at the same time expressed uncertainty in the actual potential due to insufficient instability. The Day 4-8 discussions for the 24th and 25th are a

similar story. While forecaster certainty of severe weather on the 28th increased over this period, the risk of severe weather for the 29th remained highly uncertain due to the possibility of limited instability.

The Day 4-8 Outlook on the 26th was the first to include a 15% risk contour, which was drawn over southern Louisiana and southern Mississippi (Figure 3.45). The associated discussion includes the shortwave trough mentioned in the first Day 4-8 discussion associated with this event, with more certainty that there could be enough instability and moisture for supercellular development.

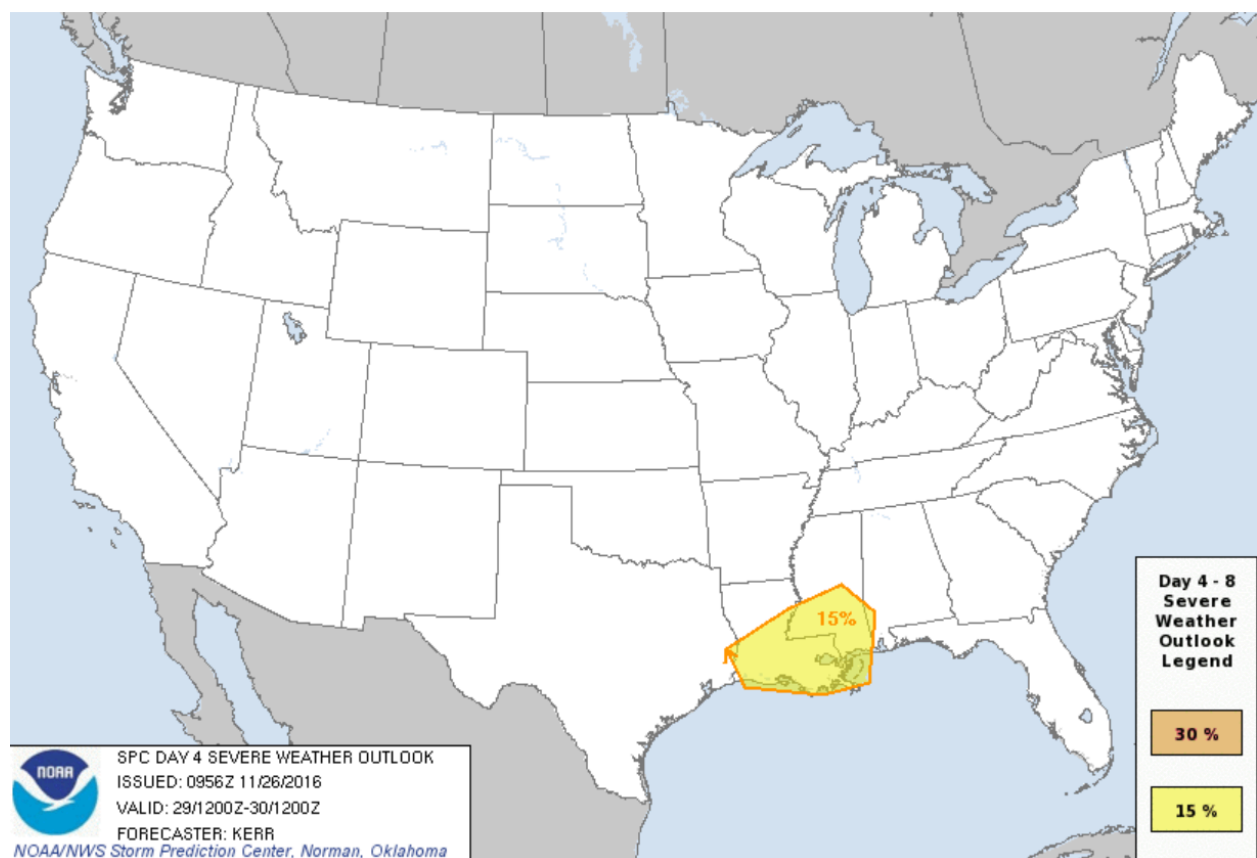


Figure 3.45: The November 26th Day 4 SPC Categorical Convective Outlook.

The Day 3 Outlook introduced a Slight risk contour in roughly the same area as the 15% contour from the previous day, along with a Marginal risk contour over Alabama and portions of Georgia (Figure 3.46). The accompanying discussion indicated that forecasters expected the upper-level shortwave trough of interest to deepen and become more positively tilted as upper-level divergence and moisture advection increased in the Slight risk region.

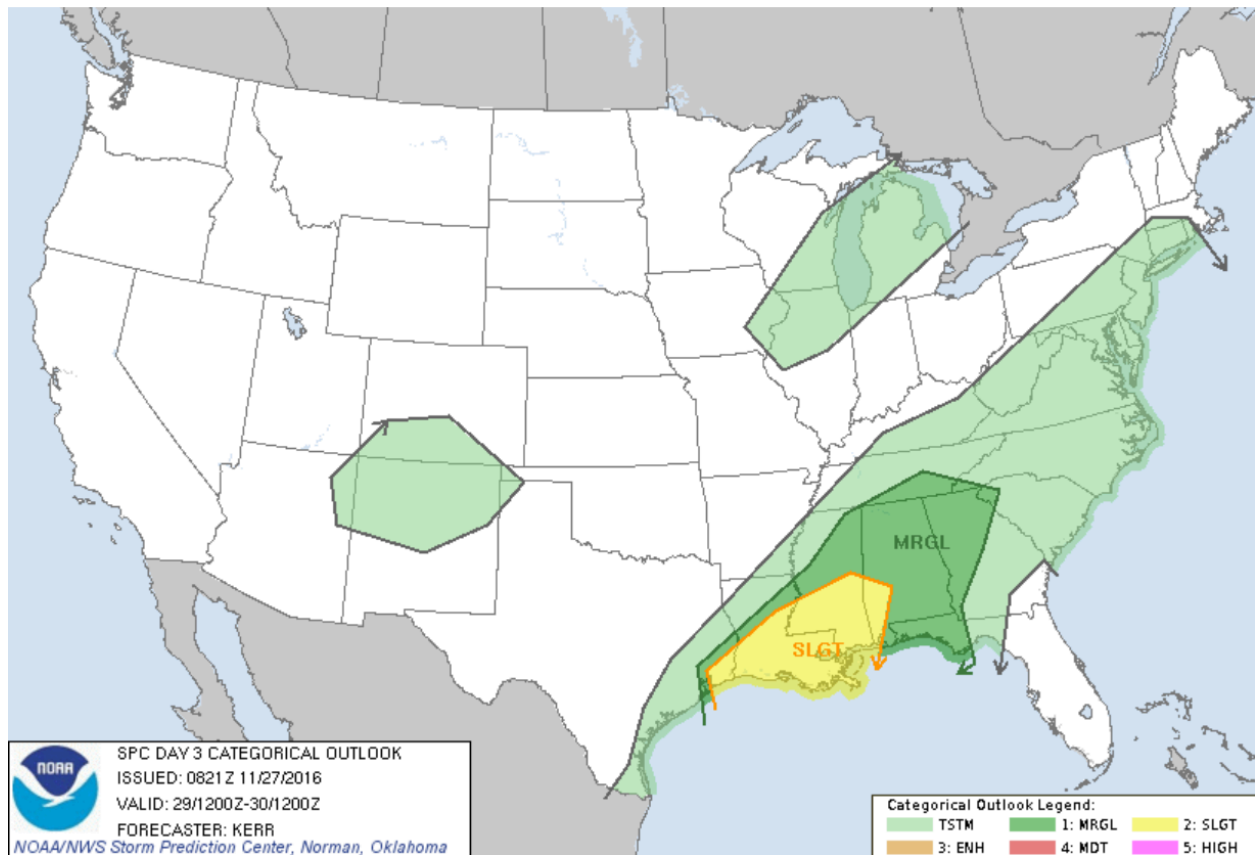


Figure 3.46: The November 27th Day 3 SPC Categorical Convective Outlook.

For the 1730 UTC Day 2 Outlook map, forecasters extended the Slight risk area into Alabama (Figure 3.47). The accompanying forecast discussion predicts warm air advection, increasing instability, and a strengthening low-level jet resulting in evening severe thunderstorm potential.

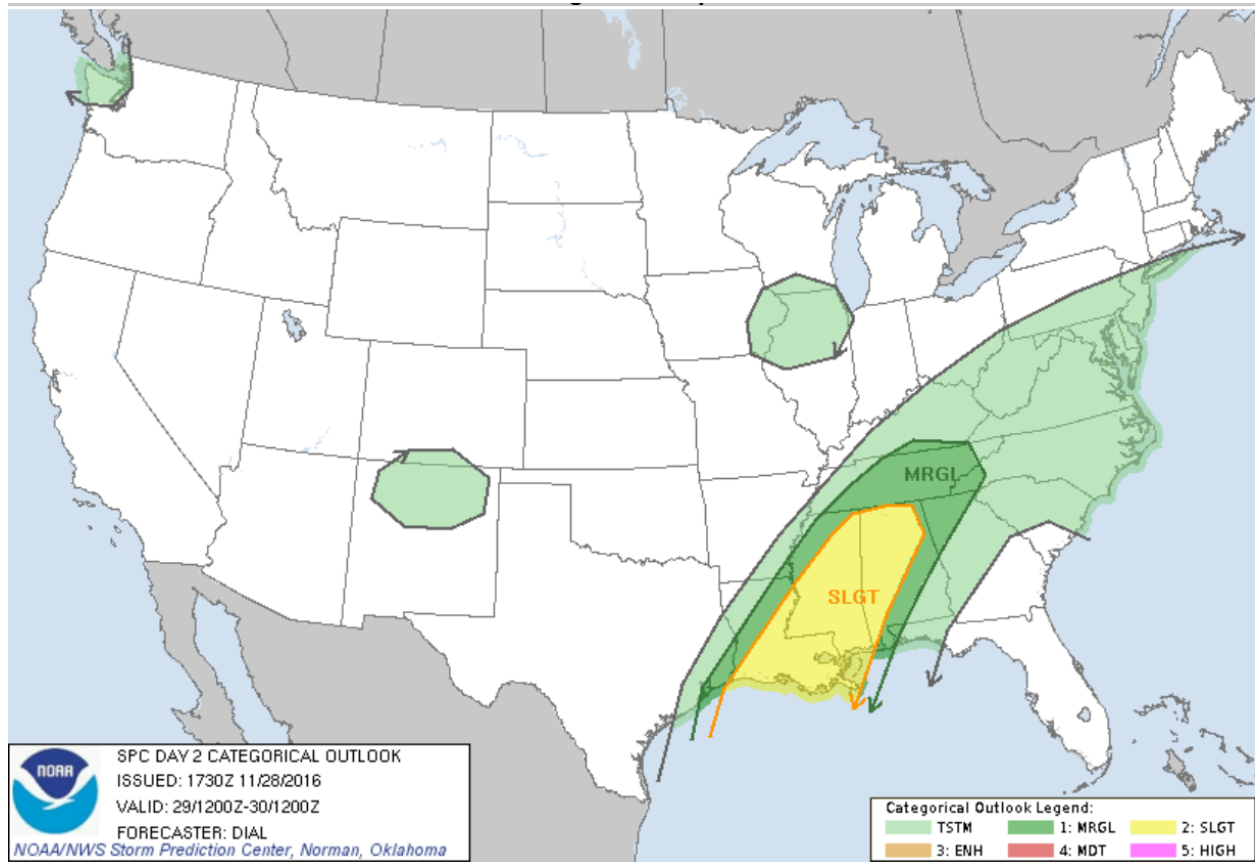


Figure 3.47: The November 28th Day 2 SPC Categorical Convective Outlook.

The 0600 UTC Day 1 Outlook map was the first to include an Enhanced risk, highlighting central Mississippi. The timing and location in the associated forecast discussion also became more specific, with forecasters predicting lingering storms in the area from the previous day's activity giving way to a second wave of severe weather on the evening of 29th. This second wave was predicted to include supercellular development accompanying tornado potential due to the presence of moist air, strong shear, and limited premature storm development ahead of the cold front. The 1300 UTC and 1630 UTC updates kept the Enhanced contour essentially the same, with a slight eastward extension of the Slight contour farther into Alabama.

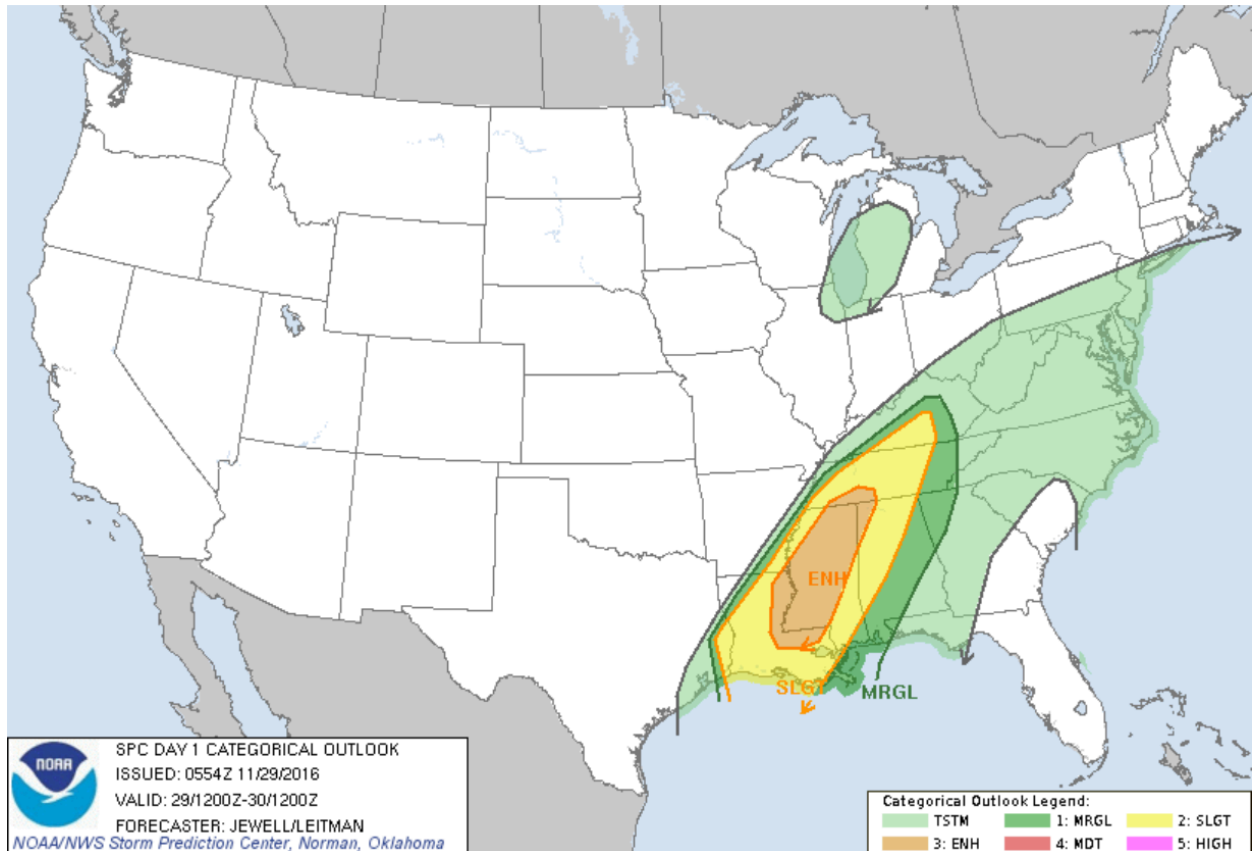


Figure 3.48: The 0600 UTC Day 1 SPC Categorical Convective Outlook.

The 2000 UTC Day 1 Outlook map was the first to include a Moderate risk contour, which covered northern Mississippi (Figure 3.49). The discussion update at this time again highlighted moisture, shear, and instability as indicators of supercellular risk, particularly in the Moderate contour region between 0000 UTC and 0400 UTC, while the post 0400 UTC threat in Alabama was considered to be mainly damaging winds, with the potential for a couple of tornadoes.

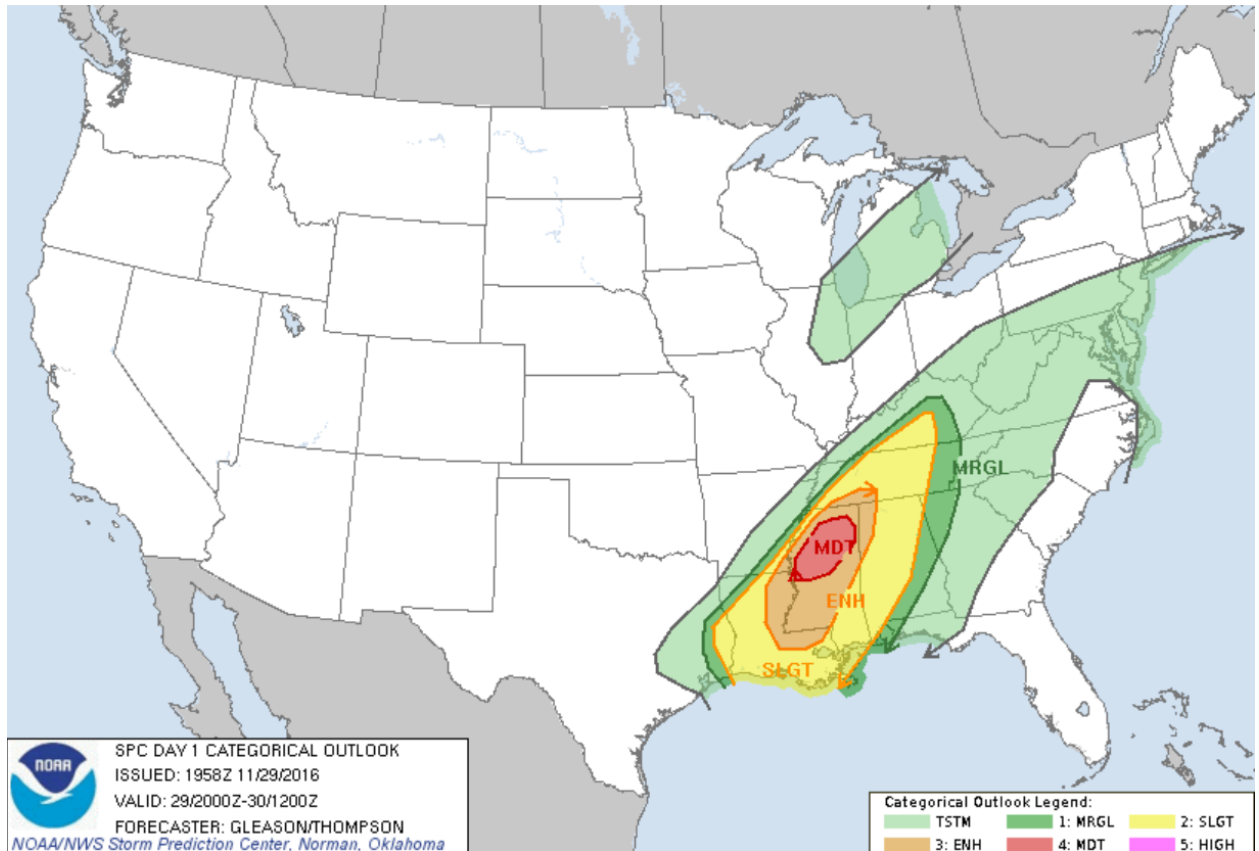


Figure 3.49: The 2000 UTC Day 1 SPC Categorical Convective Outlook.

At the 300 mb level at 2000 UTC, a deep, positively-tilted trough was present across the Northern Plains, alongside a significant upper-level jet streak stretching from New Mexico to Pennsylvania (Figure 3.50). In the Moderate risk area, upper-level divergence around $4\text{--}6 \times 10^{-5} \text{ s}^{-2}$ was present (Figure 3.50). At the 500 mb level, the same trough-and-jet-streak pattern was present (Figure 3.51). Notably, Arkansas and northern Louisiana are within the right entrance region of the 500 mb-level jet streak (Figure 3.51). At 850 mb, the same troughing pattern as above created southerly winds over the Gulf into Louisiana, Mississippi, and Alabama, bringing warm, moist air onshore (Figure 3.52). At the surface, a cold front was present across Missouri, Oklahoma, and Texas (Figure 3.53). Northeastern Alabama at the time had temperatures in the

upper 60s, with dewpoints in the upper 40s (Figure 3.53).

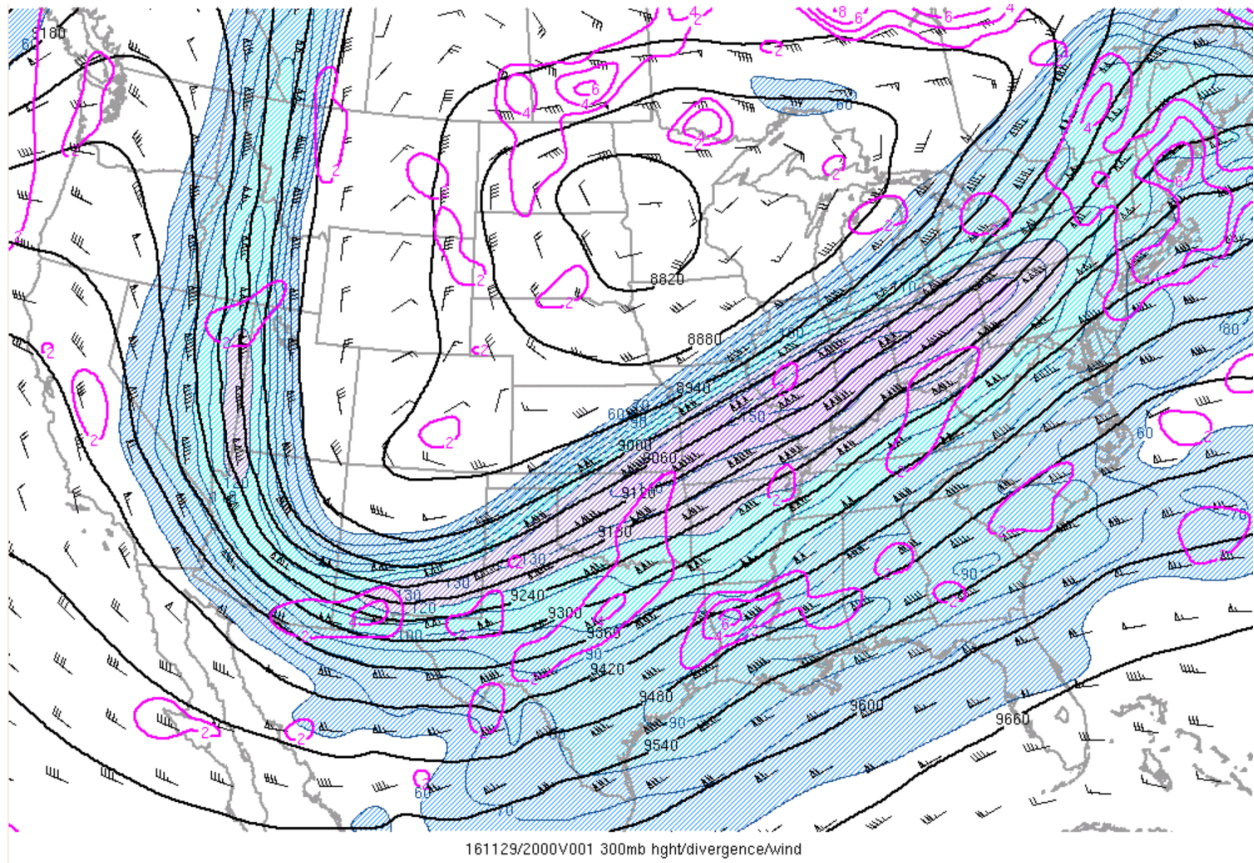


Figure 3.50: The 300mb map for 2000 UTC November 29th, 2016. The black contours represent geopotential heights (m), the shading represents wind speeds (kts), and the purple contours

represent divergence (10^{-5}s^{-1}).

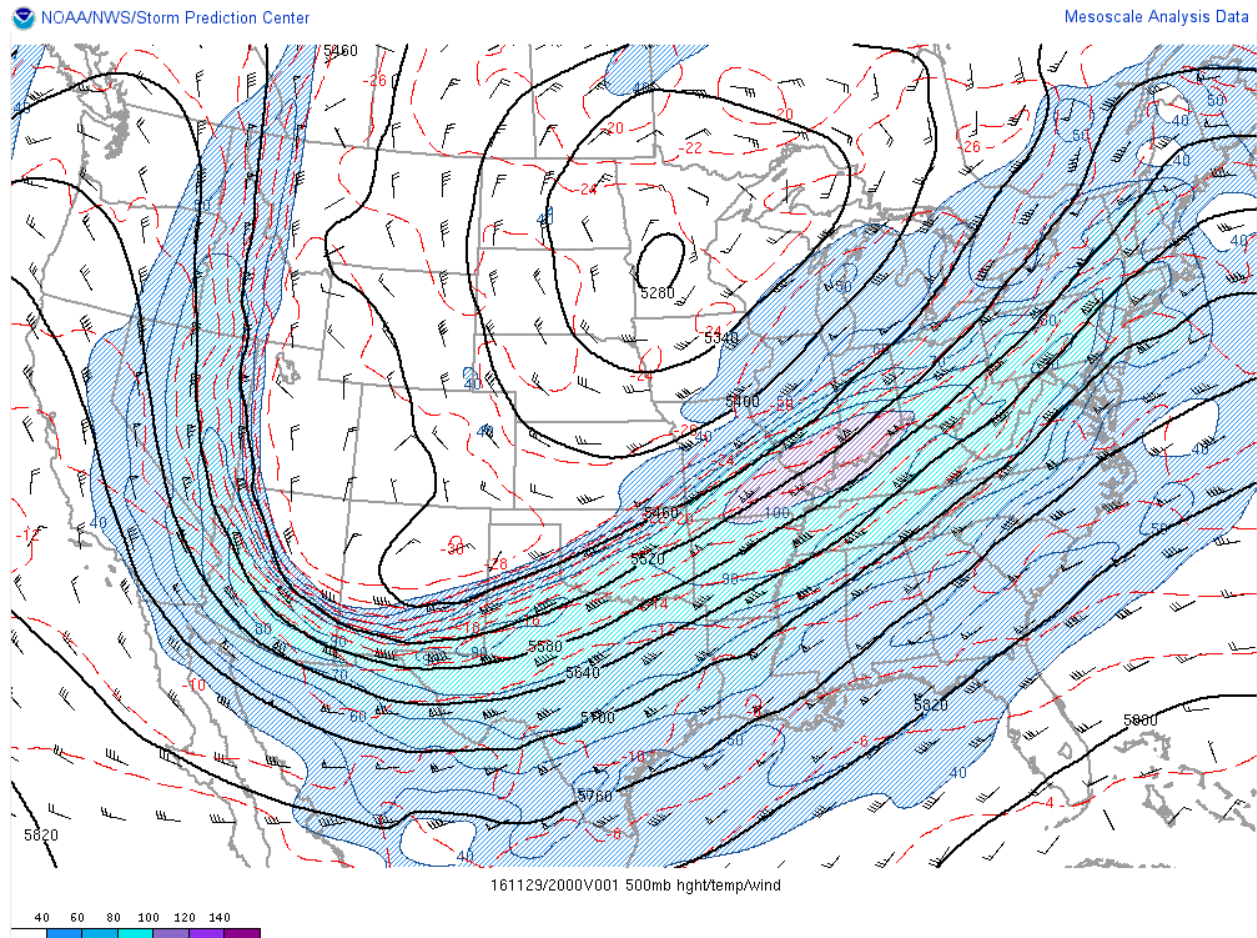


Figure 3.51: The 500mb map for 2000 UTC November 29th, 2016. The black contours represent geopotential heights (m), the red dashed contours represent temperature ($^{\circ}\text{C}$), and the shading and wind barbs represent wind speeds (kts).

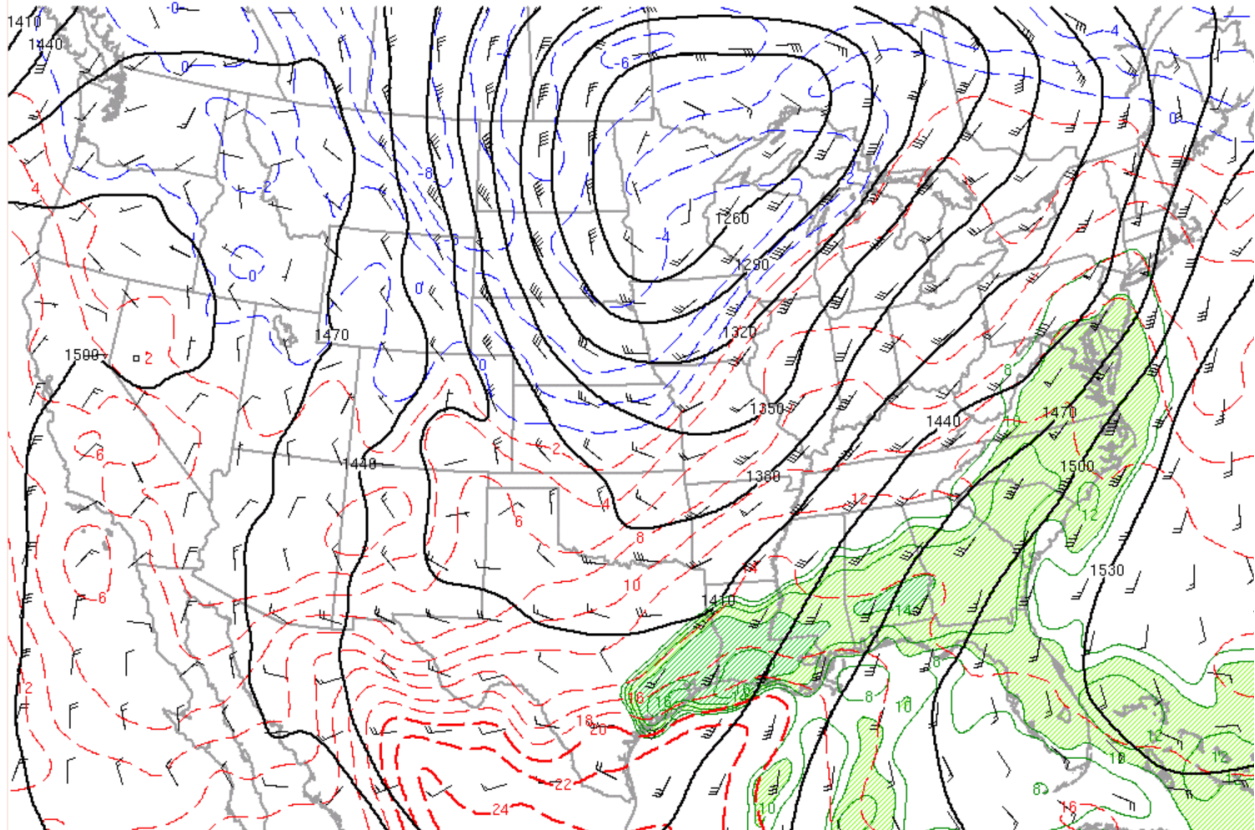


Figure 3.52: The 850mb map for 2000 UTC November 29th, 2016. The black contours represent geopotential heights (m), the dashed red contours represent temperature ($^{\circ}\text{C}$), the wind barbs

represent wind velocity (kts), and the green filled contours represent dew point ($^{\circ}\text{C}$).

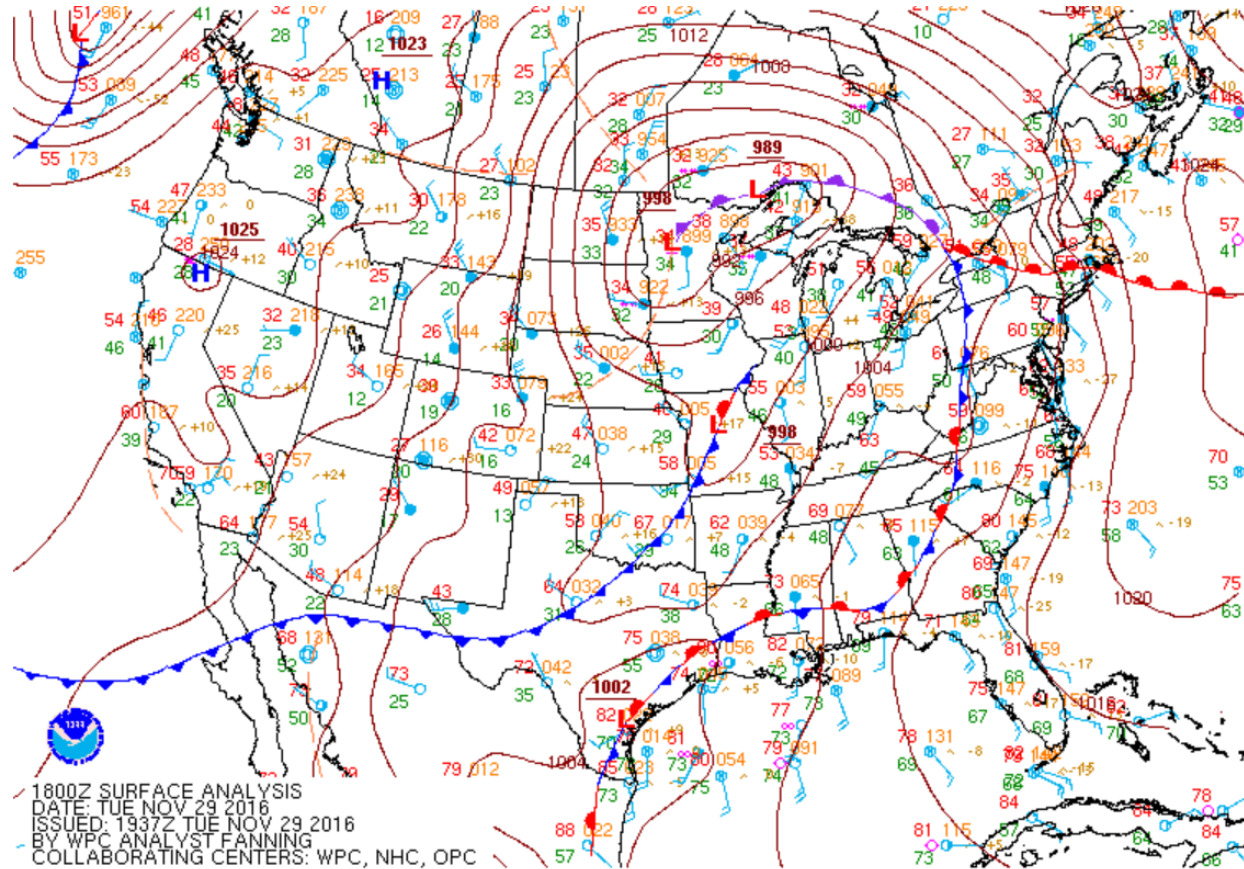


Figure 3.53: The surface map for 1800 UTC November 29th, 2016.

The tornado watch for this event was issued at 0423 UTC November 30th (10:23 pm November 29th CST) which covered a small portion of northern Alabama (Figure 3.54). Just under an hour later, a Mesoscale Discussion was issued for supercellular activity in the region which was expected to strengthen due to increasing instability, moisture, warmth, and shear (Figure 3.55).

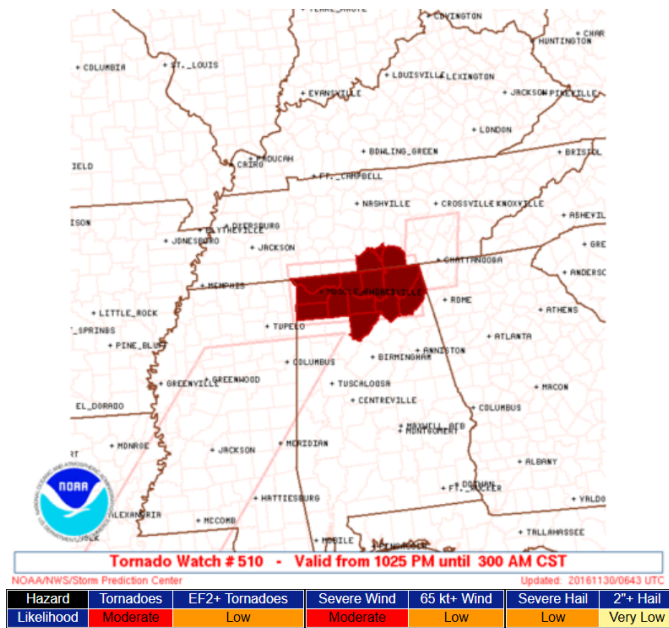


Figure 3.54: The tornado watch associated with the Rosalie/Ider tornado.

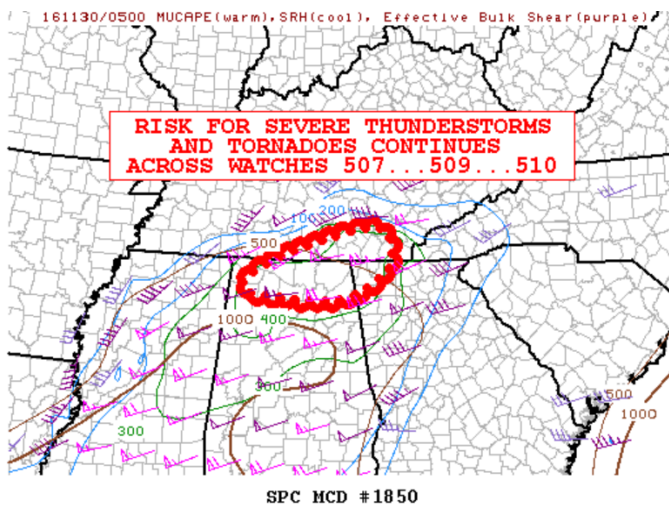


Figure 3.55: The mesoscale discussion associated with the Rosalie/Ider tornado.

The intensification of upper-level divergence in Alabama by 0600 UTC on the 30th can be seen on the 300mb map at this time (Figure 3.56), indicating strong upwards motion. At the surface, a mature low-pressure center was located in Montana, vertically stacked with the location of the center of the trough at all levels above it (Figure 3.57). From this low-pressure

center, an occluded front extended into southern Illinois, with a warm front stretching through Tennessee and a cold front extending across Arkansas, through Louisiana, and into Texas, putting Ider and Rosalie within the warm sector (Figure 3.57). Around 0300 UTC, surface temperatures near Ider and Rosalie were in the upper 60s, with dewpoints in the mid-60s and southerly winds (Figure 3.57). Further, the 0-6 km shear in northeastern Alabama at this time was around 70 knots, more than sufficient for supercellular development (Figure 3.58) (WFO Louisville). Similarly, 0-3 km storm relative helicity in the area was around $400 \text{ m}^2\text{s}^{-2}$ (Figure 3.59).

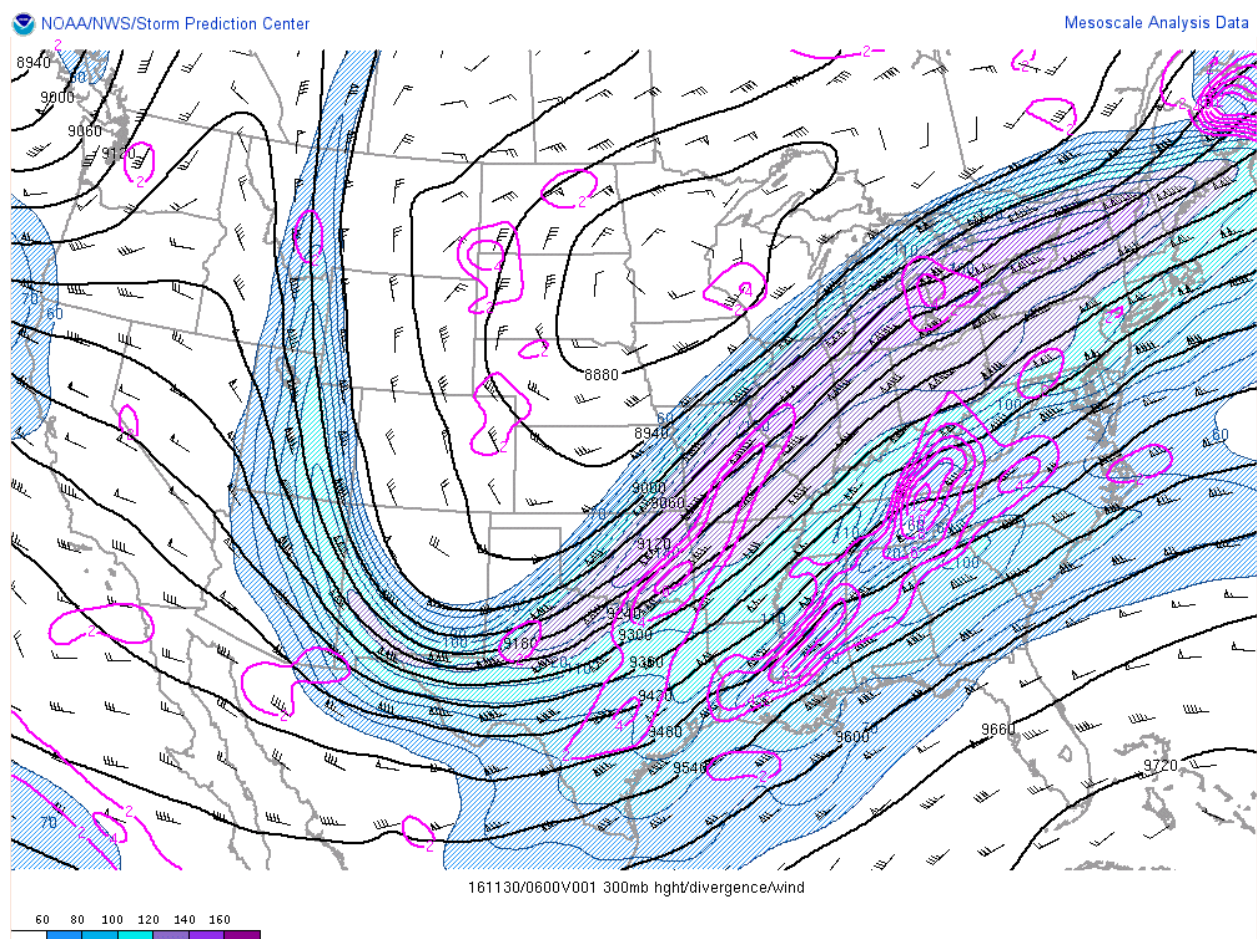


Figure 3.56: The 300mb map for 0600 UTC November 30th, 2016. The black contours represent geopotential heights (m), the shading represents wind speeds (kts), and the purple contours

represent divergence (10^{-5}s^{-1}).

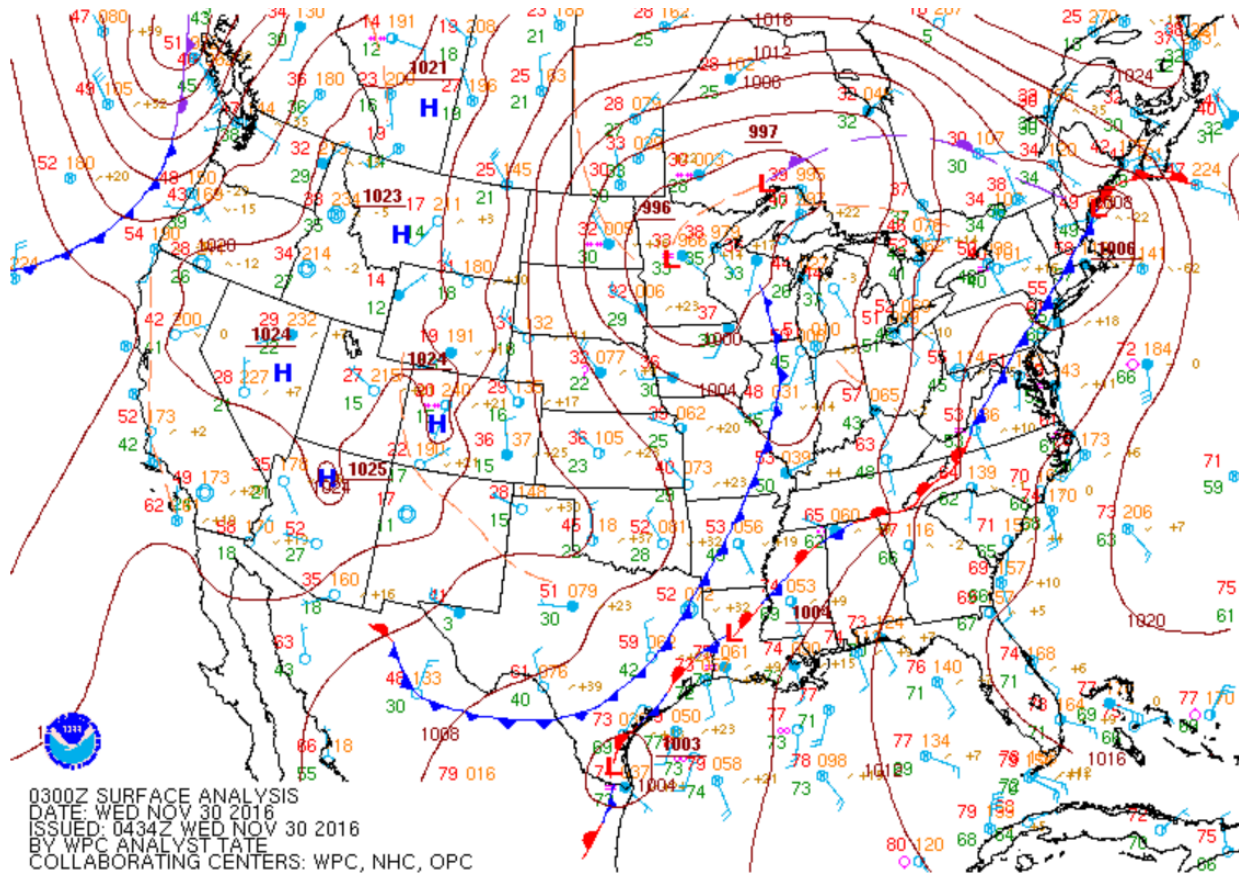


Figure 3.57: The surface map for 0300 UTC November 30th, 2016.

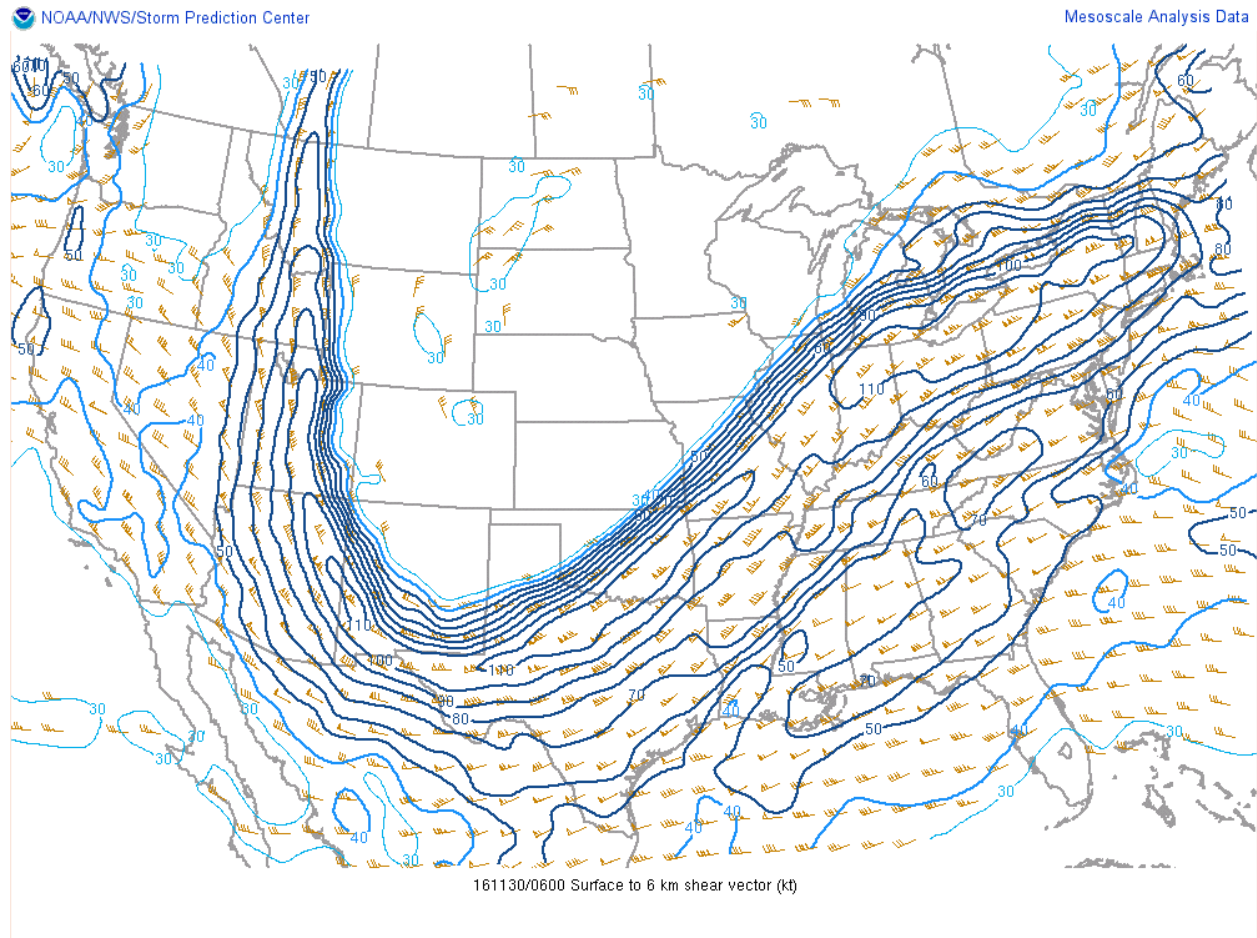


Figure 3.58: Surface to 6km shear (blue contours) for 0600 UTC November 30th, 2016.

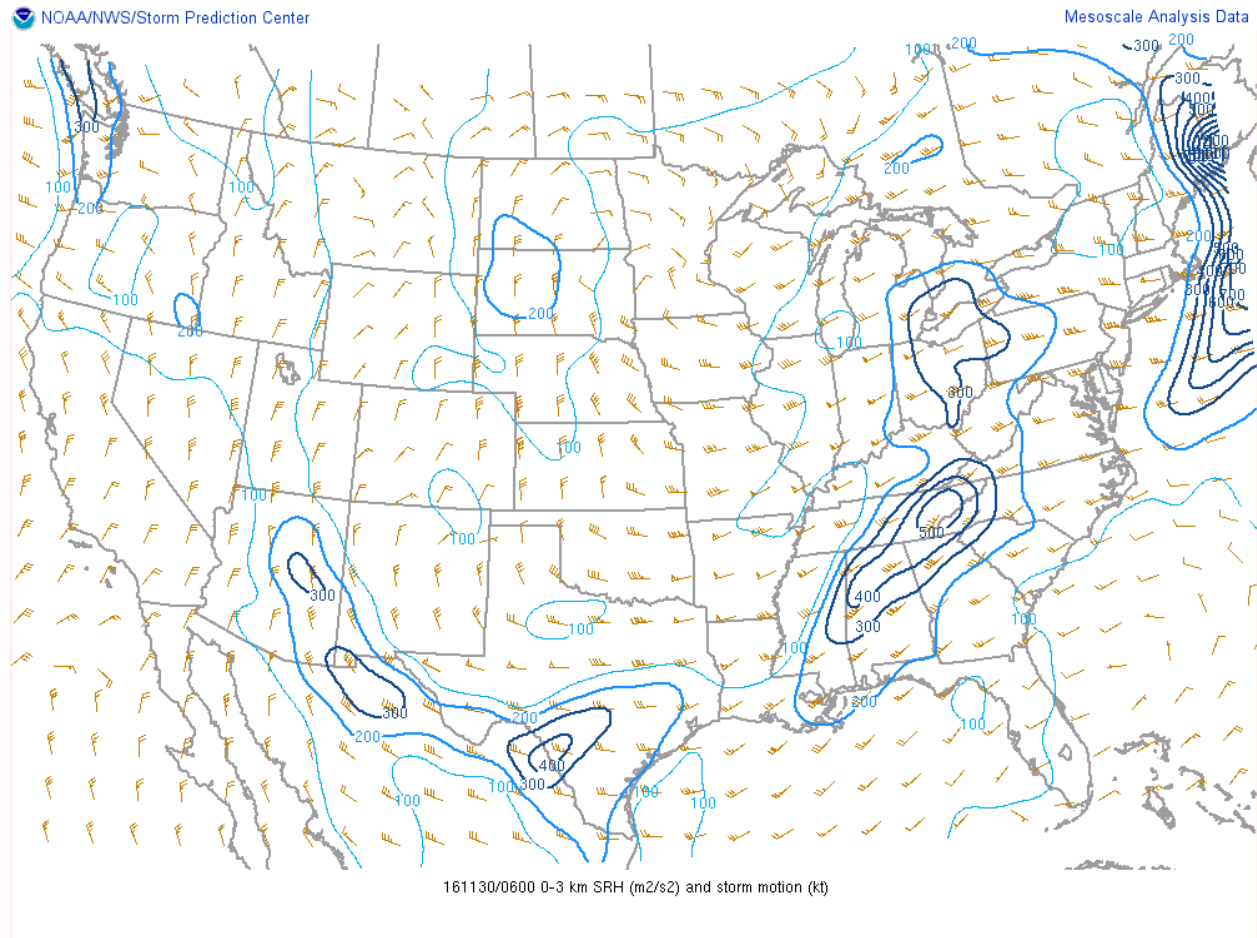


Figure 3.59: Surface to 3km storm relative helicity (m^2s^{-2}) for 0600 November 30th, 2016.

At 0602 UTC (1202 CST), a radar-indicated tornado warning was issued for Dekalb County, the county where Rosalie and Ider are located (Figure 3.60) (IEM 2026b). At the same time, the tornado touched down just to the southwest of Rosalie, then cut a path northeast through Rosalie, Shrader, and Yorks Mill before dissipating at the state line (Figure 3.61) (NOAA 2026).

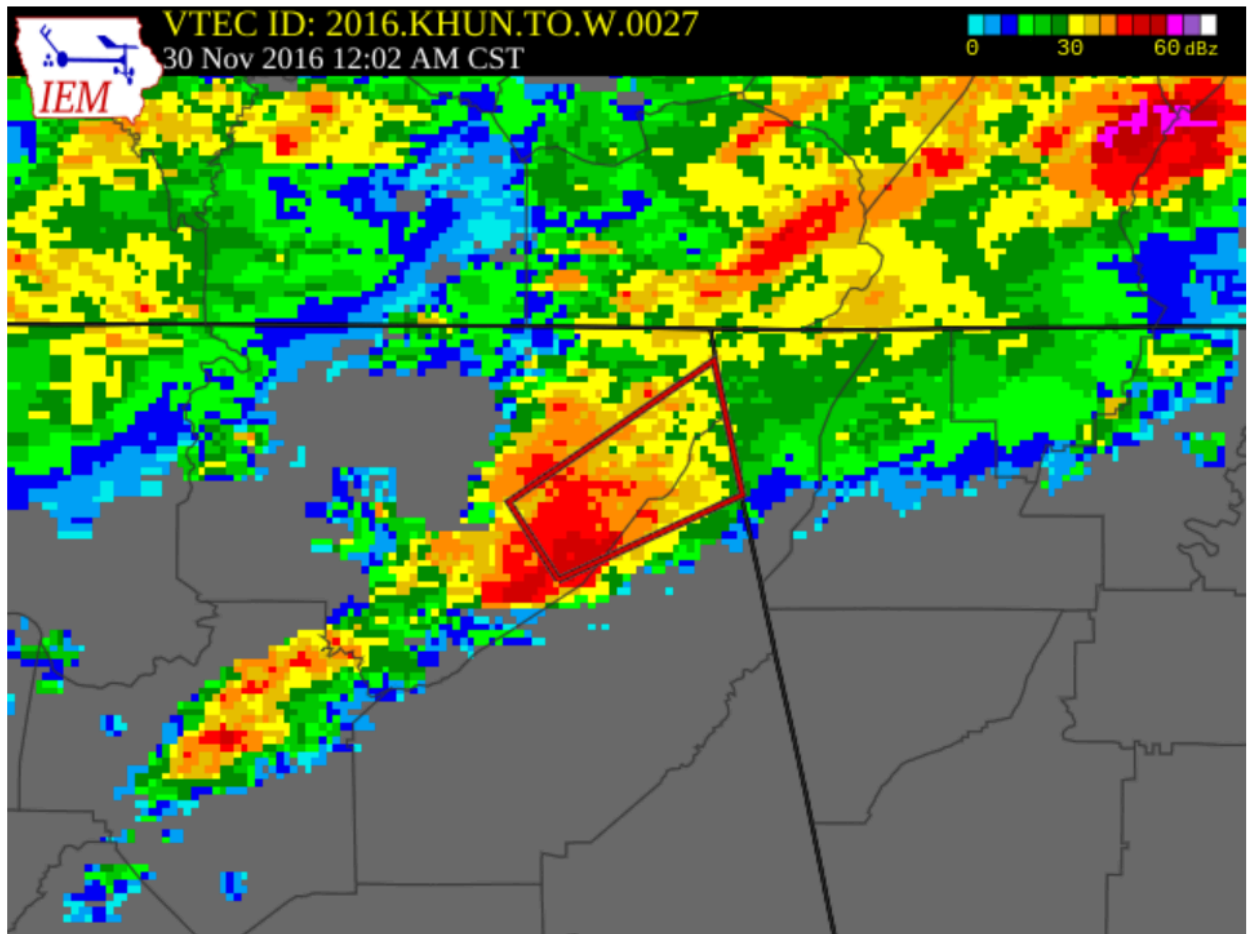


Figure 3.60: The tornado warning associated with the Rosalie/Ider tornado. Courtesy of the Iowa Environmental Mesonet.

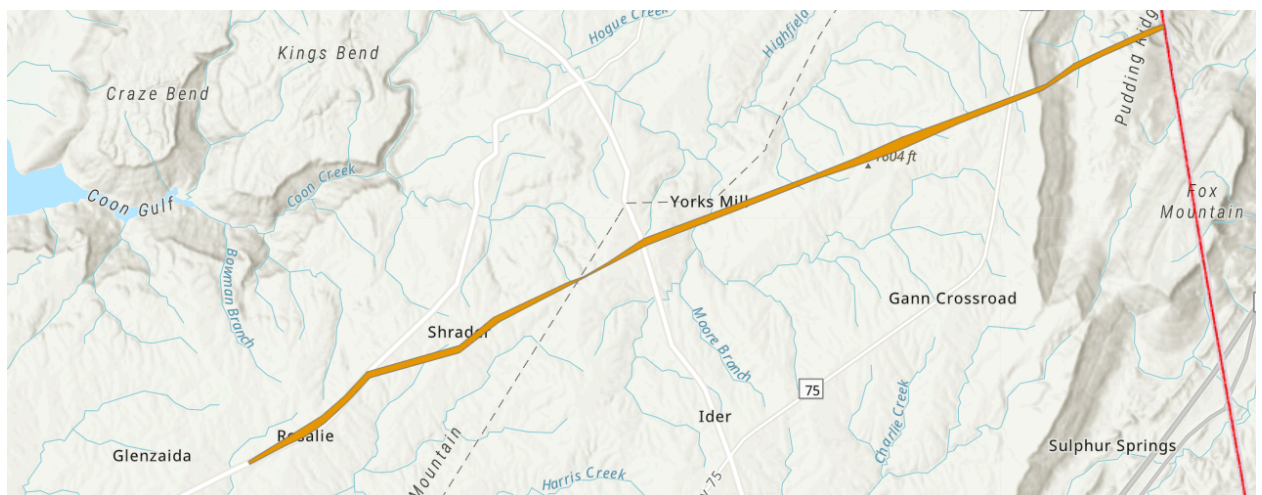


Figure 3.61: The track of the Rosalie/Ider tornado. Courtesy of NOAA.

Similar to the December 10, 2021 event, this event involved storms that tracked far outside of the maximum threshold area. While the outlook contours were elongated towards the northeast likely to capture this movement, the direction of storm motion appears to have been slightly more eastward than expected, which caused the resulting severe weather reports at the end of the storm tracks to occur within the Marginal and General Thunderstorm contours rather than the Slight. Additionally, reports of tornadic storms in particular began on the eastern edge of the Moderate contour rather than in the center, which meant that fewer reports were captured overall. The Moderate contour was also relatively small in area. As discussed in Chapter 2, smaller Moderate contours are associated with a larger proportion of tornado reports occurring outside of the maximum threshold area. If the Moderate contour had been extended northeastward, then it undoubtedly would have captured a larger number of reports.

This storm caused three deaths and ten reported injuries (NWS Huntsville). All three deaths occurred in the same mobile home in a region of EF-2 damage (NWS Huntsville). Extensive damage to houses, mobile homes, and commercial buildings was reported (NWS Huntsville). This included a commercial daycare center where seven of the ten reported injuries occurred, the destruction of which led to the EF-3 designation for this event (NWS Huntsville).

3.5 Summary

From these four cases stem multiple explanations for the occurrence of tornado reports outside of the maximum threshold area. In the first event, December 10th, 2021, the storms that initially formed within the maximum threshold area moved outside of that area over time, while additional, more broadly scattered reports occurred just north of the maximum threshold area. During the second event, March 28th, 2022, the forecasters correctly predicted storm formation

in Iowa, however, the storms produced tornadoes earlier and farther westward than expected. In addition, the Jonesboro tornado formed from an unusually strong pseudo-single-cell within a QLCS. Forecasters for the third event, July 7th, 2016, had to contend with a large degree of uncertainty and model inconsistencies due to a relatively messy environment and shortwave-based setup. Finally, the fourth event, November 29th, 2016, had storms form within the maximum contour, but then maintain strength and track outside of the area.

Additionally, it appears that the general focus of the maximum threshold contour placement is the site of most likely storm initiation, rather than the overall area that storms could impact, at least for events in which long-tracked storms occur, such as the December 10th and November 29th events. In these cases, the initial tornado reports for the long-track storms were captured in the maximum threshold areas, however, the later reports occurred in lower-threshold areas. This could either be a deliberate choice made by SPC forecasters or an unintentional artefact of the Categorical Outlook creation process. Overall, there is no one explanation for the occurrence of reports outside of the maximum threshold area, rather, multiple factors, such as model uncertainty, difficult-to-forecast environments, and long-track storms, seem to each play a role.

Chapter 4: A Survey-Based Investigation of the Inverse Bullseye Effect

4.1 Survey Data and Methods

The Severe Weather and Society Survey is a nationally representative annual online survey created by the Institute for Public Policy Research and Analysis (IPPRA) to gather data about how the US public interacts with severe weather hazards and products (e.g. tornado watches and warnings). The 2025 edition of the Severe Weather and Society Survey (WX25), the ninth of this series of surveys, was fielded from October 20-31, 2025 and included 1188 participants ages 18 and over (Krocak et al. 2026). The breakdown of participant demographics is shown in Figure 4.1.

Table 1: Demographic Representativeness of WX25 Respondents		
	U.S. Adult Population* (%)	Participants (%)
Gender		
Female	51.0	52.4
Male	49.0	47.6
Age		
18 to 29	20.1	13.1
30 to 49	33.8	32.2
50 to 64	23.2	27.8
65 and up	22.9	26.9
Education		
HS or less	37.3	29.4
Some college/2-yr degree	28.5	28.2
4-yr/post-graduate degree	34.2	42.4
Race/Ethnicity		
White	59.2	65.0
Black or African American	11.6	9.9
Hispanic	18.2	17.2
Other Race	11.0	7.9
Income		
<\$50,000	25.9	24.9
>\$50,000	74.1	75.1
NWS Region		
Eastern	31.4	33.5
Southern	27.8	23.2
Central	20.3	22.2
Western	20.5	21.0

Figure 4.1: The demographic table from the 2025 edition of the Severe Weather and Society Survey (Krocak et al. 2026).

Similar to the analysis of SPC Storm Reports and Convective Outlooks, this study focuses on the Day 1 Categorical Outlook, which comprises a set of six questions of the 188 posed in WX25. To begin this set of questions, participants were shown an example of an SPC Public Severe Weather Outlook (a Categorical Outlook that has been edited to be more regionally specific and user-friendly for a general audience) (Figure 4.2).

The outlook map for this graphic and the following graphics were created using a Python script (courtesy of Sean Ernst), which combines archived SPC Categorical Convective Outlook shapefiles and a map of the US to generate SPC-style outlook maps. This script was modified to more closely mimic the public version of the outlook with the addition of city names and locations (Simplemaps 2025), adjustments to the threshold legend and colors, and a “zoomed-in” regional scope. These maps were then added to a PowerPoint template designed to mimic an SPC social media post.

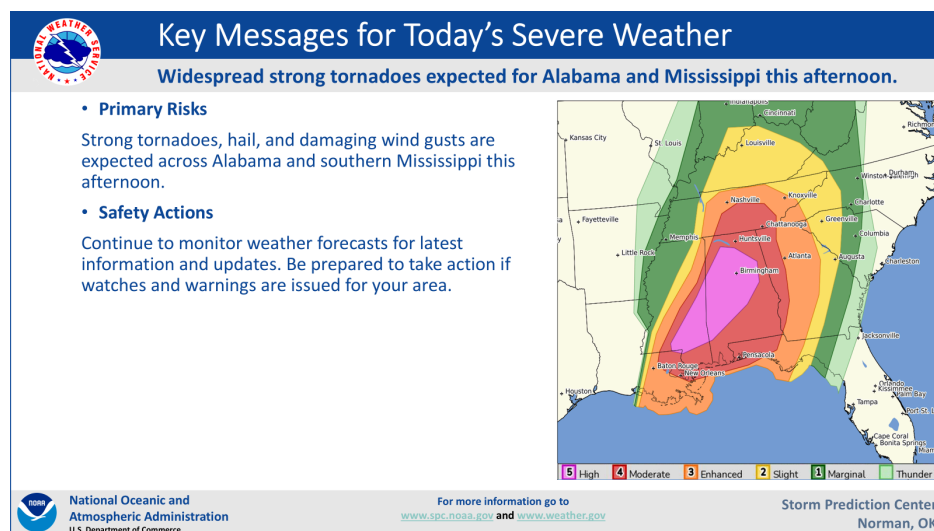


Figure 4.2: The first graphic shown to participants in the SPC Outlook section of WX25.

On the same page, participants were asked to indicate whether they had previously seen an SPC Outlook. This question was used to determine participants' prior knowledge of and experience with SPC Convective Outlooks. Participants were also asked to indicate their level of confidence in understanding the graphic on a 1-5 Likert-style scale, with 1 indicating “Not at all confident” and 5 indicating “Extremely confident.” This question was used to understand participants' perceived confidence in their ability to accurately read and understand the graphic.

Participants then clicked to the next page of the survey, which contained a new Convective Outlook graphic in the same style as the first. The new graphic seen by participants was one of six randomly selected graphics based on the 16:30 UTC December 10, 2021 SPC Categorical Convective Outlook (Storm Prediction Center 2026a). This issuance was chosen as it is an example of an event in which significant severe weather occurred outside of the maximum threshold area. On each graphic, the location of Edwardsville, IL was marked with a star and the letter “A.” Participants were asked to imagine that they were at location “A” during the time indicated by the graphic. Edwardsville was chosen as the location of interest due to its location in the Enhanced contour on all versions of the map and the fact that a tornadic storm impacted the area on December 10, 2021.

To determine the effect of being in the highest or not-highest threshold in the graphic on participants’ risk perceptions, each graphic depicted either an Enhanced risk as the highest threshold or a Moderate risk as the highest threshold. To determine the effect of a reminder sentence on risk perceptions, one of three options (no reminder, verbal, or numeric) was included in the text of the graphic. Examples of these graphics can be seen in Figure 4.3.



Figure 4.3: The six randomized graphics shown to participants: Enhanced and Moderate graphics with no reminder (a., b.), Enhanced and Moderate graphics with a verbal reminder (c., d.), Enhanced and Moderate graphics with numeric reminder (e., f.).

On the same page as the new graphics, participants were shown five additional questions. The first question asked participants to indicate the probability from 0-100% in 10% increments that severe weather (tornadoes, strong winds, or hail) would impact their location using a dropdown menu. This question was used to gain a numerical understanding of how participants

perceived their risk. Secondly, participants were asked to indicate the probability that severe weather would impact their location on a 1-5 Likert-style question, with 1 being “Very unlikely to experience severe weather” and 5 being “Very likely to experience severe weather.” This question gave insight into how participants thought about their risk in a verbal sense. Together, these first two questions allowed for a comparison between participants’ numerical sense of probability and verbal sense of probability (e.g. a participant might indicate a “61-70%” chance numerically and “Very likely...” verbally).

The third question asked participants to indicate the level of significance they believed the impacts from the potential severe weather would be for Location A on a 1-5 scale, with 1 being “Not at all significant” and 5 being “Extremely significant.” Similarly, the fourth question asked participants to indicate their level of concern about severe weather occurring at their location on a scale of 1-5, with 1 being “Not at all concerned” and 5 being “Extremely concerned.” These questions were intended to allow for a more nuanced view of participants’ risk perceptions, as one participant might believe that severe weather is highly likely, but might not be concerned about it because they perceive the impacts to be of little significance, while another might believe that severe weather is not likely, but may still be very concerned about the possibility that it will occur because they perceive the potential impacts to be highly significant.

Table 4.1: The survey questions from WX26 that were included in this study.

Questions	Response Options
-----------	------------------

co_prev_exp: Have you ever seen a Convective Outlook before?	0 - No 1 - Yes 2 - Maybe
co_conf_ab: How confident are you in your ability to understand the Convective Outlook?	1 - Not at all confident 2 - Slightly confident 3 - Moderately confident 4 - Very confident 5 - Extremely confident
co_num_prob: Based on this Convective Outlook, what is the probability that Location A will experience severe weather?	Dropdown list of 0-100% likelihoods in 10% intervals
co_verbal_prob: Based on this Convective Outlook would you say that Location A is...	1 - Not at all likely to experience severe weather 2 - Not very likely to experience severe weather 3 - Somewhat likely as not to experience severe weather 4 - Very likely to experience severe weather 5 - Extremely likely to experience severe weather

co_verbal_sig: If Location A were to experience severe weather, how significant do you think the impact might be?	1 - Not at all significant 2 - Not very significant 3 - Somewhat significant 4 - Very significant 5 - Extremely significant
co_concern: Based on this Convective Outlook, how concerned are you about severe weather occurring at Location A?	1 - Not at all concerned 2 - Not very concerned 3 - Somewhat concerned 4 - Very concerned

4.2 Survey Analysis

The first phase of analysis focused on determining whether a difference in perceived numeric likelihood of severe weather existed between participants who saw the Enhanced-as-maximum map compared to the Moderate-as-maximum map when no reminder was given (i.e. whether the Inverse Bullseye Effect was present in this scenario). Using R, participants who were not shown a reminder were selected from the survey dataset and grouped by the type of map they were shown. Participants who chose not to answer the numeric likelihood question were excluded from this phase of analysis. This process resulted in a total of 367 participants in the “No Reminder” group, 184 of whom saw the Enhanced-as-maximum map, and 183 of whom saw the Moderate-as-maximum map. From there, the proportion of

participants within each group who selected each of the 10 numeric answer choices was calculated. The results of this process are depicted in Figure 4.4 below.

The second phase of analysis was identical to the first, but focused on the verbal probability question. Of the 391 “No Reminder” participants who chose to answer the verbal probability question, 193 saw the Enhanced-as-maximum version of the map, while 198 saw the Moderate-as-maximum version. The results of this analysis can be seen in Figure 4.5 below.

The third phase of analysis focused on the effect, or lack thereof, of including the verbal and numeric reminders on participants’ perceived numeric likelihood. As before, participants were grouped based on the map version they saw, however, in this phase participants were also grouped by the type of reminder (“No Reminder”, “Verbal Reminder”, or “Numeric Reminder”) they received. In total, 1120 participants answered the numeric likelihood question, the breakdown of which can be seen in Table 4.2. The means and standard error at the 99% level were calculated for each of the six groups using R, and are shown below in Figure 4.6. Additionally, an independent 2-sample t-test was performed to determine the statistical significance of the difference between the means under each of the reminder types.

The fourth phase of analysis was identical to the third, but with a focus on the verbal likelihood question. A total of 1178 participants responded to this question, the breakdown for which is shown in Table 4.2. As before, the means and standard errors at the 99% level were calculated using R, and are shown in Figure 4.7 below.

The fifth and sixth phases were the same as the third and fourth, but with a focus on the Significance and Concern questions, which had 1178 and 1182 participants (Table 4.2), respectively. As with the previous phases, results from this analysis are presented in Figures 4.8 and 4.9.

Table 4.2: The number of participants within each treatment group (left side) for each question of interest (top).

Treatment	Number of Participants- Numeric Question	Number of Participants- Verbal Question	Number of Participants- Significance Question	Number of Participants- Concern Question
Enhanced, No Reminder	189	197	198	198
Moderate, No Reminder	182	199	200	199
Enhanced, Verbal Reminder	195	199	199	199
Moderate, Verbal Reminder	183	191	191	191
Enhanced, Numeric Reminder	177	189	188	190
Moderate, Numeric Reminder	194	203	202	205
Total	1120	1178	1178	1182

4.3 Survey Results

Figure 4.4 shows the proportion of respondents in the “No Reminder” group, broken down by the highest threshold shown on the map, who selected each of the 10 numeric probability choices. From this graph, it is apparent that a higher percentage (2.14%) of participants who saw the Moderate threshold on the map selected “0-10%” than those who saw only the Enhanced threshold (1.12%) on the map. Additionally, a much higher percentage (18.23%) of respondents who saw the Enhanced threshold as the maximum selected “91-100%” compared to those who saw the Moderate threshold (3.49%).

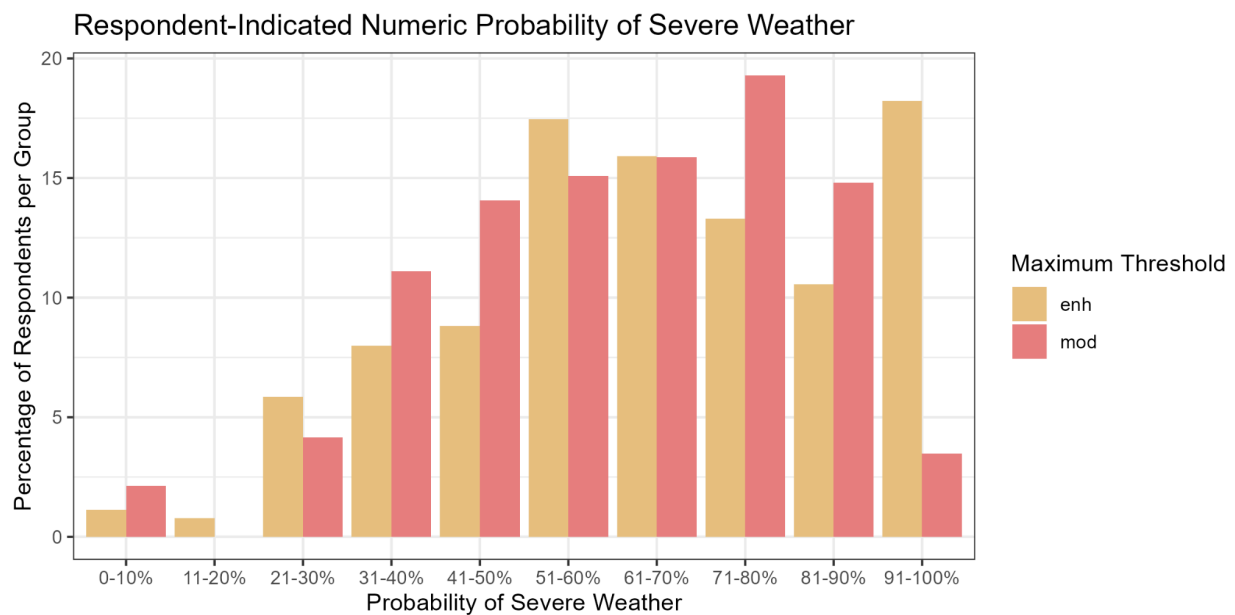


Figure 4.4: A bar graph of the proportion of respondents who did not see a reminder and who saw Enhanced as the maximum threshold (orange) or Moderate as the maximum threshold (red) by numeric probability selection.

Figure 4.5 shows a similar pattern occurring for the selection of verbal probabilities. In this case, only 0.52% of respondents who saw Enhanced as the highest threshold selected “Not at all likely” while 2.15% of respondents in the Moderate-as-maximum group selected that option. On the other end of the scale, 19.25% of the Enhanced-as-maximum group believed that severe weather was “Extremely likely” to occur at Location A, while only 6.91% of those who saw the Moderate threshold selected this option.

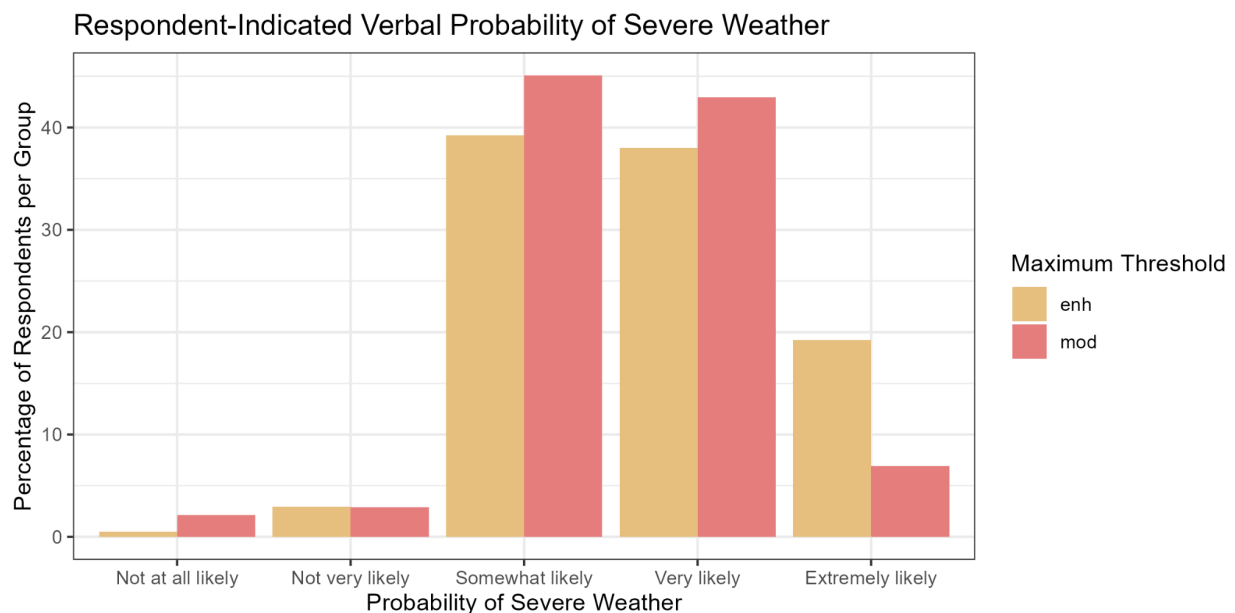


Figure 4.5: A bar graph of the proportion of respondents who did not see a reminder and who saw Enhanced as the maximum threshold (orange) or Moderate as the maximum threshold (red) by verbal probability selection.

Figure 4.6 includes the numeric probability question results from all participants broken down by the type of reminder shown (No Reminder, Verbal Reminder, and Numeric Reminder) and by the maximum threshold shown (Enhanced or Moderate). The mean answer choice of each

group is represented as a point, and the standard error at the 99% level is represented as the whiskers. In the first panel of Figure 4.6, it can be seen that the mean answer choice for those who did not see a reminder sentence and only saw Enhanced as the maximum threshold was 6.96 on the 10-point answer list, while the mean answer choice for those without a reminder but with Moderate as the maximum threshold was 6.53, indicating a slight deficit (-0.43) in mean likelihood judgement between the two groups. This difference between the means was found to be significant to a 90% confidence level ($p = 0.072$) using an independent 2-sample t-test. The deficit between means increased to -0.54 when the verbal reminder was introduced, as the mean likelihood judgement for the Enhanced-as-maximum group in this case decreased slightly to 6.85 and the mean likelihood judgement for the Moderate-as-maximum group decreased to 6.31. The difference in means was found to be significant at a 95% level ($p = 0.027$). The numeric reminder caused a more substantial change, as the mean likelihood judgement in the Moderate-as-maximum group (6.74) was higher (by 0.18) than that of the Enhanced-as-maximum group (6.56). The difference between means was not significant in this case ($p = 0.44$). It is worth noting that all of these mean likelihood judgement values fell between answer choice 6 (“51-60%”) and answer choice 7 (“61-70%”) on the survey questionnaire.

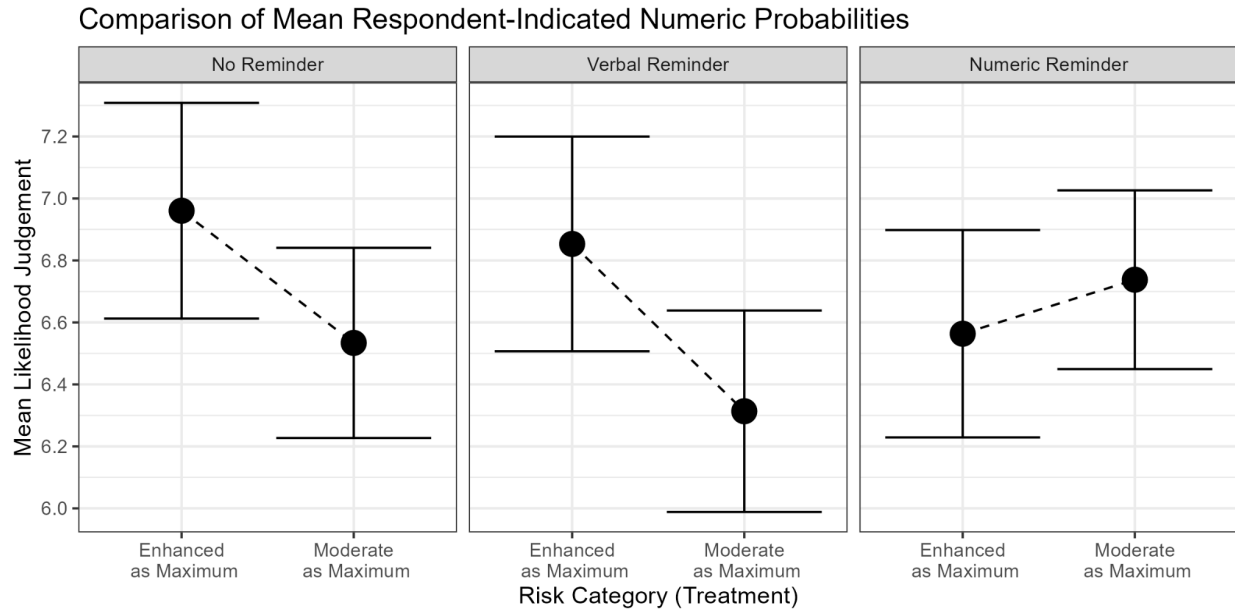


Figure 4.6: The mean answer choices for the numeric probability question for participants who saw No Reminder, a Verbal Reminder, or a Numeric Reminder and either Enhanced as the maximum threshold or Moderate as the maximum threshold.

Figure 4.7 shows the same participant stratifications as above for the verbal probabilities question. When no reminder was shown, the mean likelihood judgement for the Enhanced-as-maximum group was 3.73 on the 5-point answer list, while the mean likelihood judgement for the Moderate-as-maximum group was 3.50, indicating a deficit of -0.23 between the two groups. This difference in means was found to be significant at a 99% confidence level ($p = 0.0073$). When a verbal reminder was shown, the mean likelihood judgement was 3.67 for the Enhanced-as-maximum group, but 3.54 for the Moderate-as-maximum group, resulting in a -0.13 deficit, which was not significant ($p = 0.17$). Finally, when a numeric reminder was provided, the mean likelihood judgement was 3.65 for the Enhanced-as-maximum group and 3.56 for the Moderate-as-maximum group, a -0.09 deficit, which was also not significant ($p =$

0.35). Just as before, it is worth noting that all mean values shown in Figure 4.7 fell between two answer options: 3: “Somewhat likely” and 4: “Very likely.”

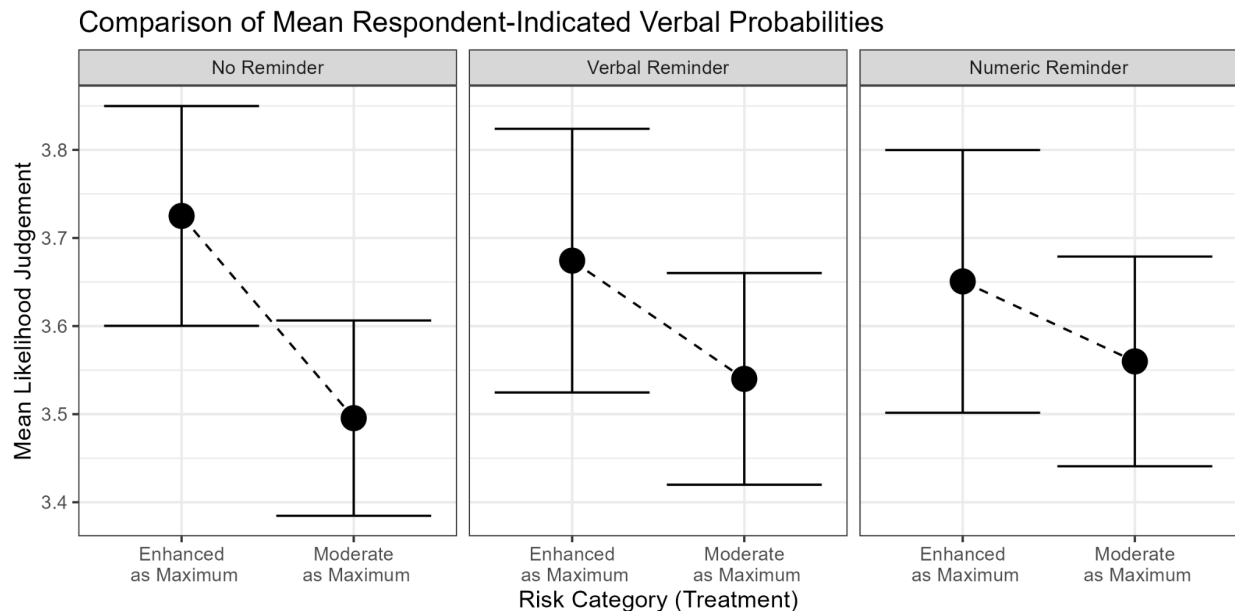


Figure 4.7: The mean answer choices for the verbal probability question for participants who saw No Reminder, a Verbal Reminder, or a Numeric Reminder and either Enhanced as the maximum threshold or Moderate as the maximum threshold.

Figure 4.8 shows the mean significance of severity selected by each group of participants. In all cases, the significance of potential severe weather at Location A was rated higher when Enhanced was shown alone, compared to when a Moderate contour was included. Under the verbal reminder conditions, the mean significance rating of participants who saw Enhanced as the maximum threshold was higher than under the “No Reminder” condition (3.54 compared to 3.47), but the significance perceptions of those who saw Moderate as the maximum were lower (3.32 compared to 3.38). The numeric reminder group reported higher mean significance

perceptions overall (3.55 for Enhanced-as-maximum, 3.48 for Moderate-as-maximum). The difference in means within reminder types was not found to be significant under the “No Reminder” or “Numeric Reminder” conditions, but was significant at the 95% level under the verbal condition ($p = 0.012$).

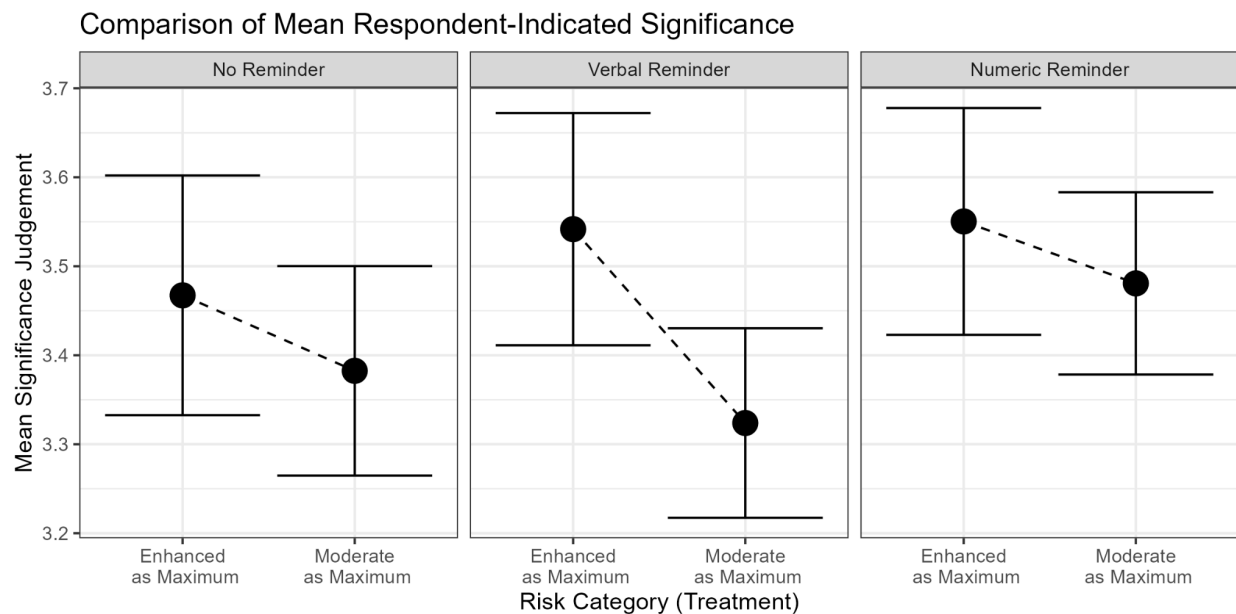


Figure 4.8: The mean answer choices for the significance question for participants who saw No Reminder, a Verbal Reminder, or a Numeric Reminder and either Enhanced as the maximum threshold or Moderate as the maximum threshold.

Similar to the significance results, the mean level of concern was higher among participants who saw Enhanced as the maximum threshold compared to those who saw Moderate as the maximum (Figure 4.9). However, these differences were quite small across the board. Participants who saw no reminder and Enhanced as the maximum threshold had a mean concern level of 3.49, while those who saw no reminder and Moderate as the maximum reported a mean concern level of 3.46, a difference of 0.03 which was not statistically significant. The verbal

reminder group had the largest difference, with mean concern levels of 3.52 and 3.40 for the Enhanced and Moderate groups, respectively, which resulted in a difference of 0.12 that was also not statistically significant. As with the significance question, mean concern levels were highest among the numeric reminder group for both those who saw Enhanced only (3.57) and those who saw Moderate as the highest threshold (3.54). Again, this difference (0.03) was not found to be statistically significant.

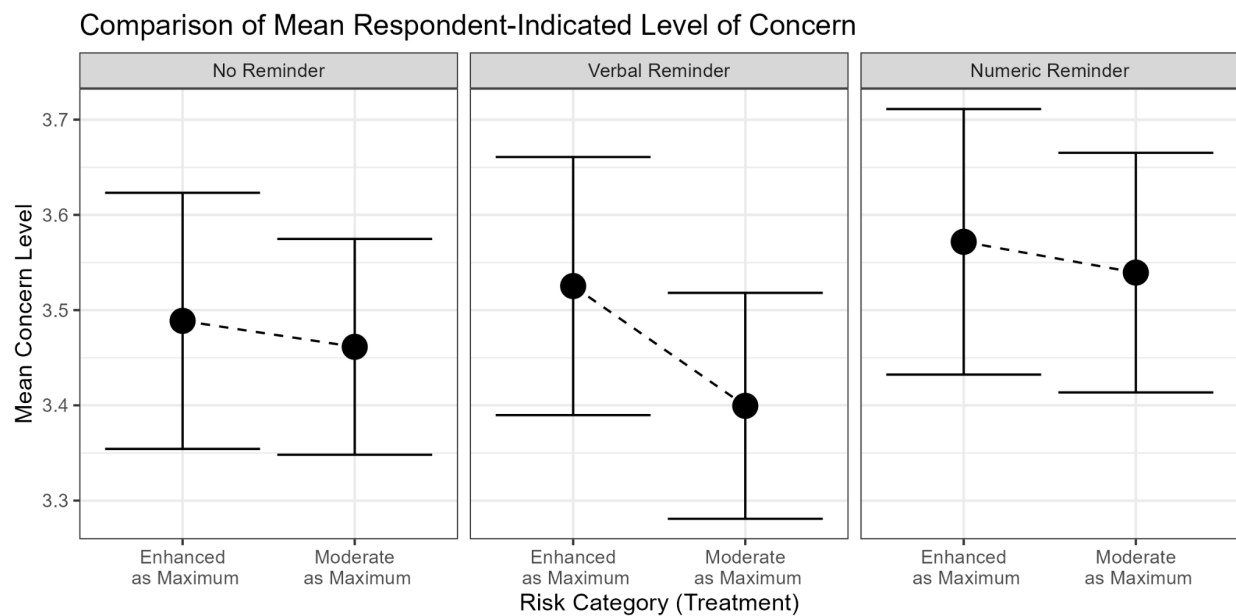


Figure 4.9: The mean answer choices for the concern question for participants who saw No Reminder, a Verbal Reminder, or a Numeric Reminder and either Enhanced as the maximum threshold or Moderate as the maximum threshold.

Chapter 5: Discussion

5.1 To what extent does the Inverse Bullseye Effect occur in practice?

The climatology work conducted in this study indicates that tornado reports not only occur outside of the maximum threshold area, but do so roughly 50% of the time. Reports of weak tornadoes (EF0 and EF1) occurred outside of the maximum threshold with more frequency than reports of strong tornadoes (EF2+). It is perhaps possible that weaker tornadoes are simply less predictable, especially in the outlook timeframe, than stronger storms. It is also possible that forecasters could be most concerned with the potential for significant tornadoes and therefore focus their efforts and maximum thresholds on regions where these storms are most likely.

A higher proportion of tornado reports fell outside of the maximum threshold area when the maximum threshold was caused at least in part by the tornado potential. Similar to the strong tornadoes, it is likely that forecasters may focus their efforts on predicting the location of tornadic storms on days when these storms are more likely to occur, and thus are able to capture a larger percentage of them within the maximum threshold area.

In addition, when stratified by region, outlooks with their centroids located in the southeast had generally lower proportions of both strong and weak tornado reports falling outside of their maximum threshold areas than the other regions. One possible influencing factor in this is the occurrence of tropical storm based tornadoes in the region. A breakdown of proportion of tornadoes outside of the maximum threshold area by region and month revealed that a higher proportion of tornado reports in the southeast fall within the maximum threshold area during the months of August and September, which aligns with the peak in the Edwards et al. (2012) climatology of tropical cyclone-related tornadic events. However, it should be noted

that only 16 outlook issuances were present for the southeast during these months, so further study would be needed to investigate this possible link.

For most threshold area stratifications, tornado reports occurred outside of the maximum threshold area more frequently when the maximum threshold area was small. This is likely due to larger thresholds by definition covering a larger land area, meaning that they are able to capture more widely dispersed tornadoes than a smaller threshold area.

5.2 Does the Inverse Bullseye Effect empirically influence risk perceptions?

Overarchingly, participants who did not receive a reminder and who were shown the version of the Categorical Convective Outlook with the Moderate risk as the maximum threshold selected lower likelihood judgements than those who saw only the Enhanced risk as the maximum threshold, indicating that the Inverse Bullseye Effect had an impact on likelihood judgements.

One potential influencing factor for the presence of the Inverse Bullseye Effect could be the impact of the discrete demarcation of the Enhanced and Moderate areas, which may have caused the impression that severe weather would be contained within the Moderate area. Previous work has indicated that state borders can impact people's perceptions of the risk posed by a hazard occurring in another state, causing decreased risk perceptions for out-of-state locations compared to in-state despite the hazard being located equidistantly between them (Mishra and Mishra 2010). This is reflected in Reed's 2024 study on the use of discrete versus continuous color scales in the SPC probabilistic hail outlook, which found that survey participants who were shown that their location was just outside the highest risk of hail were more likely to rate their risk of hail higher when presented with a continuous graphic compared

to a discrete graphic similar to the current Categorical Convective Outlook. Thus, it is possible that the demarcation between the Moderate and Enhanced contours had some impact on viewer's likelihood judgements.

Another potential factor in the presence of the Inverse Bullseye Effect is the idea that the inclusion of a higher threshold on the map may signal to viewers that forecasters are more confident in their forecast for that region compared to lower threshold areas. Previous work has indicated that higher-probability forecasts are perceived as being more accurate and as being created by a more confident forecaster (Bagchi and Ince 2015). In the case of this study, participants who saw Enhanced as the highest threshold on the map may have believed that the forecaster was most confident and accurate in in their region, while those who saw Moderate as the highest threshold may have believed that the forecaster was most confident and accurate in forecasting for the the Moderate risk area and less so when forecasting for the Enhanced.

5.3 What, if anything, can be done to reduce the Inverse Bullseye Effect?

The inclusion of a verbal reminder had little effect on either verbal or numeric likelihood judgements. This may have been in part due to the use of “some possibility” in this version of the reminder sentence. Previous work has found that words of estimative probability are not necessarily associated with a specific numeric likelihood and therefore one person may associate a term with a different numeric probability than another (Lenhardt 2020; Beyth-Marom 1982). Thus, it is possible that the phrase “some possibility” could have been interpreted as a relatively high likelihood by some respondents and a relatively low likelihood by others, rendering it inadequate for reducing the impact of the Inverse Bullseye Effect.

In light of the unreliability of words of estimative probability, Ripberger et al. (2022) recommended the use of numeric probabilities either alongside or in place of verbal probabilities. Results from respondents who received the numeric reminder indicated that it had a larger effect than the verbal reminder on mean verbal and numeric likelihood judgements for those who saw Moderate as the highest threshold, but caused a decrease in likelihood judgements for those who saw the Enhanced contour as the maximum. It is possible that participants who had Enhanced as the highest risk area saw the phrase “Historically, about 60% of severe weather reports occur outside of the area of highest risk” and interpreted it as meaning that their risk of severe weather was relatively low. Essentially, the numeric reminder could be helpful for those outside of the maximum threshold area, but it could also be detrimental to the risk perceptions of those within the maximum threshold area.

5.4 Implications

This work has found a disconnect between the reality of storm report distribution in relation to the the maximum threshold area, in which approximately 50% of tornado reports occur outside of this area, and the risk perceptions held by members of the public, who generally believe that their risk of severe weather is lower when a higher risk threshold than their own is present on the map, even when verbal reminders of risk are included. Additionally, while numeric reminders decreased the Inverse Bullseye Effect, they also caused lowered risk perceptions for those who were in the Enhanced-as-highest scenario.

These lowered risk perceptions could have a negative impact on an individual’s level of preparedness for severe weather outside of the maximum threshold area. Lindell and Perry (2012) indicate that risk perceptions are an important aspect of the protective action

decision-making process. An individual who believes that their risk of severe weather is relatively low may intentionally or unintentionally fail to take proper precautions, such as paying extra attention to the weather, cancelling or rescheduling plans, or gathering necessary supplies. For example, someone hosting an outdoor event may see that their location is outside of the maximum threshold area on the Categorical Convective Outlook, believe that their risk of severe weather is relatively minimal, and fail to adjust their plans for the possibility of severe weather. This could leave them vulnerable to storms that form or move outside of the maximum threshold area, especially if they do not pay attention to or are unable to receive subsequent watches and warnings.

Chapter 6: Conclusions

6.1 Limitations

One potential limitation of this work is the use of SVRGIS point tornado reports as a proxy for actual tornado occurrence. While these reports have been reviewed by the SPC and the National Centers For Environmental Information, there is still the possibility for erroneous reporting (Carbin 2010). Additionally, tornadoes that occur in more heavily populated areas are more likely to be reported than those that occur in rural or unpopulated areas (Anderson et al. 2007; Elsner et al. 2013; Potvin et al. 2022). However, this discrepancy has decreased from the 1970s through the mid-2010s due to increasing reporting frequency in more rural areas (Elsner et al. 2013).

Another potential limiting factor to this work is the use of a nonprobability sample of a panel of online survey participants, who opted-in to taking the 2025 Severe Weather and Society Survey. It is possible that the participants who chose to complete this survey may be more interested in, and potentially more knowledgeable about, the weather. This means that participants taking this survey may, on average, have slightly more familiarity with the SPC Categorical Convective Outlook than a completely random sample.

Finally, due to the inclusion of the set of experiment questions used in this study within a preexisting survey, the number of questions, and thus the variety of outlook-reminder permutations that could be included, were necessarily limited. Thus, only the difference in perceptions between two risk levels (Enhanced and Moderate), and three reminder sentence variations (No Reminder, Verbal Reminder, and Numeric Reminder), were tested.

6.2 Future Work

This study brings forth several avenues for future exploration. The use of mapped contours to depict probabilistic information is not limited to the SPC Categorical Convective Outlook. The SPC itself issues categorical Fire Weather Outlooks that use contours to depict the risk of fire weather conditions on a three-point scale (Figure 6.1) (Storm Prediction Center 2026b). The Weather Prediction Center issues Excessive Rainfall Outlooks using nearly the same categorical levels and contour styles as both the Convective and Fire Weather outlooks (Figure 6.2) (Weather Prediction Center 2026). Also within the weather and climate space, the Climate Prediction Center issues long-term precipitation and temperature outlooks that use contours filled as diverging color scales to depict the probability of above- or below-normal precipitation and temperatures (Figures 6.3a and 6.3b) (Climate Prediction Center 2026a, b). Future work may be needed to fully understand the implications of the Inverse Bullseye Effect on these and similar probabilistic map styles.

As limited utility was found in the tested verbal and numeric reminders, future work may include additional exploration into methods to reduce the impact of the Inverse Bullseye Effect for those outside of the maximum threshold area, while maintaining heightened risk perceptions for those located within the area of maximum risk. These avenues may include additional tests of specific phrases that could be used, building off of the work contained within this study, or perhaps, additional testing of representations of risk using continuous scales, building off of Reed et al. 2024.

Storm Prediction Center Day 1 Fire Weather Outlook

Created: Fri Mar 14 06:08:02 UTC 2025

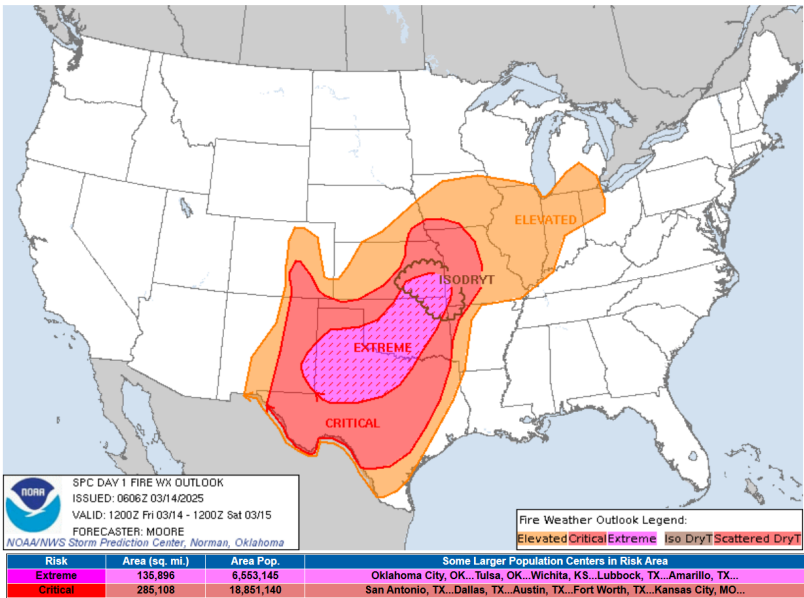


Figure 6.1: An example of a Fire Weather Outlook issued by the Storm Prediction Center.

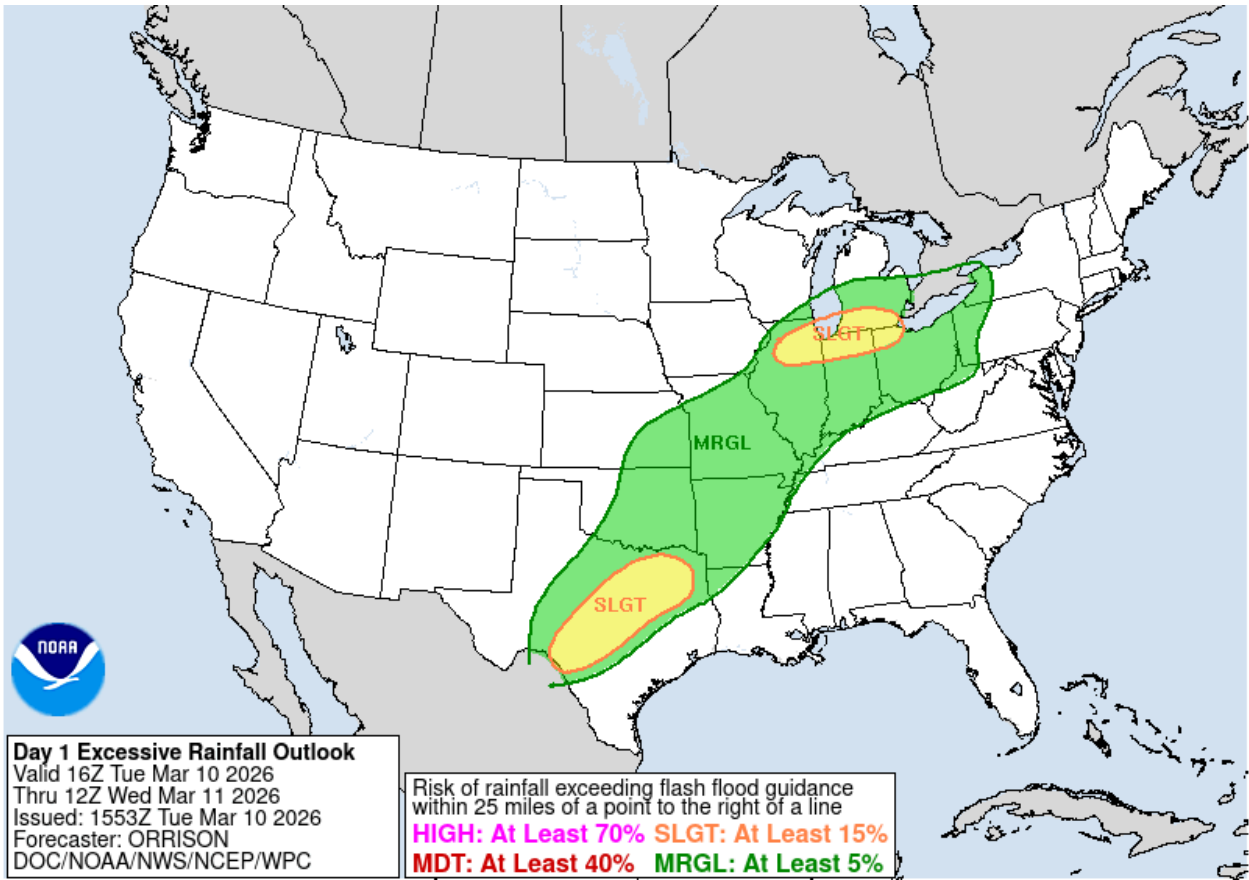


Figure 6.2: An example of an Excessive Rainfall Outlook issued by the Weather Prediction Center.

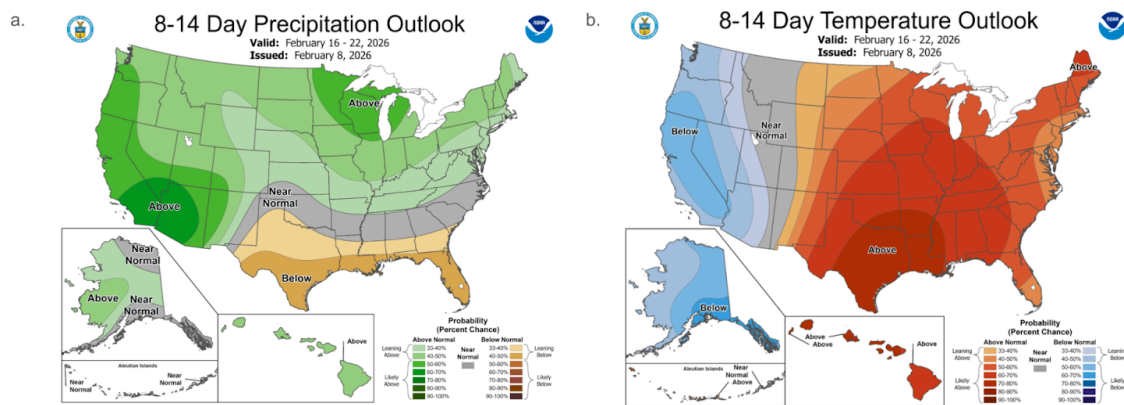


Figure 6.3: Examples of the Climate Prediction Center's Precipitation Outlook (a) and Temperature Outlook (b.).

6.3 Summary

This work sought to understand the implications of the Inverse Bullseye Effect for the SPC Categorical Convective Outlook through a climatology of 2000 UTC Day 1 outlooks, a series of case studies of incidents where a higher proportion of tornado reports fell outside of the maximum threshold area, and a survey-based investigation of the presence of the Inverse Bullseye Effect in interpretations of the outlook by members of the public and potential mitigation techniques. The key findings from this work include:

- The proportion of tornado reports outside of the maximum threshold area varies when stratified by maximum threshold level, region, season, and area of the maximum threshold.

- Generally, tornado reports are more likely to fall outside of the area of maximum risk when the reports are for weak (EF0 or EF1) tornadoes, when the maximum threshold level is high-end (Moderate or High), when the maximum threshold is not based on the tornado threat, and when the area of the maximum threshold is small.
- Additionally, tornado reports in the southeast are less likely to fall outside of the maximum threshold area than reports in other regions.
- The Inverse Bullseye Effect does empirically influence risk perception when no reminder is given.
 - Both numeric and verbal likelihood judgements are higher when participants are in the Enhanced region without Moderate on the map (when enhanced is the highest threshold present).
 - Both numeric and verbal likelihood judgements are lower if people are in the Enhanced region with Moderate on the map.
- The addition of reminders that reports can occur outside of the maximum threshold area has mixed impacts on these likelihood judgements.
 - Simply including a verbal reminder had minimal effects on both the numeric and verbal likelihood judgements.
 - The inclusion of a numeric reminder has a larger impact on likelihood judgements, however, they may negatively impact risk perceptions of the highest threshold.

Bibliography

Anderson, C. J., C. K. Winkle, Q. Zhou, and J. A. Royle, 2007: Population influences on tornado reports in the United States, *Wea. Forecasting*, **22**, 571-579, <https://doi.org/10.1175/WAF997.1>.

Bagchi, R. and E. Chandon Ince, 2015: Is a 70% forecast more accurate than a 30% forecast? How level of a forecast affects inferences about forecasts and forecasters. *Journal of Market Research*, **53**, 31-45, [10.1509/jmr.12.0526](https://doi.org/10.1509/jmr.12.0526).

Balžekienė, A., J. M. Echavarren, and A. Telešienė, 2024: The effect of proximity on risk perception: A systematic literature review. *Current Sociology*, **73**, 975-994, <https://doi.org/10.1177/00113921241250047>.

Beyth-Marom, R., 1982: How probable is probable? A numerical translation of verbal probability expressions. *Journal of Forecasting*, **1**, 257-269, <https://doi.org/10.1002/for.3980010305>.

Bitterman, A., M. J. Krocak, J. T. Ripberger, S. Ernst, J. E. Trujillo- Falcón, A. Gaviria Pabón, C. Silva, and H. Jenkins-Smith, 2023: Assessing public interpretation of original and linguist-suggested SPC risk categories in Spanish. *Wea. Forecasting*, **38**, 1095-1106, <https://doi.org/10.1175/WAF-D-22-0110.1>.

Brooks, H., C. A. Doswell III, X. Zhang, A. M. A. Chernokulsky, E. Tochimoto, B. Hanstrum, E.

De Lima Nascimento, D. M. L. Sills, B. Antonescu, and B. Barret, 2019: A century of progress in severe convective storm research and forecasting. *A Century of Progress in Atmospheric and Related Sciences: Celebrating the American Meteorological Society Centennial, Meteor. Monogr.*, No. 59, Amer. Meteor. Soc., 18.1-18.41, <https://doi.org/10.1175/AMSMONOGRAPHIS-D-18-0026.1>.

Carbin, G., 2010: SPC tornado, hail, and wind database format specification (for .csv output).

accessed 10 June 2025,

https://www.spc.noaa.gov/wcm/data/SPC_severe_database_description.pdf.

Climate Prediction Center, 2026a: 8-14 Day Precipitation Outlook. accessed 16 March 2026,

<https://www.cpc.ncep.noaa.gov/products/predictions/814day/814prcp.new.gif>.

Climate Prediction Center, 2026b: 8-14 Day Temperature Outlook. accessed 16 March 2026,

<https://www.cpc.ncep.noaa.gov/products/predictions/814day/814temp.new.gif>.

Corfidi, S. F., 1999: The birth and early years of the Storm Prediction Center. *Wea. Forecasting*,

14, 507-525, [https://doi.org/10.1175/1520-0434\(1999\)014<0507:TBAEYO>2.0.CO;2](https://doi.org/10.1175/1520-0434(1999)014<0507:TBAEYO>2.0.CO;2).

Edwards, R. A. R. Dean, R. L. Thompson, and B. T. Smith, 2012: Convective modes for

significant severe thunderstorms in the contiguous United States. Part III: Tropical

cyclone tornadoes. *Wea. Forecasting*, **27**, 1507-1519,
<https://doi.org/10.1175/WAF-D-11-00117.1>.

Edwards, R. and F. Otsby, 2024: Time Line of SELS and SPC. Storm Prediction Center, accessed 10 June 2025, <https://www.spc.noaa.gov/history/timeline.html>.

Elsner, J. B., L. E. Michaels, K. N. Scheitlin, and I. J. Elsner, 2013: The decreasing population bias in tornado reports across the Central Plains. *Wea. Climate Soc.*, **5**, 221-232,
<https://doi.org/10.1175/WCAS-D-12-00040.1>.

Ernst, S., J. Ripberger, M. J. Krocak, H. Jenkins-Smith, and C. Silva, 2021: Colorful language: Investigating public interpretation of the Storm Prediction Center Convective Outlook. *Wea. Forecasting*, **36**, 1785-1797, <https://doi.org/10.1175/WAF-D-21-0001.1>.

Ernst, S., B. J. Fellman, Z. Rosen, M. J. Krocak, I. L. Jirak, J. Ripberger, H. Jenkins-Smith, 2025: Investigating how NWS meteorologists, emergency managers, and the public interpret conditional intensity forecasts for severe weather. *Wea. Forecasting*, **40**, 507-524, <https://doi.org/10.1175/WAF-D-24-0109.1>.

Herman, G. R., E. R. Nielson, and R. S. Schumacher, 2018: Probabilistic verification of Storm Prediction Center convective Outlooks. *Wea. Forecasting*, **33**, 161-184,
<https://doi.org/10.1175/WAF-D-17-0104.1>.

Hitchens, N. M. and H. E. Brooks, 2012: Evaluation of the Storm Prediction Center's Day 1 Convective Outlooks. *Wea. Forecasting*, **27**, 1580-1585,
<https://doi.org/10.1175/WAF-D-12-00061.1>.

Hitchens N. M. and H. E. Brooks, 2014: Evaluation of the Storm Prediction Center's Convective Outlooks from Day 3 to Day 1. *Wea. Forecasting*, **29**, 1134-1142,
<https://doi.org/10.1175/WAF-D-13-00132.1>.

Hitchens, N. M. and H. E. Brooks, 2017: Determining criteria for missed events to evaluate significant severe convective outlooks. *Wea. Forecasting*, **32**, 1321-1328,
<https://doi.org/10.1175/WAF-D-16-0170.1>.

IEM, 2026a: SPC Convective and Fire Weather + WPC Excessive Rainfall Outlooks. accessed 5 April 2025, <https://mesonet.agron.iastate.edu/request/gis/outlooks.phtml>.

IEM, 2026b: NWS Watch / Warning / Advisory Search. accessed 1 June 2026,
<https://mesonet.agron.iastate.edu/vtec/search.php?mode=bypoint>.

Johnson, V. A., K. E. Klockow-Mcclain, R. A. Pepler, and A. M. Person, 2021: Tornado climatology and risk perception in Central Oklahoma. *Wea. Climate Soc.*, **13**, 743-751,
<https://doi.org/10.1175/WCAS-D-20-0137.1>.

Kellner, O. and D. Niyogi, 2014: Land surface heterogeneity signature in tornado climatology: an illustrative analysis over Indiana, 1950-2012. *Earth Interact.*, **18**, 1-32, <https://doi.org/10.1175/2013EI000548.1>.

Krocak, M. J., J. T. Ripberger, S. Ernst, C. L. Silva, and H. C. Jenkins-Smith, 2022: Exploring the differences in SPC Convective Outlook interpretation using categorical and numeric information, *Wea. Forecasting*, **37**, 303-311, <https://doi.org/10.1175/WAF-D-21-0123.1>.

Krocak, M., A. Bitteman, J. Ripberger, H. Jenkins-Smith, L. Harvey, B. Fellman, 2026: WX25. Harvard Dataverse. <https://doi.org/10.7910/DVN/NHERIH>.

Lenhardt, E. D., R. N. Cross, and M. J. Krocak, 2020: How likely is that chance of thunderstorms? A study of how National Weather Service forecast offices use Words of Estimative Probability and what they mean to the public. *Journal of Operational Meteorology*, **8**, 64-78, <https://doi.org/10.15191/nwajom.2020.0805>.

Lindell, M. K. and R. W. Perry, 2012; The protective action decision model: Theoretical modifications and additional evidence. *Risk Analysis*, **32**, 616-632, [10.1111/j.1539-6924.2011.01647.x](https://doi.org/10.1111/j.1539-6924.2011.01647.x).

Malloy, K. and M. K. Tippet, 2025: Forecasting U.S. tornado outbreak activity and associated environments in the Global Ensemble Forecast System (GEFS), *Wea. Forecasting*, **40**, 593-608, <https://doi.org/10.1175/WAF-D-24-0138.1>.

- Market, A., R. Griffin, K. Knupp, A. Molthan, and T. Coleman, 2019: A spatial analysis of land surface roughness heterogeneity and its relationship to the initiation of weather tornadoes, *Earth Interact.*, **23**, 1-28, <https://doi.org/10.1175/EI-D-18-0010.1>.
- Marshall, T. and G. Woodall, 2022: Damage survey of the Jonesboro Arkansas tornado: March 28, 2020. ResearchGate, Accessed 19 August 2025, https://www.researchgate.net/publication/365174723_Damage_survey_of_the_Jonesboro_Arkansas_tornado_March_28_2020.
- Mishra, A. and H. Mishra, 2010: Border bias: The belief that state borders can protect against disasters. *Psychological Science*, **21**, 1582-1586, <https://doi.org/10.1177/0956797610385950>.
- Murphy, A. H., 1993: What is a good forecast? An essay on the nature of goodness in weather forecasting. *Wea. Forecasting*, **8**, 281-293, [https://doi.org/10.1175/1520-0434\(1993\)008<0281:WIAGFA>2.0.CO;2](https://doi.org/10.1175/1520-0434(1993)008<0281:WIAGFA>2.0.CO;2).
- NCEI, 2026: Storm events database. accessed 1 June 2026, <https://www.ncei.noaa.gov/stormevents/>.
- NOAA, 2026: Damage assessment toolkit. accessed 1 June 2026, <https://apps.dat.noaa.gov/stormdamage/damageviewer/>.

NWS Huntsville, n.d.: November 29th and 30th severe weather/tornado outbreak. accessed 20 June 2026, https://www.weather.gov/hun/hunsur_2016-11-29#8.

NWS St. Louis, n.d.: December 10, 2021 tornado outbreak, accessed 12 August 2025, <https://storymaps.arcgis.com/stories/6c870871d11c4c009294bb1a840ea9ec>.

NWS Wichita, n.d.: July 7th tornadoes.... accessed 1 June 2026, <https://www.weather.gov/ict/July7thTornadoes>.

Palmer, A., 2021: Amazon drivers sought safety at warehouse as tornado hit but found only death and destruction. CNBC, Accessed 12 August 2025, <https://www.cnbc.com/2021/12/20/amazon-warehouse-in-illinois-hit-by-tornado-killing-6.html>.

Potvin, C. K., C. Broyles, P. S. Skinner, and H. Brooks, 2022: Improving estimates of U.S. tornado frequency by accounting for unreported and underrated tornadoes. *J. Appl. Meteor. Climatol.*, **61**, 909-930, <https://doi.org/10.1175/JAMC-D-21-0225.1>.

Reed, J., 2024: The effect of modifying the Storm Prediction Center Convective Outlook scale on perceived risk level. *Weather*, **79**, 280-284, <https://doi.org/10.1002/wea.4599>.

Ripberger, J., A. Bell, A. Fix, A. Forney, W. Livingston, C. Gaddie, C. Silva, and H.

Jenkins-Smith, 2022: Communicating probability information in weather forecasts:

Findings and recommendation from a living systematic review of the research and

literature, *Wea. Climate Soc.*, **14**, 481-498, <https://doi.org/10.1175/WCAS-D-21-0034.1>.

Simplemaps, 2025: United States cities database, accessed 15 September 2025,

<https://simplemaps.com/data/us-cities>.

Storm Prediction Center, n.d.: SPC products. accessed 30 September 2025,

<https://www.spc.noaa.gov/misc/about.html>.

Storm Prediction Center, 2025: SVRGIS. accessed 10 June 2025,

<https://www.spc.noaa.gov/gis/svrgis/>.

Storm Prediction Center, 2026a: SPC severe weather events archive. accessed 1 June 2026,

<https://www.spc.noaa.gov/exper/archive/events/>.

Storm Prediction Center, 2026b: Storm Prediction Center Day 1 Fire Weather Outlook. accessed
16 March 2026,

https://www.spc.noaa.gov/products/fire_wx/2025/250314_1200_fwdy1_print.html.

Weather Prediction Center, 2026: Excessive Rainfall Outlook. accessed 2 April 2026,

https://www.wpc.ncep.noaa.gov/archives/web_pages/ero/ero.shtml.

WFO Louisville, n.d.: Severe weather forecasting tip sheet: WFO Louisville,

https://www.weather.gov/media/lmk/soo/SvrWx_Fcstg_TipSheet.pdf.

Williams, C., A. Grundstein, and J. So, 2022: An examination of the SPC's Convective Outlook products and risk category system among members of the public. NA18OAR4590366, 55 pp., https://repository.library.noaa.gov/view/noaa/44639/noaa_44639_DS1.pdf.

Woods, B. and Genetti D., 2021: Sand Road residents remain positive amid destruction. The Edwardsville Intelligencer, Accessed 12 August 2025,

<https://www.theintelligencer.com/news/article/Sand-Road-residents-reflect-on-damage-by-tornado-16699095.php>.