The OMEGA Project

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Abstract

Since the inception of the Storm Prediction Center (SPC), a primary objective of the SPC has been to successfully forecast tornado outbreaks. Over the last couple of years, a research team has developed several tools to help forecasters to better anticipate tornado outbreaks. One tool is the Outlook Machine Assembling Algorithm (OMEGA). OMEGA is generated by combining the Significant Tornado Event Probability (STEP), and the Loken Tornado Probability guidance products. OMEGA generates outlook-like tornado probability contours. Verification results show that OMEGA performs best with events of ten or more tornadoes. OMEGA is particularly strong at forecasting tornado outbreaks and has been calibrated to successfully forecast High-Risk worthy events. A four-year back-test from mid 2020 to mid 2024 has been examined to show performance statistics for OMEGA relative to its ability to forecast High-Risk worthy tornado outbreaks. During that four-year period, there were 14 High-Risk worthy tornado outbreaks. For the 06Z Day 1 Outlook, the OMEGA algorithm successfully generated a 30 percent contour, or a High-Risk forecast, for 10 of the 14 (71.4%) High-Risk worthy events, while achieving a false alarm ratio of about 50 percent.

In addition, the OMEGA team has created an algorithm called Risk Impact Value (RIV). RIV is a number that estimates tornado event magnitude. RIV has been used to calibrate the tools created by the OMEGA team. One of these tools includes the Tornado Outbreak Indicator (TOI). TOI generates a probability for a High-Risk worthy event based on the translation speed, positioning, and strength of the 500 mb jet, and the Significant Tornado Parameter (STP). The OMEGA team has shown that as the 500 mb jet translation speed increases, the EF-scale, path length, total number and percent coverage for tornadoes all go up.

1. Introduction

The Storm Prediction Center (SPC) began in 1952 when the Severe Local Storms Unit (SELS) was created by the U.S. Government. During the first year of existence, three major tornado outbreaks occurred from late April to early June, 1953. From April 28 to May 2 of that year, tornadoes killed 36 people, including five F4 tornadoes in Texas, Alabama, Tennessee and Georgia. Then, from May 9 to May 11, a series of tornadoes killed 144 people, including an F5 at Waco, Texas, which killed 114. The outbreak of tornadoes was not done. From June 7 to 9, tornadoes killed 243 people. This included an F5 at Flint, Michigan that killed 116 and an F4 at Worcester, Massachusetts that killed 90. During the six-week period, 16 violent tornadoes (14 F4s and 2 F5s) killed 423 people.

This active period highlighted a strong need for convective outlooks to warn of these high impact events. In 1954, the unit moved to Kansas City, and in 1955, SELS began to issue convective outlooks. The unit became the National Severe Storms Forecast Center (NSSFC) in 1966, and in 1968 began issuing severe weather watches. On April 2, 1982, SPC issued the first High Risk and "Particularly Dangerous" tornado watch.

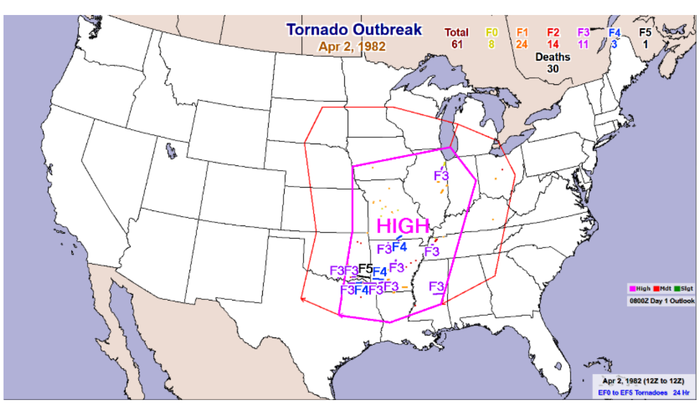


Figure 1. The first ever High Risk, issued on April 2, 1982 at 08Z by the NSSFC, which became the SPC in October of 1995. Inside the High Risk were 10 F3s, 3 F4s and 1 F5, which killed 30 people.

From 1982 to 2024, there have been 158 High Risk issuances. These forecasts, collectively with the National Weather Service warning system, national media network and local emergency managers, have no doubt had a strong impact on reducing the negative community impacts from these events.

The OMEGA project is focused on helping forecasters to better discriminate these high-end tornado outbreaks from events that are more moderate in nature. The three main objectives for the OMEGA Project are listed below.

Goals of the OMEGA Project

1) **Establish a way to compare tornado events based on the potential to negatively impact communities.**

   In response, Risk Impact Value (RIV) was developed.

2) **Find a better way to discriminate High Risk events from Moderate Risk events using developed tools.**

   In response, the OMEGA team developed a 500 mb jet analysis method, which was created to help forecasters differentiate between High Risk and Moderate Risk events. 500 mb jet translation speed is key.

3) **Develop and calibrate a tornado probability guidance product to help forecasters to anticipate High-Risk worthy tornado outbreaks (RIV >= 4) using identifiable thresholds (ex. 30+ contours).**

   In response, the Outlook Machine Ensembling Algorithm (OMEGA) tornado probability was developed by combining Loken with the Significant Tornado Event Probability (STEP). The contouring scheme has been calibrated to maximize performance.

2. Risk Impact Value (RIV)

Over the years, High Risk issuances by the SPC have primarily been for tornado outbreaks, although a few wind-driven Highs have been issued. There has been a lot of discussion on what constitutes a tornado-driven High Risk. There are various opinions on when a High Risk should be issued. One common theme is that a High-Risk worthy tornado outbreak should involve multiple long-track EF3 to EF5 tornadoes that make a substantial negative impact on one or more communities.

At the start of the OMEGA Project, Risk Impact Value (RIV) was envisioned to be a number based on tornado track data, estimating the negative community impact of a tornado outbreak.

It took 2 ½ years to create the RIV algorithm. First, the tornado data for each event was divided into several categories, including number of EF2s, EF3s, EF4s, EF5s, 25 to 49.9 mile tracks, 50 to 99.9 mile tracks, 100+ mile tracks, total tornadoes, deaths and tornado percent coverage. For each category, the tornado outbreak of record was found from 1950 to 2022. For example, when F5 tornadoes are considered, April 3, 1974 was the event of record with seven. For the EF5 category, a tornado event was ranked based on where it fell in the distribution. If the event had two EF5s, then the event's EF5 percentile was 28.6% (2 of 7) relative to the April 3, 1974 event. The percentiles for each category were added to get a number for each case. A weighting system was developed based how this number sorted the cases. After extensive evaluation, the weighting system favored high-end tornadoes (EF4s and EF5s) and tornado tracks over 25 miles in length. RIV was calculated for 217 cases from 2000 to 2022.

The first version of the algorithm calculated RIV for the conterminous area of tornado outbreak, in which no tornado could be separated by more than 175 statute miles. Once RIV was calculated for a subset of events, it was observed that RIV was relatively close to the number of fatalities for many events. This spurred an effort to calibrate RIV to the database average for event fatalities. The algorithm was fine-tuned to handle the exponential increase associated with events with RIV greater than 10. After the algorithm was complete, several forecasters were consulted for feedback. The forecasters suggested the ordering of events looked reasonable.

During RIV development, a value of 4 appeared to be a good threshold for High-Risk worthy events, based on what forecasters have communicated throughout the years. From 2000 to 2022, the annual return frequency for RIV >= 4 events associated with non-tropical systems was 3.3. This is close to the SPC historical High Risk issuance rate of 3.7 per year from 1982 to 2023. Issuing High Risks at a rate in line with the number of RIV >= 4 events per year seems reasonable, and the OMEGA team recommends that RIV = 4 be used as a threshold to verify whether a High Risk outlook is successful or not.

Table 1 shows five different ways an event can reach RIV = 4. An event with fewer tornadoes can have a higher RIV if those tornadoes include high-end and long-track tornadoes.

Risk Impact Value

High Risk Thresholds For Various Tornado Outbreaks

Total Tors	% Cov Tors	EF2s	EF3s	EF4s	EF5s	25-49 M Tracks	50-99 M Tracks	100+ M Tracks	Killer Tors	Deaths	RIV
10	30%	1	0	0	1	1	0	0	0	0	4.0
20	30%	8	1	1	0	1	0	0	0	0	4.0
30	40%	5	1	1	0	1	0	0	0	0	4.0
40	40%	5	2	0	0	1	0	0	0	0	4.0
50	50%	7	1	0	0	0	0	0	0	0	4.0

Table 1. Five hypothetical cases in which event RIV = 4.

Two daily RIV lists follow, showing the top 20 events from 2000 to 2024 and 1950 to 2024. Deaths are listed for each event.

RIV Top 20 Events (2000 to 2024)

Rank	Date	RIV	Deaths
1	April 27, 2011	252.8	316
2	April 12, 2020	93.2	30
3	March 31, 2023	85.4	23
4	May 24, 2011	82.0	18
5	February 5, 2008	69.7	57
6	December 10, 2021	49.1	89
7	May 4, 2003	46.4	38
8	March 12, 2006	38.3	8
9	April 26, 2011	38.2	3
10	November 17, 2013	35.3	8
11	March 2, 2012	33.8	41
12	November 10, 2002	23.3	32
13	June 17, 2010	13.5	3
14	April 28, 2014	12.8	15
15	May 25, 2024	12.2	14
16	May 22, 2011	11.2	159
17	April 14, 2012	10.1	6
17	April 16, 2011	10.1	26
18	April 15, 2011	9.9	8
19	April 26, 2024	9.5	1
20	April 24, 2010	9.5	10

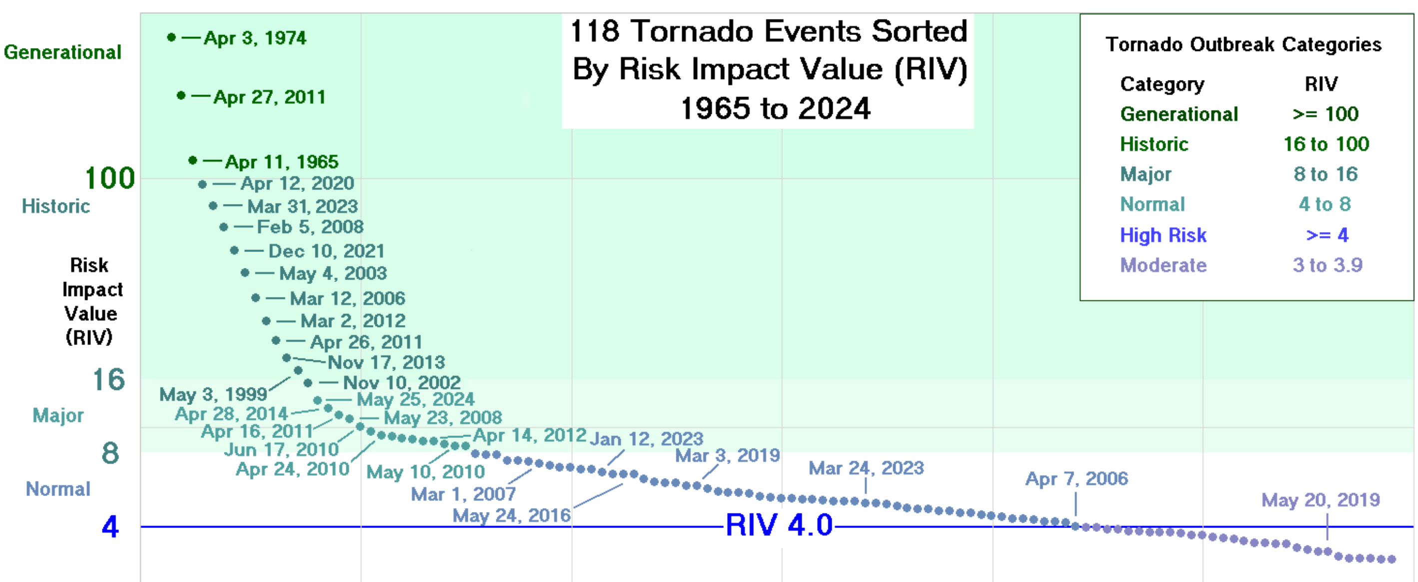


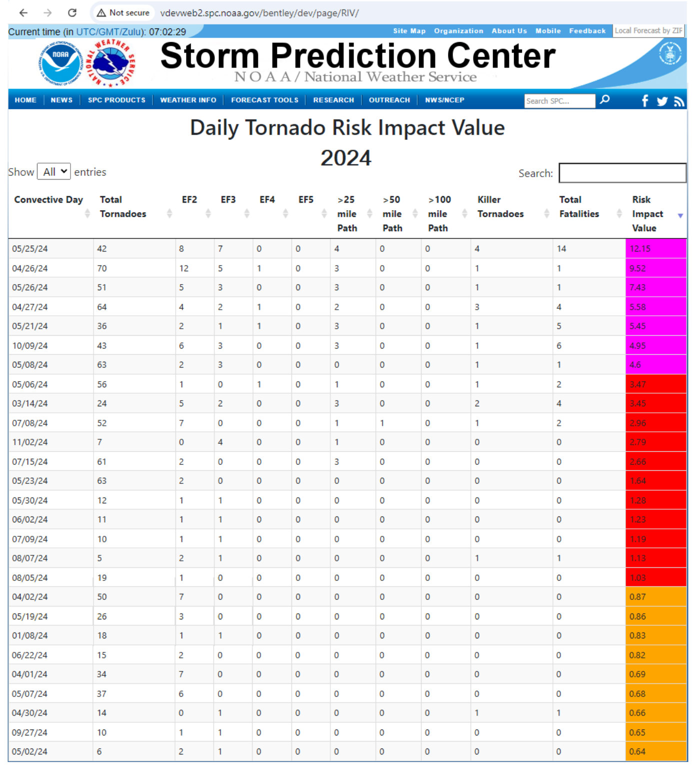
Figure 2. A graph shows the distribution of 118 tornado outbreaks and events selected from the years of 1965 to 2024, using the original RIV equation. The RIV 4.0 threshold in blue shows the low-end threshold for High Risk events.

Top 20 Events (1950 to 2024)

Rank	Date	RIV	Deaths
1	April 3, 1974	405.8	310
2	April 27, 2011	252.8	316
3	May 31, 1985	169.4	76
4	May 27, 1973	136.2	9
5	April 11, 1965	125.6	260
6	June 7, 1984	116.6	13
7	June 2, 1990	116.1	9
8	March 13, 1990	106.1	2
9	June 4, 1955	97.9	0
10	April 12, 2020	93.2	30
11	March 21, 1952	87.5	205
12	June 8, 1974	87.5	22
13	March 31, 2023	85.4	23
14	April 2, 1982	85.3	30
15	May 24, 2011	82.0	18
16	June 16, 1992	80.8	1
17	April 26, 1991	73.7	21
18	February 5, 2008	69.7	57
19	Nov. 22, 1992	68.2	10
20	May 20, 1957	68.0	44

After the initial version of RIV was complete, a webpage was developed to display a daily RIV. This version of RIV does not use the conterminous area of a tornado outbreak, but rather calculates the RIV over the entire continental United States on a daily basis. The webpage version of RIV tries to limit low population bias by increasing RIV when tornadoes occur in low population density areas. In those areas, RIV is increased the most when long-track tornadoes occur. The resultant RIV tries to estimate the total negative impact of a tornado event that occurs with a population density of 100 people per square mile.

An example of the RIV webpage (internally available at the SPC) is shown in Figure 3, with the year 2024 displayed. For this particular example, the days are sorted by the highest RIV for the year, which is the column furthest to the right and color coded. The pink color fill denotes RIV >= 4, which is for High-Risk worthy events. The red color fill denotes RIV 1.00 to 3.99, which is for Moderate Risk events. The orange color fill denotes RIV 0.36 to 0.99, which is for Enhanced Risk events. Information on RIV is available upon request including daily totals from 1950 to 2024.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Storm Prediction Center

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Daily Tornado Risk Impact Value

2024

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Convective Day	Total Tornadoes	EF2	EF3	EF4	EF5	>25 mile Path	>50 mile Path	>100 mile Path	Killer Tornadoes	Total Fatalities	Risk Impact Value
05/25/24	42	8	7	0	0	4	0	0	4	14	12.15
04/26/24	70	12	5	1	0	3	0	0	1	1	9.52
05/26/24	51	5	3	0	0	3	0	0	1	1	7.43
04/27/24	64	4	2	1	0	2	0	0	3	4	5.58
05/21/24	36	2	1	1	0	3	0	0	1	5	5.45
10/09/24	43	6	3	0	0	3	0	0	1	6	4.95
05/08/24	63	2	3	0	0	0	0	0	1	1	4.6
05/06/24	56	1	0	1	0	1	0	0	1	2	3.47
03/14/24	24	5	2	0	0	3	0	0	2	4	3.45
07/08/24	52	7	0	0	0	1	1	0	1	2	2.96
11/02/24	7	0	4	0	0	1	0	0	0	0	2.79
07/15/24	61	2	0	0	0	3	0	0	0	0	2.66
05/23/24	63	2	0	0	0	0	0	0	0	0	1.64
05/30/24	12	1	1	0	0	0	0	0	0	0	1.28
06/02/24	11	1	1	0	0	0	0	0	0	0	1.23
07/09/24	10	1	1	0	0	0	0	0	0	0	1.19
08/07/24	5	2	1	0	0	0	0	0	1	1	1.13
08/05/24	19	1	0	0	0	0	0	0	0	0	1.03
04/02/24	50	7	0	0	0	0	0	0	0	0	0.87
05/19/24	26	3	0	0	0	0	0	0	0	0	0.86
01/08/24	18	1	1	0	0	0	0	0	0	0	0.83
06/22/24	15	2	0	0	0	0	0	0	0	0	0.82
04/01/24	34	7	0	0	0	0	0	0	0	0	0.69
05/07/24	37	6	0	0	0	0	0	0	0	0	0.68
04/30/24	14	0	1	0	0	0	0	0	1	1	0.66
09/27/24	10	1	1	0	0	0	0	0	0	0	0.65
05/02/24	6	2	1	0	0	0	0	0	0	0	0.64

Figure 3. A webpage showing daily RIV for the year 2024, with the total number of each category including tornadoes, EF-scale, track length, killers, and fatalities. The webpage displays the years from 1950 to current, and is available internally within the SPC. Data from the webpage is also available upon request.

While RIV was calibrated using event fatalities, the OMEGA team has decided not to use RIV as a fatality estimate. As can be seen in Figure 4, RIV does appear to be somewhat close to the fatality average, mainly for events with RIV >= 4. For events on the middle and right side of the chart (RIV < 4), the variance for event fatalities is quite large. While RIV may still appear to be close to the average, event fatalities rarely end up near the average. A lot of the variability has to do with structural integrity along the tornado's path. This is not considered when calculating RIV.

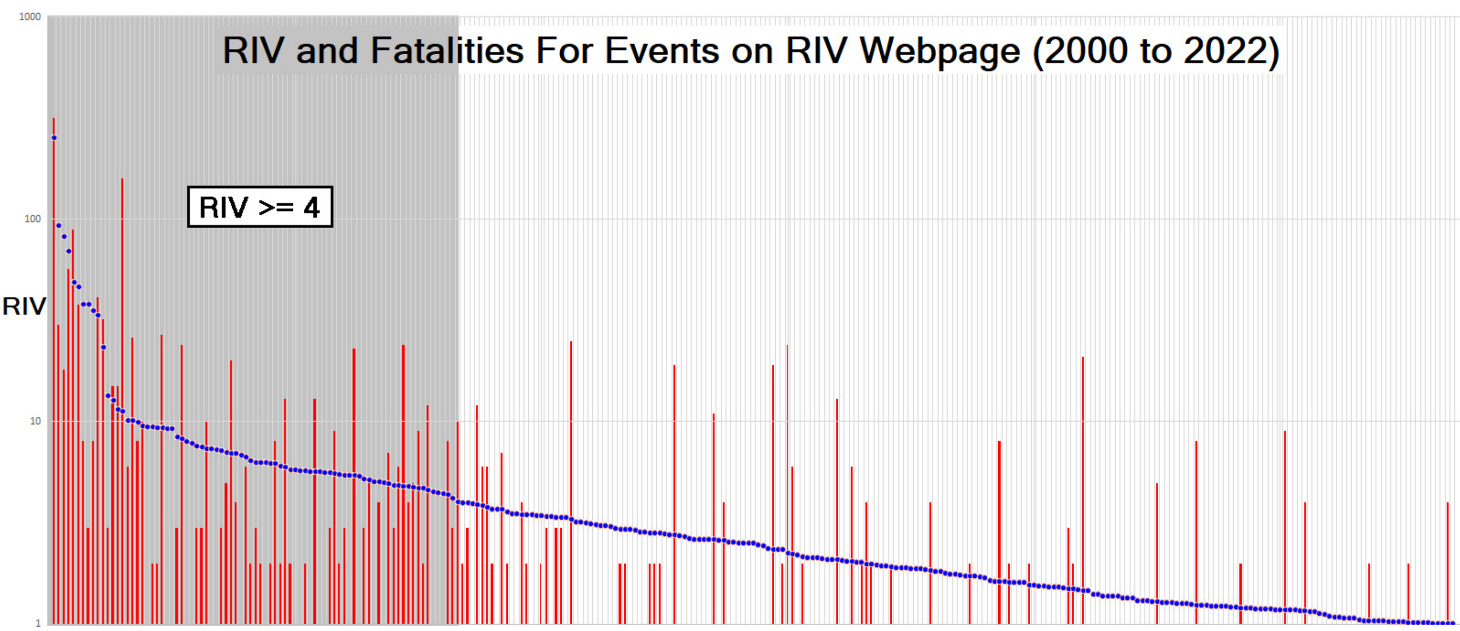

Figure 4. A graph showing RIV and fatalities for events in the RIV database from 2000 to 2022. RIV appears to be somewhat close to the fatality average for events with RIV >= 4. However, the variance in fatalities is large on the middle and right side of the chart, where event fatalities rarely end up near the average. For this reason, RIV is not considered a fatality estimate.

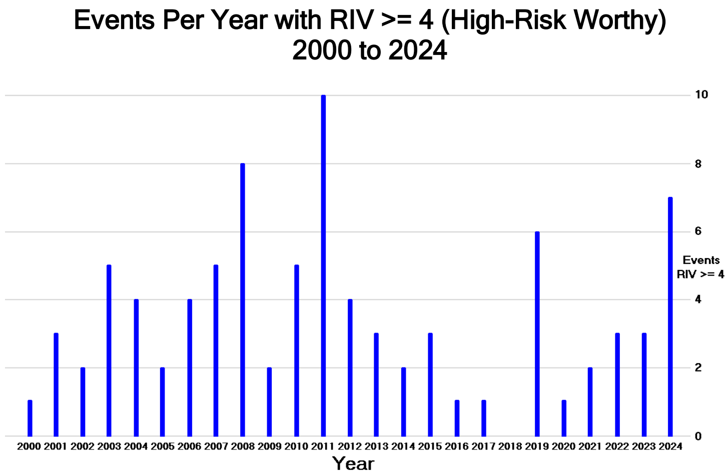

Figure 5. Events per year with RIV >= 4 (High-Risk worthy). The years with the greatest number of events with RIV >= 4 were 2008, 2011 and 2024. Through the 25-year period, the average number of events with RIV >= 4 per year was 3.4.

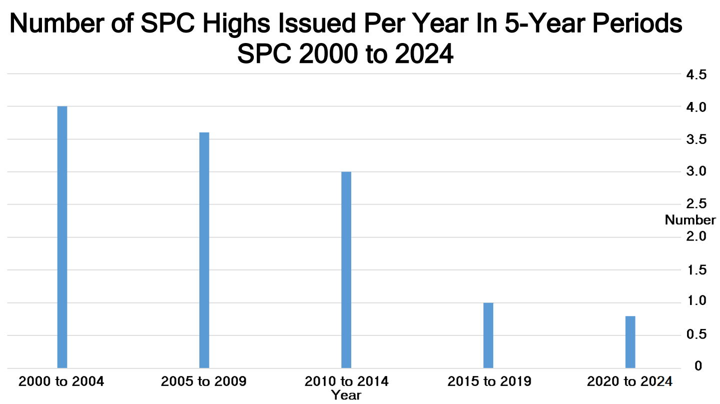

Figure 6. Number of SPC High Risks issued per year in 5-year periods from 2000 to 2024. A steady drop in the number of High Risk issuances is evident in the 25-year period.

Figure 6 shows that over the 25-year period from 2000 to 2024, the number of SPC High Risk issuances per year has steadily decreased from four in the 2000 to 2004 period, to less than one in the 2020 to 2024 period. This is a notable drop. However, it is more important to see how many High Risks were issued by SPC relative to the number of High-Risk worthy events (RIV >= 4) that were occurring. Figure 7 reveals that from 2000 to 2004, about one High Risk was issued for every event with RIV >= 4. From 2020 to 2024, this dropped to about one High Risk issued for every four events with RIV >= 4. In the 25-year period, the drop is steady for High Risk issuance rate relative to the number of chances that a High Risk could be issued successfully.

One possible reason for this downtrend could be that the SPC went from a three-category system to a five-category system in 2014. Before the change, the High Risk category was the top third of the system. After the change, the High Risk category was the top fifth of the system. The change involved adding Enhanced and Marginal Risk Categories. After the change, forecasters have been having a harder time getting to the High Risk category, due to the ramp-up outlook process.

A second possibility for the downtrend in High Risk issuance rate relative to the number of events with RIV >=4, could be that forecasters have become more conservative. Feedback among SPC forecasters suggests that forecasters are more reluctant to issue High Risk because the decision can have a large impact on regional economies. The High-Risk decision has the potential to inadvertently shut down entire areas of the country within multi-state regions. The High-Risk decision may set into motion an increase in staffing for parts of Federal and State government agencies including National Weather Service Forecast Offices, the Federal Emergency Management Agency (FEMA), and local Emergency Manager operations. In addition, the decision may impact planning for local television stations, schools, businesses and families. For that reason, forecasters appear hesitant to issue High Risk, unless uncertainty has been eliminated for a High-Risk worthy event.

From April 2, 1982 to December 31, 2009 (27.8 Years), the SPC High Risk issuance rate was 4.8 times per year. Since January 1, 2010 (14.3 Years), the SPC High Risk issuance rate has dropped to 1.8 times per year. During the existence of SPC, the number of High-Risk worthy events (RIV >= 4) have remained relatively steady between three and four per year. Matching the historic High Risk issuance rate of three per year on average, has been a common topic of discussion among SPC forecasters.

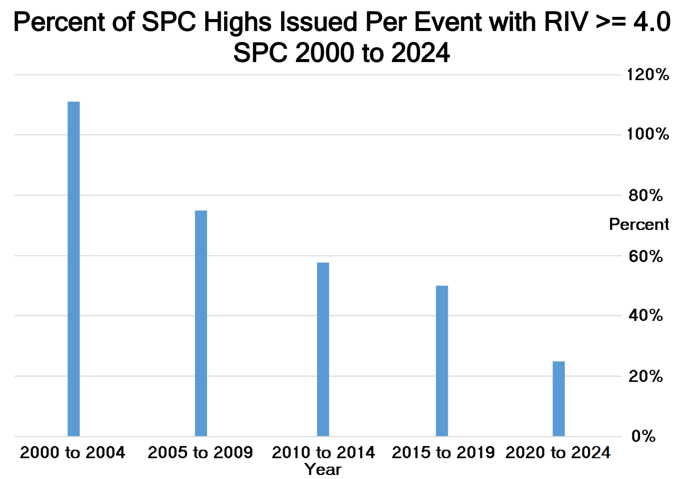

Figure 7. Percent of SPC Highs issued relative to RIV >= 4 events from 2000 to 2024. A steady drop is evident in SPC High Risk issuance rate relative to the number of chances that a High could be issued successfully.

An important question is, "Why should SPC issue High Risks using RIV >= 4 as a goal for verification?"

1) RIV >= 4 events have an annual return frequency of about three, which corresponds relatively closely to the SPC historical High Risk issuance rate. Using RIV >= 4 keeps High Risk consistent historically.

2) RIV >= 4 events are rare, and unlikely to impact the same area of the U.S. more than one time per year. By issuing High Risk for RIV >= 4 events, these forecasts are issued frequently enough to have the maximum impact concerning the positive public response, but not too frequently to desensitize the public.

3) By setting the verification bar at a reasonable level, it is more likely that the historic once-in-a-decade tornado outbreaks will be in High Risk when they occur.

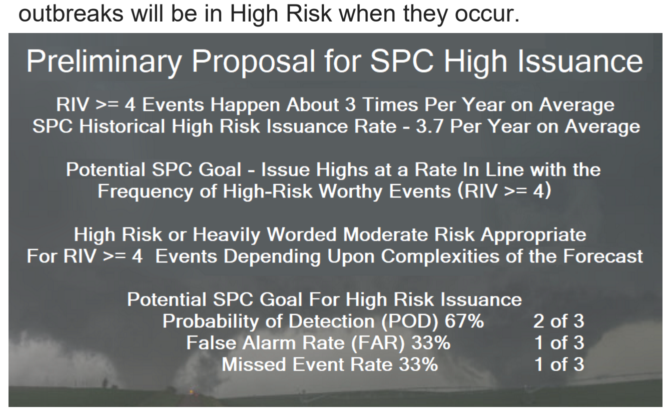

Figure 8. Preliminary Proposal for SPC High Risk issuance.

3. The Tornado Outbreak Indicator (TOI)

One of the primary goals of this project was to develop tools to help forecasters to better discriminate between Moderate and High Risk. Past tornado outbreaks were examined for clues as to what made these events special. Analysis of the historic April 27, 2011 tornado outbreak revealed that the translation speed of the 500 mb jet was anomalously fast at 58.5 knots (Figure 9). In addition, analysis showed that for April 3, 1974, the 500 mb jet was also anomalously fast at 51.1 knots (Figure 9). Based on these and other events, a hypothesis was made that tornado outbreaks associated with fast-moving mid-level jets are often more productive than for those with slow-moving jets.

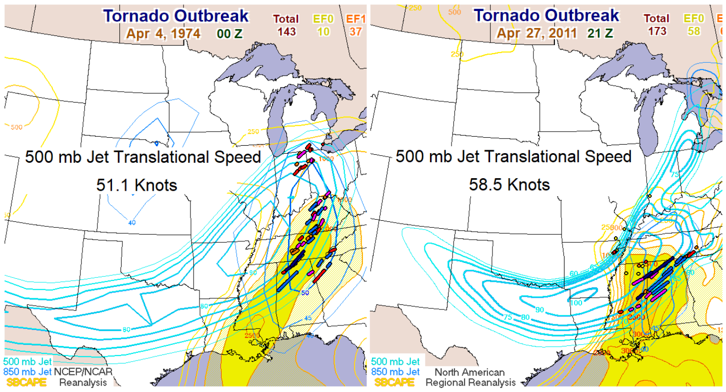

Figure 9. The 500 mb jet position at 00Z on April 4, 1974 (left), and the 500 mb jet position at 21Z on April 27, 2011 (right). In both cases, the 500 mb jet translation speed was above 50 knots. Tornado outbreaks associated with a 500 mb jet translation speed above 40 knots, have more potential to be high-end.

The first study looking at 500 mb jet translation speed was done in 2015. 500 mb jet translation speed was compared to the forward speed of the associated 500 mb trough. It was found that 500 mb jet translation speed was the better indicator between the two, and that 500 mb jets associated with high-end tornado outbreaks often translate at speeds above 40 knots. In 2021, work began to create a database looking at the relationship between tornadoes and the 500 mb jet translation speed. The database included tornado outbreaks, regional tornado events, isolated tornado clusters and null cases. Analysis was done on 212 cases to find the 500 mb jet translation speed for each case within an 18 hour window between 06Z the night before and 00Z on the day of the event.

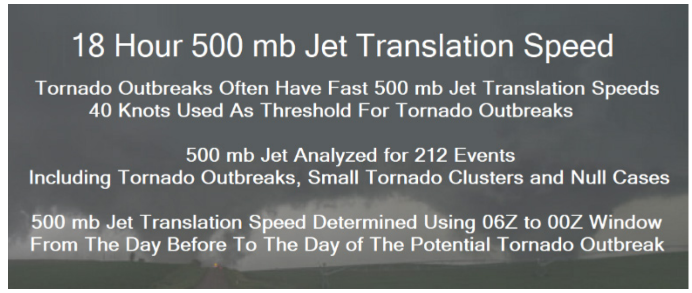

Figure 10. Results of the 500 mb jet translation speed database (212 events) confirm that 40 knots is a good threshold to use to discriminate high-end tornado outbreaks from lower-end ones. To do the analysis, the 500 mb jet translation speed was calculated using an 18 hour window between 06Z the night before and 00Z on the day of the event.

After analysis for the database was finished, Table 2 was made showing the number of occurrences for each category relative to the 500 mb jet translation speed. On the table, an increase in occurrence is seen in all of the columns as the 500 mb jet translation speed increases. Concerning tornado characteristics, columns that increase by at least an order of magnitude from the bottom range (< 25 knots) to the top range (>= 50 knots) are number of EF4s, number of EF5s, number of EF4+, track length 25 to 50 miles, track length 50 to 100 miles, track length 100+ miles, number of killer tornadoes and number of deaths.

At the 40 knot threshold, the event RIV crosses four, the average tornado outbreak indictor value (TOI) crosses four, the average probability of a High Risk event crosses 50 percent, and the maximum outlook tornado probability contour crosses 30 percent. TOI and the High Risk Probability will be discussed in more detail on page 7.

Finally, a slight increase is seen in Significant Tornado Parameter (STP) from near 5 at the bottom range to around 7 at the top range. While STP is important, the subtlety of the increase reinforces the notion that 500 mb jet translation speed plays an important role in discriminating tornado outbreaks.

Average for 212 Tornado Outbreaks, Regional Tornado Events, Isolated Tornado Clusters and Null Cases (2000 to 2023) Based on 500 mb Jet Translation Speed
Includes Highs, Moderates, Events with RIV >= 4 and Null Cases

500 mb Jet Range of Translation Speed	500 mb Jet Average Translation Speed	500 mb Jet Max Wind Speed	Total Number of Tornadoes	Tot % Coverage Based on Verification Page	Average Number of EF2s	Average Number of EF3s	Average Number of EF4s	Average Number of EF5s	Average Number of EF2+ Tornadoes	Average Number of EF4+ Tornadoes	Number of Cases in Range
>= 50 Kts	56.4	101.0	59.4	41.8%	11.5	5.0	3.0	0.5	20.0	3.6	22
45 to 49.9 Kts	47.2	91.0	48.3	36.5%	8.2	3.6	0.9	0.1	12.8	1.0	38
40 to 44.9 Kts	42.5	88.9	35.1	28.1%	4.6	2.2	0.4	0.0	7.3	0.5	31
35 to 39.9 Kts	37.5	82.7	35.1	27.6%	5.6	1.5	0.3	0.0	7.4	0.3	33
30 to 34.9 Kts	32.5	81.9	25.7	23.2%	3.1	0.9	0.1	0.0	4.2	0.2	45
25 to 29.9 Kts	28.2	83.2	17.2	17.7%	1.9	0.5	0.2	0.1	2.6	0.2	19
< 25 Kts	19.1	80.6	18.8	23.4%	2.3	0.7	0.1	0.0	3.0	0.1	24
500 mb Jet Range of Translation Speed	**Average Number of 25 to 50 Mile Tracks**	**Average Number of 50 to 100 Mile Tracks**	**Average Number of 100+ Mile Tracks**	**Average Number of Killer Tornadoes**	**Average Number of Deaths**	**Average Event RIV**	**Average Event TOI**	**Avg Probability High Risk Event with RIV >= 4.0**	**Max Forecast Tornado Prob Contour**	**Average Maximum STP**	**Percent SPC High Risk Outlooks**
>= 50 Kts	3.3	1.0	0.2	5.5	51.2	47.2	4.49	84.4%	55	7.1	36.4%
45 to 49.9 Kts	1.9	0.5	0.1	2.3	10.8	14.2	4.37	74.6%	49	6.9	39.5%
40 to 44.9 Kts	1.5	0.3	0.0	1.5	3.8	5.3	4.08	55.5%	39	6.1	35.5%
35 to 39.9 Kts	0.9	0.1	0.0	1.0	3.3	3.8	3.65	32.3%	27	5.9	36.4%
30 to 34.9 Kts	0.4	0.0	0.0	0.6	4.8	2.7	3.19	17.0%	20	5.5	22.2%
25 to 29.9 Kts	0.4	0.1	0.0	0.4	1.6	2.1	2.68	7.5%	15	4.7	26.3%
< 25 Kts	0.3	0.0	0.0	0.2	0.3	2.0	1.99	3.0%	11	4.9	12.5%

Table 2. The number of occurrences of each column is shown relative to seven ranges in 500 mb jet translation speed. For tornadoes, an increase is seen across all columns as the 500 mb jet translation speed goes up, with the sharpest increase in the violent tornado column. The number of long track tornadoes also have a sharp increase, as well as number of killer tornadoes, deaths, event RIV and average probability of High Risk.

One question that is often asked is, "Why are fast-moving mid-level jets favorable for high-end tornado outbreaks." The OMEGA team has had several internal discussions on this topic, and have opened discussion among SPC forecasters and other meteorologists. Here are some hypotheses that were proposed.

Five Reasons That a Fast-moving 500 mb Jet Is Favorable For a Tornado Outbreak In a Supportive Environment

1) A stronger low-level jet response occurs over the moist sector, such that low-level shear is increased early in the event, rather than late in the event. A late response of the low-level jet is often a failure mode for a potential tornado outbreak. For the failed scenario, discrete cells develop ahead of a slow-moving mid-level jet, but low-level shear remains too low for a tornado outbreak to materialize, until the brunt of the event is over. A tornado outbreak is more likely if the mid-level jet is fast, because the low-level jet responds early in the event when supercells have just become mature and have a long residence time ahead of them.

2) Areas of extreme meso-beta scale lift (50 to 100 miles in width) are created along the edges of a fast moving mid-level jet. The exact lift enhancement depends upon the mid-level jet's speed, shape, size and orientation. These areas of very strong lift can move in conjunction with well-organized supercells for extended time periods, greatly enhancing their potential to produce long-track strong to violent tornadoes

3) There is greater potential that the next day's warm sector will remain undisturbed. This is true because a fast-moving mid-level jet travels farther in distance from one day to the next, making it less likely that the previous night's convection will be able to reach the warm sector of the impending tornado outbreak by the time the outbreak begins. In contrast, slow-moving jets often cannot outrun the previous night's convection. This happened on April 2, 2024 shown in Figure 12. For that case, outflow from the previous night's storms stabilized the warm sector, helping to prevent a tornado outbreak, expected in Ohio later in the day.

4) Supercells are more likely to be discrete in association with a fast-moving mid-level jet. These fast mid-level jets are generally pointed more east-to-west, which is less likely to result in squall-line development, and more likely to result in discrete supercell development. Slow moving mid-level jets are often turned toward a north-northeast-to-south-southwest or north-to-south orientation, which causes the large-scale ascent on the eastern edge of the jet to be parallel to the western edge of the warm sector. This can result in a linear MCS, which moves across the moist sector and limits tornado outbreak potential.

5) Cell initiation occurs ahead of the mid-level jet in a weaker deep-layer shear environment. This prevents a scenario in which extreme deep-layer shear causes developing convection to struggle. The result is that more supercells are ongoing as the fast-moving mid-level jet approaches. As these supercells become organized, extreme levels of shear and lift arrive quickly in association with the mid-level jet. These fully developed mature storms can handle the extreme shear and take advantage of the environment without being overwhelmed.

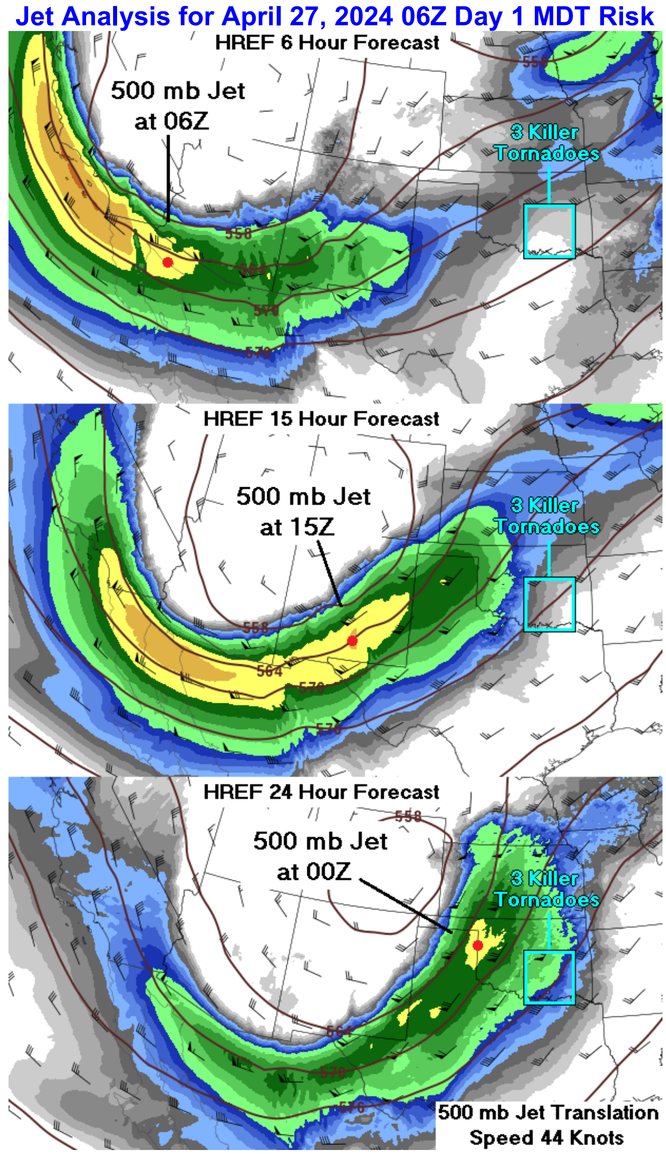

Figure 11. The 500 mb jet forecast by the HREF for April 27, 2024. In the graphic, the position of the jet is marked by the red dot at 06Z (top), 15Z (middle) and 00Z (bottom). The maximum within the jet was tracked over the 18 hour period from southwest New Mexico to far northwest Oklahoma. For this 500 mb jet, the translation speed was 44 knots, which is within the range of favorability for high-end tornado outbreaks.

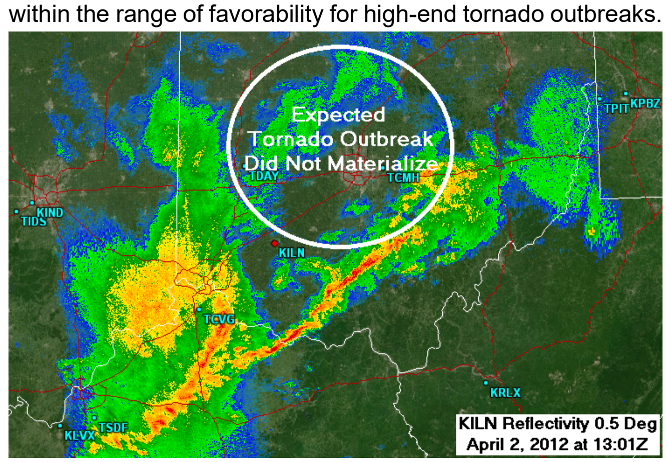

Figure 12. Reflectivity radar depiction from KILN (Cincinnati, Ohio) at 13:01Z on April 2, 2024. That morning, two line segments associated with the previous night's convection, overspread the warm sector. The outflow from this convection stabilized the warm sector ahead of a relatively slow-moving mid-level jet, which thwarted a potential tornado outbreak that was originally expected later that day in Ohio.

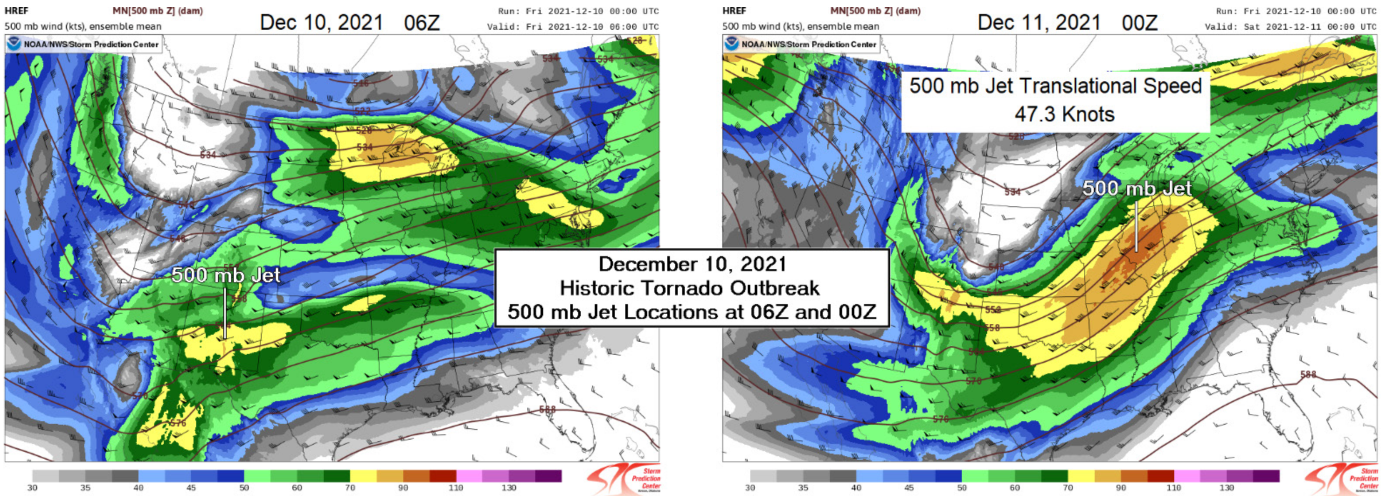

Figure 13. For December 10, 2021, the 500 mb jet's starting location at 06Z (left) and ending location at 00Z (right). The 500 mb jet translation speed for this historic tornado outbreak was 47.3 knots using the 00Z HREF from the evening before the event.

An equation was designed by the OMEGA team that uses data associated with the 500 mb jet, to calculate a value called the Tornado Outbreak Indicator (TOI). For 500 mb jet translation speed above 45 knots, TOI relies on the direction and distance of the 500 mb jet from the expected tornado outbreak to increase or decrease the number. A 500 mb jet at 325 degrees and relatively close to the outbreak's centroid is favored most, while jets that are further away from the outbreak are favored less as the distance to the outbreak increases. For a 500 mb jet translation speed below 45 knots, TOI relies less on direction and distance, and more on the 500 mb jet translation speed to compute the number, increasing this reliance as the jet translation speed drops. Also, an 18 hour 500 mb jet max wind near 90 knots is favored, becoming less favored as the value gets further away from this number. During summer (June, July, August), the TOI jet analysis technique uses the 300 mb jet, which is often more defined than at lower levels. The month of July is favored less than other months because 300 mb jets moving faster than 40 knots in July are rare and are generally too small to generate High-Risk worthy tornado outbreaks.

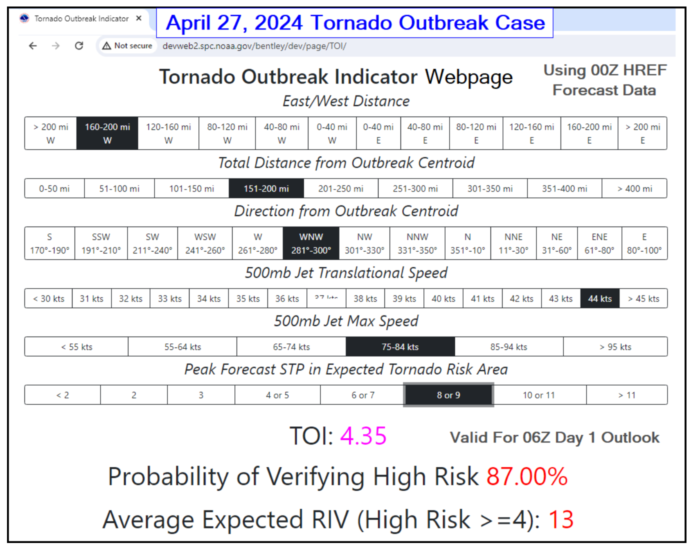

Figure 14. The TOI webpage is shown with values entered for the April 27, 2024 tornado outbreak. A resultant TOI and probability of verifying High Risk are given. The webpage was used for the event in real-time by members of the OMEGA team.

In Figure 14, the TOI webpage is shown, in which SPC forecasters can input values from the 500 mb jet analysis to generate a TOI. TOI values >= 4 are associated with fast-moving 500 mb jets that are more likely to result in High-Risk worthy tornado outbreaks. In addition, a probability of verifying High Risk is also generated by the webpage using the TOI and the maximum STP in the expected outbreak area from 18Z to 06Z.

For events with tornado outbreak potential, 215 cases were examined in the period from 1965 to 2023. The TOI webpage was used to enter the 500 mb jet analysis (fall, winter, spring) and 300 mb jet analysis (summer). For each event, the TOI webpage generated a High Risk Probability, which is plotted on Figure 15. An S distribution is evident on the graph. Most events that had a High Risk probability of greater than 50 percent verified with RIV >= 4, while most of the events with less than a 50 percent chance of verifying High Risk had RIV < 4. The OMEGA team is recommending that a forecaster strongly consider issuing a High Risk, when the TOI webpage probability of verifying High Risk is greater than 50 percent.

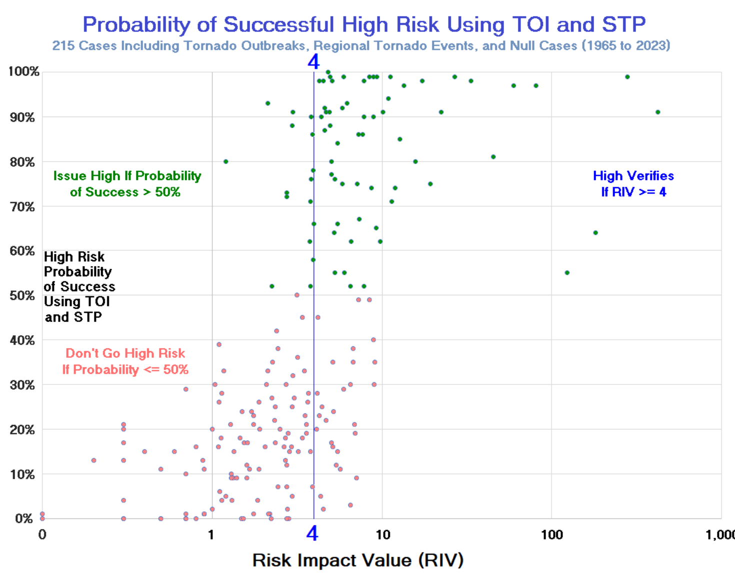

Figure 15. The probability of verifying High Risk for 214 events from 1965 to 2023 using TOI and STP, generated by the TOI webpage. A High Risk probability greater than 50 percent is most often associated with a High-Risk worthy tornado outbreak (RIV >= 4), while false alarm cases were most often associated with a High Risk probability of less than 50 percent.

The left side of Figure 16 shows the RIV and TOI for actual SPC High Risk issuances from 2000 to 2023. During the 24-year period, actual SPC High Risk issuances using the RIV >= 4 threshold verified 47.5% of the time. 84% of the actual Highs with a TOI < 4 were false alarms. In the right side of Figure 16, events in the period with TOI >= 4 are added, while the Highs issued with TOI < 4 are taken away. The new result would be 71 Highs issued during the 24-year period, with a verification rate of 78.9% (56 of 71) for events with RIV >= 4. The back-test suggests that using High-risk probability from the TOI webpage could significantly improve the SPC High Risk verification rate.

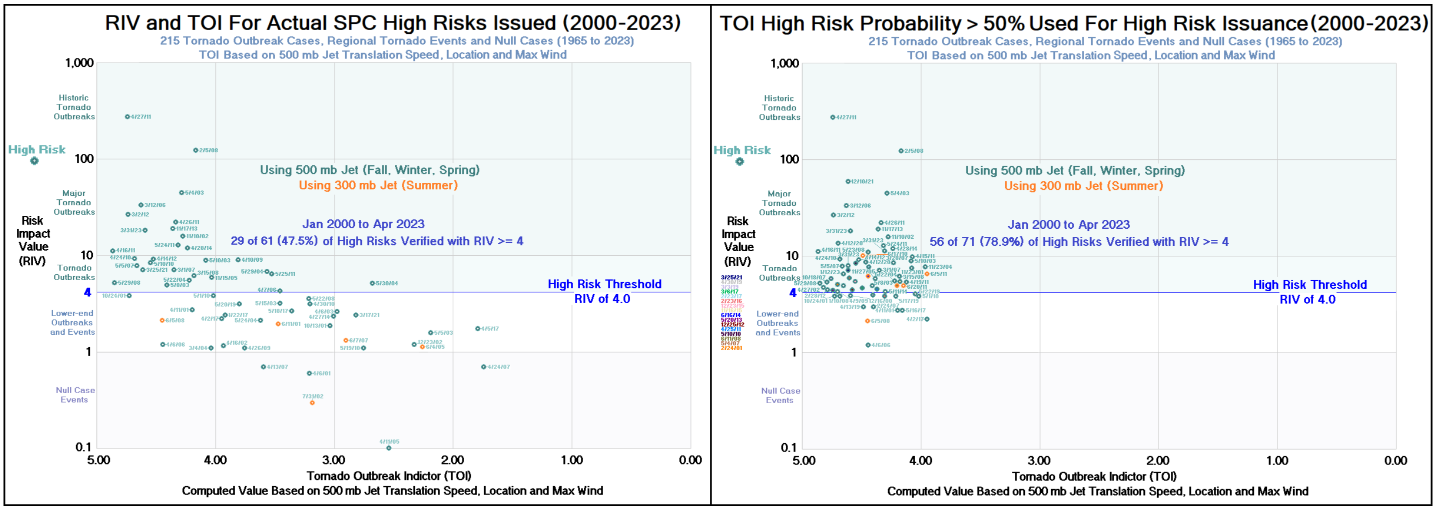

Figure 16. At left, RIV and TOI for actual SPC High Risk Issuances from 2000 to 2023. Of Highs that had a TOI < 4, 26 of 31 (83.9%) were false alarms. Of Highs that had a TOI of >= 4, 24 of 30 (80%) verified with RIV >= 4. At right, using the TOI webpage, a High was hypothetically issued for each past case if the High Risk probability was greater than 50 percent, while Highs with a High Risk probability less than 50 percent were dropped. The result is that 56 of 71 Highs (78.9%) verified with a High-Risk worthy event (RIV >= 4), which is a substantial improvement over the actual SPC High Risk verification rate of 47.5 percent.

TOI High Risk Probabilities (06Z Day 1 Outlook) and Resultant RIV For Day 1 Event

Percent of Cases RIV >= 4	High Risk Prob TOI Webpage RIV >=4	Date	Outlook Used For Analysis and Prior To Potential Upgrade	Day 1 RIV
	99%	25-Mar-21	1730Z Dy2	6.7
	97%	31-Mar-23	1730Z Dy2	85.4
	95%	10-Dec-21	1630Z Dy1	49.1
	95%	3-Mar-19	1730Z Dy2	5.4
89%	91%	21-May-24	1730Z Dy2	5.1
	87%	27-Apr-24	06Z Dy1	4.8
	84%	14-Mar-24	1730Z Dy2	3.4
	80%	12-Apr-20	1730Z Dy2	93.2
	78%	12-Jan-23	13Z Dy1	6.0
	69%	31-Mar-23	1730Z Dy2	85.4
75%	69%	25-May-24	1730Z Dy2	11.5
	69%	24-Mar-23	1730Z Dy2	4.5
	64%	19-Apr-19	06Z Dy1	1.9
	43%	6-May-24	1730Z Dy2	3.4
	39%	2-Jan-23	1730Z Dy2	0.4
	39%	27-May-19	06Z Dy1	7.8
	38%	22-May-19	1630Z Dy1	4.2
30%	33%	1-Apr-24	1730Z Dy2	0.7
	32%	20-May-24	06Z Dy1	0.1
	31%	22-Apr-20	1730Z Dy2	2.1
	29%	19-Apr-20	1730Z Dy2	2.8
	29%	16-Dec-19	1630Z Dy1	7.5
	26%	20-May-19	1730Z Dy2	3.5
	22%	4-Apr-23	1730Z Dy2	1.0
	22%	17-Mar-21	1730Z Dy2	0.7
	20%	8-May-24	06Z Dy1	4.4
	20%	2-Apr-24	1730Z Dy2	0.9
	19%	4-Apr-23	1730Z Dy2	1.0
	19%	4-Nov-22	1630Z Dy1	6.0
23%	19%	17-May-19	1730Z Dy2	2.9
	12%	2-Mar-20	1630Z Dy1	3.3
	11%	2-Mar-23	1730Z Dy2	0.3
	10%	26-Apr-24	1730Z Dy2	9.2
	8%	19-May-24	06Z Dy1	0.8
	7%	19-Apr-23	13Z Dy1	3.1
	5%	17-May-19	1730Z Dy2	2.9

Figure 17. Re-analyzed TOI High Risk probabilities for 36 cases. The percent of cases with RIV >= 4 (far left) are next to the median for each quartile (second column to left). Each quartile's percentage of cases is relatively close to the median, suggesting that the TOI probability of High Risk is calibrated reasonably well.

In Figure 17, a back-test is shown with re-analysis of the 500 mb jet for 36 cases using the TOI webpage. High risk probabilities were generated for each event using the 00Z HREF from the evening before and broken into four percentage quartiles. The High Risk probability is the second column to left with the resulting event RIV at the far right. For each quartile, the percentage of cases with RIV >= 4 is at the far left. Each quartile's percentage is shown in the middle of that quartile's distribution. The average for each quartile appears to be relatively close to each quartile's median, suggesting that the TOI probability of verifying High Risk is calibrated reasonably well.

Automated 500 mb Jet Streak Analysis (Hagelslag)

To analyze the 500 mb jet more efficiently, additional software is being developed at the National Center for Atmospheric Research (NCAR). The software, using the program Hagelslag, will display automated calculations of 500 mb jet translation speed at hourly intervals for jet streaks that are located across the continental United States. The software is planned for use by forecasters at SPC and at Weather Forecast Offices (WFOs) to track mid-level jet streaks in real-time.

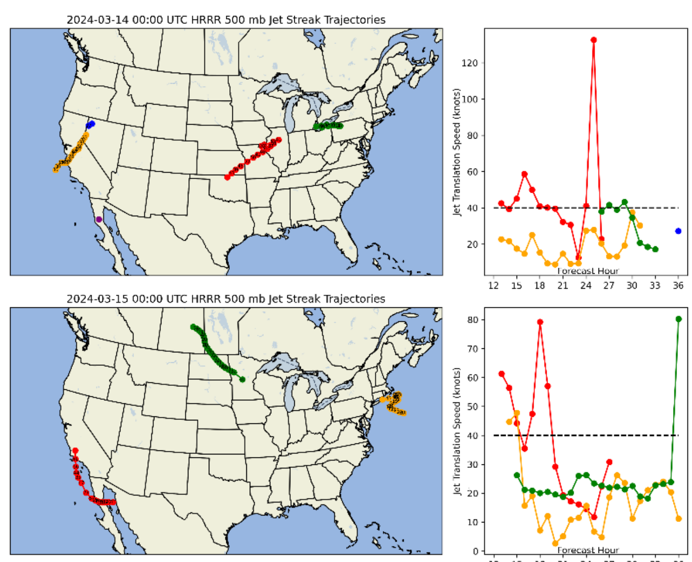

Figure 18. An automated 500 mb jet streak analysis using software developed at NCAR from a program called Hagelslag. In addition to colored jet streak locations, a graph will show hourly translation speeds for each jet.

4. OMEGA (Outlook Machine Ensembling Algorithm)

In 2022, the OMEGA team came up with the idea to combine Loken machine-learning-based tornado probabilities with the Significant Tornado Event Probability (STEP), to create a more effective tornado probability tool. The team decided to name the tool the Outlook Machine Ensembling Algorithm (OMEGA). The idea was to develop a tornado probability tool using machine-learning and human-learning to maximize performance. Two goals below were made.

1) OMEGA should be an effective tool at discriminating High Risk events from Moderate Risk events. OMEGA should specialize at predicting tornado outbreaks, so that forecasters can trust the output when issuing High Risks.

2) OMEGA should be effective at forecasting tornadoes on a daily basis. OMEGA should be calibrated well to outlook tornado probabilities so that forecasters can be confident when using the output. OMEGA should be competitive when compared to other tornado forecasting tools for all tornadoes.

Loken Tornado Probability

The Loken probability tool follows the methodology described in Loken et al. (2020) to create 24-hr, day-1 spatial forecast probabilities for severe hail, wind, and tornadoes within 40 km of a point. The current version of the Loken probability tool uses predictors based on forecast output from the High-Resolution Ensemble Forecast System, Version 3 (HREFv3; e.g., Farrar 2021; Harrison et al. 2022; SPC 2024b) and target data from unfiltered local storm reports on the SPC website (SPC 2024a) that have been mapped to an approximately 80 km grid. In this approach, the target data is binarized such that 80 km grid boxes containing at least one observed storm report are counted as "yes" targets, while all other 80 km points are counted as "no" targets. The current real-time HREFv3-based system is trained on data from 183 dates spanning February to August of 2021. The general approach for preprocessing the HREFv3 data is similar to that used in Loken et al. (2020). First, HREFv3 data are temporally aggregated by computing, for each member at each HREFv3 grid point, a 24-hr maximum or minimum, depending on the field (Table 3). Next, the temporally-aggregated fields from each member are upscaled to an approximately 80 km grid by computing the spatial maximum or minimum of each field within each 80 km grid box. An ensemble mean is taken at each 80 km point, and final predictors for each point include ensemble mean values at the point of prediction as well as the eight nearest 80 km grid points. Latitude and longitude from the point of prediction are also included as predictors (Table 3) to allow the product to learn spatial relationships in the data.

Loken Probability Tool Predictors, Organized by Preprocessing Strategy
Maximum
1 km simulated reflectivity
Upward vertical velocity
0-3 km and 2-5 km updraft helicity
Product of MUCAPE and 10m-500 hPa wind shear
Supercell Composite Parameter (SCP)
Significant Tornado Parameter (STP)
Significant Hail Parameter (SHIP)
Number of HREFv3 points containing greater than 30 dBZ maximum hourly reflectivity
0-1 km and 0-3 km storm-relative helicity
0-1 km and 0-3 km energy helicity index
Maximum hourly 10 m wind speed
Minimum
Downward vertical velocity
Constant
Latitude
Longitude

Table 3. Loken Probability Tool predictors, organized by spatiotemporal preprocessing strategy.

Random-forest classifiers from the Python module Scikit-Learn (Pedegrosa et al. 2011) are used to obtain final hazard probabilities at each 80 km point. Separate random forests are used to predict each hazard, although this work only uses the tornado forecast probabilities. Importantly, the Loken Probability Tool forecast probabilities are designed to predict the likelihood of at least one observed storm report within 80 km of a point and are not adjusted for report density or intensity. Since SPC outlooks account for both severe weather likelihood and intensity, the Loken Probability Tool, by itself and in its original form, does not make predictions that directly map to final SPC categories for tornadoes or any other hazard.

Significant Tornado Event Probability (STEP)

STEP was first created at the SPC in 2005 as an equation to help forecasters to anticipate EF2+ tornadoes. In 2008, STEP was adapted into a complex non-linear algorithm. The primary equation is shown below, with the 17 parameters used by the STEP algorithm below that.

Primary Equation For STEP

$$\frac{\text{STP Prob.} >= 3 \; + \; \dfrac{\text{SCP Prob.} >= 3 \text{ x } \text{3 Hr. Conv. Precip. Prob.}}{131}}{2}$$

$$+ \text{ 500 mb Vorticity} - \text{Abs(Surface Dewpoint} - 65) + (\text{CIN} + 100 \text{ x } .05)$$

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17 SREF Parameters Used By The STEP Algorithm

Probability Parameters
Significant Tornado Parameter Probability >= 3
Supercell Composite Parameter Probability >= 3
Probability of Convective Precipitation >= .01 inches

Wind Shear Parameters
0-1 km Shear (knots)
Surface to 850 mb Wind Direction Difference (knots)
Surface to 850 mb Wind Speed Difference (knots)

Lift Parameters
500 mb Vorticity
700 mb Vertical Velocity
900 to 650 mb Frontogenesis

Thermodynamic Parameters
Convective Inhibition - CIN (J/kg)
Surface to 850 mb Temperature Difference (deg F)
Surface to 700 mb Temperature Difference (deg F)
Surface to 500 mb Temperature Difference (deg F)

Moisture Parameters
Surface Dewpoint (deg F)
Mean-layer LCL (m)
Surface to 850 mb Dewpoint Difference (deg F)
Surface to 500 mb Dewpoint Difference (deg F)

To create the STEP algorithm, a human-learning technique was used on 75 cases from 2005 to 2008. Each equation was created manually using meteorological concepts, and then performance tested. If the performance was positive, then the equation was kept, but if it was negative, the equation was discarded. The STEP algorithm was built by back-testing events. The primary goal for STEP was to forecast significant tornadoes (EF2+), and to maximize performance on high-end tornado outbreaks.

STEP consists of Gempak code, and a series of scripts that generate output using the SREF and HREF. STEP is available in a 3 hour format using a 0 to 100 probability scale, going out to 87 hours. STEP is also available in a 24 hour format which generates outlook-like tornado probabilities (2, 5, 10, 15, 30) for day 1, day 2 and day 3.

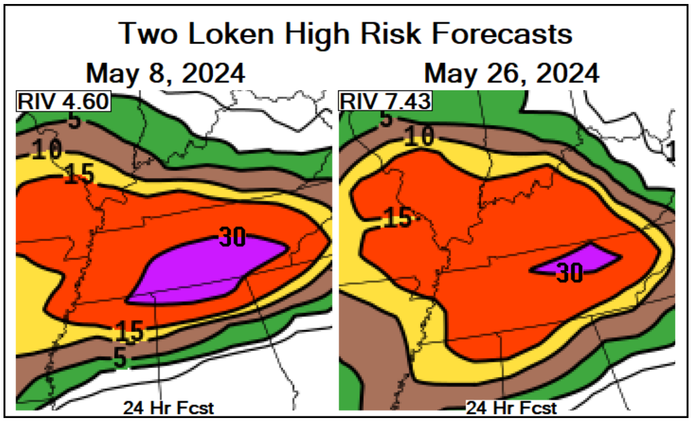

Figure 19. Two Loken High Risk forecasts for May 8, 2024 and May 26, 2024. These forecasts were from the 00Z HREF, about 24 hours before the events. Both contributed to successful SPC Moderate Risks, and verified with RIV >= 4 events.

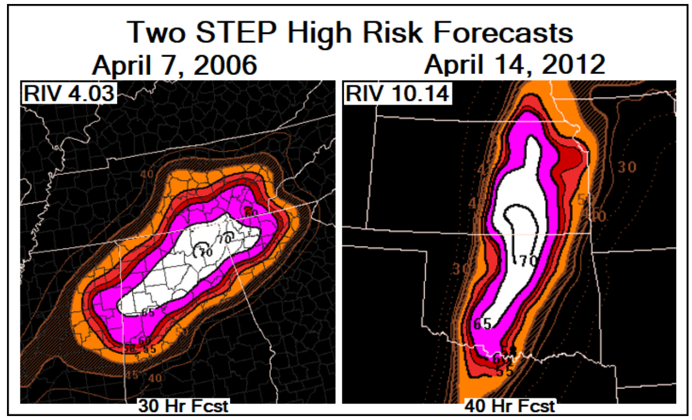

Figure 20. Two STEP High Risk forecasts for April 7, 2006 and April 14, 2012, 30 hours and 40 hours in advance, respectively. The 3 Hour STEP shown uses a 0 to 100% probability. The 70 contours convert to 30 contours on the 24 Hour STEP. These two forecasts contributed to successful SPC Day 2 High Risks, both of which verified with RIV >= 4 events.

To create OMEGA, a procedure was developed that accomplishes a series of tasks to create the output. These tasks are listed below.

1) Inside the Loken 2 contour, OMEGA displays the highest value between STEP and Loken.

2) Outside the STEP 2 contour, Loken is reduced by 50 percent.

3) Outside the Loken 2 contour, STEP is reduced to zero.

After the tasks are complete, a few contouring adjustments are done to improve calibration. The first is executed all year long to increase contours between 1 and 1.99 into the 2 to 4.99 range, to improve performance on isolated events. The second contour adjustment involves running a specialized discriminator equation to be used to improve calibration for 5, 10 and 15 contours. For example, a 15 contour can be reduced to a 10 or 5 contour if the discriminator equation shows less potential. If the equation has a strong signal for a Moderate Risk event, then the 15 contour is retained.

The discriminator equation includes the following parameters.

700-400 Differential Positive Vorticity Advection (DPVA)
700 mb Temperature (Celsius)
Significant Tornado Parameter (STP)

The discriminator equation is not used on 30 contours. If a 30 contour is generated for OMEGA from either STEP or Loken, no contour adjustment is made.

Figure 21 shows an example of how STEP and Loken are combined to create OMEGA for the April 19, 2023 case. 24 Hour STEP is on the left, and Loken is on the right, with the OMEGA output in the middle. For this event, Loken generates a 10 contour centered over northeast Kansas, while STEP generates a 10 contour in southern Oklahoma. The combined result is that OMEGA has two 10 contours, one north and one south. Other than STEP, OMEGA was the only tornado probability tool that generated a 10 contour in southern Oklahoma, where two EF3 tornadoes occurred.

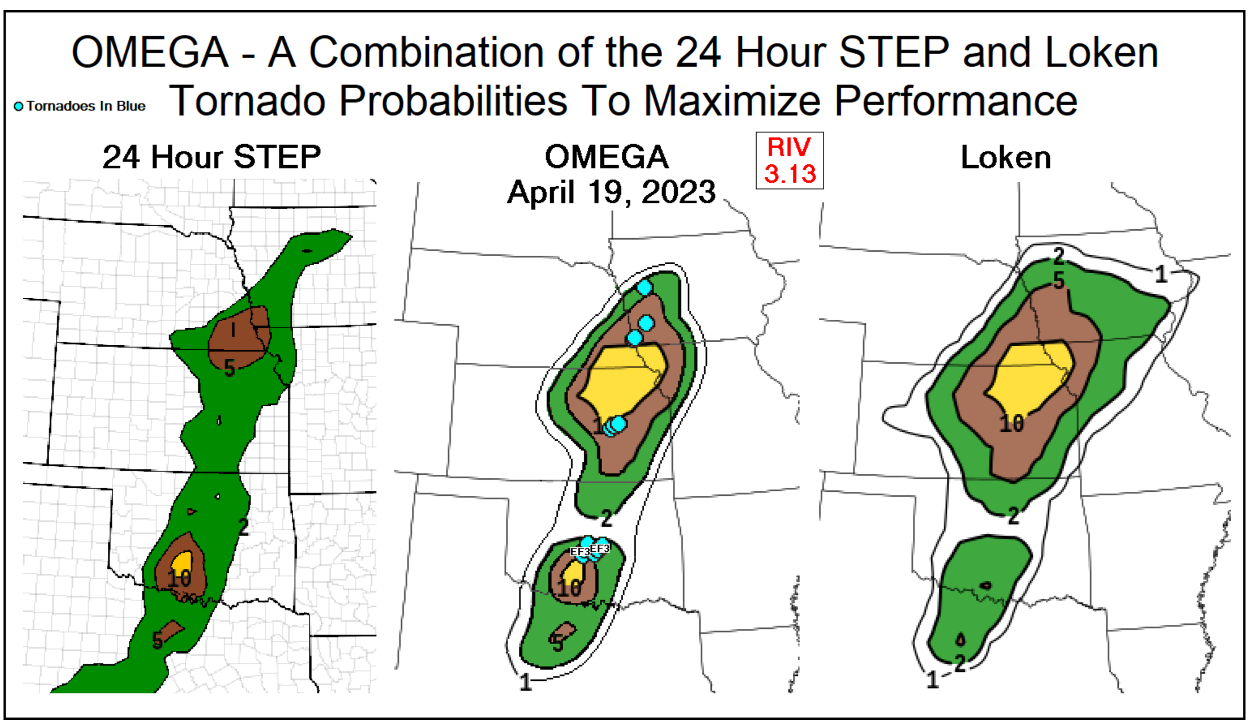

Figure 21. The example shows the tornado event from April 19, 2023. The 24 Hour STEP is at left and the Loken tornado probability is at right. The two are combined to create OMEGA (center). Loken contributes a 10 contour over northeast Kansas and STEP contributes a 10 contour in southern Oklahoma. Other than STEP, OMEGA was the only tornado probability tool to generate a 10 contour in Oklahoma, where all other tools had a 5 contour or less.

In Figure 22, a five-tool comparison is shown for the historic tornado outbreak on March 31, 2023. OMEGA (top center) was back-tested for this event. OMEGA produced a maximum contour of 60 in northern Illinois. Two closed 30 contours (one north and one south) were generated near the axis of the tornado outbreak. A 30 contour was not generated by any of the other tornado tools. The tornado outbreak had an RIV of 85.4.

In Figure 23, a three-tool comparison is shown for the historic tornado outbreak on December 10, 2021. OMEGA was back-tested for this event. A 30 contour was generated from western Tennessee into western and central Kentucky. A 165 mile track EF4 occurred near the 30 contour. OMEGA is the only tool that generated a 30 contour for this tornado outbreak, which had an RIV of 49.1.

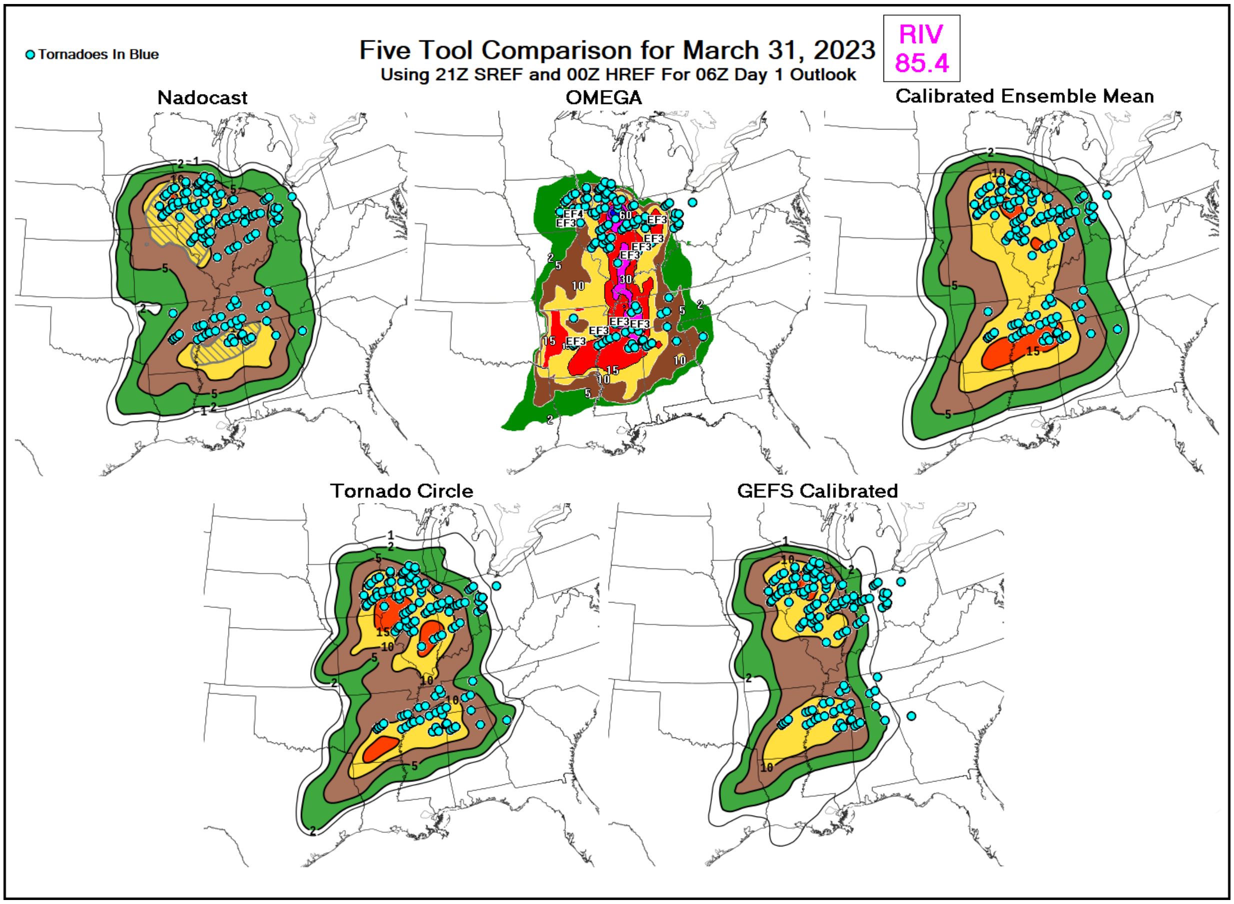

Figure 22. Output from the five tornado tools for the March 31, 2023 tornado outbreak. OMEGA, which was back-tested for this event, had a 60 contour in northern Illinois. OMEGA had two 30 contours near the axis of the event, with one north and one south. Other than STEP, OMEGA was the only tool to forecast a high-end tornado outbreak for this day. The event verified as a historic tornado outbreak, with an RIV of 85.4.

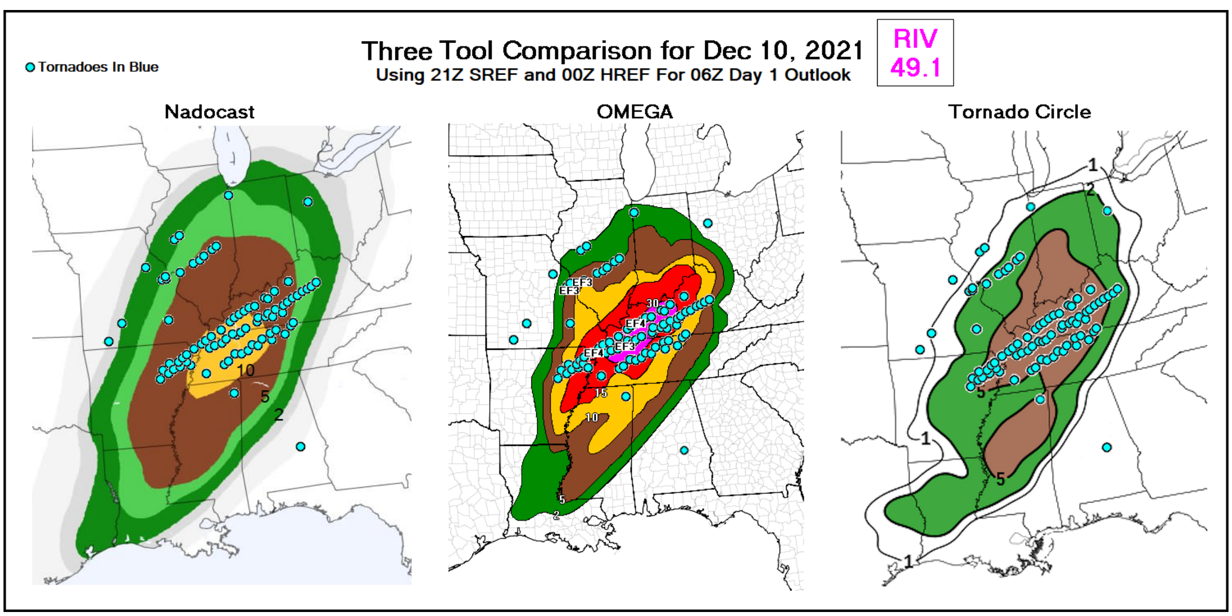

Figure 23. Output from the three tornado tools from the tornado outbreak on December 10, 2021. OMEGA was back-tested for this event. OMEGA had a 30 contour from northwestern Tennessee into western and central Kentucky, where a 165 mile tornado EF4 track occurred. This was a historic tornado outbreak with RIV of 49.1.

The first version of OMEGA was created in the fall of 2023, and calibrated on 29 cases. OMEGA was back-tested on several high-end events and the 30 contour appeared to be calibrated well to High-risk worthy tornado outbreaks (RIV >= 4). 30 contours generated by OMEGA contributed to successful forecasts of several high-end tornado outbreaks during the spring 2024 convective season.

During the summer of 2024, 30 contours were verified for eight tornado tools over the period of record for each tool on forecasts generated from either the 00Z HREF, 21Z SREF or 00Z GEFS. All forecasts were examined and each 30 contour identified was recorded. If a High-Risk worthy tornado outbreak (RIV >= 4) occurred on that day, and at least one EF3 tornado associated with the High-Risk worthy tornado outbreak occurred inside the 15 contour that surrounded the 30 contour, or the EF3 tornado occurred within 225 statute miles of the 30 contour, then the 30 contour was considered a success. If the described condition was not satisfied, the 30 contour was a false alarm.

This objective technique was used to create the chart in Figure 24. The Probability of Detection (POD), False Alarm Rate (FAR), and Critical Success Index (CSI) is shown for each tool.

OMEGA and STEP had a CSI more than double that of the other tools. When adding Loken to STEP to create OMEGA, the CSI for 30 contours increased to 0.40. For OMEGA on RIV >= 4 events, STEP verified six, while Loken verified three. Both generated a 30 contour on one case. When added together, OMEGA had successful 30 contours on 10 total RIV >= 4 events. Adding Loken to STEP made a substantial improvement by increasing POD 21 percent, while only increasing FAR by about 10 percent. While OMEGA and STEP outperformed compared to the other tools, this was expected due to the training set, which included a more active time period with many high-end tornado outbreaks.

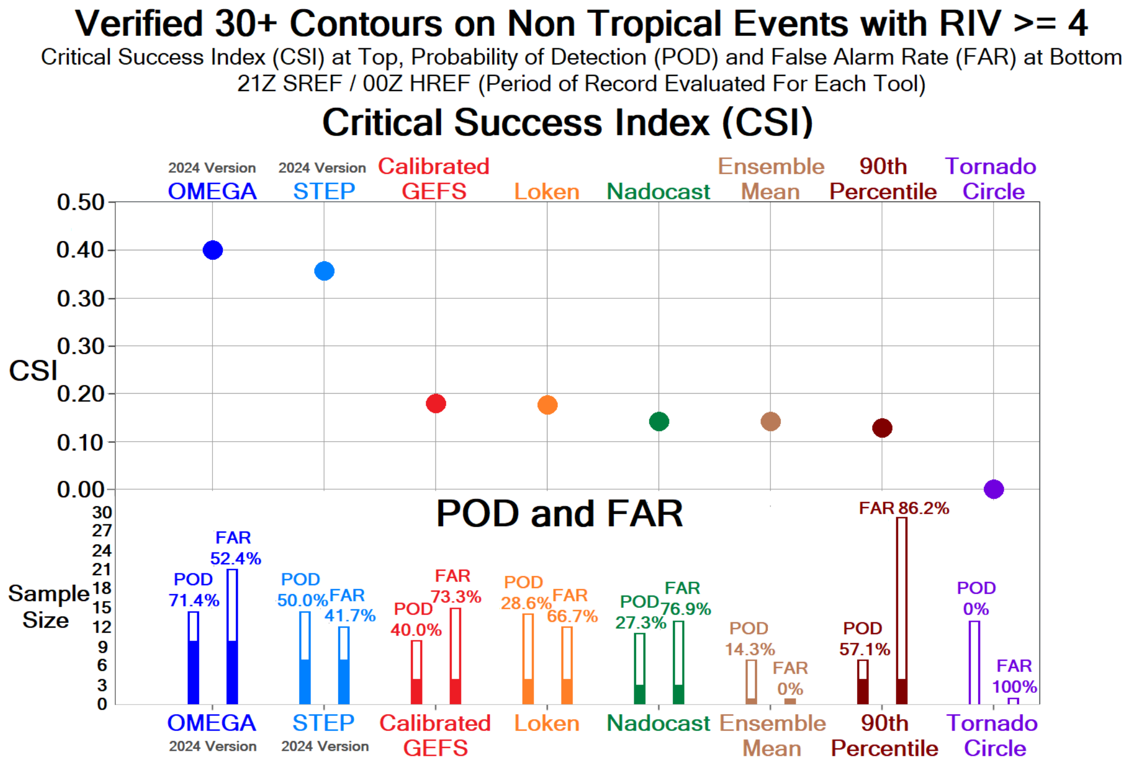

Figure 24. Objective verification of all 30 contours by each tool generated using the 00Z HREF, 21Z SREF, or 00Z GEFS during the tool's period of record. The evaluated forecasts were valid for the 06Z Day 1 Outlook, except for Ensemble Mean and 90th Percentile, which were valid for the 13Z Day 1 Outlook. POD, FAR and CSI is shown for each tool. When adding Loken to STEP to create OMEGA, the CSI on 30 contours increased from 0.37 to 0.40, suggesting the two work well together. The CSI for OMEGA and STEP was more than double any of the other tools. When adding Loken to STEP to create OMEGA, the POD increased 21%, while the FAR only increased about 10%.

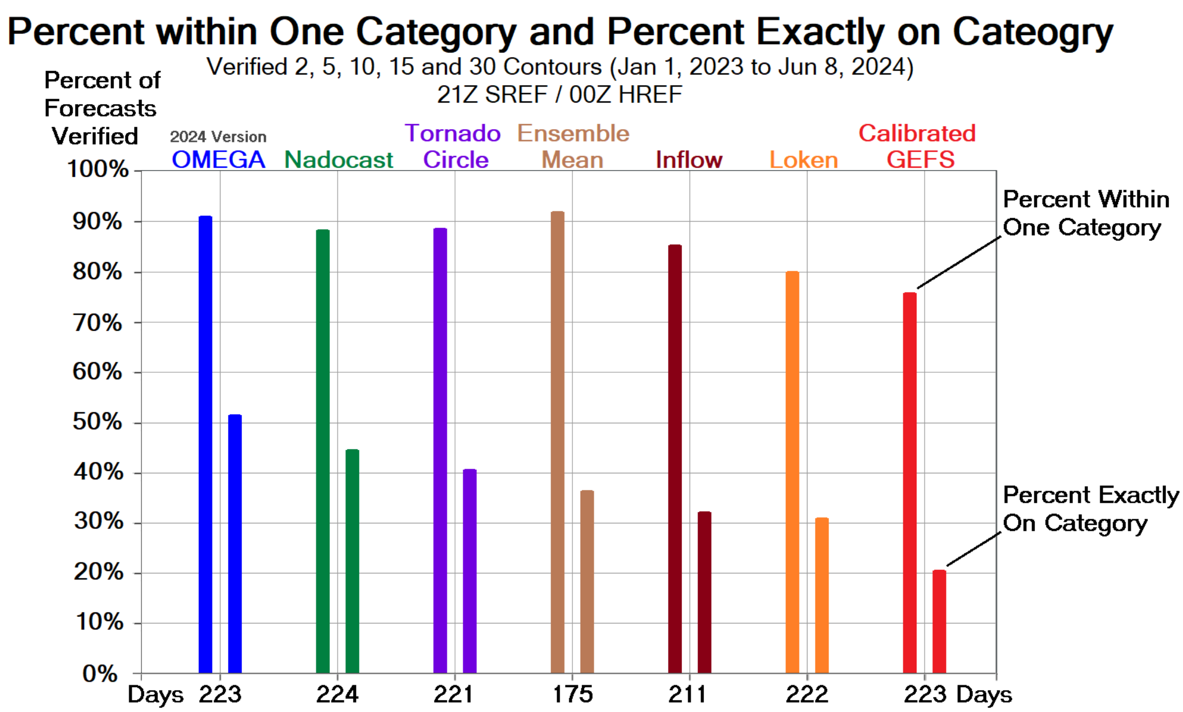

Figure 25. Objective verification of all contours by each tool generated using the 00Z HREF, 21Z SREF, or 00Z GEFS for the period from January 1, 2023 to June 8, 2024. The evaluated forecasts were valid for the 06Z Day 1 Outlook, except for Ensemble Mean and Inflow, which were valid for the 13Z Day 1 Outlook. The contour verification system in Table 4 was used to verify each forecast. The longest vertical column for each tool is the percent of forecasts "within one category", and the short vertical column is the percent of forecasts "exactly on the category". While Ensemble Mean was unavailable for 50 of the days, it lead in the "percent within one category". OMEGA lead in the "percent exactly on category".

Contour Verification System

30+ Contour - RIV >= 4.00

15 Contour - RIV = 1.00 to 3.99

10 Contour - RIV = 0.36 to 0.99
10 Contour - RIV = 0.07 to 0.35 and >= 10 Tors with No Sig, or 5 to 9 Tor with >=1 Sig

5 Contour - RIV = 0.02 to 0.35 and 3 to 9 Tor with No Sig, or 1 to 4 Tor with 1 Sig

2 Contour - RIV = 0.01 to 0.05 (1 or 2 Tors with No Sig)

Table 4. A contour verification system for the results in Figure 25. The system uses RIV only for 30 and 15 contours, while using RIV and magnitude qualifiers for 10, 5 and 2 contours.

Figure 25 shows verification of all contours for seven tornado probability tools from January 1, 2023 to June 8, 2024. For each tool, all available forecasts were generated by either the 00Z HREF, 21Z SREF or 00Z GEFS. The evaluated forecasts were valid for the 06Z Day 1 Outlook, except for Ensemble Mean and Inflow, which were valid for the 13Z Day 1 Outlook. There were 225 days evaluated, when at least one tornado occurred in the continental U.S.

For each tool, all forecasts in the period were examined and the maximum contour over the continental U.S. was recorded for each day. Most of the max contours were entirely over the U.S. mainland, but when one was over water, it was only verified as a maximum if it touched the U.S. coastline. The contour verification system in Table 4 was used to verify each tool's maximum contour. For each tool, the long vertical column in Figure 25 is the percent of forecasts "within one category", and the short vertical column is the percent of forecasts "exactly on the category".

For OMEGA, the 2023 version was run for each day from March 13, 2023 to June 8, 2024. For 27 days at the start of 2023, OMEGA was calculated manually, replicating the code to maintain objectivity. Out of the 225 days, the maximum contour for two daily forecasts could not be determined with certainty and were not included. After the maximum contour was recorded for each day, a contouring adjustment was applied using thresholds for the 2024 version. The 2024 version of OMEGA is planned for release in December 2024.

Considering contour verification for all tools relative to reported tornadoes, Ensemble Mean was the best for "percent within one category". In the period, Ensemble Mean was not available for 50 days, which was a limitation. OMEGA was the best for the "percent exactly on category", with just over 50 percent of the daily forecasts verifying successfully.

During 2024, the best forecast by OMEGA was for April 27, 2024 (Figure 26). For that day, OMEGA contributed to a Moderate Risk that was issued over parts of Oklahoma, north Texas and southeast Kansas. A High Risk was strongly considered but was not feasible due to the double upgrade that would have been necessary. The event verified as High-Risk worthy, with RIV of 5.58. Figure 26, shows the 15Z OMEGA forecast, which had a 30 contour over east-central Oklahoma. On the left side of the graphic, a radar depiction from KTLX shows several tornadic supercells ahead of a line extending across east-central Oklahoma. These storms produced three killer tornadoes, with one EF4 and two EF3s. This tornado cluster occurred just to the south of the OMEGA 30 contour.

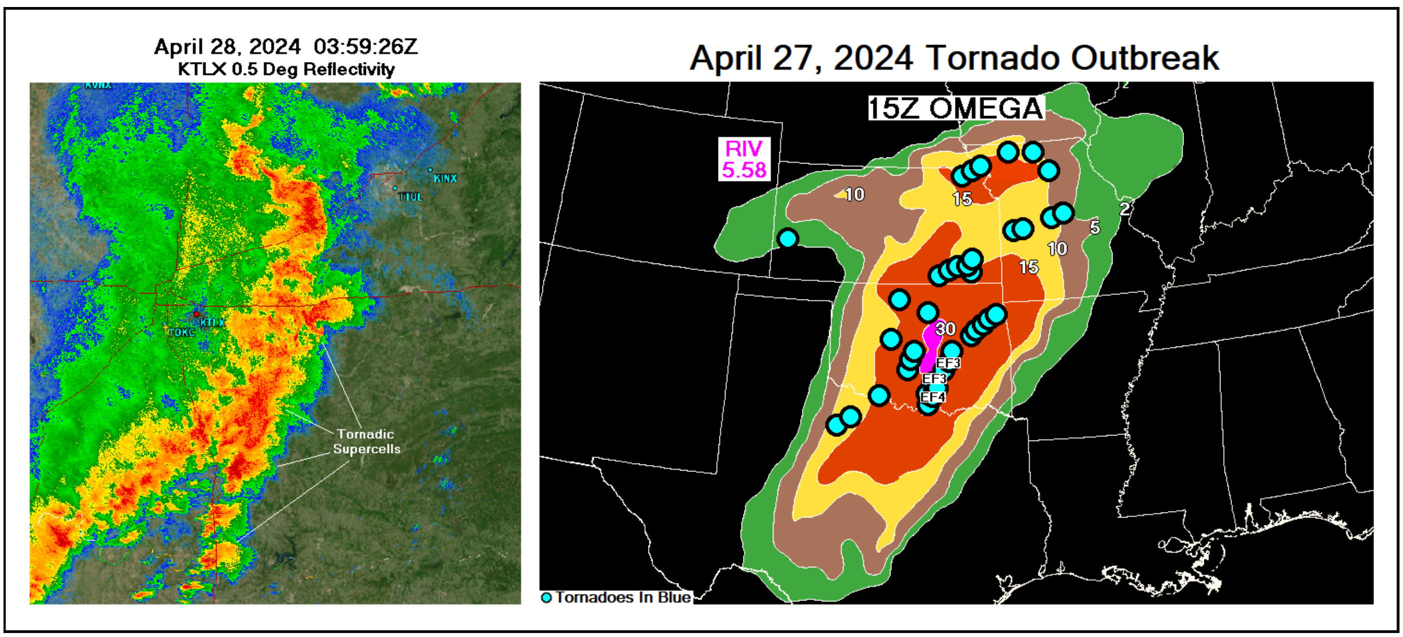

Figure 26. In 2024, OMEGA had its best forecast for the April 27, 2024 tornado outbreak. This OMEGA forecast was generated at 15Z and had a 30 contour in east-central Oklahoma, where three killer tornadoes occurred (2 EF3s and 1 EF4). The radar image from KTLX (at left) shows several high impact tornadic supercells ahead of a line across east-central Oklahoma.

5. Conclusion

The first goal of the OMEGA project was to establish a way to compare tornado outbreaks based on the potential to negatively impact the community. The second goal was to develop a forecast method to help forecasters to better discriminate High Risk tornado outbreaks from Moderate Risk events. The third goal was to develop a tornado probability guidance that would forecast all tornadoes well, and maximize performance on high-end tornado outbreaks.

To address the first goal, Risk Impact Value (RIV) was developed over a period of 2 1/2 years. RIV consists of an algorithm that uses tornado data from an event to generate a number that estimates the total negative impact that a tornado outbreak has on the community. While RIV considers all tornadoes for the calculation, RIV heavily weighs violent tornadoes and long-track tornadoes. RIV >= 4 appears to be a good threshold to verify High Risk issuances.

Three reasons listed to use RIV >= 4 as a High Risk threshold.

1) RIV >= 4 events have an annual return frequency of about three, which corresponds relatively closely to the SPC historical High Risk issuance rate. Using RIV >= 4 keeps High Risk issuance consistent historically.

2) RIV >= 4 events are rare, and unlikely to impact the same area of the U.S. more than one time per year. By issuing High for RIV >= 4 events, these forecasts are issued frequently enough to have the maximum impact concerning a life-saving public response, but not too frequently to desensitize the public.

3) By setting the verification bar at a reasonable level, it is more likely that the historic once-in-a-decade tornado outbreaks will be in High Risk when they occur.

A preliminary proposal of guidelines for SPC High Risk issuance include

1) High Risk or Heavily Worded Moderate Risk Is Appropriate for RIV >= 4 Events (High-Risk Worthy) Depending Upon Forecast Uncertainty

2) POD for SPC High Risks - Goal Should Be To Verify Two Out of Every Three High Risk Forecasts (67%).

3) FAR for SPC High Risks - Goal Should Be To Allow For One False Alarm Out of Every Three High Risk Forecasts (33%).

4) Missed Event Rate For SPC High Risks - Goal Should Be To Allow For One Missed Event Out of Every Three Events with RIV >= 4 (33%).

The second goal of the OMEGA Project was to develop a forecast technique to help discriminate High Risk events from Moderate Risk events. It was found that a fast-moving 500 mb jet translation speed is favorable for high-end tornado outbreaks if the environment ahead of the jet is supportive. For 500 mb jet translation speed, a threshold of 40 knots was an effective low-end threshold to discriminate high-end tornado outbreaks from lesser events. An analysis method for analyzing the 500 mb jet has been documented for consistency.

To satisfy the second goal, a webpage called the Tornado Outbreak Indicator (TOI) was developed. To use the webpage, the forecaster inputs data from the 500 mb jet, which then generates guidance to help the forecaster better anticipate High-Risk worthy tornado outbreaks. In addition to a TOI value, the webpage generates a probability of verifying High Risk based on the 500 mb jet information and maximum STP across the expected tornado outbreak area. This High Risk probability has been calibrated over 36 events and appears to be reliable.

The third goal of the OMEGA project was addressed by developing a tornado probability tool by combining the Loken Tornado Probability with the Significant Tornado Event Probability (STEP). The resulting tool is called the Outlook Machine Ensembling Algorithm (OMEGA). The 2023 version of OMEGA contributed to several successful SPC tornado outlooks during the 2024 convective season. Verification of 30+ contours for High Risk forecasts shows that OMEGA prominently stands out among the tornado tools with a Critical Success Index score of 0.40. Verification of all contours (2, 5, 10, 15 and 30) for OMEGA had OMEGA leading in the "percent exactly on category".

In the future, additional analysis is planned to show the significance of SPC High Risks, relative to their potential to create a strong community response. Also in the future, the OMEGA team is planning to issue verification maps of various tornado probability tools to assist SPC forecaster evaluations. Finally, plans are to continue to improve the OMEGA tornado probability tool by moving the input data to a more reliable atmospheric model, and to introduce a new machine-learning component into the OMEGA process to increase performance.

6. References

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