Current Weather Studies 11
Tornadoes

From the severe weather outbreak on 31 March 2023, we will isolate individual thunderstorms and their characteristics that lead to tornadoes. Before focusing attention on the specific conditions, though, we discuss a broader analysis of tornadoes and their statistics.

Spring 2023 Tornadoes

Tornado statistics are compiled by NOAA's Storm Prediction Center (SPC), part of the National Centers for Environmental Prediction (NCEP). As of 6 April 2023, the preliminary number of tornado event days is 38, a sum which is above normal for this point in the year. An **event day** is a calendar day when a tornado observation is listed by the SPC. It does not account for multiple tornadoes on a single day, for instance, if 10 tornadoes are reported, it is still only reported as one event day.

Spring is the most active season for tornadoes, with May typically the most active month. Last year in 2022, May did indeed stand out as the month with the greatest number of event days (23), but July was not far behind with 20 event days. The full listing of event days by month for the past two decades is updated daily and available from the SPC.

The SPC archives storm reports for the U.S., as well as all of their forecast discussions and graphical products. **Figure 1** shows tornado activity for 2023; so far, it was initially quite active then waned a bit before picking up again in March. Unfortunately, tornadoes produced fatalities in every month so far this year; such tornadoes are termed *killer tornadoes*. Killer tornadoes are tallied by the SPC.

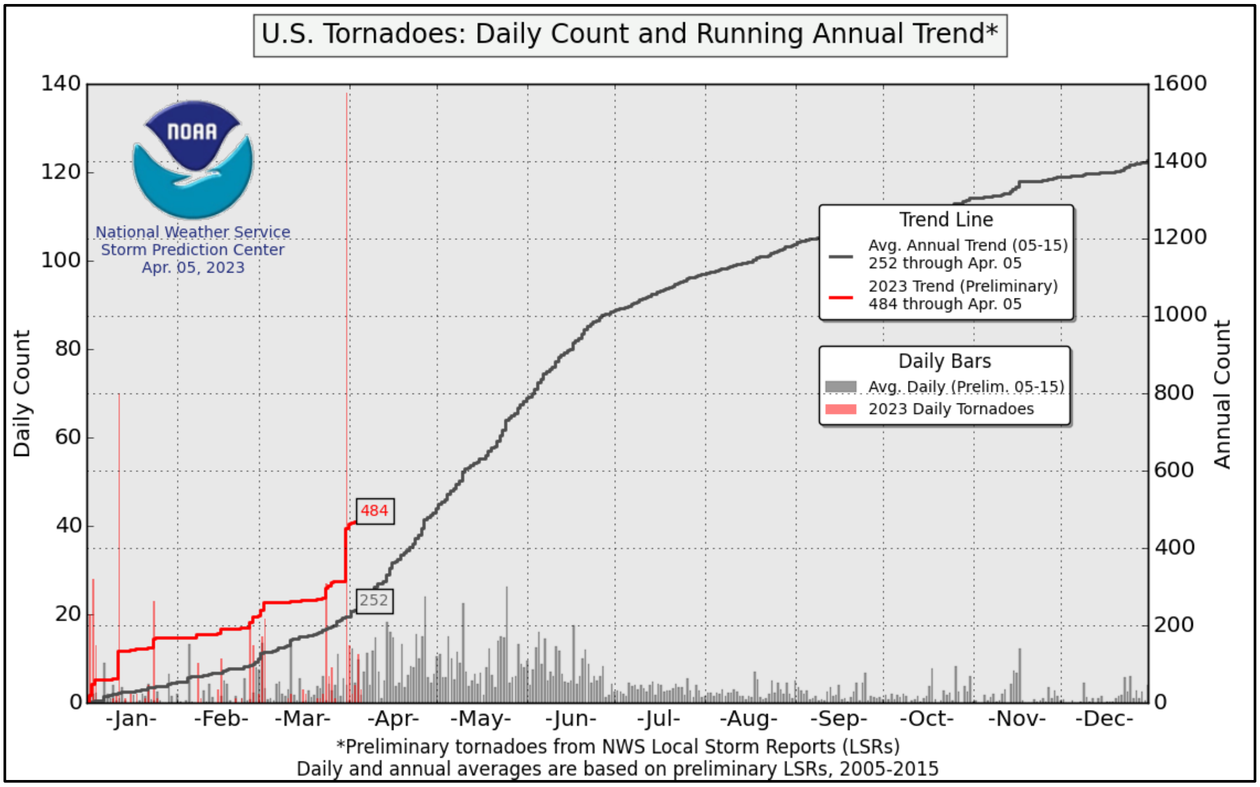


Figure 1. SPC tornado reports for 2023 from NWS Local Storm Reports as of 5 APR 2023. Daily and annual averages are based upon preliminary from 2005–2015. Vertical faint dotted lines mark the end of each month. [SPC]

Data in Figure 1 are still considered preliminary. The NWS must go out on-site and confirm that the damage matches the reports, so SPC reports are considered preliminary as it can take days to weeks to complete.

1. For the first three months and first few days of April in 2023, there were 38 event days with 484 total preliminary tornado reports. On average, each event day had almost ______ tornadoes reported.

   a. 3
   b. 7
   c. 13
   d. 20

2. The black line in Figure 1 represents the running total of the average number of tornado reports for 2005–2015. When compared with the 2023 red tally line, it is evident that this year is currently ______ the longer-term trend.

   a. less active than
   b. more active than

3. Along with the tally line, Figure 1 has a daily tornado count. Individual bars show that some event days have more tornadoes than others. Most of the months so far in 2023 have been very active with big event days. The only month with fewer than 20 tornadoes on a single day was ______.

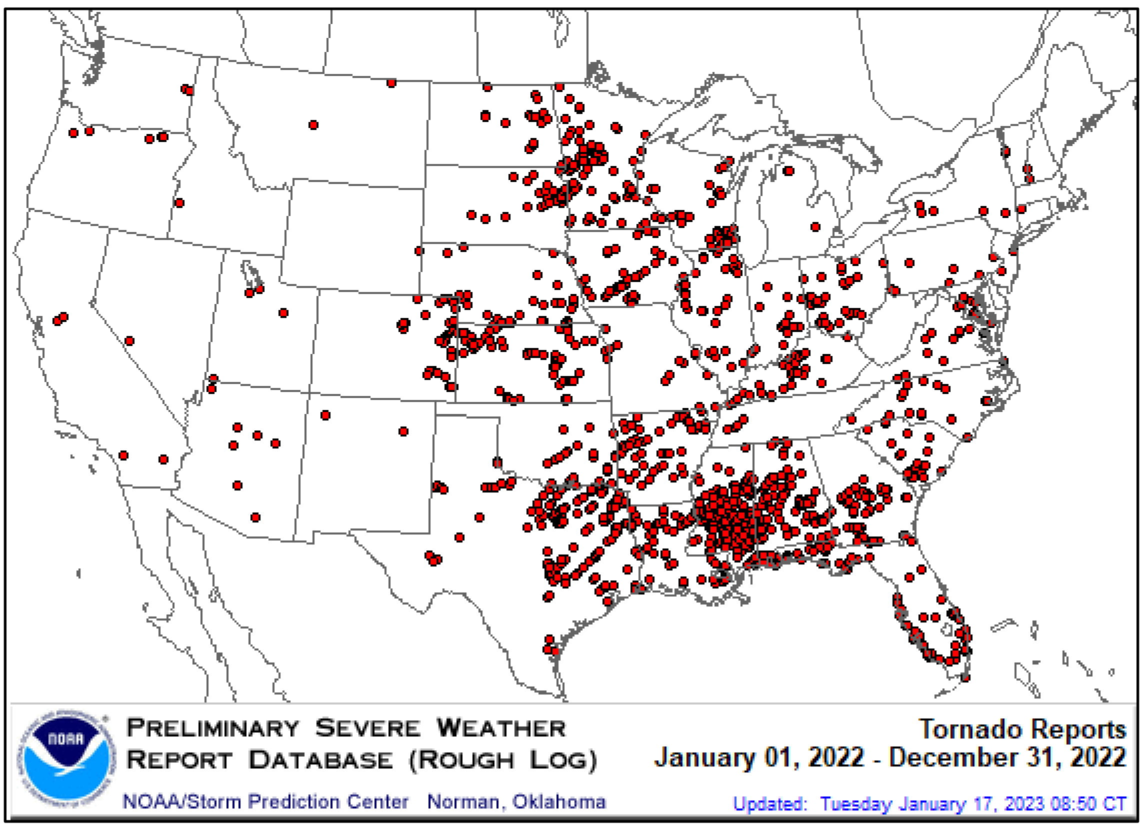
   a. January
   b. February
   c. March
   d. April

4. There is one spike in Figure 1 that stands out, with nearly 140 reported tornadoes on 31 March 2023. That single day represented roughly ______ of the total number of tornadoes in 2023. While this may not occur every year, it is more likely in the spring season.

   a. 8%
   b. 11%
   c. 17%
   d. 28%

2022 Tornadoes

Figure 2 shows a preliminary count and daily tally of tornado reports for all of 2022.



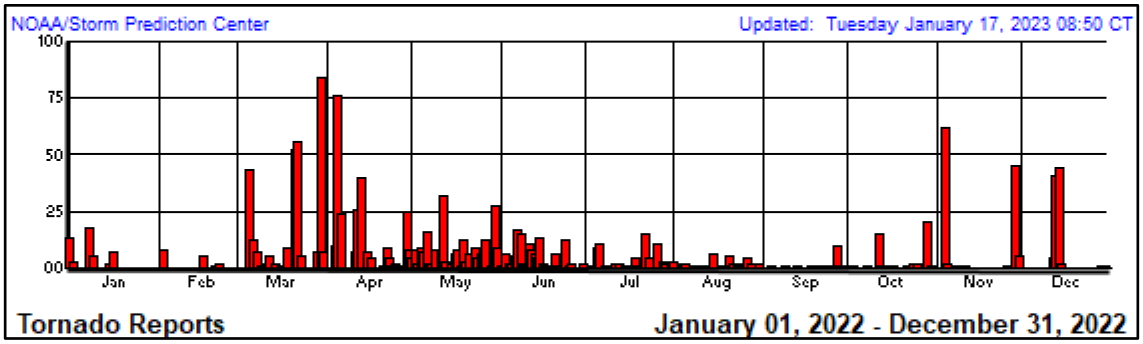


Figure 2. Map and log of 2022 Tornado Reports and the monthly chronology thereof. [SPC]

5. In 2022, despite the anomalous number of event days in the months of November and December, the month that stands out dramatically as having the largest number of reported tornadoes on individual days was ______.

   a. March
   b. May
   c. September

6. Another standout observation from 2022 (Figure 2) was that nearly every state in the lower 48 contiguous states reported a tornado. Which of the following states, however, did NOT report a tornado in 2022?

   a. Arizona
   b. New York
   c. Idaho
   d. Maine

Thunderstorms and Tornadoes

As seen in Figure 1, there was an extensive tornado outbreak on 31 March 2022. **Figure 3** depicts the surface weather conditions at the early part of the day. It is almost a week after the 24 and 25 March 2023 maps in *CWS 10*. The pattern here shows similarities to that previous study, most notably with another potent low-pressure system emerging out of the Plains states. There are, however, some important differences. This cyclone has a much more distinct warm sector with an easily identifiable warm front. Moreover, the central lowest pressure in this system is already much lower than previous week's iteration.

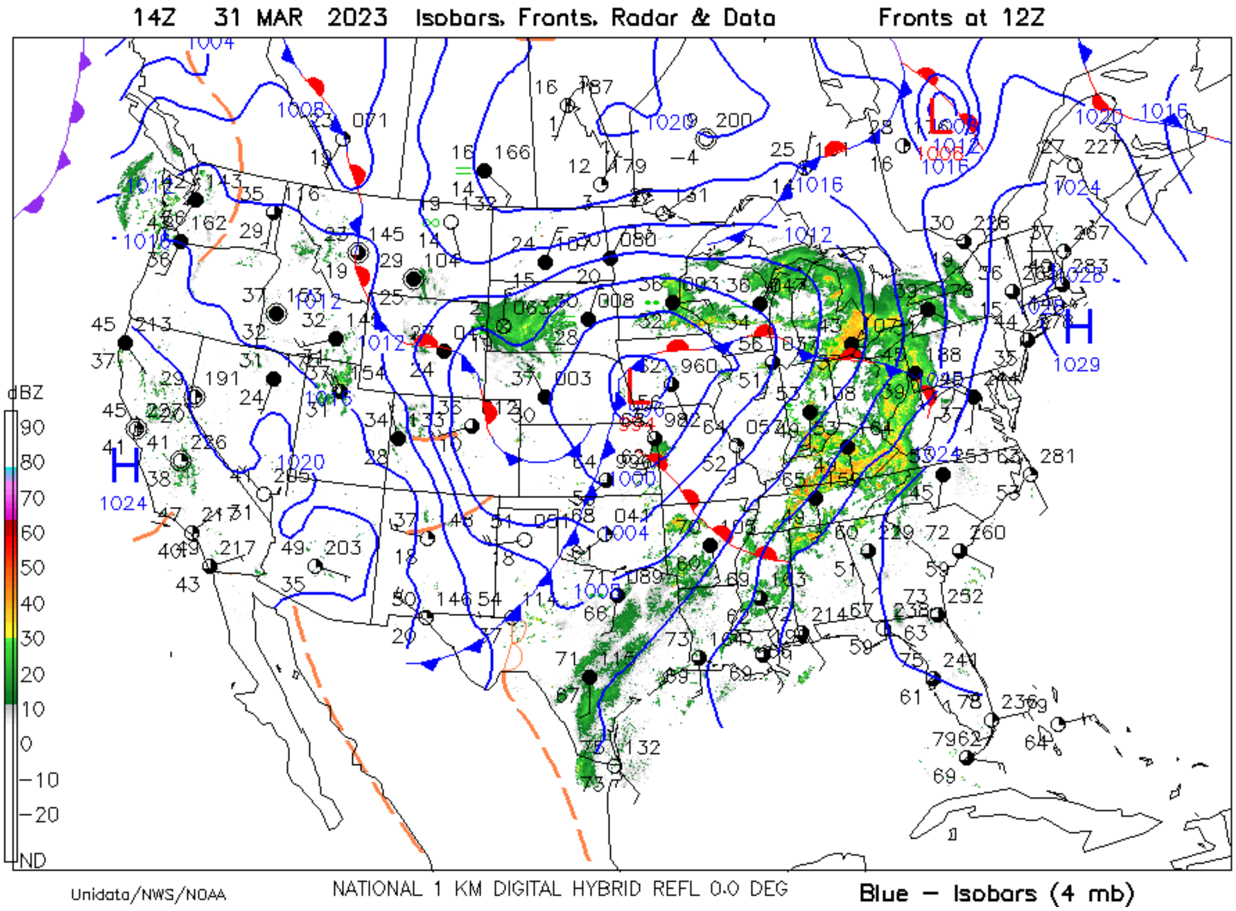


Figure 3. Analyzed weather map with isobars, fronts, radar, and data for 14Z 30 MAR 2022. Fronts were analyzed two hours prior to other data.

One significant ingredient for thunderstorms to form from larger atmospheric dynamics is a frontal boundary with large gradients in temperature and/or moisture on either side of the front. Significant moisture (high dewpoint temperatures) differences in the warm air mass (warm sector) ahead of the cold front can be observed in Figure 3, as well as a robust thermal gradient.

7. Compare the temperature in Little Rock, AR (70°F) in Figure 3, within the warm sector of the approaching low, to the temperature in Amarillo, TX. There was a ______°F difference between these two stations.

   a. 9
   b. 19
   c. 21
   d. 37

Figure 4 depicts the surface weather features 8 hrs after Figure 3 as the low intensified further, dragging a blustery cold front through Texas and forcing a warm front northeastward. The nascent thunderstorms from Figure 3 had been supercharged by the daytime heating, some of which were forming into discrete cells (supercells) and others into semi-linear formations called squall lines. These squall lines (evident in Figure 4) surged out ahead of the cold front and had some bowing, which is known to also spin-up tornadoes. Radar evidence of tornadoes imbedded in this system is presented later, showing one particular thunderstorm with an embedded, radar-indicated tornado in Arkansas.

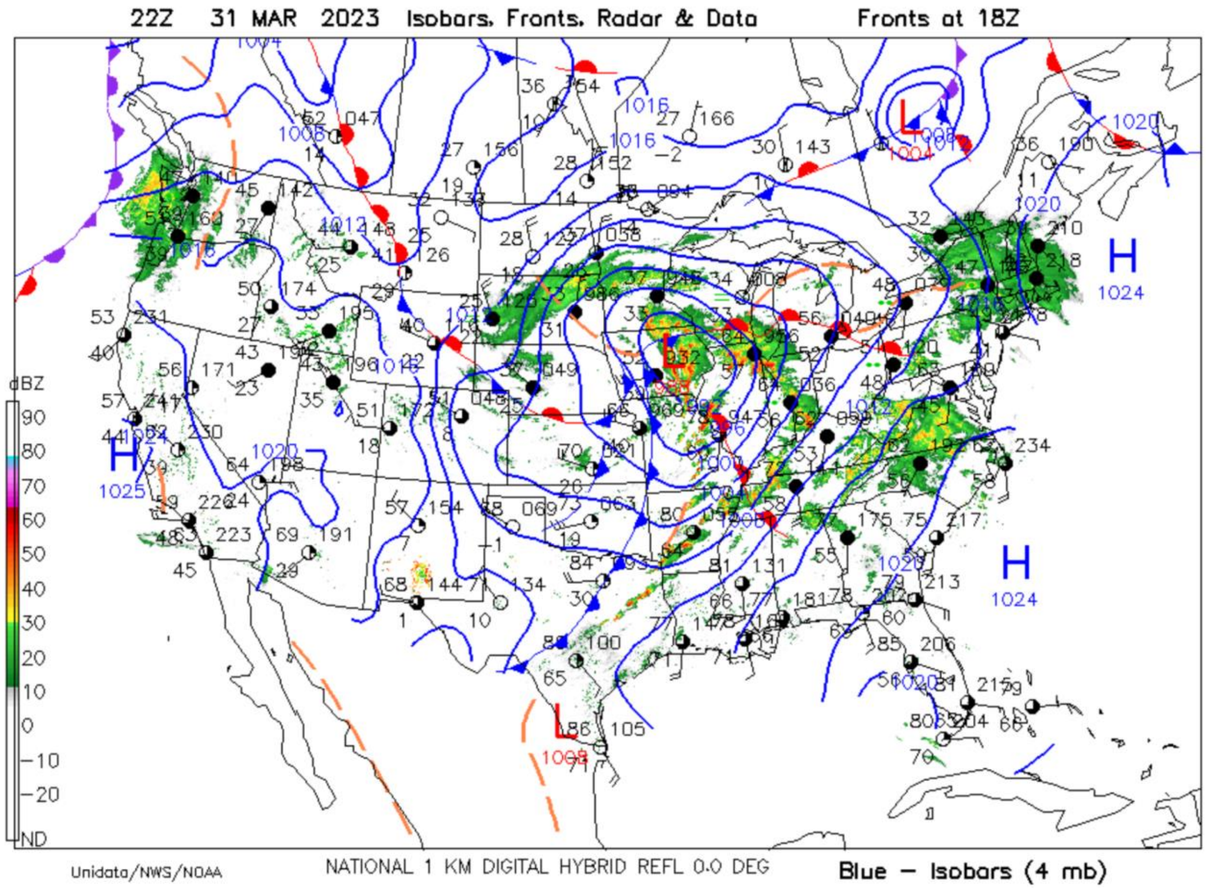


Figure 4. Analyzed weather map with isobars, fronts, radar, and data for 22Z 31 MAR 2023. Fronts were analyzed four hours prior to other data.

8. The robustness of this low was more evident in Figure 4, with closer isobar spacing around the central lowest pressure. In fact, Des Moines reported a 993.2 mb value, which was ______ than the observation in Des Moines, IA in Figure 3, validating the greater intensity.

   a. lower
   b. higher

A thunderstorm with a high likelihood of producing a tornado will also rotate about its own vertical axis. The energy from the parent thunderstorm’s rotation can be translated down to the ground. Once a rotating funnel cloud produced from that rotation extends from the parent thunderstorm and contacts the ground, a tornado is “born.”

A mechanism that helps initiate the rotation of individual thunderstorms is *wind shear*. Wind shear can result from a change in wind direction and/or wind speed with height. **Figure 5** shows the direction and speed of winds at the 300 mb constant pressure surface from radiosonde data just two hours after Figure 4.

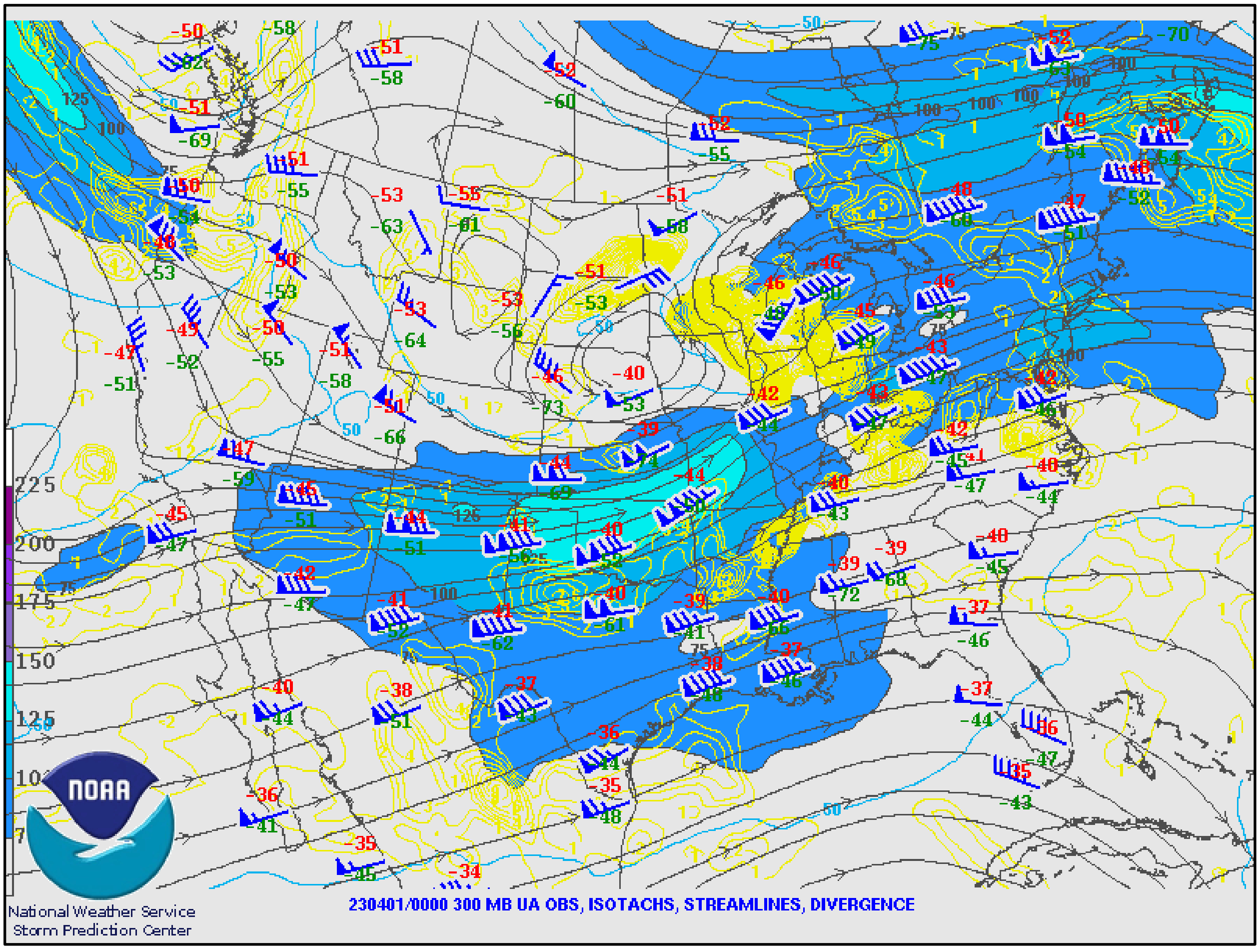


Figure 5. Analyzed weather map with 300 mb upper-air observations, isotachs (blue lines of equal wind speed with shading), streamlines (black connected arrows showing air parcel pathway), and divergence (in yellow, showing net outflow of air) for 00Z 1 APR 2023.

9. Ahead of the cold front and within the warm sector of the cyclone, such as in St. Louis, MO, winds at the surface (Figure 4) predominantly come from the south. However, when examining winds aloft (Figure 5) in the same region (e.g., Lincoln, IL and Kansas City, MO), the dominant wind direction was from the ______.

   a. southwest
   b. southeast
   c. northwest
   d. northeast

10. In addition to the direction change with height, there is also a change in speed. Figure 4 shows St. Louis reported wind with one long feather, while in Figure 5, nearby winds aloft (at nearby Springfield, MO) with two flags, three long feathers, and one short feather. Therefore, in this cyclone's warm sector, from these data in Missouri, the wind speeds from the surface to 300 mb increased by about **______** kts.

    a. 75
    b. 90
    c. 110
    d. 125

Another ingredient for severe weather, and tornadoes, is the effective outflow of air aloft. We can measure by analyzing divergence aloft. Although a complicated procedure to quantify, you can visualize this concept by examining how winds flow away from one another on an upper-air map, like Figure 5.

11. In Figure 5, both streamlines (black lines) and individual station plots show winds downstream of the trough axis **______** with increasing distance from the Arkansas/Missouri region. In other words, compare the wind directions at Green Bay, WI and Nashville, TN. They have differing vector trajectories. These examples are confirmed with yellow areas of divergence.

    a. merge together
    b. spread apart

Tornado Outbreaks

The SPC alerts the public and its partners of threatening weather by county. For 31 March 2023, numerous tornado watches and advisories were published. **Figure 6** shows a snapshot for this event, essentially the same time as Figure 4.

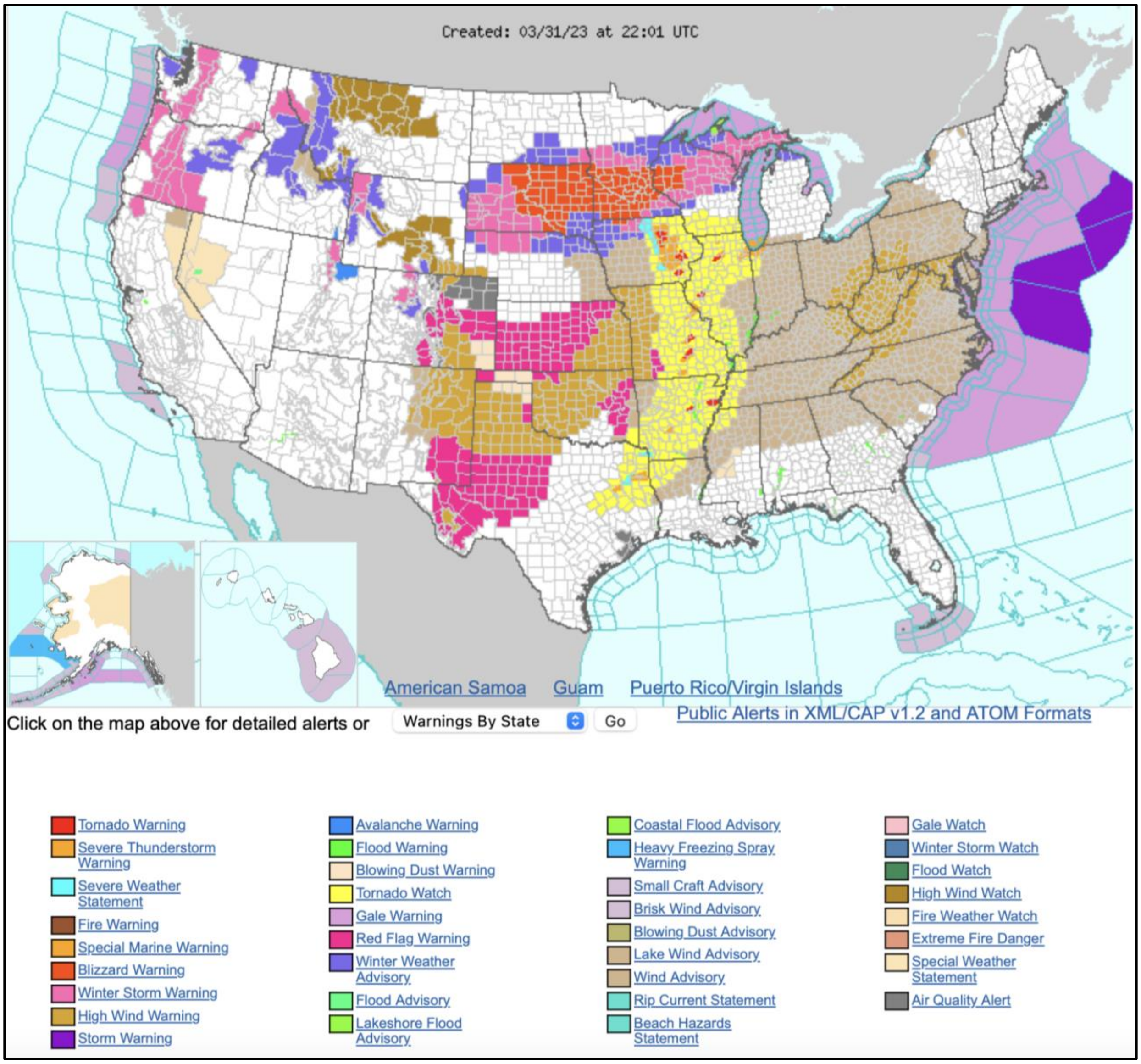


Figure 6. Watches, warnings, and advisories by state and county for 2201Z 31 MAR 2023. [NWS]

12. Figure 6 identifies Tornado Watches (yellow) issued in the same regions we previously examined. There were also multiple active Tornado Warnings (bright red) in these states. In Figure 6, which state is NOT under a Tornado Watch?

    a. Missouri
    b. Nebraska
    c. Iowa
    d. Arkansas

Figure 7 is the track map of one tornado in the 31 March 2023 Arkansas outbreak surveyed by the NWS-Little Rock office. The map in Figure 7 shows a portion of central Arkansas and the Little Rock metropolitan area. An orange stripe identifies the tornado path's length just north of the city's downtown. This track is one of multiple reported tornadoes that "left their marks" across Arkansas, Tennessee, and Iowa (and other states). For an interactive suite of storm data and spatial perspective from NWS reports, please visit this site.

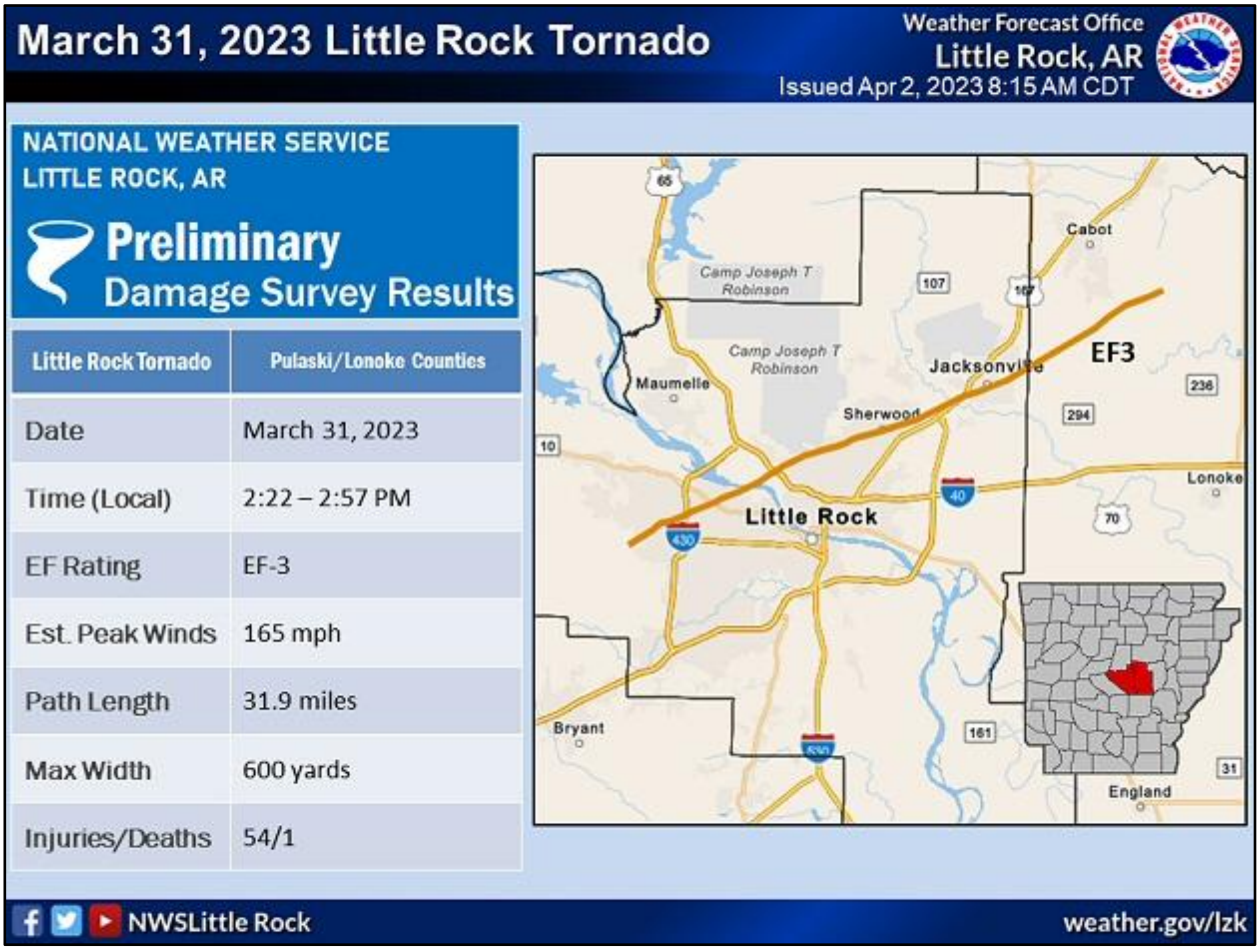


Figure 7. Little Rock tornado path length depiction. The orange banding is derived from both radar and ground-truth evidence. [NWS]

The NWS-Little Rock office provided additional statistics for this tornado on the left side of Figure 7, which are characteristic of moderate-to-strong southeastern tornadoes.

13. From the elapsed time on the ground and length of the damage path, the average ground speed of the Little Rock tornado was approximately ______ mph.

    a. 17
    b. 25
    c. 39
    d. 55

14. From the track in Figure 7, the Little Rock tornado, which first touched down just west of Little Rock, moved toward the ______. This direction aligned with the direction of upper-air winds at that time, such as seen in Figure 5 winds aloft at Springfield, MO.

    a. west
    b. east
    c. northwest
    d. northeast

Tornado path length and width typically increase with increasing EF-scale, so that tornadoes of greater intensity have longer and wider paths. They also are more likely to have faster motion, and thus the potential to do more damage. For more detail on this topic, check out this [AMS journal article] from renowned meteorologist, Harold Brooks.

Figure 8 is a view of both the radar reflectivity (left) and radial velocity (right) at 1924Z (2:24 p.m. CDT) on 31 March from the NWS-Little Rock Doppler radar, scanning central Arkansas for the thunderstorms that produced the Little Rock tornado. The pink star represents the precise site of the radar platform (just north of Little Rock in the center of each frame).

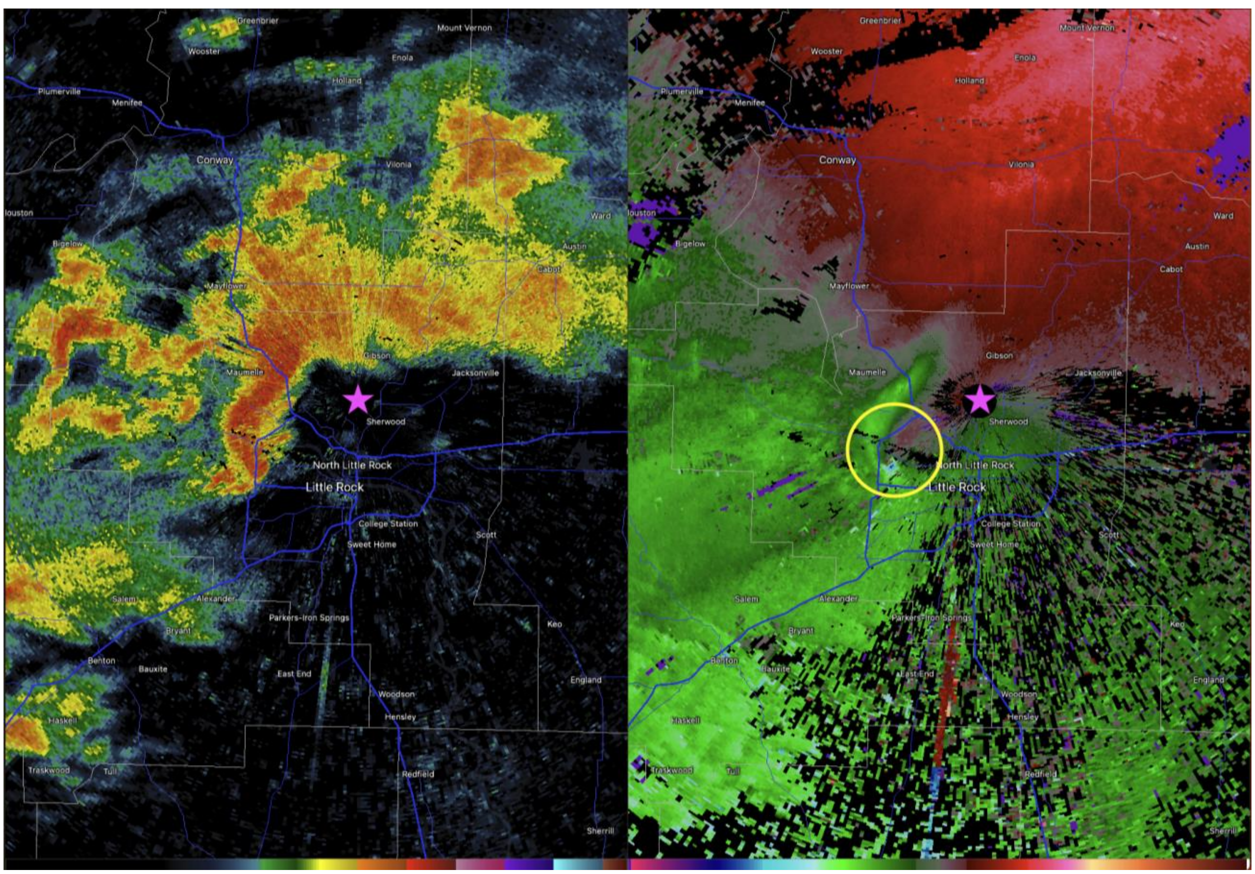


Figure 8. Radar depiction of precipitation at 1924Z 31 MAR 2023 in both reflectivity (left) and velocity (right) modes from the Little Rock, NWS radar site (KLZK) in central Arkansas. [RadarScope]

Watch a multi-loop animation of Figure 8. A larger image of Figure 8 is available at Figure 8-enhanced.

15. The left-panel reflectivity in Figure 8 shows the intense precipitation in red-colored pixels associated with a broken line of severe thunderstorms. The brightest red was just ______ of Little Rock, AR and identified the most intense reflectivity, which is often from large raindrops, hail, or debris in the air. Figure 8 is near the beginning of the tornado's life cycle identified in Figure 7.

    a. southeast
    b. northwest
    c. east

The right view of Figure 8 is the radial velocity from the NWS Doppler Radar. A yellow oval highlights the area of interest and evidence supporting tornadic characteristics. The red pixels immediately juxtaposed to bright green inside the yellow oval displays a *tornadic vortex signature* (*TVS*). Recall from *Investigation 7B* that red denotes Doppler velocities away from the radar site and green toward.

16. Imagine a short arrow pointing from the Little Rock radar site (pink star symbol just north of the Little Rock city label in each frame) toward the red pixel patch inside the yellow oval near Little Rock. Also imagine a short arrow toward the radar site across the immediately adjacent bright green pixels. This pair of arrows represents the radial velocities away from and toward the radar's location for the mesocyclone. Recalling *Investigation 7B*, the pattern of arrows suggests a ______ circulation as seen from above.

    a. counterclockwise
    b. clockwise

Summary

Despite the above-average number of tornadoes so far this year, conditions necessary for a continued uptick in frequency and intensity of tornado formation are very likely to increase. Many of the typical weather features for tornadoes were present in this case study and, as was noted earlier, it doesn't need to be a big event day for there to be perilous conditions. Even seemingly innocuous tornado events pose danger to humans and our built environment. A myriad of these event statistics is archived by the Storm Prediction Center. The SPC also maintains a robust Frequently Asked Questions page.

You can also check for a further description of the EF-scale.