

Mid-South Severe Weather Climatology Study

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The Mid-South is known for its volatile and deadly weather. Ashley (2007) showed that the Mid-South leads the country in the relative frequency of killer tornadoes. Unlike much of the United States, the Mid-South can have severe weather at any time during the year.

There were two primary motivators for this study. The first motivating factor for this study was to educate the public, media and weather forecasters on the frequency and tendencies of severe weather across the Mid-South and to use the results of the study to disprove some severe weather myths/stereotypes that are commonly heard in the region. Some of the myths are “the bluffs protect our area,” “tornadoes do not cross the Mississippi River” and “most tornadoes occur during the day.” The results of this study prove all of these local myths are incorrect. The second motivating factor was to replicate the previous climatology study, entitled “Severe Weather Climatology for the NWSFO Memphis County Warning Area,” by Gaffin and Smith (1995). By replicating this study, 18 more years of severe weather data are added. This includes the tornado outbreaks of March 1, 1997, January 17-22, 1999, May 4-8, 2003, April 2, 2006, the Super Tuesday Outbreak of February 5, 2008, July 30, 2009, May 1-2, 2010 and the Late April 2011 Tornado Outbreak. This study also includes the famous bow echo event from July 22, 2003, locally referred to as “Hurricane Elvis.” In addition to the previous study, calculations were performed for severe weather related to the El Nino Southern Oscillation (ENSO) cycle since it is believed that tornadoes are more frequent during La Nina years. Statistics for daytime/nocturnal events were also calculated due to the elevated number of nocturnal events that occur in the Mid-South compared to other tornado prone regions across the United States. The rest of the paper is broken into five sections: a data and methodology section, a section for each severe weather type (wind, hail and tornadoes) and a conclusion section.

Data and Methodology:

The data in this study were collected across the Mid-South, specifically the National Weather Service Memphis’ County Warning Area, which is comprised of 56 counties in northeastern Arkansas, northern Mississippi, the Missouri Bootheel and West Tennessee. The data for the tornadoes starts in 1870 and the data for the wind and hail starts in 1955. The wind and hail data was collected from the Storm Prediction Center’s “Severe Weather Database Files

1950-2011” (SPC 2012). On the Storm Prediction Center webpage, it is stated that these databases were collected using the National Weather Service Storm Data. Initially, this data included all the reports for the entire country. The program ArcMap 10 was used to eliminate all the data except for the Mid-South reports. These reports compose the final databases for wind and hail.

The tornado database used for this study was the Mid-South Tornado Database (Mid-South Tornadoes 2012). This dataset is composed of data from a couple of sources: the book Significant Tornadoes 1680-1991 and from the National Weather Service Storm Data. This database includes any tornado that has moved across a portion of the Mid-South. Therefore, any tornado that initially formed in neighboring County Warning Areas, or CWAs, is included. As a result, the tornado fatality calculations also include those fatalities that occurred outside of the Mid-South. The Mid-South Tornado database extends from 1870 to 2011. Unfortunately, in the earlier years of the database, there are likely many weak, F-0 and F-1, tornadoes that are unaccounted for. This is because the F-1 tornadoes were counted regularly after 1950 and the F-0 tornadoes were later than that, in the 1970s, due to advances in technology and reporting.

The majority of the calculations for the three severe weather phenomena were performed using formulas and macro scripts in Microsoft Excel. A few calculations required data from outside sources. The first of these was the daytime/nocturnal calculations, which used the sunrise and sunset times from the NOAA Solar Calculations for 35 degrees North, 90 degrees West, a reasonable set of coordinates to use for the Mid-South (National Oceanic and Atmospheric Administration 2012). Any tornadoes, hail reports or wind reports in which the date or time was not known were not included in these calculations. The ENSO calculations were assisted by the Climate Prediction Center’s table entitled “Cold and Warm Episodes by Season” (Climate Prediction Center 2012). These values were assigned to each month in which the tornadoes, hail reports or wind reports occurred. This database only goes back to 1950 so all calculations for tornadoes only include data from 1950 on. The entire wind and hail datasets are included in these calculations since these datasets only go back to 1955.

The calculation of nocturnal tornadoes can be quite complicated. In order to have a truly representative nocturnal tornado dataset, the sunrise and sunset times were used. This idea came from two studies: Ashley, Krmenc and Schwantes (2008) and Kis and Straka (2010). As noted in their study, Kis and Straka (2010) pointed out that there is a bias “towards the later afternoon/early evening tornadoes.” This type of mentality will not work for the Mid-South as proven by one of the more notable tornadoes to strike the Mid-South: the EF-4 tornado that struck Union University in Jackson, Tennessee on February 5, 2008. Earlier studies set time frames in which tornadoes would be classified as nocturnal by using specific times throughout the year; for example, any tornado between 9 p.m. and 7 a.m. would be classified as nocturnal. Using these settings, the tornado that struck Union University would have been counted as a daytime tornado since it occurred at 6:59 p.m. Local Standard Time (LST). All time references in this study use Local Standard Time. However, the tornado struck it was completely dark outside since sunset on that day was 5:32 pm. Kis and Straka (2010) also point out an EF-3 nocturnal tornado from February 5, 2008 that killed 23 people in Tennessee. Since tornadoes often occur

in the Southern United States during the winter months, the sunrise/sunset calculation must be used in order for tornadoes to be appropriately separated into daytime or nocturnal tornadoes.

Another reason to avoid the Great Plains mind of thinking is that the Mid-South and Southern United States are more likely to get tornadoes at any time of the day compared to the Great Plains. This is hinted at in the paper by Kis and Straka (2010). The National Climatic Data Center has done some studies on tornado climatology by hour (NCDC 2012). Their calculations were normalized by dividing by the total number of tornadoes for each region. Therefore, in order to make the comparison between NCDC's calculations and the hourly calculations for the Mid-South, I normalized the hourly data for this region as well. Figure 1 shows the results of this normalization. Figure 2 shows the NCDC hourly tornado plot for the traditional Tornado Alley. Figure 3 shows the NCDC hourly tornado plot for Dixie Alley. As you can see from the figures, the tornado statistics for the Mid-South closely resemble the trend commonly seen across Dixie Alley. Average values over 0.02 during the night and maximum values of 0.10 for the Mid-South plot correlate closely with the Dixie Alley plot. The Tornado Alley plot from NCDC suggests a stronger diurnal trend whereas the Dixie Alley plot indicates a higher percentage of nocturnal tornadoes.

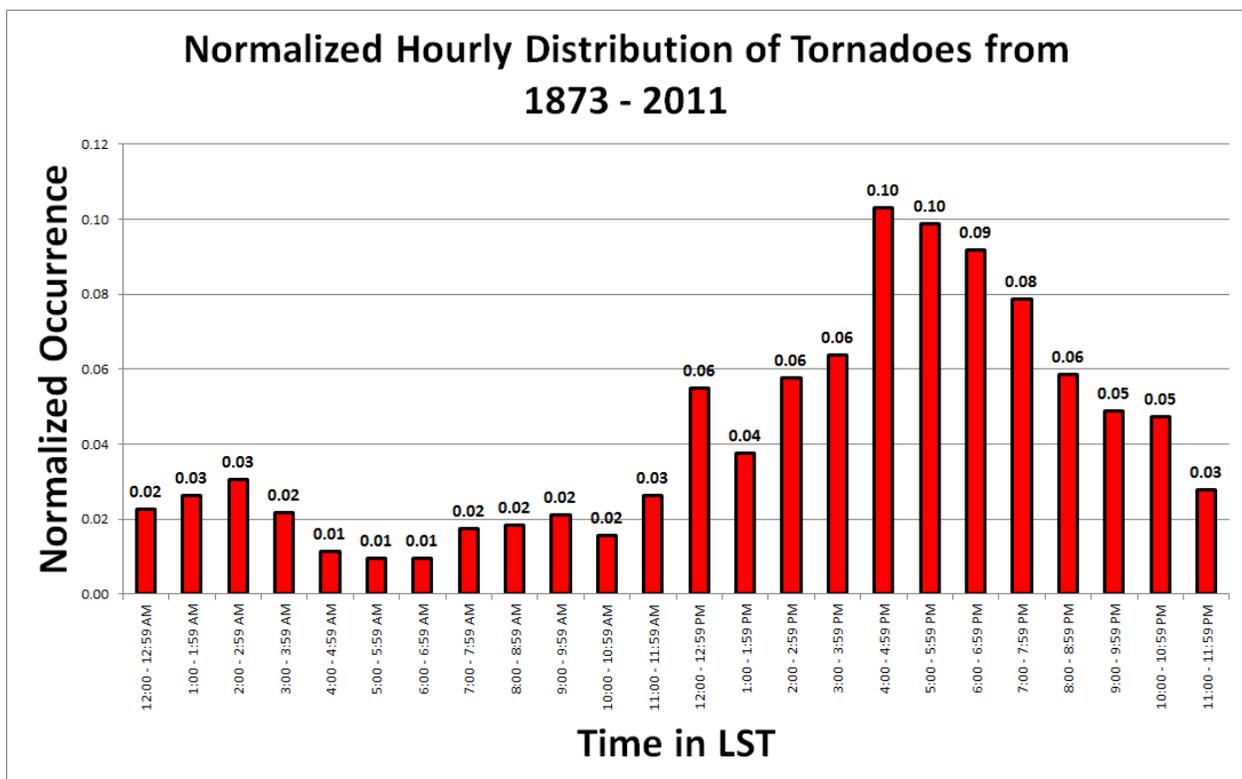


FIG 1. The normalized hourly distribution (in LST) of tornadoes to strike the Mid-South from 1873 through 2011. The number of tornadoes to occur each hour was divided by the total number of tornadoes to strike the Mid-South.

Tornado Time of Occurrence - Tornado Alley (TX, OK, KS, MO, IA, NE, SD)

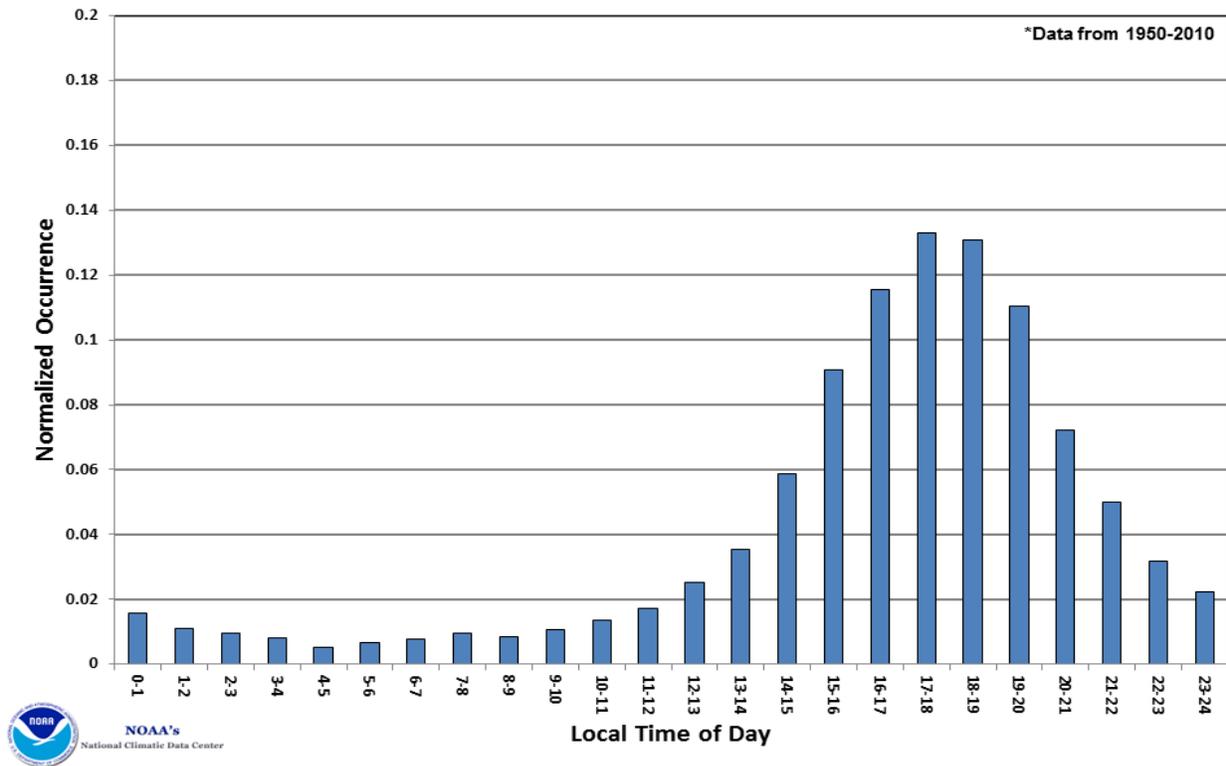


FIG 2. The normalized hourly distribution (in LST) of tornadoes to strike in Tornado Alley from 1950 through 2010. The number of tornadoes to occur each hour was divided by the total number of tornadoes to strike Tornado Alley. For this calculation, Tornado Alley includes the states of Texas, Oklahoma, Kansas, Missouri, Iowa, Nebraska and South Dakota. This plot is from the National Climatic Data Center (NCDC) study on U.S. Tornado Climatology (NCDC 2012).

Tornado Time of Occurrence - Dixie Alley (LA, AR, MS, AL, TN, GA)

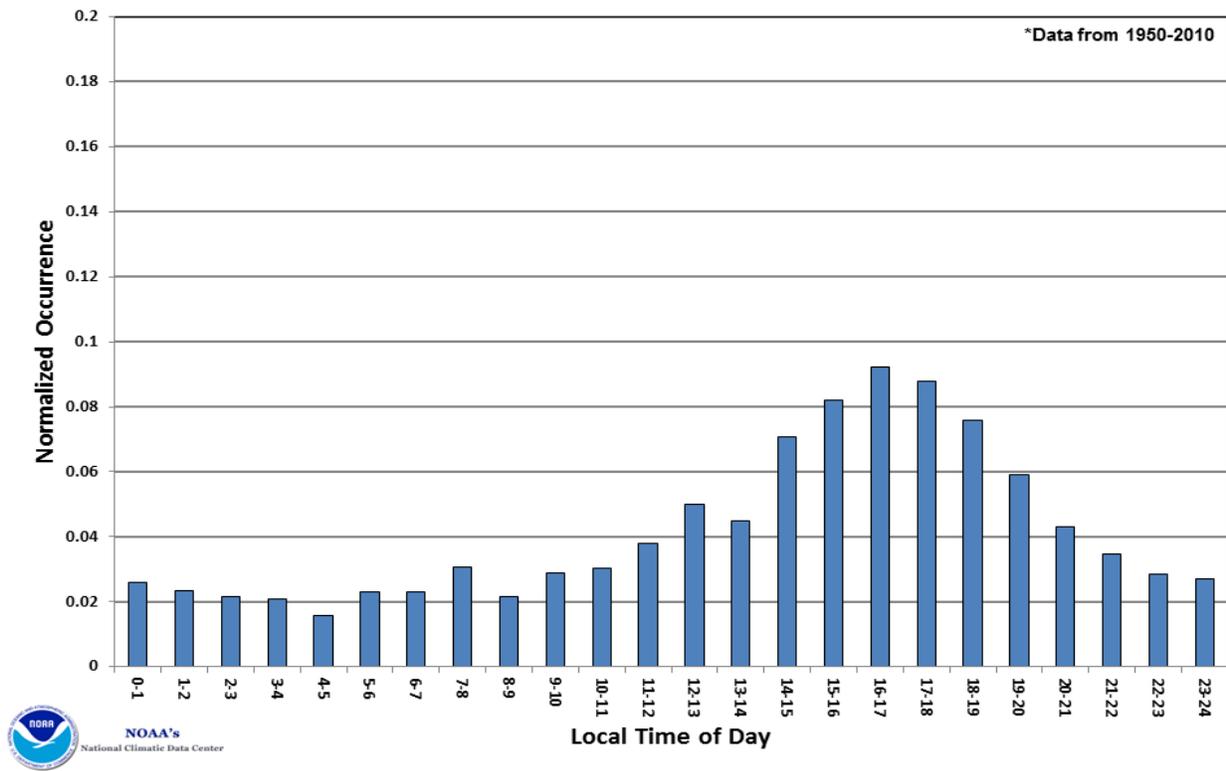


FIG 3. The normalized hourly distribution (in LST) of tornadoes to strike in Dixie Alley from 1950 through 2010. The number of tornadoes to occur each hour was divided by the total number of tornadoes to strike Dixie Alley. For this calculation, Dixie Alley includes the states of Louisiana, Arkansas, Mississippi, Alabama, Tennessee and Georgia. This plot is from the National Climatic Data Center (NCDC) study on U.S. Tornado Climatology (NCDC 2012).

Finally, calculations were also performed to see if El Nino, La Nina or ENSO Neutral conditions brought more severe weather than the others. To explain the calculation, I will use the data for tornadoes. The year 1950 was the first year that records were kept on the ENSO Monthly Index so this is the first year that these values are assigned to the tornadoes. Again, any tornadoes before 1950 are excluded while the entire hail and wind data sets are included since those datasets begin in 1955. Next, the ENSO Index was assigned to each tornado based on the month in which the tornado occurred. The ENSO Index values are based on three months of data so the midpoint month was taken to be the month that was assigned to the tornadoes. Then, the tornadoes were placed into three groups: El Nino, La Nina and ENSO Neutral Conditions. Figure 4 shows what this looks like for the tornadoes.

Distribution of Tornadoes based on ENSO Conditions from 1950 - 2011

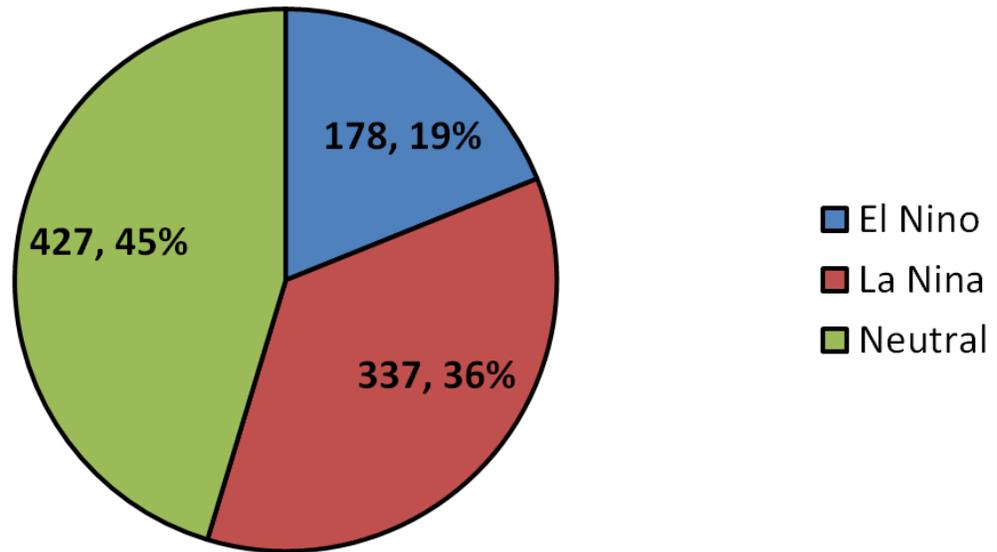


FIG 4. The distribution of tornadoes to strike the Mid-South by ENSO conditions from 1950 through 2011. The tornadoes were categorized as ENSO Neutral (green), La Nina (Red) or El Niño (blue) based on the month in which the tornadoes occurred. The two numbers reflect the count for each category and the percentage of the total.

Figure 4 only represents the number of tornadoes that occurred in each ENSO Index category, not the relative frequency. By this plot, it appears that ENSO Neutral conditions would experience the most severe weather. However, if you look at the distribution of the number of months each ENSO Index contained, you will see why the ENSO Neutral conditions received so many more tornadoes. Figure 5 shows the distribution of months for each ENSO Index from 1950 to 2011 while Figure 6 shows the distribution of months for each ENSO Index from 1955 to 2011. Figure 6 is used for the wind and hail calculations since the wind and hail reports only date back to 1955.

Distribution of Months Based on ENSO Conditions from 1950 - 2011

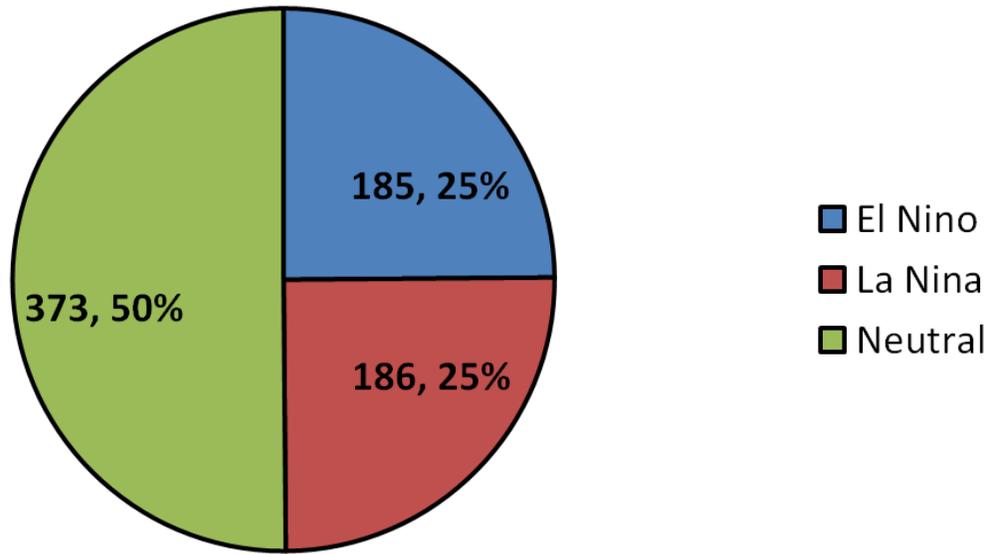


FIG 5. The distribution of the number of months for each ENSO condition based on the ENSO Index from 1950 through 2011. This calculation was done for the tornado climatology since the ENSO Index dataset only go back to 1950 while the tornado database goes back to 1873. The months were categorized as ENSO Neutral (green), La Nina (Red) or El Nino (blue). The two numbers reflect the count for each category and the percentage of the total.

Distribution of Months Based on ENSO Conditions from 1955 - 2011

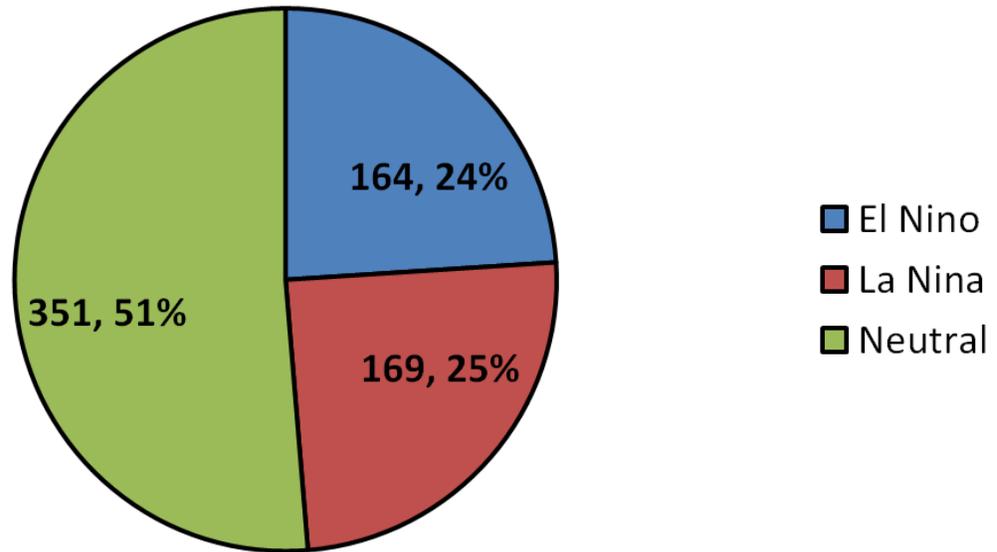


FIG 6. The distribution of the number of months for each ENSO condition based on the ENSO Index from 1955 through 2011. This calculation was done for the wind and hail climatologies since these datasets only go back to 1955. The months were categorized as ENSO Neutral (green), La Niña (Red) or El Niño (blue). The two numbers reflect the count for each category and the percentage of the total.

As you can see for both time periods, around half of the months were classified as ENSO Neutral while the other half of the months were split evenly between El Niño and La Niña. In order to calculate the average number of tornadoes for each month based on the ENSO Index, I simply divided all of the tornadoes for each ENSO Index by the number of months in each ENSO Index condition. Figure 7 represents the result of this calculation. Figure 7 does have a flaw though. This calculation factors in numerous months in which tornadoes did not occur. Therefore, the average number of tornadoes per month is much lower than the actual number of tornadoes that occurred during the months that did receive tornadoes. The same applies for the wind and hail climatology calculations. This concludes the Data and Methodology section. The next three sections will focus on wind, hail and tornado climatologies.

**Which ENSO Conditions Bring More Severe Weather?
Average Number of Tornadoes per Month from 1950 -
2011**

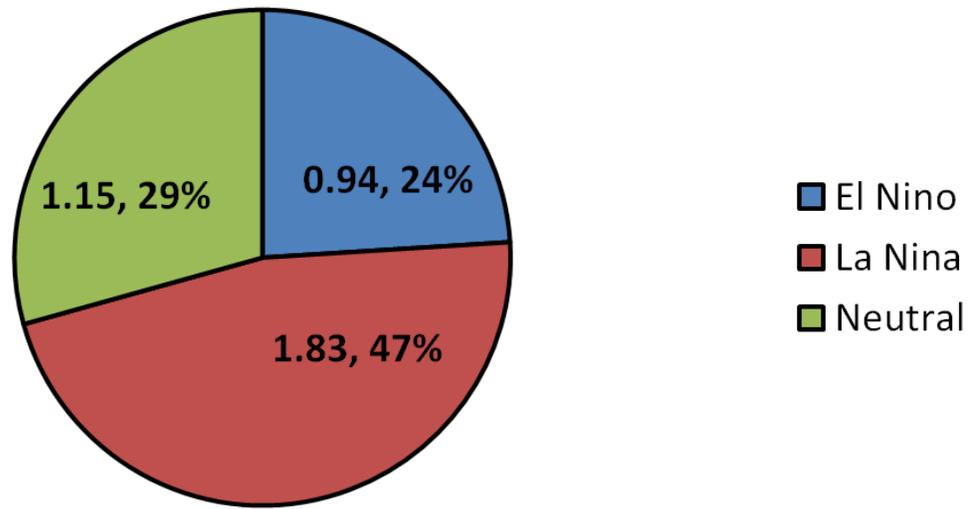


FIG 7. The average number of tornadoes per month to strike the Mid-South by ENSO conditions from 1950 through 2011. The tornado per month averages were categorized as ENSO Neutral (green), La Nina (Red) or El Nino (blue) based on the month in which the tornadoes occurred. The two numbers reflect the average number of tornadoes each month for each category and the percentage of the total.

Wind Climatology:

Damaging wind events are fairly frequent across the Mid-South. Figure 8 shows that the Mid-South has averaged around 35 wind report days each year over the past 30 years. Wind reports continue to go up as a result of a higher population and better reporting networks, not as a result of an increase in damaging wind events. This was also determined by the previous climatology study performed by Gaffin and Smith (1995).

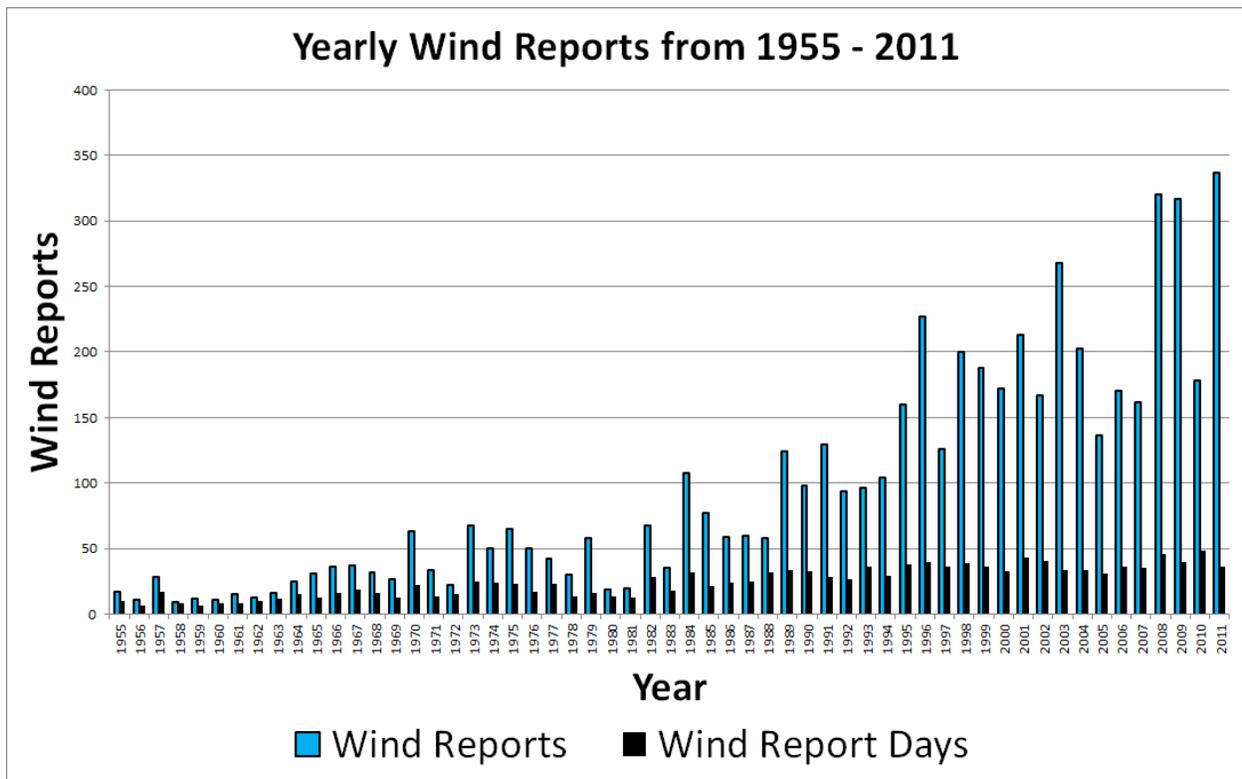


FIG 8. The distribution of yearly Mid-South wind reports from 1955 through 2011. The graph represents total number of wind reports for each year (blue) and the number of wind report days (black).

According to Figure 9, damaging wind events happen most frequently in the month of May. However, April, June and July also receive a significant amount of wind damage reports as well. There is a second peak in damaging wind reports that occurs in November. This is a result of the secondary severe weather season the Mid-South receives in the fall; however, the month of November pales in comparison to the main severe weather season with respect to wind of April through July.

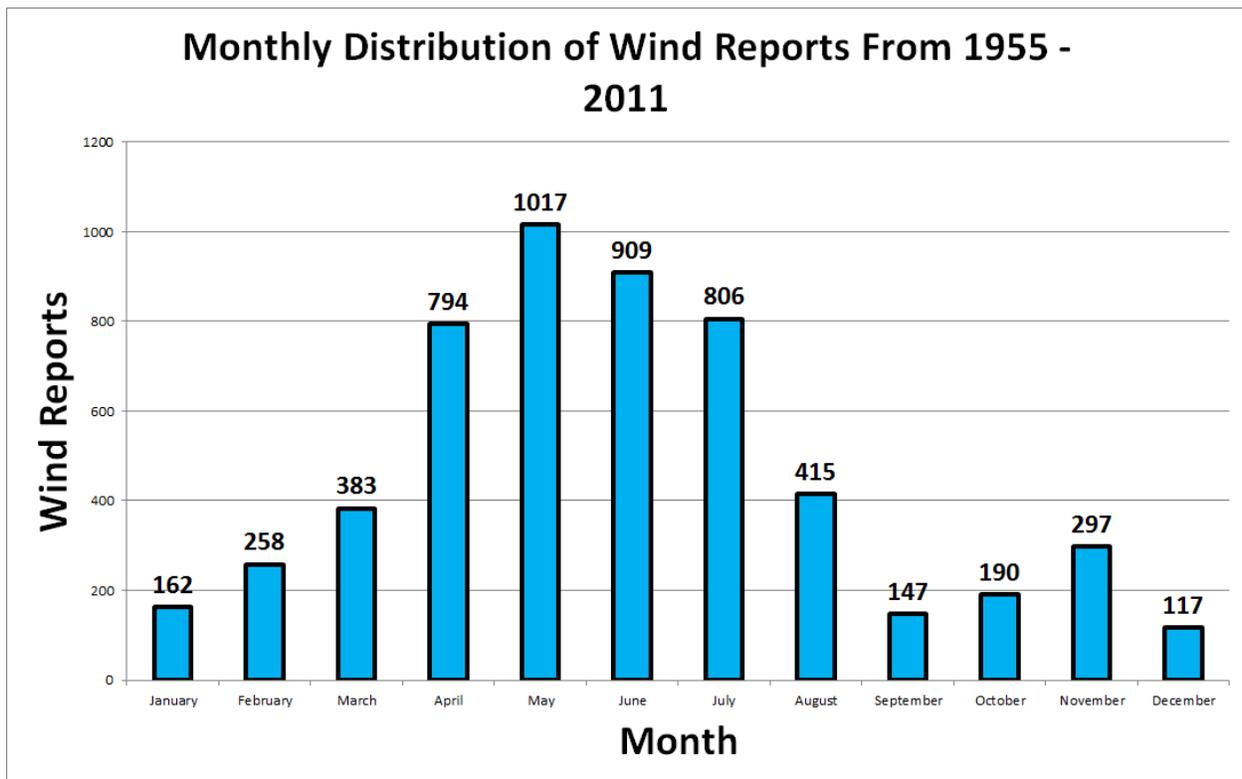


FIG 9. The distribution of monthly Mid-South wind reports from 1955 through 2011. The graph represents total number of wind reports for each month (blue).

Figure 10 shows that the peak time for wind reports is from 5:00 p.m. to 6:00 p.m. The numbers of reports slowly descend as the night wears on and into the morning hours. Then, the numbers of reports begin to increase again in the late morning hours. Figure 10 is similar to the diurnal temperature curve which relates to the energy potential available for storms. Since a large portion of the wind reports occur in the months of May, June and July, the peak of the hourly wind reports is in the late afternoon and early evening hours. This is a result of the daily diurnal convection that forms across the region in the summer months.

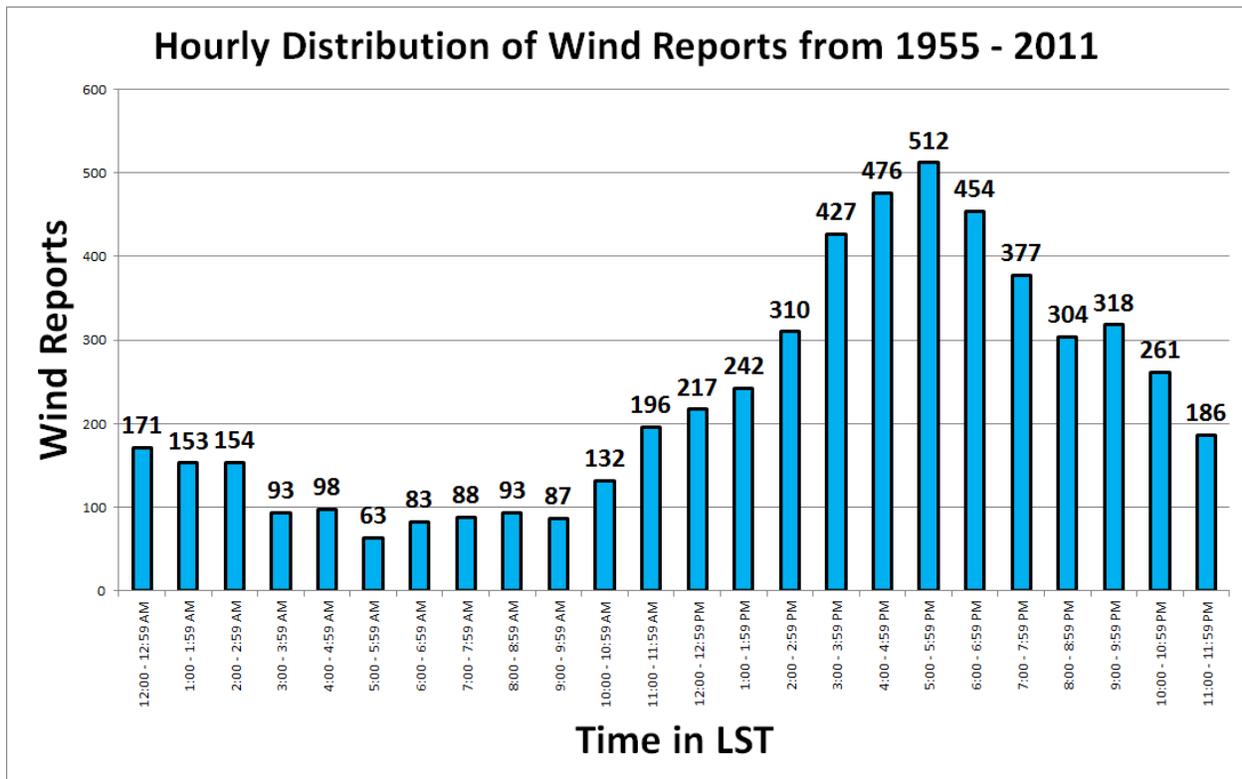


FIG 10. The hourly distribution (in LST) of wind reports for the Mid-South from 1955 through 2011. The graph represents the total number of wind reports for each hour (in blue).

However, there is still a large amount of reports that happen in the overnight hours as you see in Figure 11. Figure 11 shows that 43% of the wind reports received by NWS Memphis occur at night. The 43% includes the severe storms that occur in February, March and April. In these three months, the majority of wind reports happen during the late evening and overnight hours as seen in Figure 12. It is also interesting to note that the majority of reports in October, November and December also occur at night. The majority of reports during June, July and August happen during the daytime hours. This is expected since most of the convection during these months is diurnally driven. The three months of June, July and August and their large number of reports are the main reason that the daytime reports outweigh the nocturnal reports by a large margin.

Distribution of Daytime vs. Nocturnal Wind Reports from 1955 - 2011

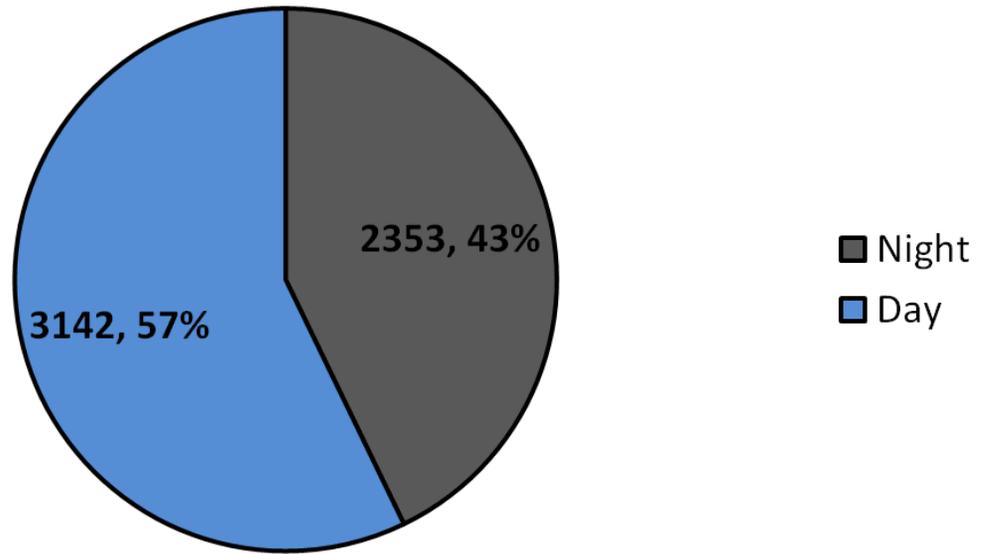


FIG 11. The distribution of daytime and nocturnal wind reports based on time (in LST) and date of occurrence for the Mid-South from 1955 through 2011. The graph represents the total number of wind reports to occur between the sunrise and sunset times for each day (daytime, in blue) and the total number of wind reports to occur between sunset and sunrise times for each day (nocturnal, in grey). The two numbers reflect the count for each category and the percentage of the total.

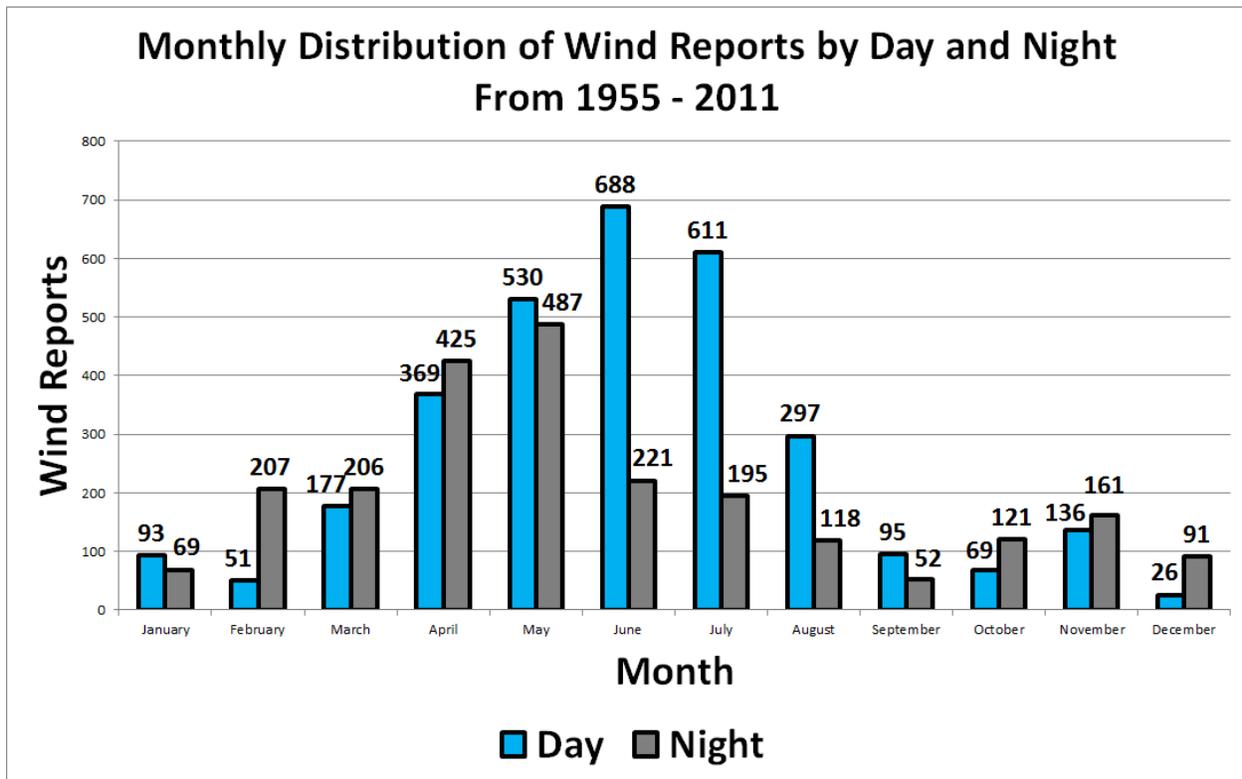


FIG 12. The distribution of daytime and nocturnal wind reports based on time (in LST) and date of occurrence for each month in the Mid-South from 1955 through 2011. The graph represents the total number of wind reports to occur between the sunrise and sunset times for each day of the month (daytime, in blue) and the total number of wind reports to occur between sunset and sunrise times for each day of the month (nocturnal, in grey).

The calculations for ENSO Index conditions were performed on the wind statistics. The results are shown in Figures 13 and 14. It was found that La Nina conditions produce a higher average number of reports per month than El Nino or Neutral conditions. The average number of reports per La Nina month was 10.35 reports per month. ENSO Neutral conditions averaged 7.73 reports per month while El Nino conditions averaged 6.30 reports per month. One thing to remember is that this factors in several months where no wind reports were received. You can get three times this amount of reports, sometimes even more, in a single event. This fact applies to hail and tornadoes as well. The calculation is not meant to calculate the average number of reports per month in which severe weather was received, just which ENSO condition produces more severe weather.

Distribution of Wind Reports Based on ENSO Conditions from 1955 - 2011

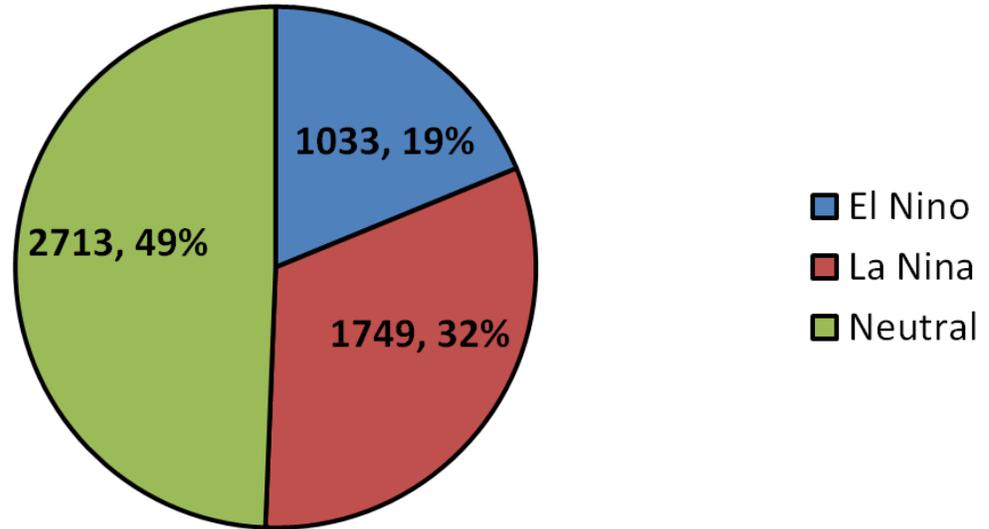


FIG 13. The distribution of wind reports across the Mid-South by ENSO conditions from 1955 through 2011. The wind reports were categorized as ENSO Neutral (green), La Nina (Red) or El Nino (blue) based on the month in which the wind reports occurred. The two numbers reflect the count for each category and the percentage of the total.

Which ENSO Conditions Bring More Severe Weather? Average Wind Reports per Month from 1955 - 2011

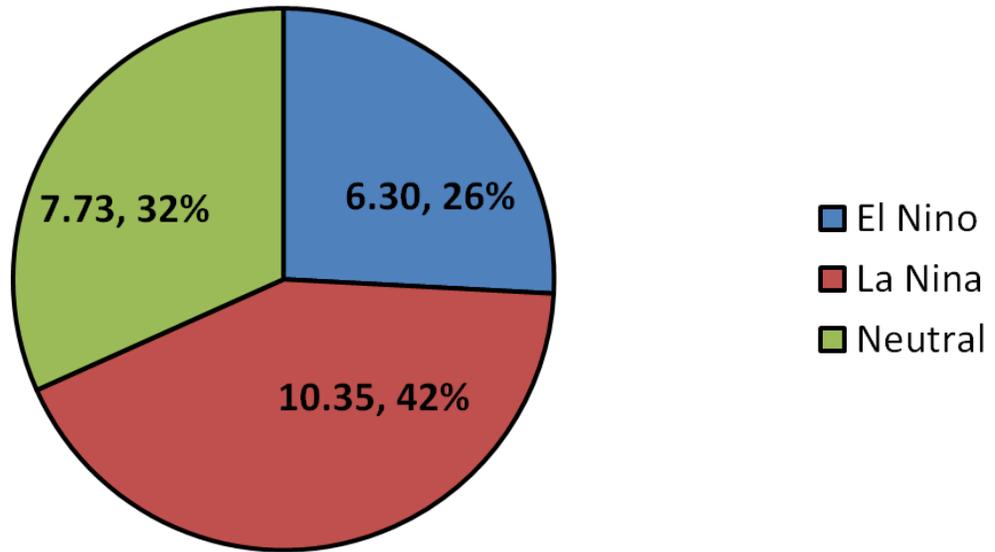


FIG 14. The average number of wind reports per month across the Mid-South by ENSO conditions from 1955 through 2011. The wind report per month averages were categorized as ENSO Neutral (green), La Nina (Red) or El Nino (blue) based on the month in which the wind reports occurred. The two numbers reflect the count for each category and the percentage of the total.

Figure 15, the final figure of the wind climatology section, shows a GIS map with all of the wind reports plotted. The total number of reports so far is 5495. One thing to remember is that each dot does not represent one report. Instead, a data point represents the location where a report was received. Therefore, one data point can represent several storm reports. That is why it seems that Figure 15 does not represent the entire set of 5495 reports.

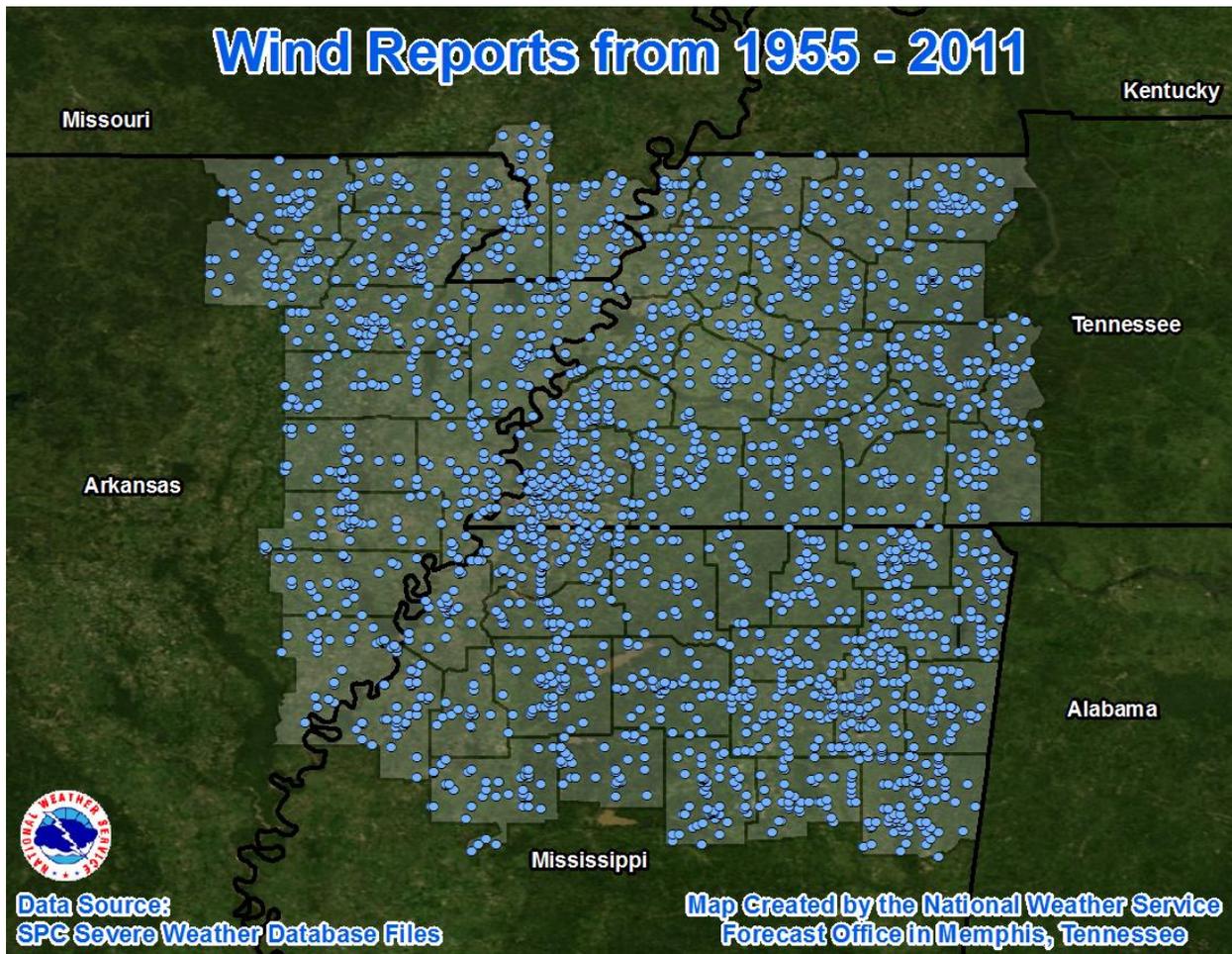


FIG 15. The geographical distribution of all wind reports across the Mid-South from 1955 through 2011. The blue points represent the locations in which wind reports have been received. One point can represent multiple wind reports that have the same latitude and longitude coordinates.

Hail Climatology:

Hail events are also quite common across the Mid-South. For this study, hail reports include penny, 0.75 inches in diameter, and nickel, 0.88 inches in diameter, size reports. This fits the previous definition of severe hail by the NWS. The previous study by Gaffin and Smith (1995) used this definition of severe hail; therefore, the same definition is used to maintain study similarities and comparisons. Figure 17 shows that hail occurs on 27 days each year on average. Like the number of wind reports, hail reports continue to trend upwards. It is also interesting to note the huge increase in reports from 1994 onwards in the number of reports. This is likely due to the installation of the KNQA WSR-88D radar and better storm verification tactics as a result of the better radar data.

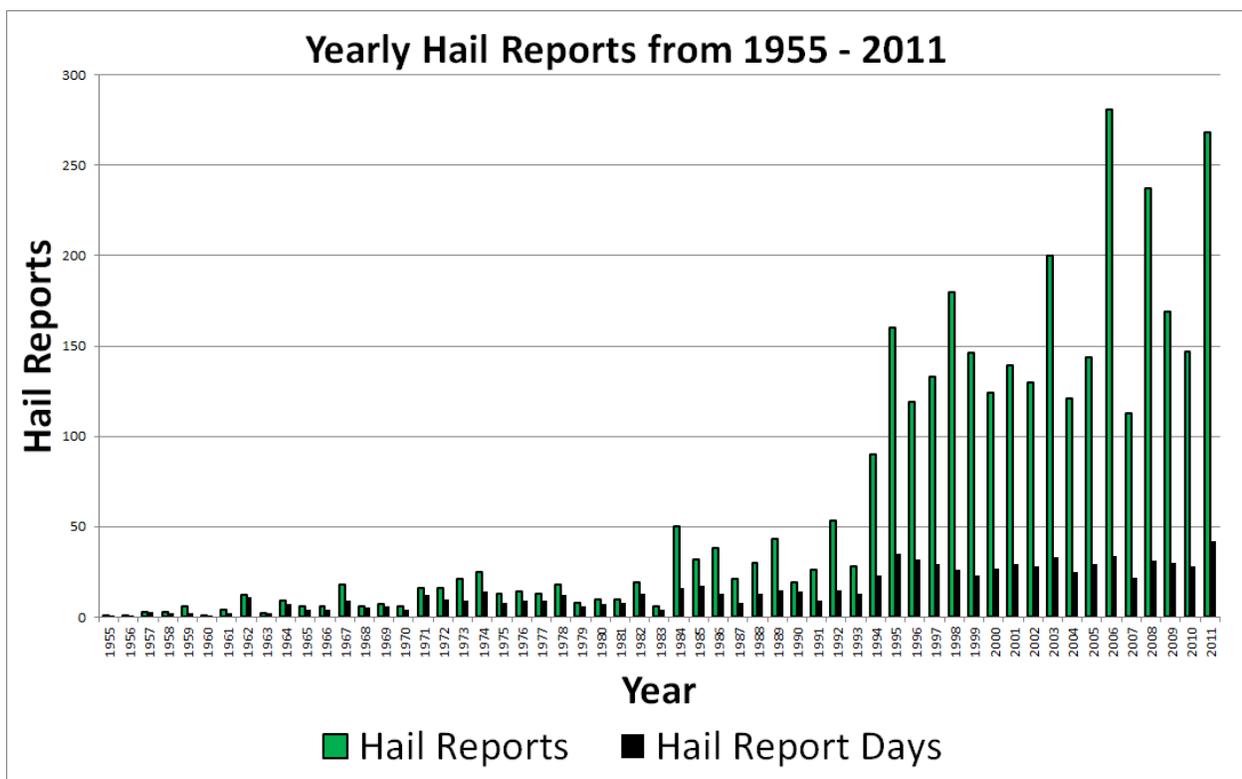


FIG 17. The distribution of yearly Mid-South hail reports from 1955 through 2011. The graph represents total number of hail reports for each year (green) and the number of hail report days (black).

According to Figure 18, the main season for hail is March through June. Figure 18 shows that there is only one severe weather season for hail and no secondary peak for the fall severe weather season. This is likely a result of the low CAPE high shear conditions that often accompany weather systems in the late fall through the winter in the Mid-South. Figure 19 shows the distribution of hail magnitudes by month. In this study, large hail is defined as hail less than 1.75 inches in diameter, giant hail is from 1.75 inches in diameter to less than 2.75 inches in diameter, and enormous hail anything greater than or equal to 2.75 inches in diameter. From Figure 19, you can see that the month of April sees the most hail overall, but also the most large, giant and enormous hail. In both Figures 18 and 19, May is the second highest month for hail reports.

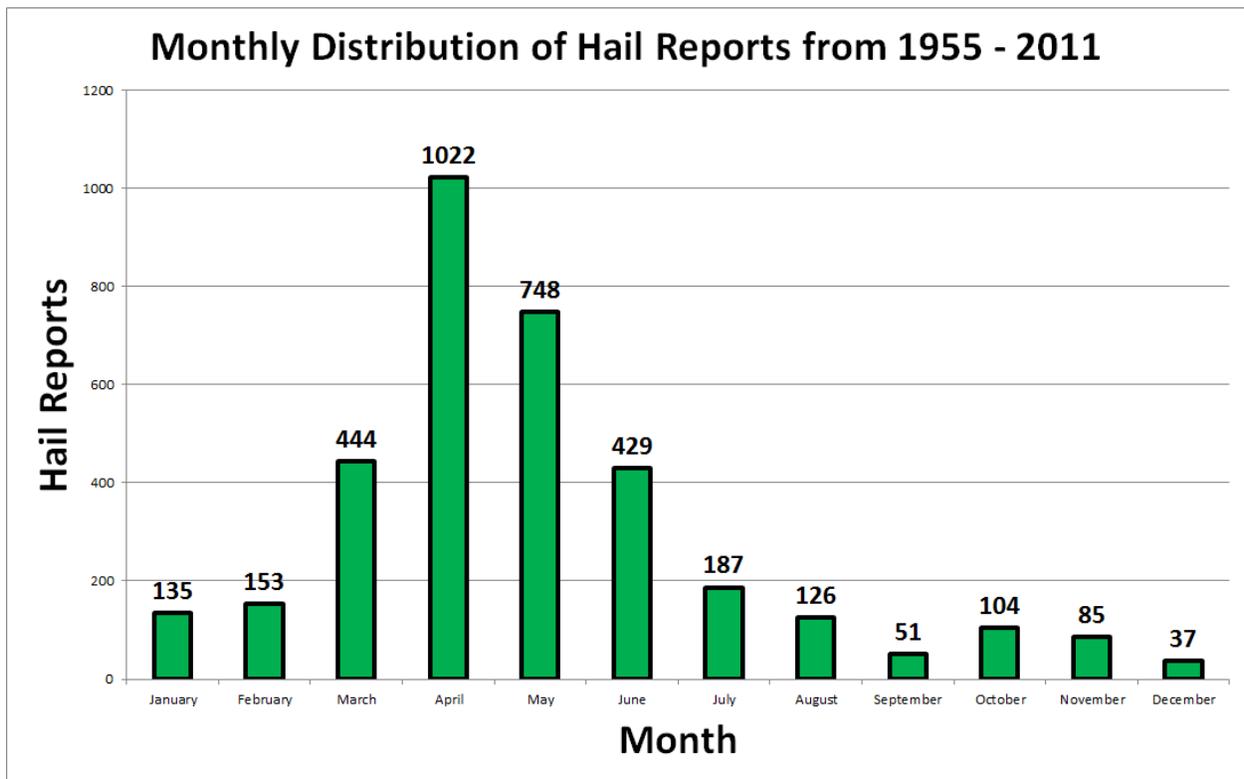


FIG 18. The distribution of monthly Mid-South hail reports from 1955 through 2011. The graph represents total number of hail reports for each month (green).

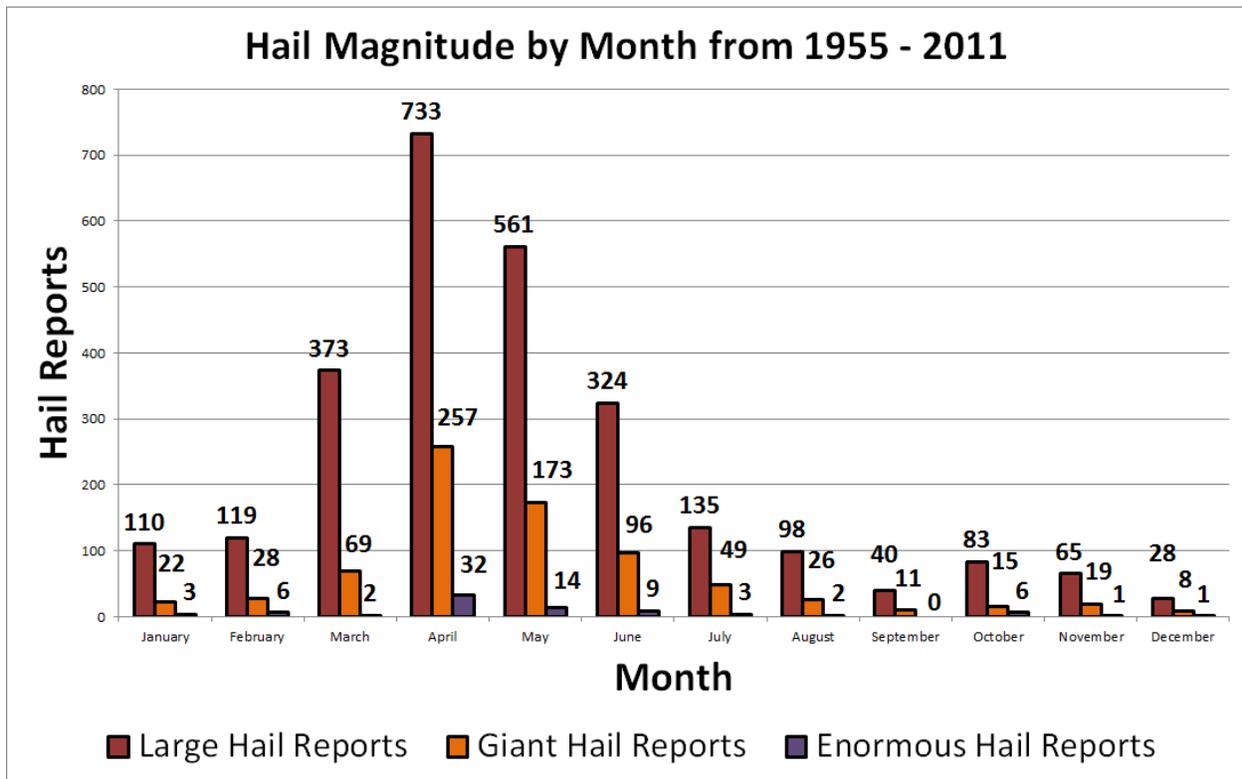


FIG 19. The distribution of monthly Mid-South hail reports by magnitude of hail size from 1955 through 2011. The graph represents total number of hail reports for each month by the magnitudes of large hail (0.75 inches in diameter to less than 1.75 inches in diameter, in maroon), giant hail (1.75 inches in diameter to less than 2.75 inches in diameter, in orange) and enormous hail (2.75 inches in diameter and greater, in purple).

The hourly distribution of hail reports, shown in Figure 20, indicates that the most hail reports are received between 4:00 p.m. and 5:00 p.m. A large number of the reports occur during the hours of maximum instability, or the warmest part of the day. The four hours from 3:00 p.m. to 7:00 p.m. account for 1430 reports out of 3521 total reports, or 40.6% of the total reports. It is also not uncommon to get hail reports in the early morning hours. Figure 20 shows a trend in the hail reports that is typical of the diurnal temperature cycle.

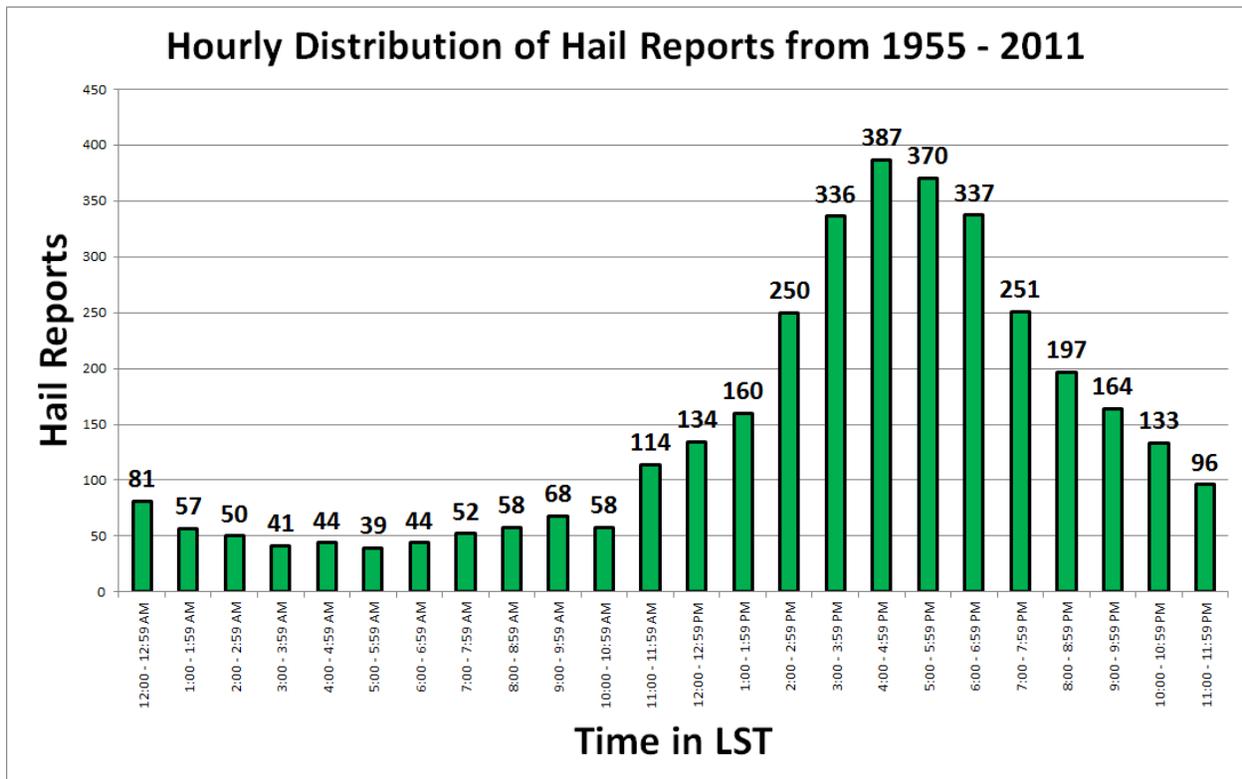


FIG 20. The hourly distribution (in LST) of hail reports for the Mid-South from 1955 through 2011. The graph represents the total number of hail reports for each hour (in green).

Figure 21, a plot of the daytime and nocturnal hail reports, shows that 63% of the hail reports received occurred during the day. This could be a result to the fact that hail reports are less frequently received during the night-time hours. However, it appears that there is a strong diurnal influence on the hail across the Mid-South. Figure 22 shows the distribution of hail reports for each hour by magnitude. From Figure 22, it is clearly visible that the number of all hail reports drops off during the late night hours through the early morning hours. Only six enormous hail reports have been received between the hours of 12 a.m. and 10 a.m., which is 7.5 percent of all enormous hail reports. Only 12.7 percent of all giant hail reports were received during this time period. The number of giant and enormous hail reports peak in the late afternoon hours, when temperatures and instabilities are highest. Figure 23 points out another interesting statistic. During the winter and early spring months, or December through March, the number of hail reports that occur in the night-time hours is more than the reports for the daytime hours. A large amount of these reports occur in the evening hours once the storms reach their peak intensity. During these months, maximum temperatures, and thus instability, are reached at around 3 to 4 p.m. and the sun has set by around 6 p.m. This would mean the storms are in a mature stage or beginning to weaken somewhat during the early evening hours, when it is already dark.

Distribution of Daytime vs. Nocturnal Hail Reports from 1955 - 2011

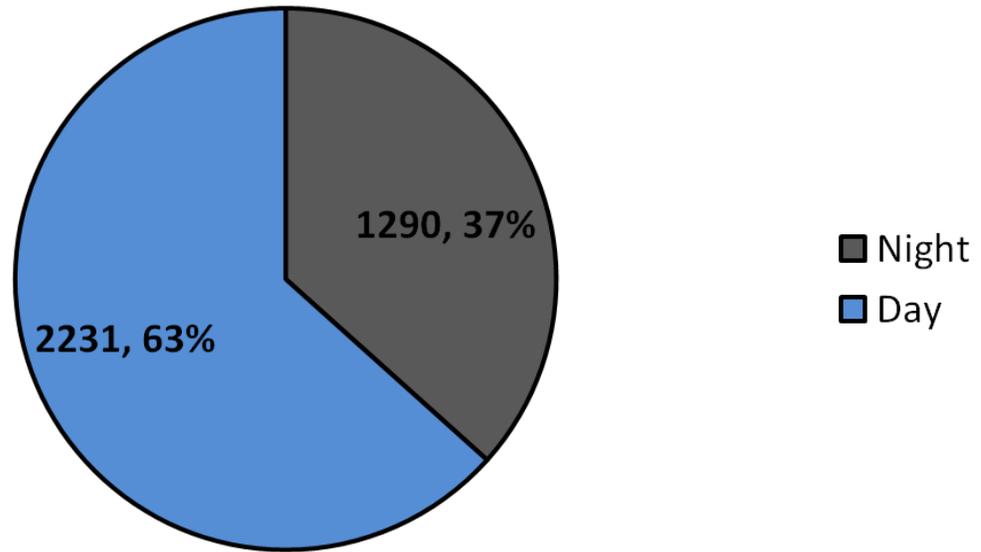


FIG 21. The distribution of daytime and nocturnal hail reports based on time (in LST) and date of occurrence for the Mid-South from 1955 through 2011. The graph represents the total number of hail reports to occur between the sunrise and sunset times for each day (daytime, in blue) and the total number of hail reports to occur between sunset and sunrise times for each day (nocturnal, in grey). The two numbers reflect the count for each category and the percentage of the total.

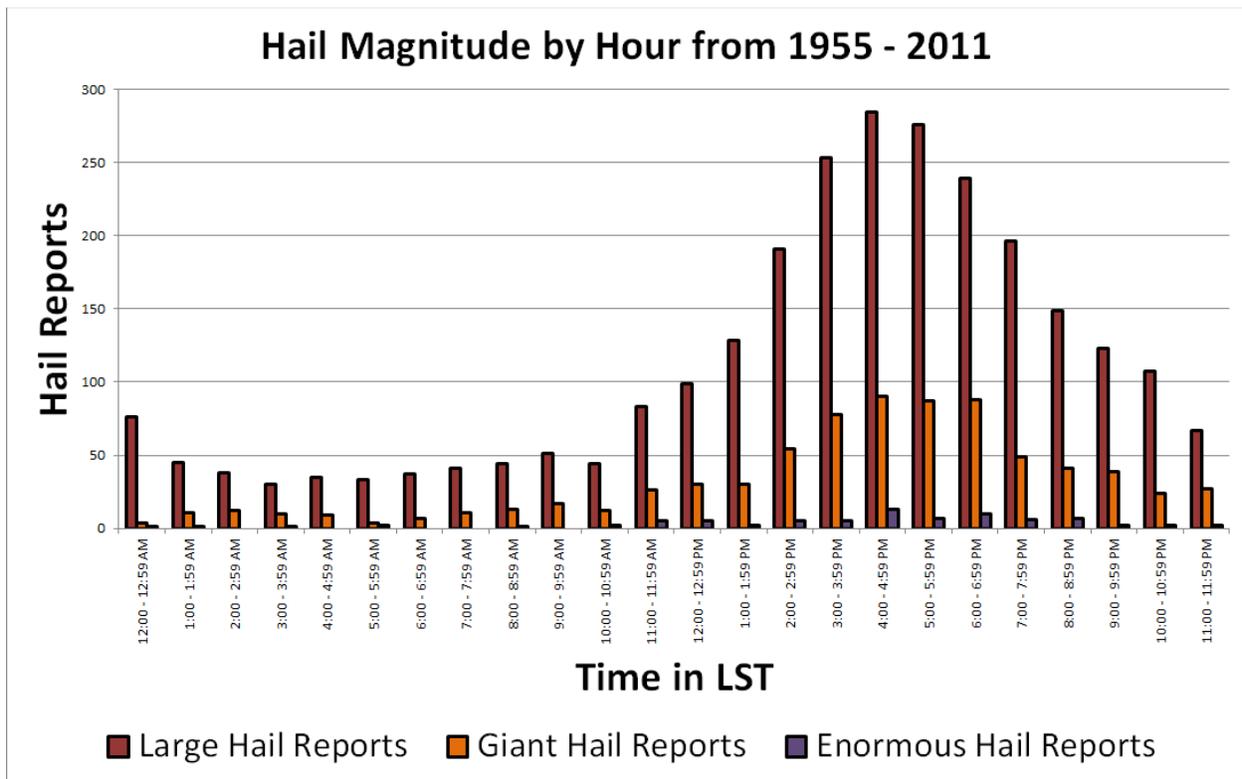


FIG 22. The distribution of hourly Mid-South hail reports by magnitude of hail size from 1955 through 2011. The graph represents total number of hail reports for each hour by the magnitudes of large hail (0.75 inches in diameter to less than 1.75 inches in diameter, in maroon), giant hail (1.75 inches in diameter to less than 2.75 inches in diameter, in orange) and enormous hail (2.75 inches in diameter and greater, in purple).

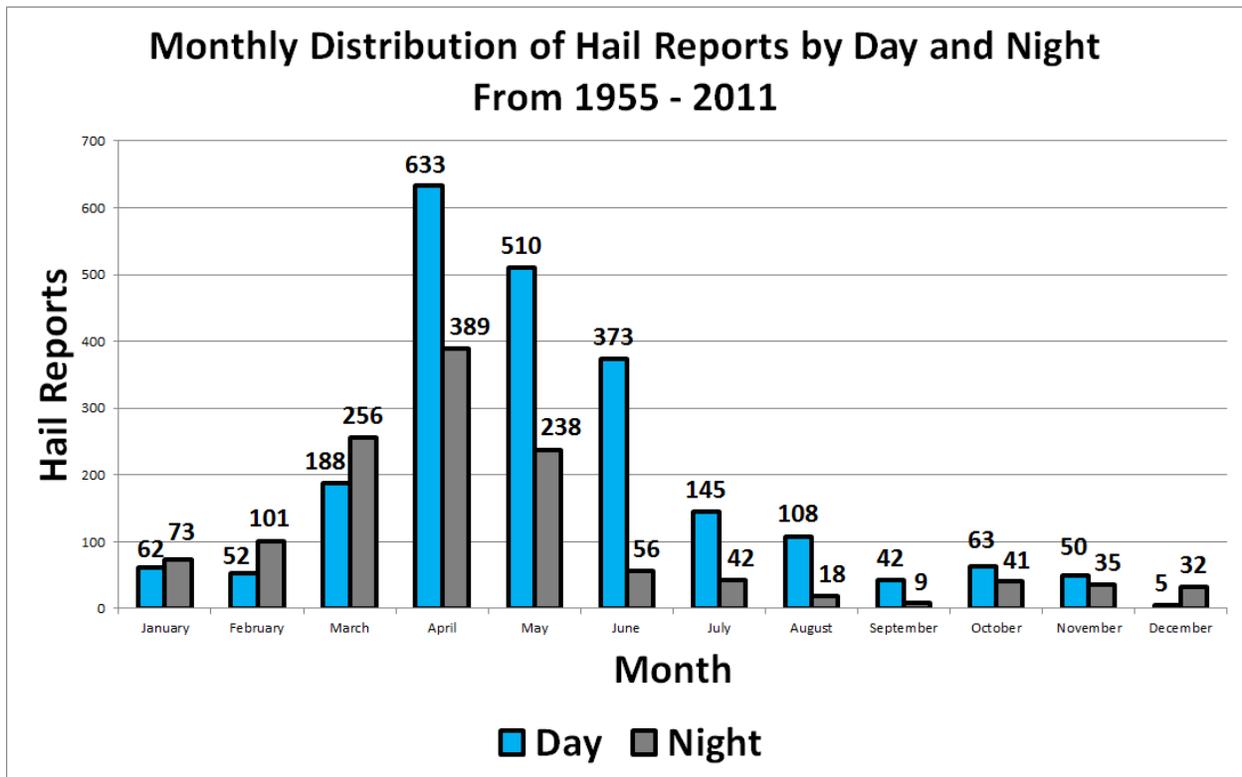


FIG 23. The distribution of daytime and nocturnal hail reports based on time (in LST) and date of occurrence for each month in the Mid-South from 1955 through 2011. The graph represents the total number of hail reports to occur between the sunrise and sunset times for each day of the month (daytime, in blue) and the total number of hail reports to occur between sunset and sunrise times for each day of the month (nocturnal, in grey).

The calculations for El Nino conditions were also performed on the hail statistics. The results are shown in Figures 24 and 25. It was found that La Nina conditions produce a higher average number of reports per month than El Nino or Neutral conditions. The average number of reports per month for a La Nina month was 6.12 reports per month. ENSO Neutral months average 5.45 reports per month while El Nino months average 3.49 reports per month. One thing to remember is that this calculation factors in several months where no hail reports were received and several months where a large number of reports were received. Therefore, the averages may seem somewhat low but that is not the goal of the calculation. The calculation was intended to determine which ENSO Index condition produced more severe weather.

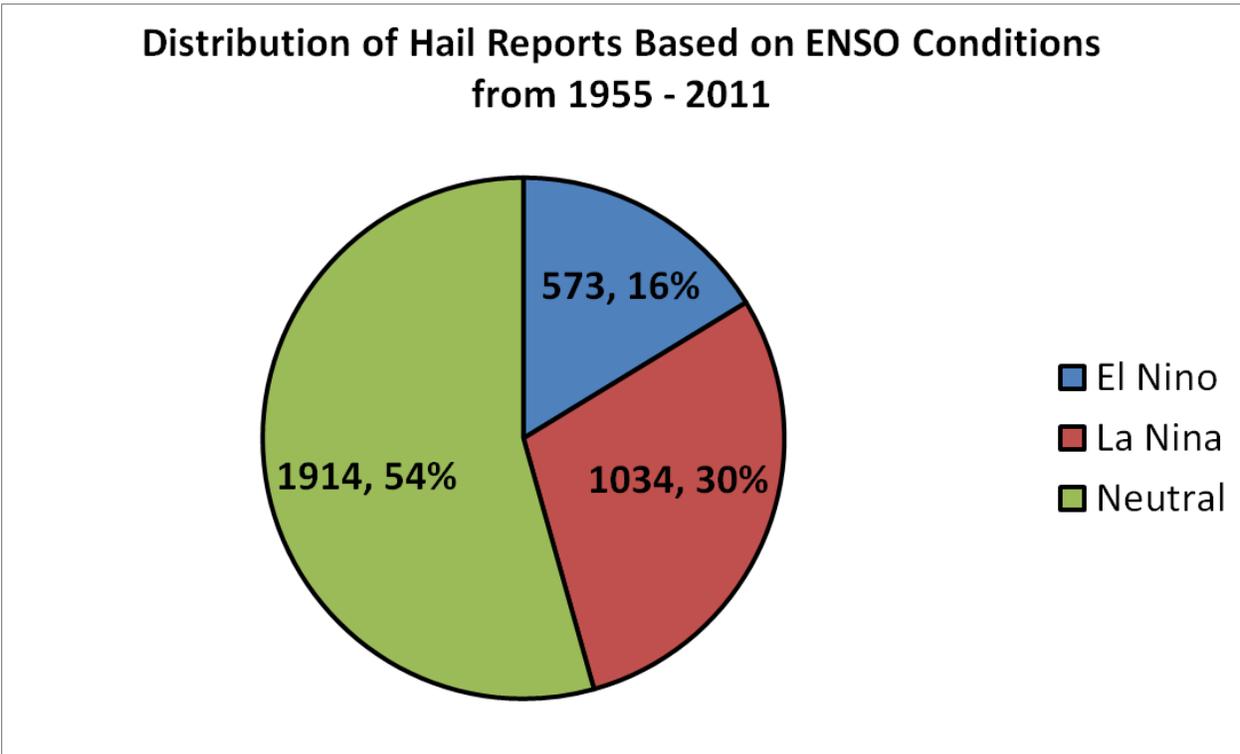


FIG 24. The distribution of hail reports across the Mid-South by ENSO conditions from 1955 through 2011. The hail reports were categorized as ENSO Neutral (green), La Nina (Red) or El Nino (blue) based on the month in which the wind reports occurred. The two numbers reflect the count for each category and the percentage of the total.

**Which ENSO Conditions Bring More Severe Weather?
Average Hail Reports per Month from 1955 - 2011**

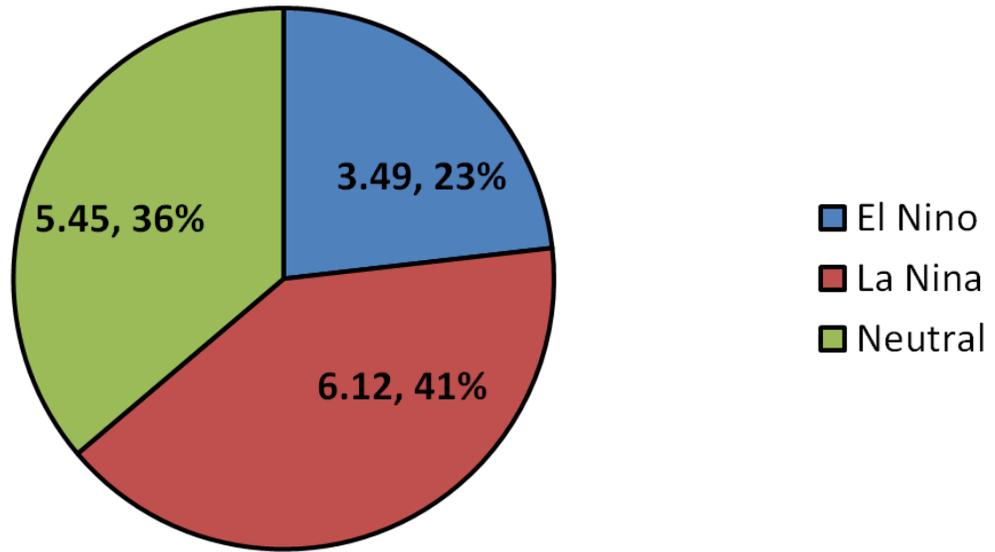


FIG 25. The average number of hail reports per month across the Mid-South by ENSO conditions from 1955 through 2011. The hail report per month averages were categorized as ENSO Neutral (green), La Nina (Red) or El Nino (blue) based on the month in which the wind reports occurred. The two numbers reflect the count for each category and the percentage of the total.

Figure 26 will be the final figure for the hail section. This figure shows the hail reports across the entire region from 1955 to 2011. The final section will focus on the tornadoes that occur across the Mid-South.

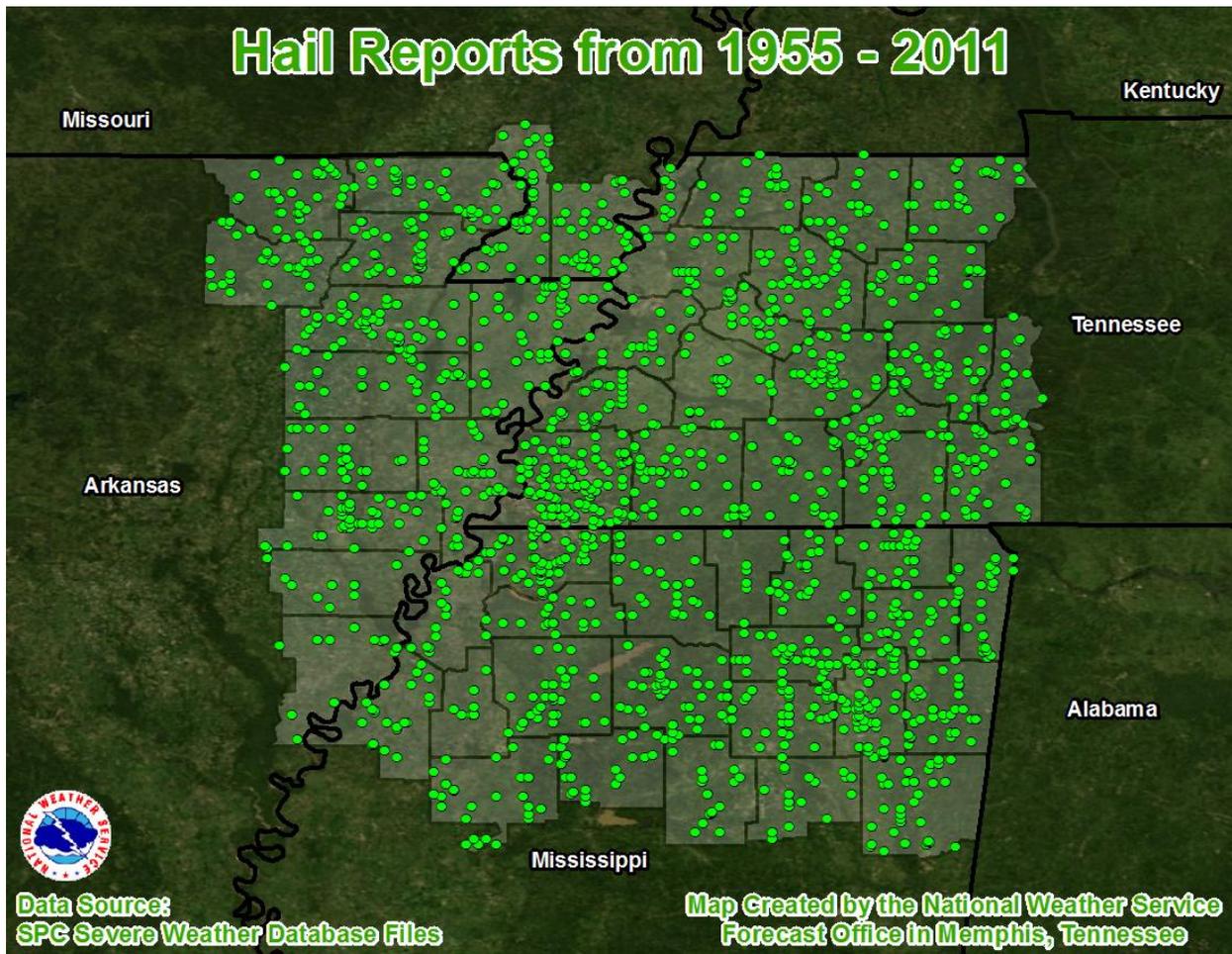


FIG 26. The geographical distribution of all hail reports across the Mid-South from 1955 through 2011. The green points represent the locations in which hail reports have been received. One point can represent multiple hail reports that have the same latitude and longitude coordinates.

Tornado Climatology:

The Mid-South is known for its tornadoes. Unfortunately, there are a couple of myths that the people of the region believe. For example, the myths “the bluffs protect our area” or “tornadoes don’t cross the Mississippi River” are false. The myth of “most tornadoes occur during the day” can also be proven incorrect for this region. The Memphis CWA is particularly known for having the highest relative frequency of killer tornadoes in the nation according to Ashley (2007). From 1873 through 2011, there have been 1152 tornadoes to strike the Mid-South. However, there are likely many tornadoes that are unaccounted for so the total of 1152 should be higher. This is because the F-1 tornadoes started to be counted regularly around 1950 and the F-0 tornadoes were later than that, in the 1970s.

Based on the last 20 years of data, the Mid-South receives on average 16.6 tornadoes per year and 1.3 killer tornadoes per year. The statistics are weighted towards the years with large tornado outbreaks as there are some years (1992, 1993, 2005 and 2007) that saw less than 10 tornadoes. The years with significant or multiple tornado outbreaks over the past 20 years are 1994, 1999, 2003, 2008, 2010 and 2011. A linear regression analysis was done for the total number of tornadoes for each year and it was interesting to note that the total number of tornadoes is going up by 0.3 every year. This is likely due to better methods for tracking, surveying and accounting for tornadoes that strike the region. This is not the case for the average number of killer tornadoes per year as these numbers have remained consistent for the past 20 years. Figure 27 shows the number of tornadoes and killer tornadoes from 1873 through 2011. The number of tornadoes per year is trending up since most tornadoes are accounted for now, not just the significant tornadoes as in earlier years. The number of killer tornadoes per year is on a slow downward trend when the entire data set is taken into account. Over the past 10 years, there have been a total of 15 killer tornadoes. 14 killer tornadoes were recorded in the year 1909 alone. The last year with more than five killer tornadoes was 1952 with nine.

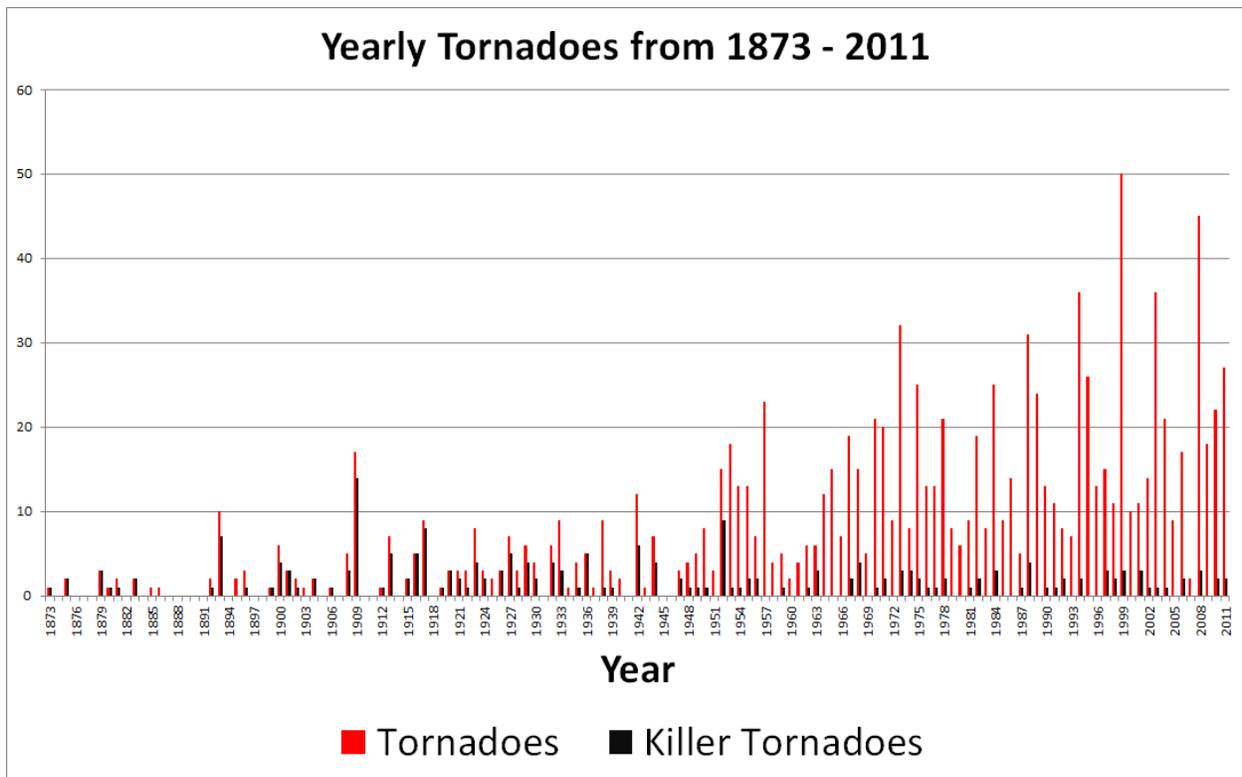


FIG 27. The distribution of yearly Mid-South tornadoes from 1873 through 2011. The graph represents total number of tornadoes for each year (red) and the number of killer tornadoes for each year (black).

According to Figure 28, April is the month in which tornadoes and killer tornadoes occur most frequently. The core of the tornado season is from March through June. The secondary severe weather season in November is also apparent in the tornado data. Note that there is also a large amount of tornadoes that have occurred in the months of January and February. January is especially affected by the outbreak in 1999 where 46 tornadoes occurred, or 48.9 percent of all tornadoes to occur in January. The month of February is also affected by a large tornado outbreak; the Super Tuesday Outbreak of February 5, 2008 saw 23 tornadoes. However, the Super Tuesday Outbreak only makes up 25.5 percent of the total number of tornadoes to strike the Mid-South in February. Figure 28 shows that the months July through October are the only months where tornadoes are relatively infrequent.

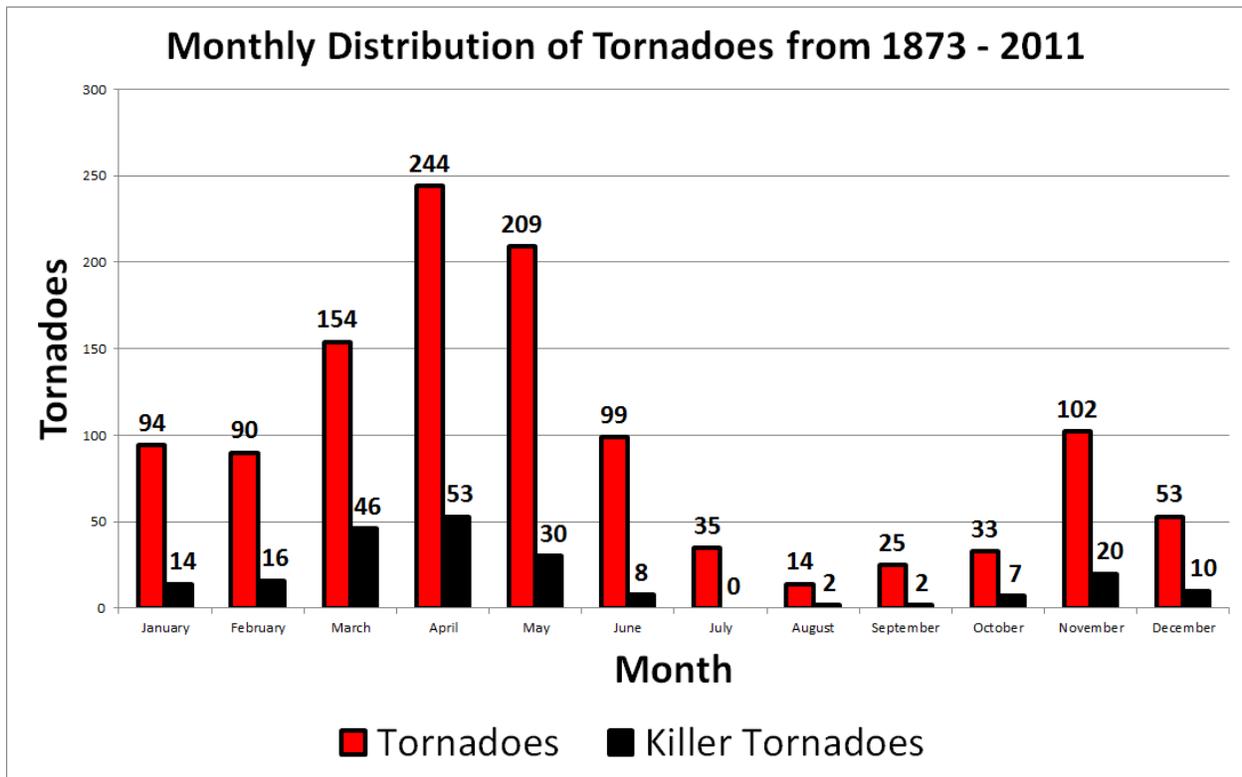


FIG 28. The distribution of monthly Mid-South tornadoes from 1873 through 2011. The graph represents total number of tornadoes for each month (red) and the number of killer tornadoes for each month (black).

Figure 29 shows that March through May are the months most likely to see violent tornadoes (F-4 and F-5). These three months account for 84% of the violent tornadoes that have struck the Mid-South. It is also interesting to note the high percentage of strong tornadoes (F-2 and F-3) from November through March. With the exception of March, this is likely another indication of the low CAPE, high shear environmental conditions that commonly occur during these months. The reason for the high number of strong tornadoes for the month of March is unknown.

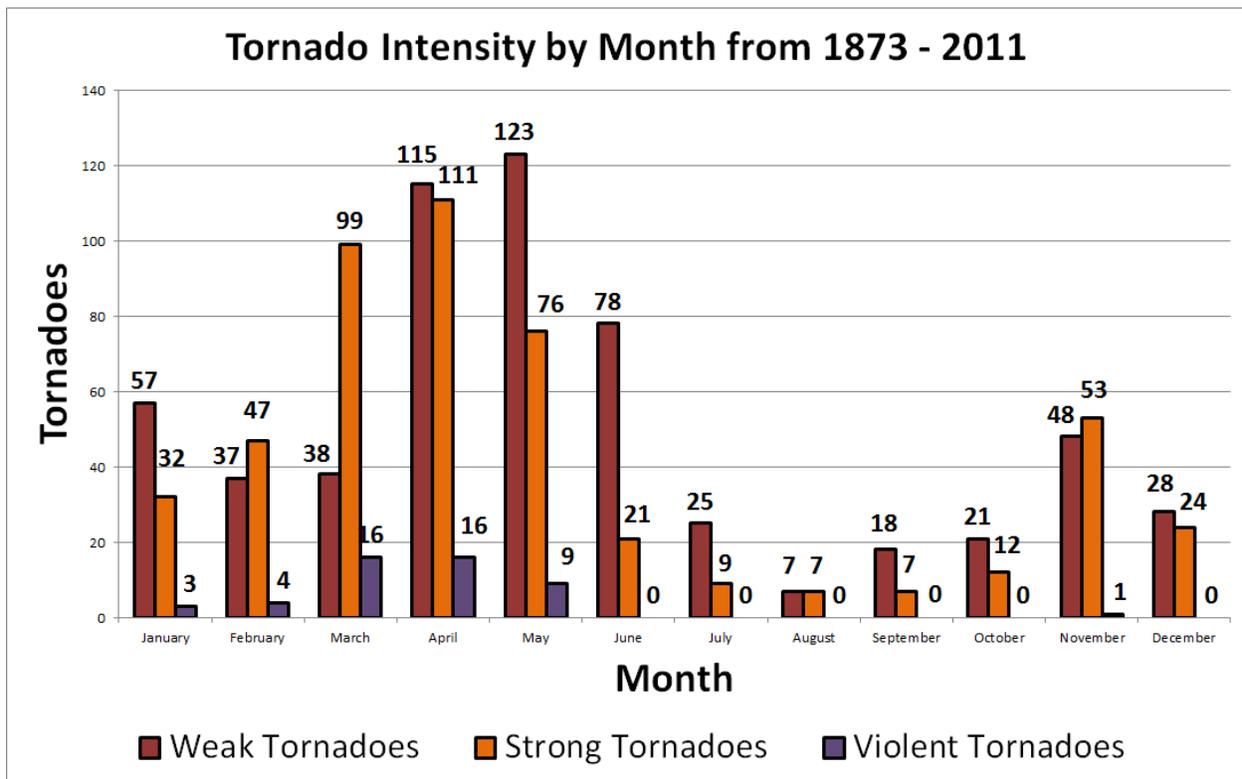


FIG 29. The distribution of monthly Mid-South tornadoes by magnitude from 1873 through 2011. The graph represents total number of tornadoes for each month by the magnitudes of weak tornadoes (in maroon; rated F-0 and F-1), strong tornadoes (in orange; rated F-1 and F-2) and violent tornadoes (in purple; rated F-4 and F-5).

The hourly trend of tornadoes is displayed by Figure 30. The most tornadoes occur between the hours of 4 p.m. and 7 p.m. The most killer tornadoes occur between the hours of 6 p.m. and 8 p.m. Based on this graph, you can tell that a large amount of tornadoes that strike the Mid-South happen when it is dark. Figure 32 will talk more about the percentages of tornadoes that are classified as daytime or nocturnal. Figure 31 shows the hourly tornado data separated by magnitude. Based on Figure 31, you can see that the majority of the violent tornadoes strike between the hours of 2 p.m. and 9 p.m. However, you can see that violent tornadoes can occur at any hour of the day. One other interesting thing to note on this graph is that the strong tornadoes outnumber the weak tornadoes between the hours of 9 p.m. and 10 a.m. This could be hinting at an influence by the low level jet, which would add a higher amount of low level shear to the atmosphere and thus a higher chance of strong tornadoes. The nocturnal stable layer could also be a factor as it would reduce the number of weak tornadoes so that only the stronger circulations make it to the ground and become tornadoes.

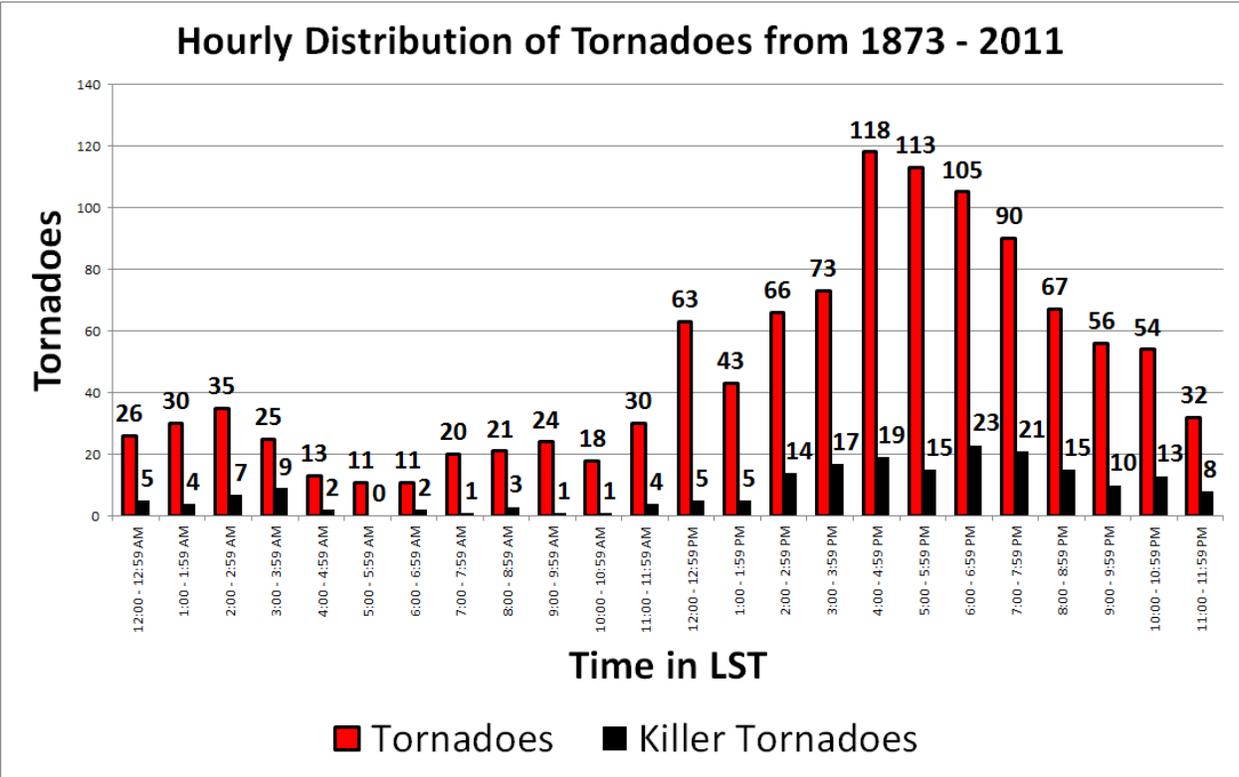


FIG 30. The hourly distribution (in LST) of tornadoes to strike the Mid-South from 1873 through 2011. The graph represents the total number of tornadoes for each hour (in red) and the number of killer tornadoes for each hour (in black).

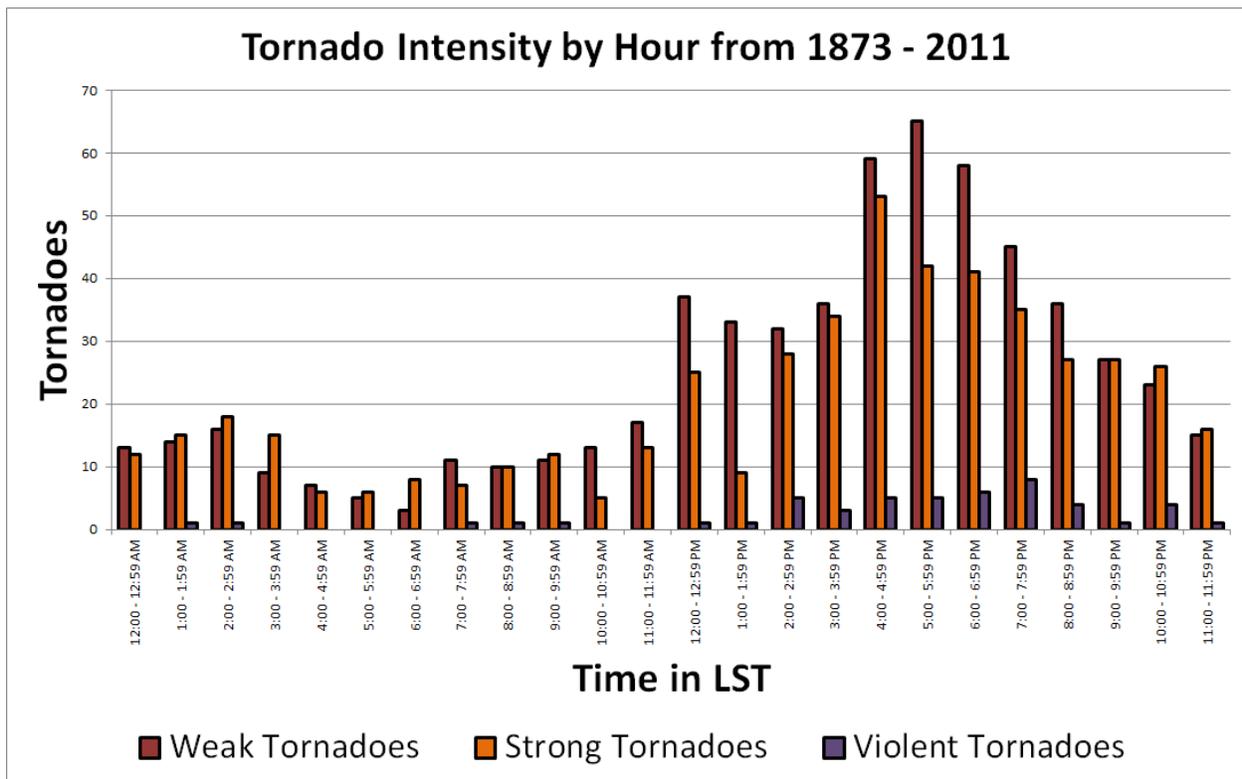


FIG 31. The distribution of hourly Mid-South tornadoes by magnitude from 1873 through 2011. The graph represents total number of tornadoes for each hour (in LST) by the magnitudes of weak tornadoes (in maroon; rated F-0 and F-1), strong tornadoes (in orange; rated F-1 and F-2) and violent tornadoes (in purple; rated F-4 and F-5).

One thing that makes the tornadoes that strike the Mid-South so dangerous is that many of them occur at night. Figure 32 shows that 46% of the tornadoes hit during the nocturnal hours according to the sunrise/sunset time calculations. Figure 33 shows that 55% of the tornadoes that result in fatalities occur during the nocturnal hours. These two facts are likely one of the reasons that the Mid-South has the highest frequency of killer tornadoes in the nation.

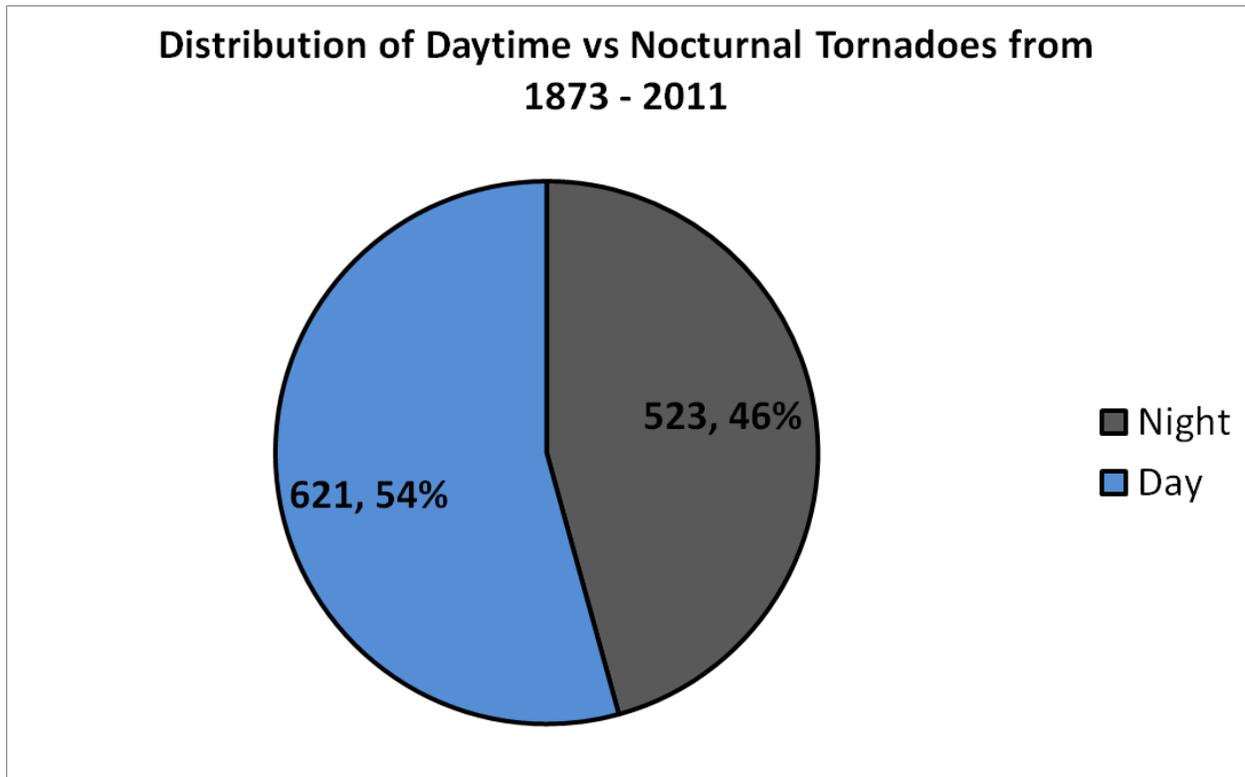


FIG 32. The distribution of daytime and nocturnal tornadoes based on time (in LST) and date of occurrence for the Mid-South from 1873 through 2011. The graph represents the total number of tornadoes to occur between the sunrise and sunset times for each day (daytime, in blue) and the total number of tornadoes to occur between sunset and sunrise times for each day (nocturnal, in grey). The two numbers reflect the count for each category and the percentage of the total.

Distribution of Daytime vs Nocturnal Killer Tornadoes from 1873 - 2011

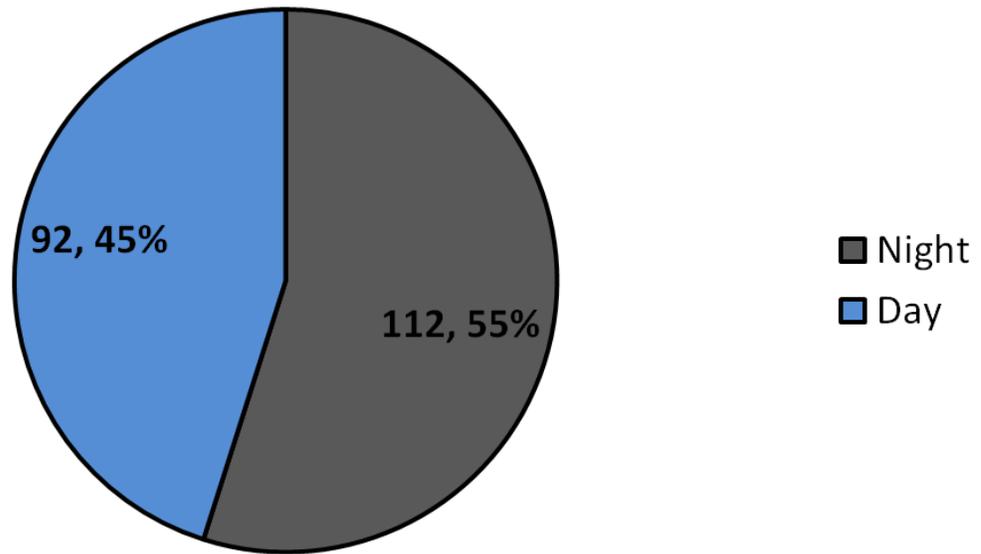


FIG 33. The distribution of daytime and nocturnal killer tornadoes based on time (in LST) and date of occurrence for the Mid-South from 1873 through 2011. The graph represents the total number of killer tornadoes to occur between the sunrise and sunset times for each day (daytime, in blue) and the total number of killer tornadoes to occur between sunset and sunrise times for each day (nocturnal, in grey). The two numbers reflect the count for each category and the percentage of the total.

Figure 34 is a plot of the monthly distribution of daytime and nocturnal tornadoes. Again, it is interesting to note that during the months of November, December, January and February, the majority of the tornadoes occur at dark. This is likely due to the fact that severe storms are reaching their mature stages as the sun sets across the Mid-South during these four months. For the rest of the months, the majority of the tornadoes occur during the day. However, these majorities are only slight majorities. During the spring months (March, April and May), 43.6% of the tornadoes occurred during the nocturnal hours. Therefore, a large number of tornadoes during the spring months still touchdown at night. From Figure 34, you can see that tornadoes can strike at night really anytime of the year. The only portions of the year that tornadoes are relatively infrequent are the summer and early fall months, or July through October.

Figure 35 shows the F-Scale distribution of tornadoes that have struck the Mid-South. You can clearly see the results of not counting the F-0 and F-1 tornadoes through the entire period. For a comparison, Figure 36 shows the F-Scale distribution of tornadoes over the past 20 years. This curve is much more representative of the actual F-Scale distribution of tornadoes that strike the region if all tornadoes to hit the Mid-South had been accurately accounted for

through the entire period of 1873 through 2011. You would expect more F-0 and F-1 tornadoes with numbers dropping off significantly as the tornado intensities increase since the violent tornadoes are much less frequent than weak tornadoes. In both Figures 35 and 36, the trend for killer tornadoes is very similar.

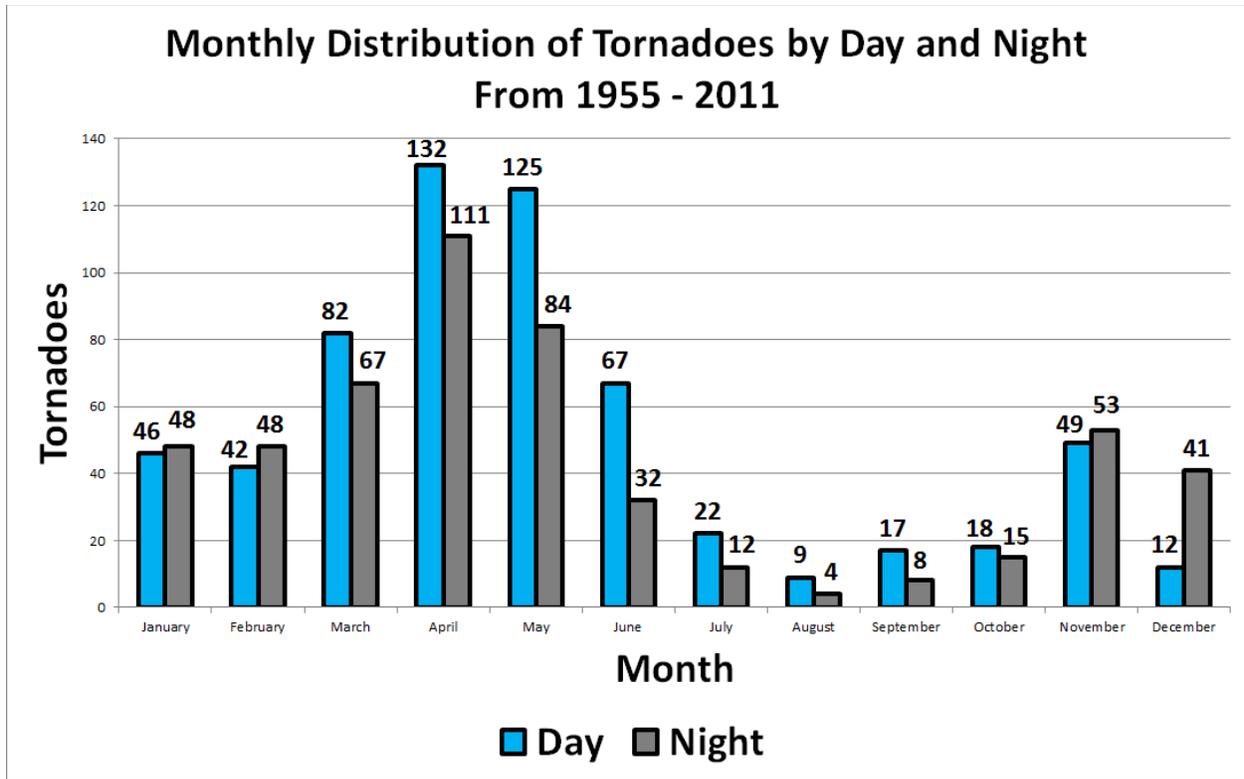


FIG 34. The distribution of daytime and nocturnal tornadoes based on time (in LST) and date of occurrence for each month in the Mid-South from 1873 through 2011. The graph represents the total number of tornadoes to occur between the sunrise and sunset times for each day of the month (daytime, in blue) and the total number of tornadoes to occur between sunset and sunrise times for each day of the month (nocturnal, in grey).

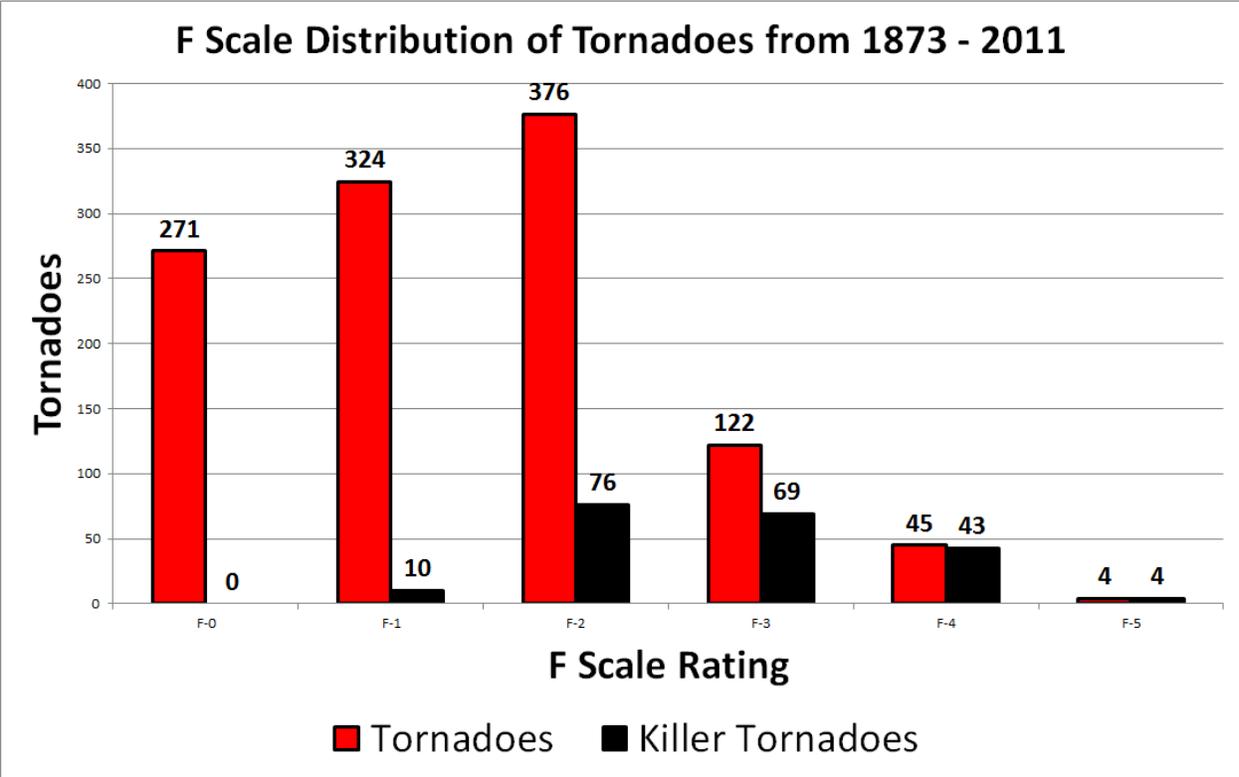


FIG 35. The F-Scale distribution of tornadoes to strike the Mid-South from 1873 through 2011. The graph represents the total number of tornadoes for F-Scale rating (in red) and the number of killer tornadoes for each F-Scale rating (in black).

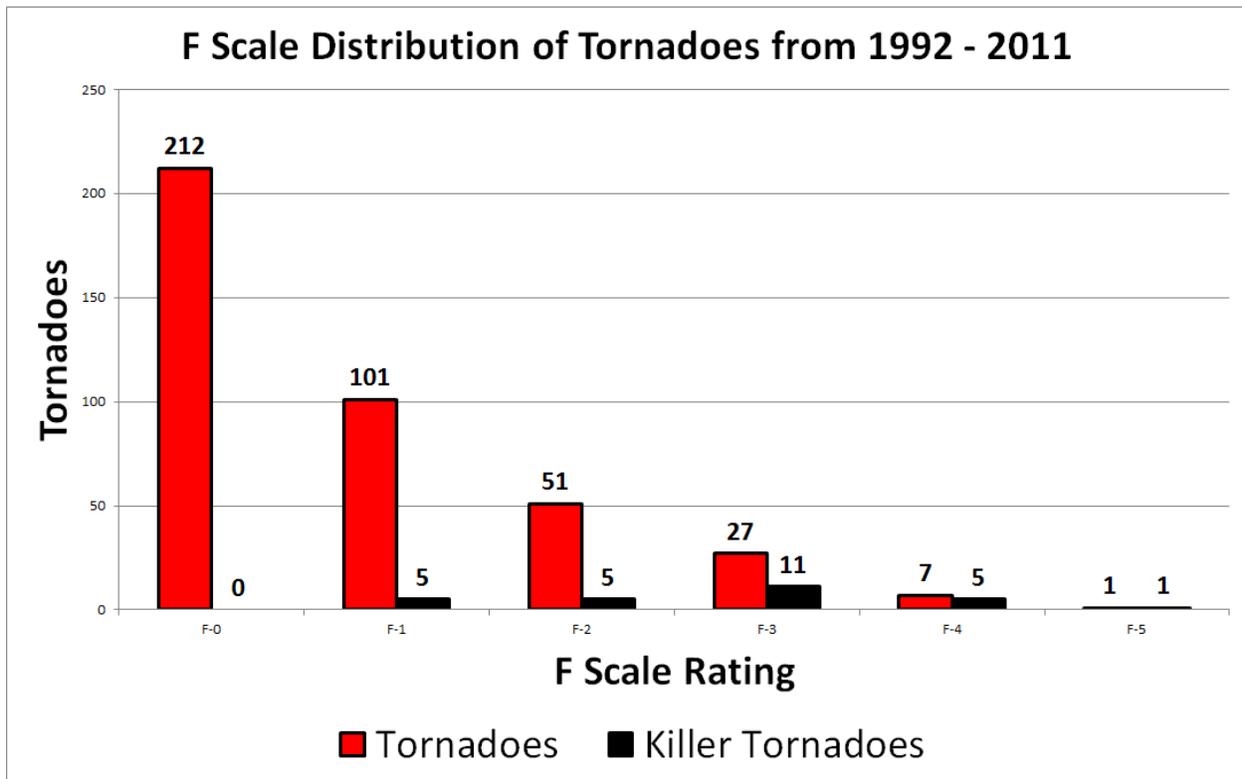


FIG 36. The F-Scale distribution of tornadoes to strike the Mid-South from 1992 through 2011. The graph represents the total number of tornadoes for F-Scale rating (in red) and the number of killer tornadoes for each F-Scale rating (in black).

The Mid-South can also see tornadoes of many lengths and widths. Figure 37 shows the breakdown of tornado widths for our area while Figure 38 shows the path lengths of tornadoes. According to Figure 37, 7% of the tornadoes that strike the Mid-South have widths greater than one fourth of a mile. Figure 38 shows us that 11% of all tornadoes that strike the Mid-South are on the ground for distances of 25 miles or more. This number could be skewed a little in favor of the longer tracked tornadoes since the earlier portions of the database did not account for the F-0 and F-1 tornadoes, which tend to travel shorter distances. Over the last 20 years, 78% of the tornadoes were less than 1/10 of a mile wide, 14% of tornadoes were 1/10 of a mile wide to less than 1/4 of a mile wide, 5% of tornadoes were 1/4 of a mile to less than 1/2 of a mile and 3% were greater than 1/2 of a mile in diameter. The calculations over the last 20 years were also done for the tornadoes lengths and it was found that 66% of the tornadoes travel less than five miles, 26% of the tornadoes travel between five miles and 25 miles, and 8% of tornadoes travel more than 25 miles. These statistics seem more typical for the Mid-South since all the weak tornadoes are accounted for due to better tracking and surveying methods.

Distribution of the Widths of Tornadoes from 1873 - 2011

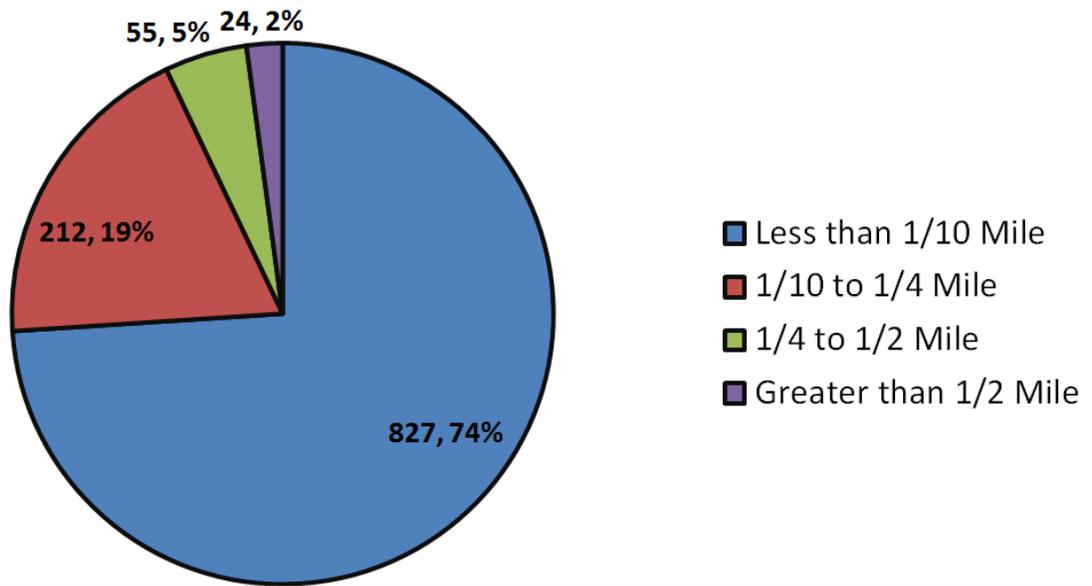


FIG 37. The distribution of Mid-South tornadoes by width from 1873 through 2011. The graph represents total number of tornadoes for widths less than a tenth of a mile (in blue), greater than or equal to a tenth of a mile to less than one quarter of a mile (red), greater than or equal to a quarter of a mile to less than one half of a mile (green) and greater than or equal to one half of a mile (purple). The two numbers reflect the count for each category and the percentage of the total.

Distribution of the Lengths of Tornadoes from 1873 - 2011

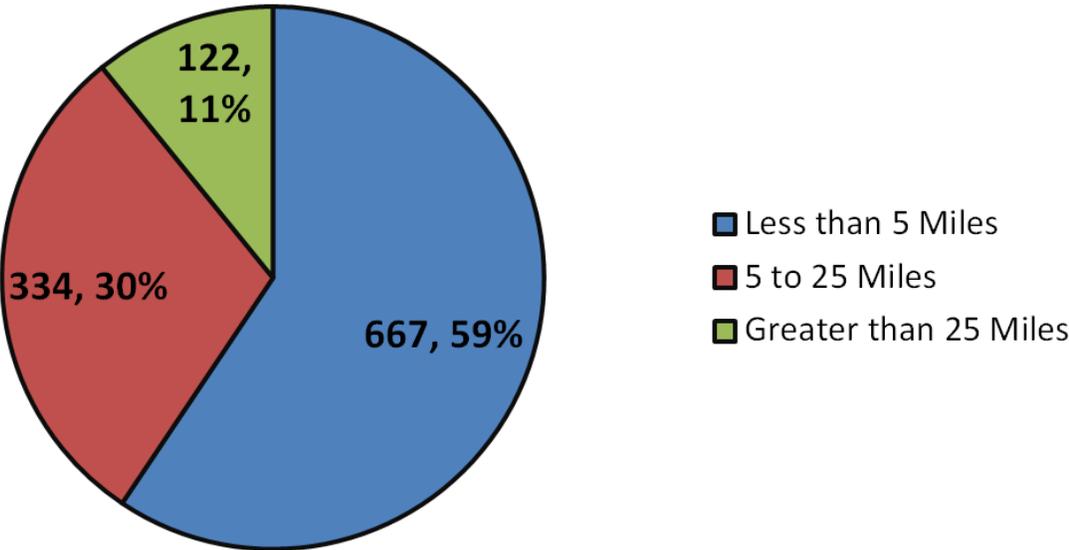


FIG 38. The distribution of hourly Mid-South tornadoes by length from 1873 through 2011. The graph represents total number of tornadoes for paths less than five miles long (in blue), greater than or equal to five miles to less than 25 miles long (red), and greater than or equal to 25 miles long (green). The two numbers reflect the count for each category and the percentage of the total.

The calculations for the El Nino conditions were also done for the tornadoes as seen in Figures 39 and 40. As with the wind and hail reports, there is a higher average number of tornadoes per month under La Nina conditions. Under La Nina conditions, there is an average of 1.83 tornadoes per month while ENSO Neutral conditions averaged 1.15 tornadoes per month and El Nino conditions averaged 0.94 tornadoes per month. This average is much higher more than El Nino or ENSO Neutral conditions. Some of the biggest tornado outbreaks the Mid-South were seen were during La Nina months. For example, the tornado outbreaks of January 1999, February 5, 2008 and April 2011 were all La Nina months. The Super Outbreak on April 3-4, 1974, which only involved a small fraction of the Memphis County Warning Area, also occurred during a La Nina month.

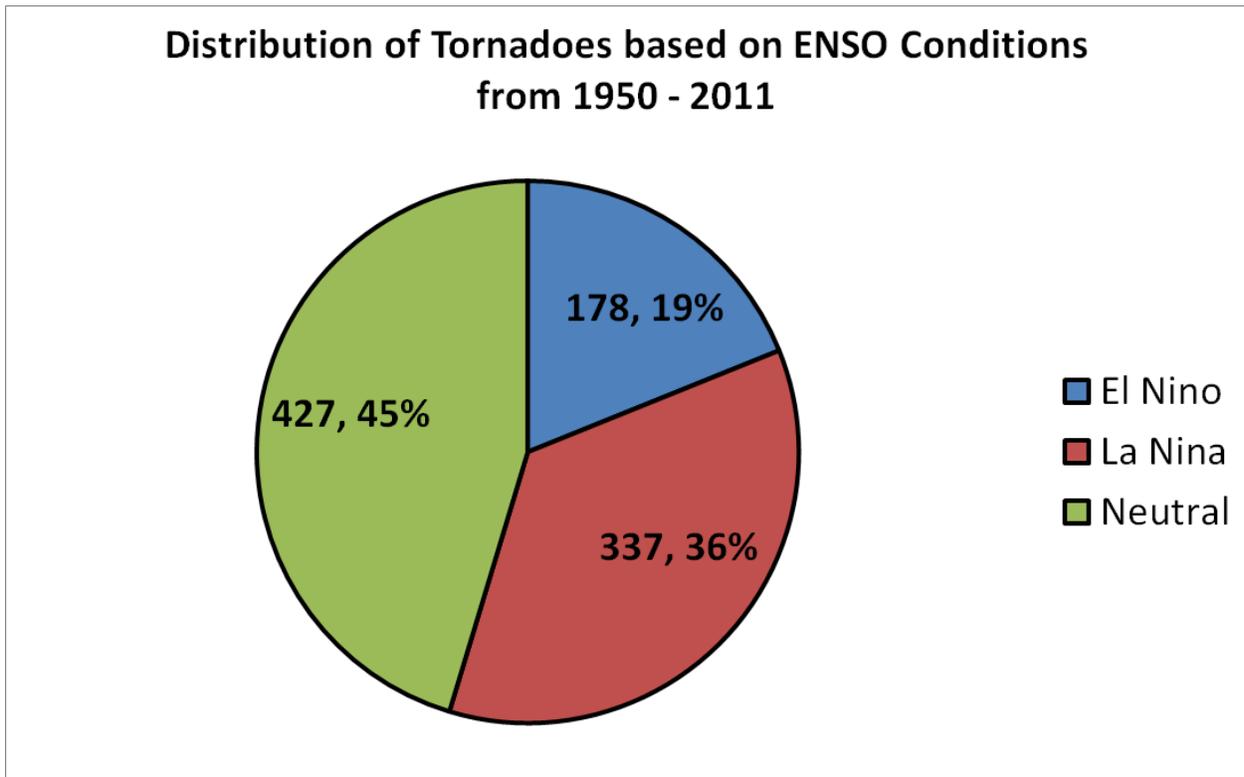


FIG 39. The distribution of tornadoes to strike the Mid-South by ENSO conditions from 1950 through 2011. The tornadoes were categorized as ENSO Neutral (green), La Nina (Red) or El Nino (blue) based on the month in which the tornadoes occurred. The two numbers reflect the count for each category and the percentage of the total.

Which ENSO Conditions Bring More Severe Weather? Average Number of Tornadoes per Month from 1950 - 2011

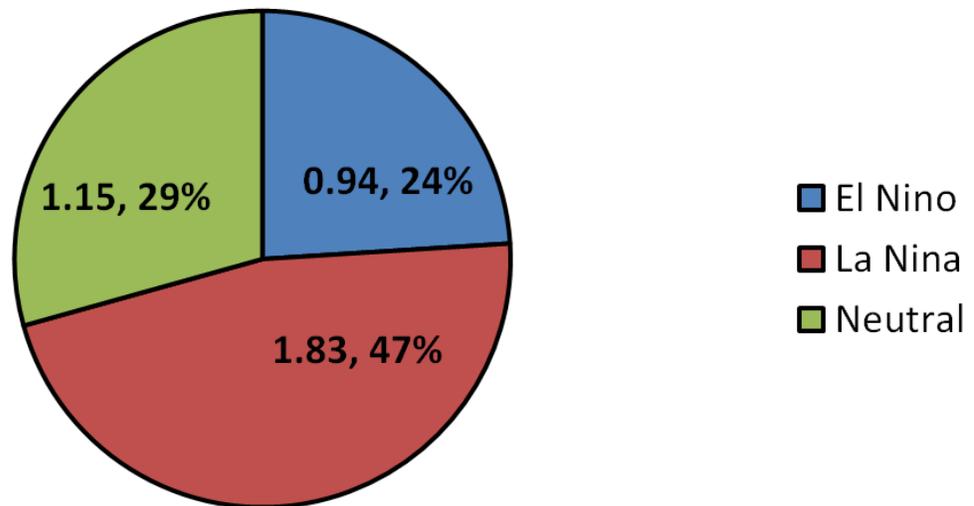


FIG 40. The average number of tornadoes per month to strike the Mid-South by ENSO conditions from 1950 through 2011. The tornado per month averages were categorized as ENSO Neutral (green), La Niña (Red) or El Niño (blue) based on the month in which the tornadoes occurred. The two numbers reflect the count for each category and the percentage of the total.

The last segment of the tornado climatology section will focus on tornado deaths. According to Figure 41, April is by far the deadliest month for tornadoes. March and May are the second and third deadliest months. You can also see the secondary severe weather season in November; however, the average number of deaths per month of November pales in comparison to the main severe weather season. November averages 0.57 tornado deaths a month while April averages 4.59 deaths a month. Figure 42 displays the day-time versus nocturnal distribution of tornado deaths. March and April have high counts for nocturnal tornado deaths yet, interestingly, the trend flips for May. The reason for this trend switch is from one day; on May 27, 1917, six tornadoes hit the Mid-South during the daytime, killing 200 people. If you eliminate this one day, May follows the same trend as March and April where nocturnal tornadoes kill more people. Figure 43 shows the total number of deaths for tornadoes that strike during the day and night. Again, the deaths from May 27, 1917 skew the total number of fatalities for the daytime. However, one could say the same thing with the April 5, 1936 Tupelo tornado which killed 216 people. This tornado was a nocturnal tornado. However, all events are included in statistics, and as a result, the number of nocturnal tornado deaths is higher than the number of daytime tornado deaths in the Mid-South. Figure 44 shows

the percentage of tornado deaths related to tornado magnitudes. One surprising finding was that over the entire time period only 12 people, or 1% of the total tornado deaths, were killed by weak (rated F-0 and F-1) tornadoes. The other 1,695 people perished from strong (rated F-2 and F-3) to violent (rated F-4 and F-5) tornadoes. Note, not all of the deaths were in the Memphis County Warning Area (CWA) as the deaths in surrounding CWAs are counted in the total if the tornado moves into the Memphis CWA.

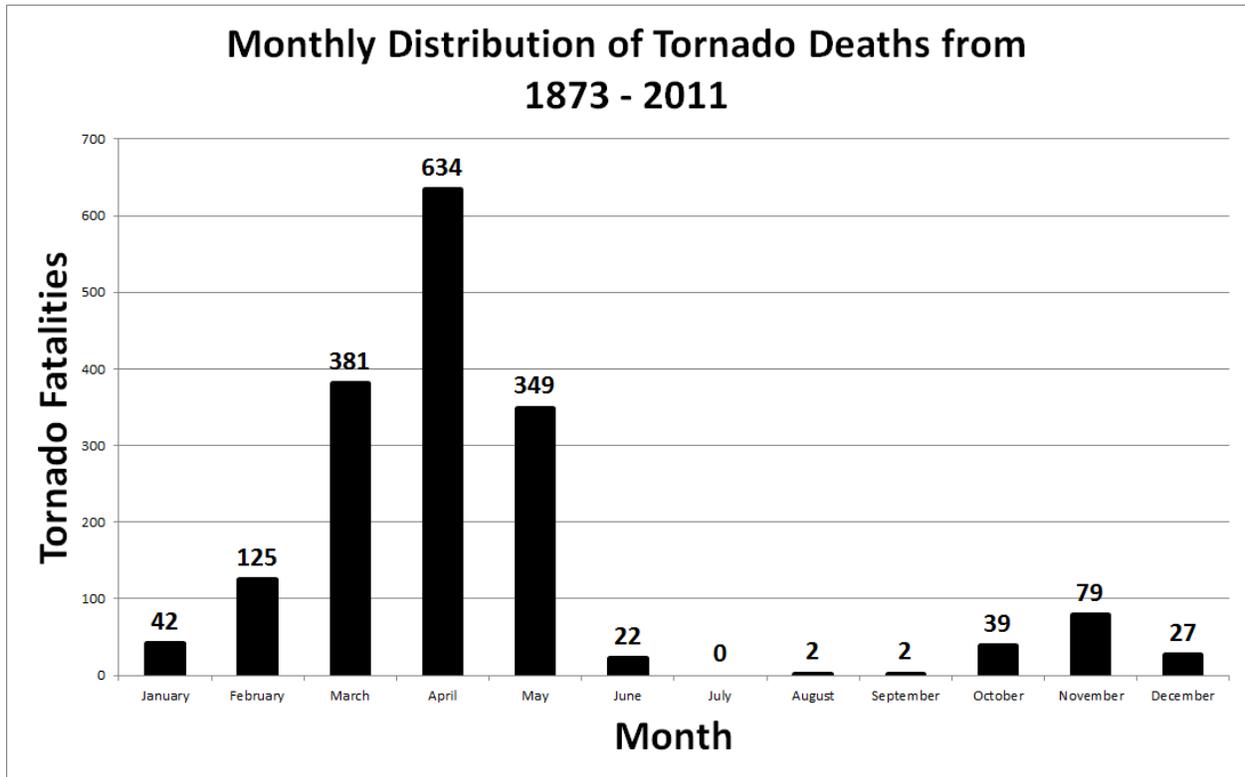


FIG 41. The distribution of monthly Mid-South tornado deaths from 1873 through 2011. The graph represents total number of tornadoes deaths for each month (in black).

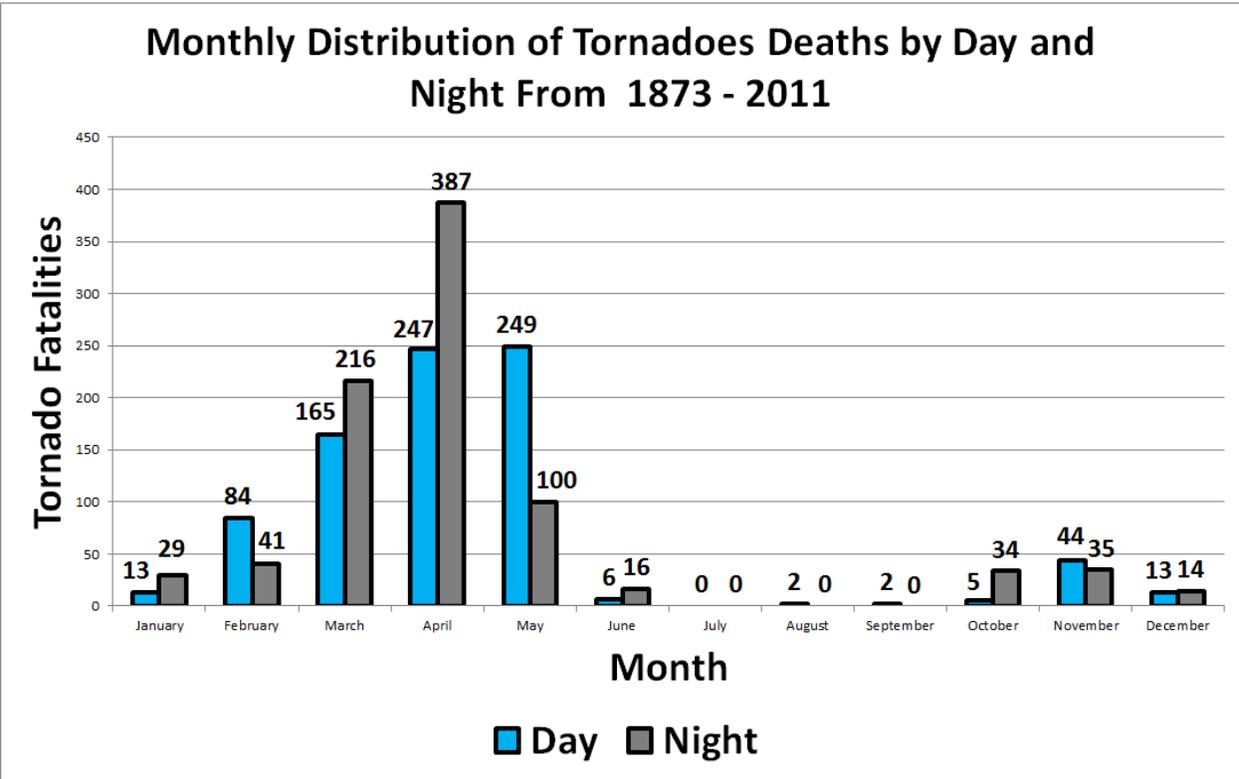


FIG 42. The distribution of daytime and nocturnal tornado deaths based on time (in LST) and date of occurrence for each month in the Mid-South from 1873 through 2011. The graph represents the total number of tornado deaths to occur between the sunrise and sunset times for each day of the month (daytime, in blue) and the total number of tornado deaths to occur between sunset and sunrise times for each day of the month (nocturnal, in grey).

Distribution of Daytime vs Nocturnal Tornado Deaths from 1873 - 2011

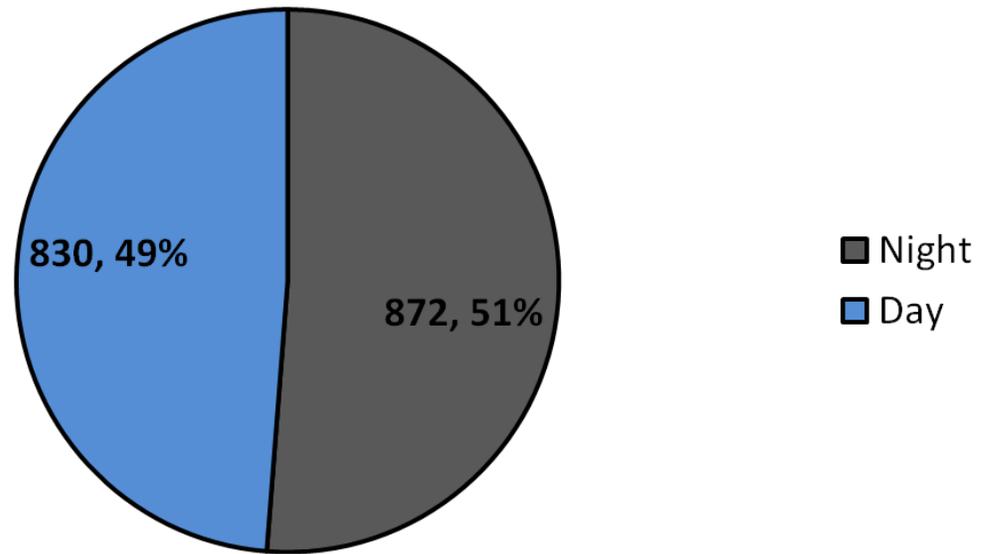


FIG 43. The distribution of daytime and nocturnal tornado deaths based on time (in LST) and date of occurrence for the Mid-South from 1873 through 2011. The graph represents the total number of tornado deaths to occur between the sunrise and sunset times for each day (daytime, in blue) and the total number of tornado deaths to occur between sunset and sunrise times for each day (nocturnal, in grey). The two numbers reflect the count for each category and the percentage of the total.

Tornado Deaths based on Tornado Intensity from 1873 - 2011

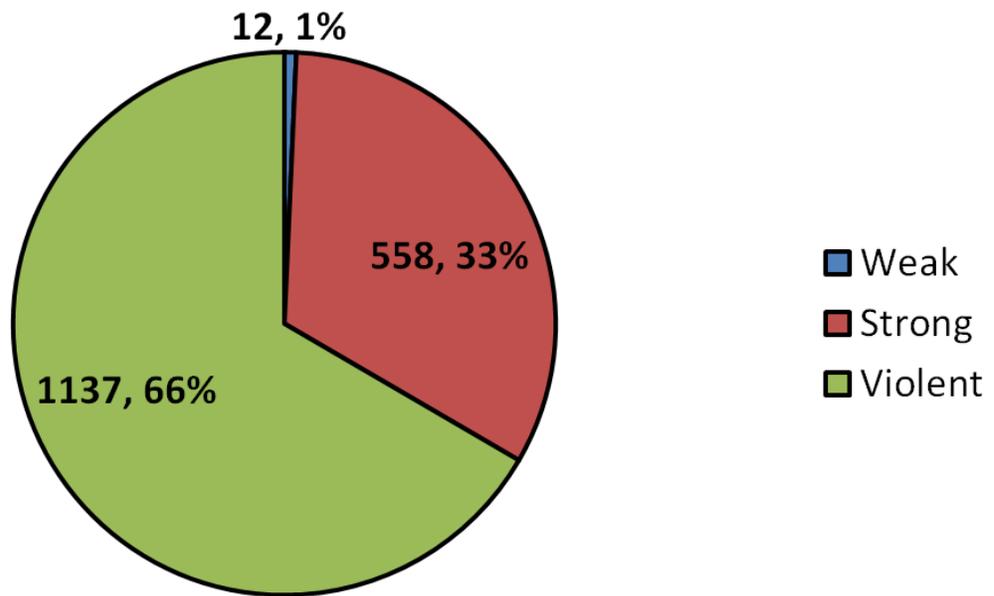


FIG 44. The distribution of tornado deaths in the Mid-South by tornado intensity from 1873 through 2011. The graph represents total number of tornado deaths for weak tornadoes (in blue; rated F-0 and F-1), total number of tornado deaths for strong tornadoes (in red; rated F-2 and F-3), and the total number of tornado deaths for violent tornadoes (in green, rated F-4 and F-5). The two numbers reflect the count for each category and the percentage of the total.

Figures 45 through 48 will be the final figures for this tornado climatology study. These figures are GIS maps displaying all of the tornadoes to strike the Mid-South (Figure 45), all of the tornadoes with path lengths greater than 50 miles (Figure 46), tornadoes that killed 20 or more people (Figure 47) and all of the violent (rated F-4 and F-5) tornadoes to ever strike the Mid-South (Figure 48). From these figures, you can also tell that tornadoes do cross the Mississippi River and make it over the bluffs.

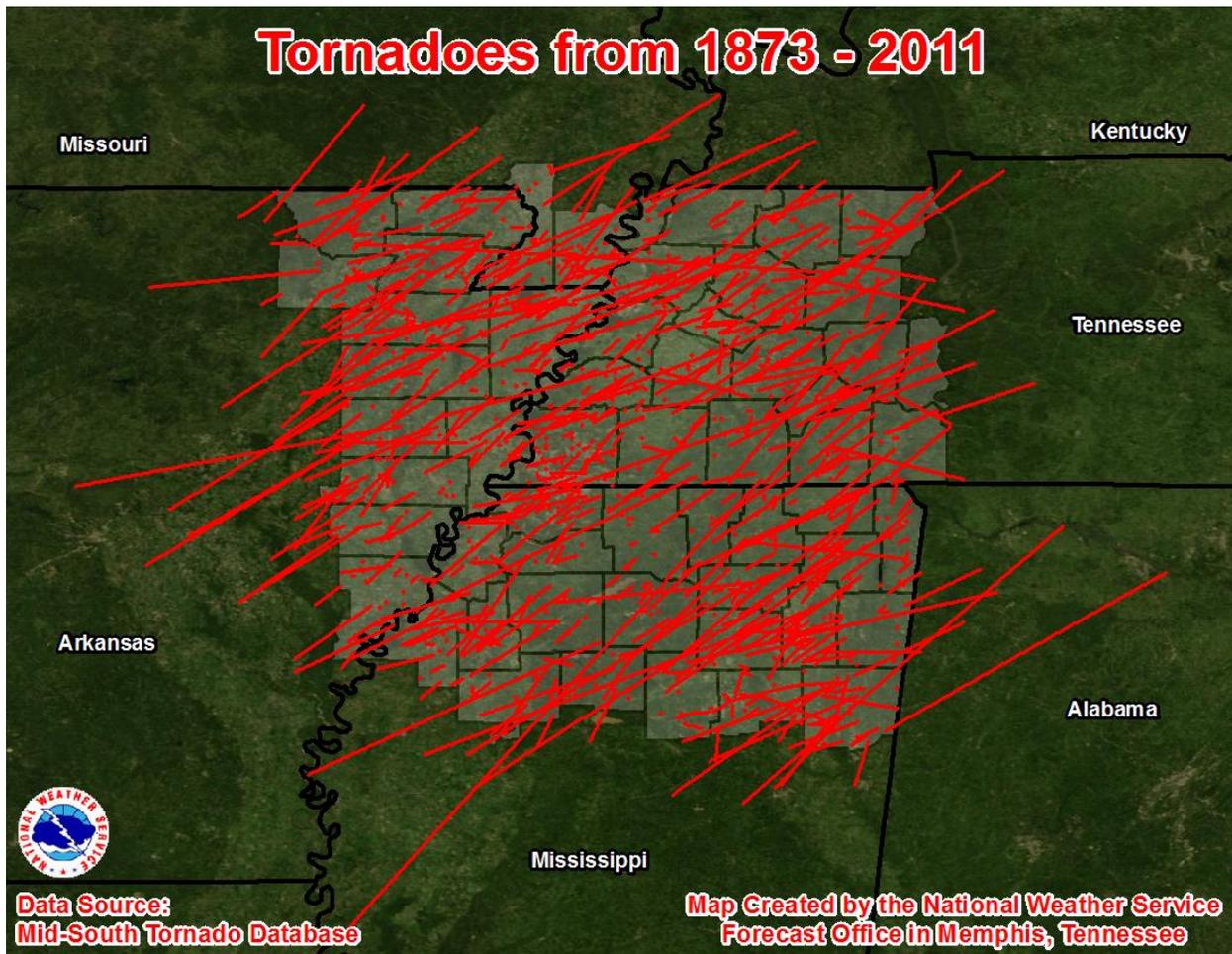


FIG 45. The geographical distribution of all tornadoes to strike the Mid-South from 1873 through 2011. Each red line or red dot represents a separate tornado occurrence.



FIG 46. The geographical distribution of all tornadoes with path lengths greater than 50 miles to strike the Mid-South from 1873 through 2011. Each red line represents a separate tornado with a path length 50 miles or greater.



FIG 47. The geographical distribution of all tornadoes with 20 or more deaths to strike the Mid-South from 1873 through 2011. Each red line represents a separate killer tornado and the black number above the line represents the number of deaths associated with that tornado.

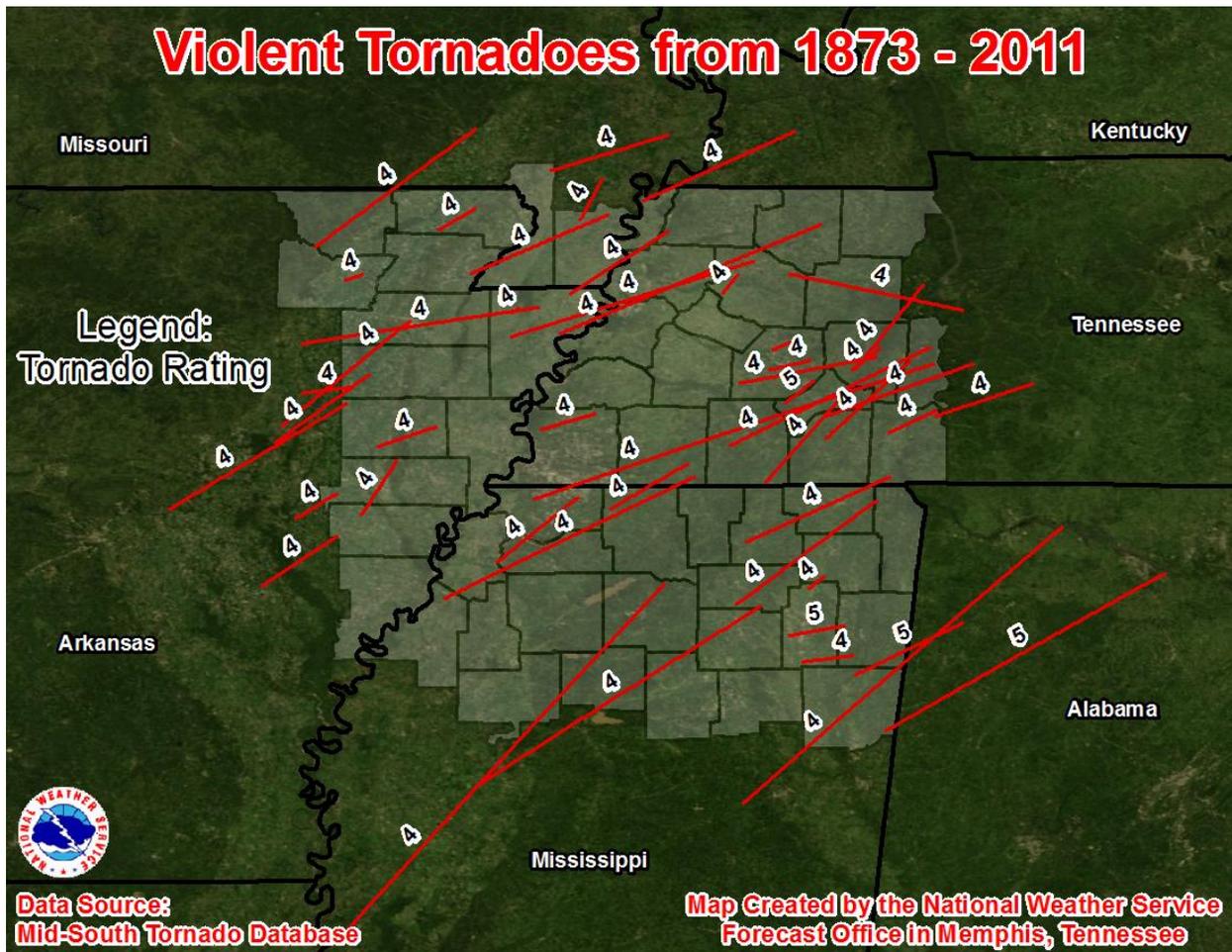


FIG 48. The geographical distribution of all violent (rated F-4 to F-5) tornadoes to strike the Mid-South from 1873 through 2011. Each red line represents a separate violent tornado. The black numbers above or beside the tornado tracks represents the F-Scale rating of the tornado.

Conclusion:

In conclusion, severe weather is common across the Mid-South. The average number of days per year in which damaging winds occurred has remained around 35 days per year for the last 30 years. The number of days in which hail occurs each year, 27 days on average, is lower compared to damaging wind days. There was a large increase in the number of hail reports around 1994, about the time when the Millington WSR-88D Radar was installed. The average number of days in which tornadoes occur each year is seven days a year. Just like the Memphis Severe Weather Climatology Study done by Gaffin and Smith (1995), the month of April continues to lead all months in frequency of tornado occurrences. However, the month of April now leads all months for the most hail reports and the month of May now leads all months for the most wind reports. This differs from Gaffin and Smith (1995) who found that May had the most hail reports and June had the most wind reports.

There are two distinct severe weather seasons for the Mid-South. The main severe weather season for damaging wind events is from April to July with a secondary severe weather season in October and November. There is only one main severe weather season for hail which is March through June. The secondary season for hail reports is not noticeable compared to the wind reports. This is likely due to the low CAPE, high shear events typically seen from the late fall and winter months. The main severe weather season for tornadoes is from March through June with a secondary severe weather season evident in November. January and February could also be included in the main severe weather season. However, these two months have totals that have been skewed by two very large severe weather events; January 1999 and the Super Tuesday Outbreak of February 5th, 2008. From all this, you can see that the Mid-South sees two distinct severe weather seasons; one in the spring and early summer from March through July and another in the fall from October through November. Either way, it is important to know that severe weather can occur during any month of the year in the Mid-South.

This study also found that severe weather can occur during any part of the day across the Mid-South. The majority of the reports of severe weather are received during the afternoon and evening hours. The influence of the diurnal temperature trend can be easily seen in the hail and wind reports. This is not true for the tornadoes. There is some evidence of the diurnal temperature trend within the tornado statistics but definitely not as evident as the hail and wind report statistics. Forty five percent of all tornadoes that strike the Mid-South occur at night. The tornadoes that strike at night account for 872 deaths, or 51% of all tornado deaths to occur in the Mid-South. Tornadoes kill people more often at night in the Mid-South with 112 killer tornadoes occurring at night, or 55% of all killer tornadoes to strike the region.

The Mid-South also has a tendency to receive long-lived, violent tornadoes. Forty nine violent (rated F-4 and F-5) tornadoes have swept through the region. These 49 tornadoes account for 1137 deaths, or 66% of all tornado deaths in the Mid-South. Seven percent of all tornadoes to strike the Mid-South have widths greater than one quarter of a mile wide and 11% of the tornadoes travel more than 25 miles.

Finally, this study also found that La Nina conditions mean more severe weather across the region. Months in which El Nino conditions were observed were found to have about half of the severe weather than months in which La Nina occurs. On average, two tornadoes, 10 wind damage reports and six hail reports occur each month when La Nina Conditions are present.

Acknowledgments:

The author would like to acknowledge the efforts of Danny Gant for his help on the GIS maps and work on computer programming and scripts. The author would also like to acknowledge Jim Belles, Tom Salem and Ben Schott for reviewing this paper and providing encouragement when problems arose.

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