

Tornado Climatology of the Joplin Area

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Abstract

The purpose of this study is to analyze tornado occurrences in and around Joplin, MO. 60 years of data from the four counties surrounding Joplin was acquired from the NOAA archive. The four counties include Jasper and Newton counties in Missouri, Cherokee County, Kansas, and Ottawa County, Oklahoma. The data consists of 141 tornado occurrences in the four counties ranging from 1951 to 2011, including 38 significant tornadoes of size F2 or larger. A data analysis will determine the probability of a tornado occurring in the Joplin area in a given week or month. Weather conditions, including temperature and humidity, from the day of the tornado occurrence were collected and will provide the information needed to determine a correlation between the weather condition and the physical properties of the tornado. The results from this study will be compared to the results from large scale studies on the United States to determine if the Joplin area has a different pattern of tornado occurrences. The goal is to provide valuable information to weather forecasters and the public. This study will add needed knowledge to the field of atmospheric science and will contribute to progress regarding the prediction of tornadoes in and around Joplin, Missouri.

Project Description

The purpose of my project was to study tornadoes that have occurred over previous years around Joplin, Missouri. I studied and compared several aspects of the previous tornadoes. These included the size, date and time of the tornadoes. The intention of my study was to determine if a pattern exists between the aspects of the tornadoes in this area. The conclusion of my project involves percentages of the chance that a tornado will occur on a given day or time and how large that tornado will most likely be.

Along with comparing the date and time of tornadoes, I studied the weather conditions before and during the event. I compared conditions including temperature, barometric pressure, humidity, wind speed, and other important data to find a connection with the tornado events. Similarities involving these conditions could help predict future tornadoes in the focused area. I made graphs and charts evaluating each condition. I also completed a statistical analysis on the data to determine if strong correlations exist between a weather condition and a tornado. My results could point to a condition to further focus on in future studies involving tornadoes. They could also give meteorologists an idea of what condition to look for on days with the highest chance that a tornado could occur, in order to provide earlier warnings to the public.

Literature Review

Tornadoes are life-threatening weather events that are very difficult to predict. Knowledge of tornadoes and how often they occur is important to many people, including emergency workers, insurance companies, and the general public. Tornado climatology studies the occurrences of tornadoes over a period of several years. My study can provide statistics about tornadoes, giving the public a better idea of when the next tornado will occur. Knowing a percentage chance of a tornado occurring on a given day can benefit people greatly. Emergency workers can be better prepared for a tornado disaster if they know that a high chance exists. Tornado warnings are often ignored or not taken seriously, causing a greater number of injuries and deaths. Knowing that there is a high chance that a tornado could occur on a certain day could make the public stay more attuned to the weather forecast and less likely to ignore the warnings on that day.

Weather conditions can be associated with tornado events. By finding a strong correlation between a weather condition or several weather conditions and tornadoes, the ability to predict a tornado event can improve. Several studies have been completed over the years to find correlations between different weather conditions and tornadoes; Colquhoun and Riley (1996), Akyuz, Chambers, and Lupo (2004), and Gaffin and Parker (2006) to name a few. Some of these studies have only focused on one weather condition, which can greatly narrow the study making it more focused. However, only looking at one condition truncates the study and makes it hard to see other relationships. By looking at several conditions over a given area, stronger correlations can be found and others can be ruled out. By combining tornado climatology with weather condition studies, a relationship can possibly be made between a weather condition like temperature and the date or time a tornado most likely occurs in a

certain area. This will greatly increase the likelihood of finding a correlation that can help predict a tornado event further in advance than already possible.

Climatology studies are important in determining results based on when and how many events occurred over a period of years. Ross and Lott (2003) used the climatology of extreme weather and climate events to conclude that global warming and population growth and movement are possible reasons why losses from extreme weather is increasing. They studied extreme events including storms, wildfires, and floods costing more than a billion dollars worth of damage from 1930 to 2003. They found from the climatology that the amount of damage was increasing over the years, and then were able to determine why. This is just one example of how a climatology study can be practical and feasible. Other researchers use climatology studies in an attempt to predict tornadoes.

Brooks, Doswell, and Kay (2003) studied tornadoes over a period of 20 years. They looked at tornadoes occurring on certain days all over the United States. From the climatology, they were able to calculate a daily probability of tornadoes and determine maximum threat days. The statistics they found were very informative, but they lack the ability to predict a tornado in a certain area. They gave a daily probability of a tornado occurring in the United States, but this doesn't help the general public prepare for a tornado event unless the probability is given for a more specified area. If, for example, this study found that tornadoes are most likely to occur on May 20th, then for the United States as a whole this is may be true. However, a specific area like Joplin, MO might see more tornadoes on May 5th, so using Brooks, Doswell, and Kay (2003) to predict tornadoes in Joplin would cause inaccurate results.

Concannon, Brooks, and Doswell (2000) performed a similar study to find the risk of a strong tornado. They looked at the United States as a whole, which could again cause problems when applying the results to a specific area. They found the probability of a tornado touching the ground and looked at the date of the touchdowns. The climatology showed that tornado touchdowns are more likely to

happen within 2 weeks of May 1 of any year. The study also resulted in the maximum frequency of strong tornadoes, in any location in the United States, to be once every 2 or 3 years. The study focused on strong tornadoes, meaning the tornadoes were categorized as an EF2 or F2 or higher. EF2 refers to the Enhanced Fujita scale used to categorize tornadoes by wind speed and damage caused. F2 refers to the Fujita scale used until 2007 when it was replaced by the Enhanced Fujita scale. The scale ranges from EF0 to EF5. To be considered a “strong” or “significant” tornado, the wind speed must be at least 111 miles per hour, which is considered an EF2. So, the result of the study was that a tornado of scale EF2 or F2 or higher will only come close to a location once every 2 or 3 years. This study focused on a very large area and made conclusions for the United States as a whole, but these results are hard to use in small-area predictions. Other studies have used tornado climatology to make these small-area predictions by focusing on a small region of the United States.

Brueske, Plourd, and Volkmer (1998) completed a study on the severe weather climatology of the Charleston, South Carolina county warning area. Their study was successful in finding the months and times most likely for a severe weather event to occur, including tornadoes, only for the Charleston area. According to the results, tornadoes are most likely to occur in April and May between 2PM and 5PM in that area. These results are slightly different than Concannon, Brooks, and Doswell (2000). The Charleston study found the most likely time for tornadoes to be about a month longer than what the United States study found. The Charleston study was more specific and determined the most likely time for a tornado, which is a major benefit of a small-area study. Brueske, Plourd, and Volkmer (1998) completed a statistical analysis of strong winds, hail, and tornadoes, including tornado intensity and the width and length of each tornado path. Tornadoes were recorded and analyzed from 1950 to 1993 and included 112 events. They were able to come to several conclusions about the Charleston area, which “provides valuable insight” (Brueske, Plourd, and Volkmer, 1998) to weather forecasters in that specific area to help improve the ability to warn the public. Brueske, Plourd, and Volkmer (1998) states

“improving knowledge of the pre-storm convective environment in the context of a detailed local climatology can only improve on the overall severe weather forecast and warning effort.” Studies with the goal of improving tornado warnings and saving lives will have greater success by focusing on a small area. Some studies aren’t only focused on the area of tornadoes being studied, but what weather variables are associated with those tornadoes.

The purpose of several studies involving tornadoes is to compare different weather events or conditions with the tornado events. Mayes, Cogil, Lussky, Boyne, and Ryrholm (n.d.) attempted to find a correlation between severe storms, including tornadoes and ENSO phase. ENSO phase stands for El Nino-Southern Oscillation which refers to changes in the temperature of the surface of the Pacific Ocean and the air surface pressure in the Pacific Ocean. They studied the number of severe storms and tornadoes during El Nino years, La Nina years, and neutral years. El Nino years occur when the Pacific Ocean has a warm surface and high air surface pressure. La Nina years occur when the Pacific Ocean has a cool surface and low air surface pressure. Neutral years refer to years that are neither El Nino nor La Nina. They resulted in a small relationship between each condition. The study looked at tornadoes and severe storms all over the United States. It did not include any other weather events, only the ENSO phase and tornadoes.

Clark, Schaffer, Gallus, and Johnson-O’Mara (2009) studied a different weather event and compared it to severe storms, including tornadoes. They looked at the location of storms relative to jet streams, which are fast moving air currents. The study was successful in concluding that tornadoes are most concentrated in the “exit region” of the jet stream. Jet streams were the only weather event compared to severe storms in this study and the area of study included the entire United States. Coquhoun and Riley (1996) studied the relationships between the intensity of tornadoes and other weather variables. They found that lower temperatures were related to greater tornado intensity and that there is no relationship between wind shear or dew point and tornadoes.

Akyuz, Chambers, and Lupo (2004) discussed ENSO phase and jet stream relationships to tornadoes, along with variations in tornado frequencies over a four-state region in their study. They looked at tornadoes of F2 scale or greater in the states of Iowa, Kansas, Missouri, and Nebraska. They were successful in finding a better understanding of the inter-annual and inter-decadal variations of tornadoes. However, the study covered a relatively large area. Because of this, their findings do not contribute helpful knowledge to local forecasters in order to help warn the public of a coming storm. Some studies focus on areas smaller than the entire United States, but these studies are still looking at an area large enough to make it difficult to improve warnings.

Gaffin and Parker (2006) completed a study on the southern Appalachian region, which is just a part of the United States, but it is still too big to make a specific prediction for a small area in order to warn the public faster. They focused on tornadoes ranked as F2 or higher. Using 54 years of data, the study compared wind directions and dew points and discussed the topography of the land in association with the significant tornadoes. The region study consists of 100 counties and 94 tornadoes. Areas of low pressure were also studied. Gaffin and Parker (2006) found tornadoes occurring within 100 kilometers of surface thermal or moisture boundaries. This study provides very valuable information to the area of study involving the topography of the land, but the results cover too large of an area to help forecasters warn the public.

More studies need to be completed on small areas of land, like the county warning area of Charleston, SC. Predictions of tornadoes in an area the size of a county or a few counties can greatly improve forecasting in that specific area, which can lead to faster warnings and fewer tornado related deaths. Studying a large area, like the United States, is way too broad. Tornadoes in South Carolina can be completely different than tornadoes in Missouri because they are so far away from each other and have different climates. For example, South Carolina is close to the ocean, so some of their tornadoes could come from hurricanes, while Missouri is in the middle of the United States and will probably not

see any tornadoes come from hurricanes. Large-area studies cannot account for these differences, whereas small-area studies can include details like hurricane caused tornadoes.

The goal of my study of the Joplin, Missouri area is to contribute valuable information to forecasters in and around Joplin. My study will focus on only four counties, unlike Gaffin and Parker's 100 counties. However, my study will be similar to Gaffin and Parker (2006) in the sense that I will cover about 50 years of data and focus only on tornadoes ranked as an EF2 or higher. I will also compare weather conditions, including wind directions and dew points, like the Gaffin and Parker study. However, I will also include other factors, like temperature and barometric pressure. These factors have proven to be correlated with tornado events in large-area studies, like in Clark, Schaffer, Gallus, and Johnson-O'Mara (2009). I would like to determine if the same correlation can be found in a small-area study of Joplin, MO.

Akyuz, Chambers, and Lupo (2004) studied part of the same area that I will study. However, my study will focus on a far smaller area of land and will include more weather factors, like temperature and dew point. The results of a smaller scale study comparing more variables will be of greater use to local weather forecasters in the attempt to warn the public of tornadoes. Comparing more variables will increase my chance of finding a correlation between weather conditions and tornadoes, therefore increasing my chance of finding a warning sign to alert forecasters of a tornado.

My study will be most similar in form to Brueske, Plourd, and Volkmer's (1998) work. However, I will be studying a completely different area of the United States. If researchers complete a number of these small-area studies, then the results should provide enough information to help forecasters warn the public of tornadoes faster and more accurately. They would be far more useful in saving lives than large-area studies. These small-area studies would also broaden our understanding of tornado activity.

The results could be studied to determine differences between tornadoes in different parts of the United States, like comparing Joplin, MO tornadoes to Charleston, SC tornadoes.

Small area climatology studies containing cities that have previously seen very large and destructive tornadoes are missing from current research. Most studies focus on the United States as a whole, or on only one weather variable. My study of the four counties surrounding Joplin, MO will add needed information about the area to current research. I compared several weather variables, including temperature, barometric pressure, dew point, wind speed, and other important conditions. I studied several aspects of tornadoes, including date, time, intensity, and path direction. I studied all of these conditions for the Joplin area and my results were determined based on correlations between any or all of these conditions. No study has been completed on the Joplin area or any other small area including as many factors as my study did. The results of my study will provide valuable information to Joplin weather forecasters, as well as provide information to the field of atmospheric science. Finding correlations between weather variables and tornadoes in the Joplin area could open up ideas for future studies to see if the same correlations are found in other areas. A small correlation found in my study could possibly contribute to finding a correlation that could predict tornadoes faster and more accurately all over the United States. This could greatly improve the warning effort and save many lives.

Significance

My project is important because it could help save lives. Joplin, Missouri was the location of one of the deadliest tornadoes in the history of tornado records. My project could give meteorologists an idea of what to look for in the future in order to warn the public faster in the Joplin area. The goal of my project was to provide information that could make tornado warnings more specific. Finding the chance that a future tornado could occur in or around Joplin could help the public know and understand when to be most prepared for a tornado. Finding a connection between weather conditions, like temperature or humidity, and tornadoes around Joplin could possibly give a time deadline to a warning. If, for example, the barometric pressure drops the same amount an hour before each tornado touches the ground, then in the future, meteorologists can watch the pressure and notify the public when they see that drop. Early warnings and knowing the chance that a tornado could occur is vital in getting people out of harm's way.

In addition to warning people of tornadoes around the Joplin area, my study could provide a basis for future studies in tornadoes. If the results from my project find a correlation between temperature and a tornado or between temperature, humidity, and several tornadoes, then a future study could focus on the similarity found and determine how relevant it is to predicting a tornado. A future project could look at the whole United States, not just one area, and determine if the same similarity occurs with every tornado touchdown in every state. My study could also be a model for a future small-area study. It will provide helpful information to the field of meteorology, even if it results in no similarities between conditions.

Methodology

To start my project, I collected data of tornadoes. The data consisted of the tornado occurrences in and around Joplin, Missouri. I retrieved the data from the National Oceanic and Atmospheric Administration's National Climatic Data Center. The NOAA had an archived record of tornadoes for the four counties surrounding Joplin from 1951 to 2012 on their website available for download by the general public. The four counties I included in my study are Jasper and Newton Counties in Missouri, Cherokee County in Kansas, and Ottawa County in Oklahoma. I chose these counties due to the fact that most tornadoes that cause damage to the city of Joplin, or surrounding cities, begin in the counties of Cherokee or Ottawa. I included Newton County because Joplin lies on the county line of Jasper and Newton Counties. Including four counties in my study gave me a larger range of data, consisting of 141 total tornadoes, than only using Jasper County.

My plan was to find out how many tornadoes have passed through these four counties over at least the past 50 years. I was successful in finding significant data because I was able to use 60 years of tornadoes in my study. My project focuses on large tornadoes, determined by the Fujita or now Enhanced Fujita scale to be an F2, or EF2, or higher. I will refer to these tornadoes as "significant" in size. Injuries and deaths are more likely with significant tornadoes, so limiting my results to the chance that a larger tornado will occur will give the public more useful information. Small tornadoes are far more common than large tornadoes. Using all 141 tornadoes to find the chance of a tornado in a certain month increases the percentage greatly compared to using only 38 significant tornadoes. Truncating my results to show the chance of a significant tornado occurring will cause less anxiety in the public. Showing a high percentage and telling the public that it is the chance of a tornado occurring could cause

unnecessary panic. The public assumes the worst, so they would look at that high percentage and picture a very strong tornado instead of a weak and short lived tornado that it most likely will be.

My data collection was broad in the sense that it included several different weather conditions for every day that a significant tornado occurred. I included what time and day the tornado touched the ground, along with what direction it was moving and how long it was on the ground. My data was somewhat hard to find, so the number of weather conditions I used was limited. I planned to use two different temperature readings from the days of the tornado, a surface temperature and an upper atmosphere temperature. I was unable to find the data for the upper atmosphere temperature, so I was only able to use the surface temperature. However, I found a website that included the minimum, mean, and maximum temperature for each day. This data came from the Weather History and Data Archive from Weather Underground. The data also included the temperature for a specific time of the day, which provided very useful and interesting information.

I completed an analysis on my data involving the frequency of tornadoes. I also used a computer program to complete a statistical analysis on the data. This analysis determined the degree of correlation between the weather conditions and the tornadoes. The program is referred to as SPSS. It is a statistical analysis program created by IBM to perform statistical testing on data. Throughout my study, I will refer to correlations from this analysis. The correlation is a Pearson correlation and is represented by the letter r . The number of data entries used in the correlation is represented by the letter N . The significance is represented by the letter p .

Results

The data collected from the NOAA National Climatic Data Center consisted of 141 total tornadoes in the four counties of Jasper and Newton County, MO, Cherokee County, KS, and Ottawa County, OK. The following maps, Figure 1 and Figure 2, define the counties involved in my study. Figure 3 shows where Joplin, Missouri is located within those counties.

Figure 1

A map of the four states of Kansas, Oklahoma, Missouri, and Arkansas. The four counties included in my study are shown directly in the middle of the map. Photo courtesy of familysearch.org.

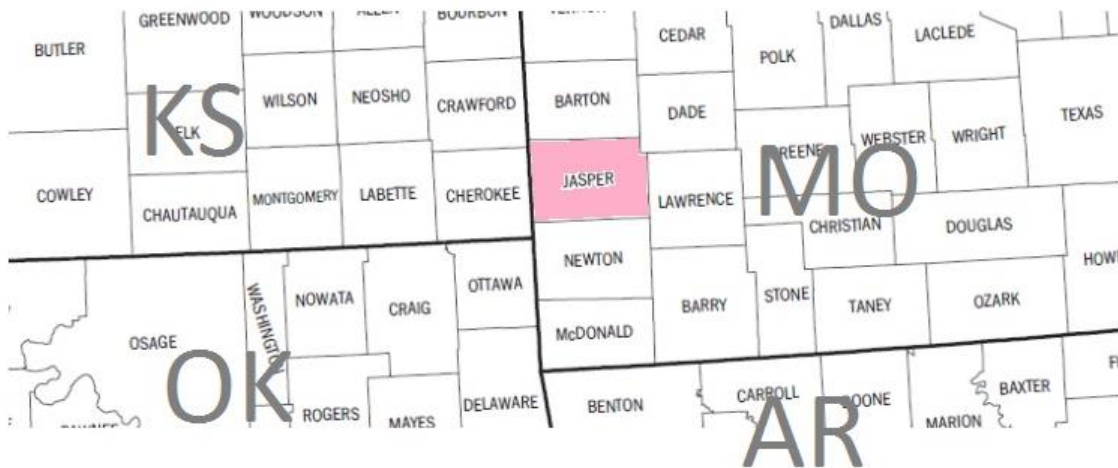


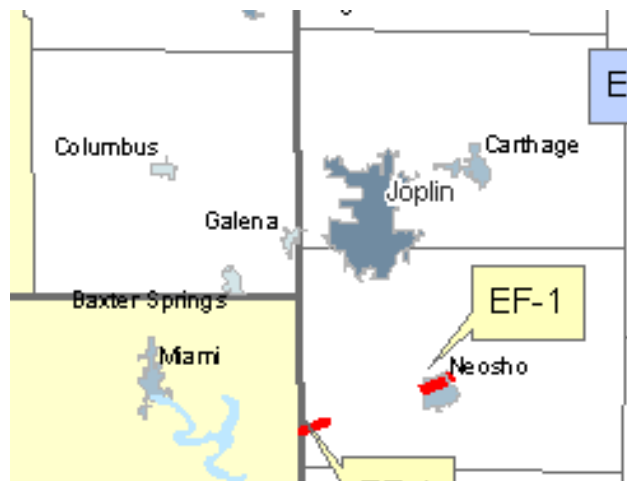
Figure 2

An enlargement of Figure 1, these are the four counties used in my study. Photo courtesy of familysearch.org.



Figure 3

The area of Joplin, Missouri is represented by the dark grey mark. Joplin is mostly located in Jasper County, but part of it lies in Newton County. Disregard the “EF-1” note. This photo is courtesy of the NOAA and the National Weather Service. It was used to display tornado reports for March 31, 2008. <http://www.crh.noaa.gov/images/sgf/events/March%2031%202008/0331Tornado%20Map.png>



Of the 141 tornadoes collected, 38 of them (27%) were significant in size and strength ranging from F2 to F5, or EF2 to EF5. 37 of the 141 tornadoes were located in Cherokee County, KS. 8 out of those 37 tornadoes in Cherokee County, KS were significant in size. 25 out of the 141 tornadoes were located in Ottawa County, OK and of those 25, 11 were significant. 41 tornadoes were located in Jasper County, MO, with 11 of those 41 being significant and 38 were located in Newton County, MO, with 8 of those 38 being significant. Figures 4 and 5 display these results.

Figure 4

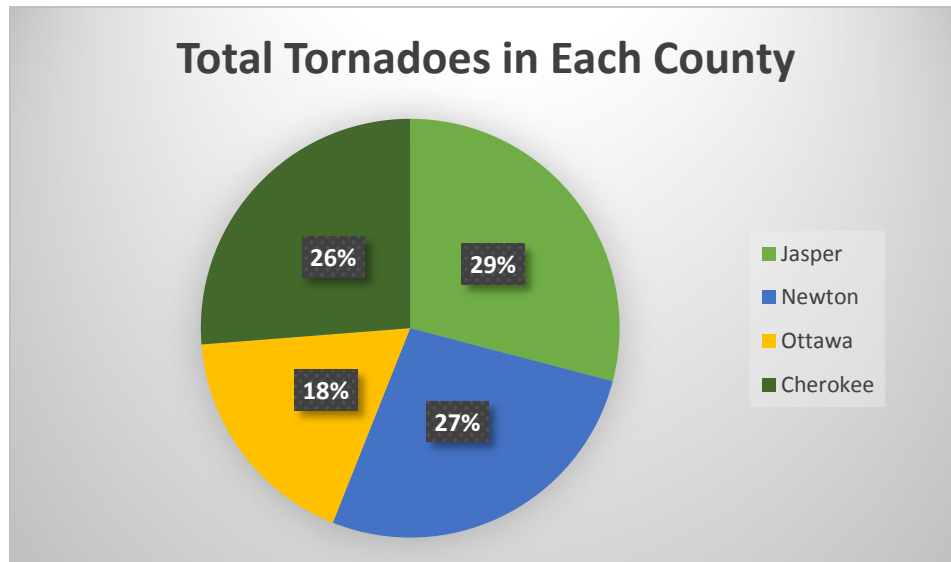
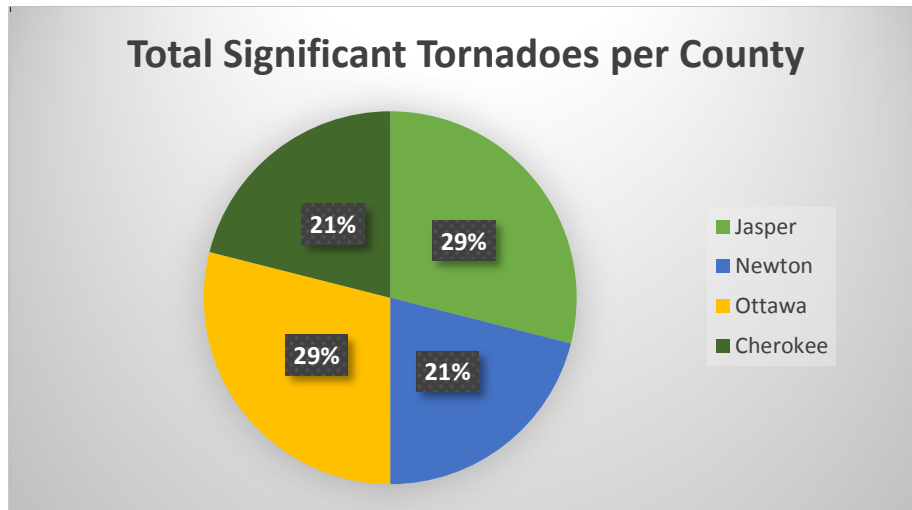


Figure 5



Significant tornadoes larger than F2, or EF2, cause the most injuries, deaths, and damage. I focused more on these tornadoes in my study for that reason. I started my study by looking at what times, weeks, months, and years these significant tornadoes occurred. I found that 19 out of the 38 tornadoes, or 50 percent, touched the ground between 4 p.m. and 8 p.m. These results are shown in Figure 6. I was able to compare my results of the Joplin area to the results from other studies, including Brueske, Plourd, and Volkmer's (1998) study on the county warning area of Charleston, South Carolina. Figure 7 displays the results for Charleston, SC. Figure 8 displays the historic trend for the entire United States provided by the NOAA. The study of the Charleston area includes every tornado of all sizes and the chart for the entire United States gives a normalized occurrence for every hour of every tornado of all sizes. My chart only displays the significant tornadoes for the Joplin area, but similarities are still present between all three graphs.

Figure 6

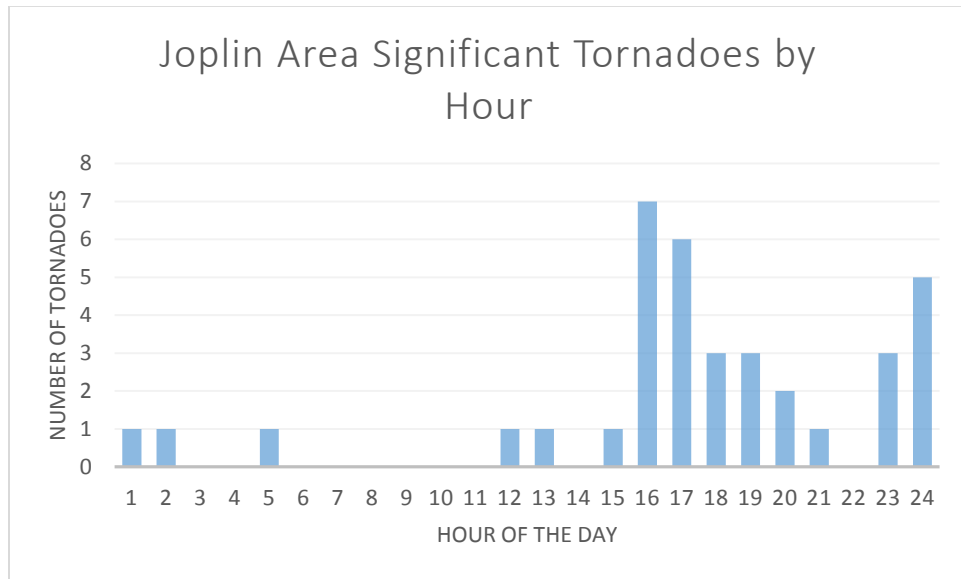


Figure 7

HOURLY DISTRIBUTION OF ALL TORNADES SEGMENTS
WITHIN THE CHARLESTON CWA

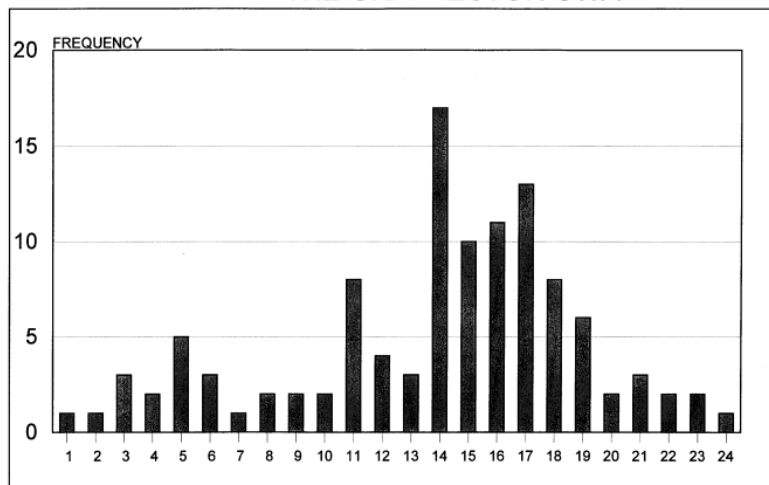
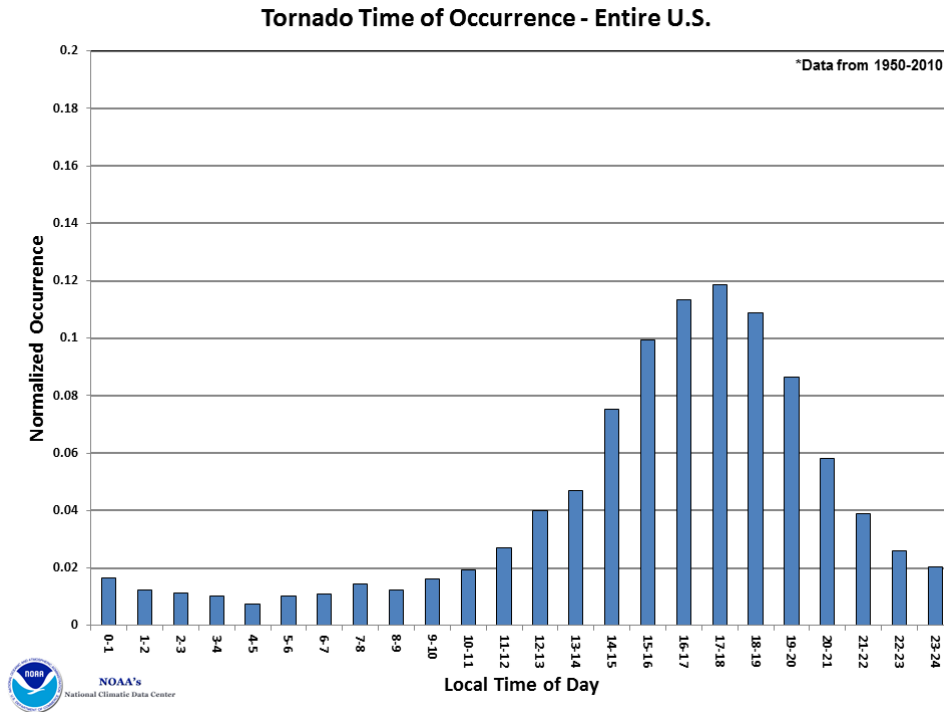


Figure 7. Hourly distribution of all tornado segments reported within the Charleston, SC, CWA during the time period 1950 through 1993. Hours labelled on the x-axis are in Eastern Standard Time.

Figure 8



Now that I had found the most likely time for a significant tornado to occur in the Joplin area, I wanted to find the most likely month. I was able to find the most likely month for a tornado of any size to occur and also for a tornado of significant size. April and May contain the most tornadoes of any size for the Joplin area with over 20 percent in each month. April contained 30 tornadoes (21.3%) and May contained 35 tornadoes (24.8%). March and June followed with 16 (11.4%) and 20 (14.2%). September had the most tornadoes for the fall season with 10 (7.1%). Figure 9 displays these results and Figure 10 displays my results for only the significant tornadoes in the Joplin area. Again, April and May contain the most significant tornadoes. May had 14 (36.8%) of the 38 significant tornadoes, while April had 8 (21.1%). Figure 11 displays the results for the Charleston, SC study of tornadoes of all sizes and Figure 12 displays the results for the entire United States, which includes all sizes of tornadoes.

Figure 9

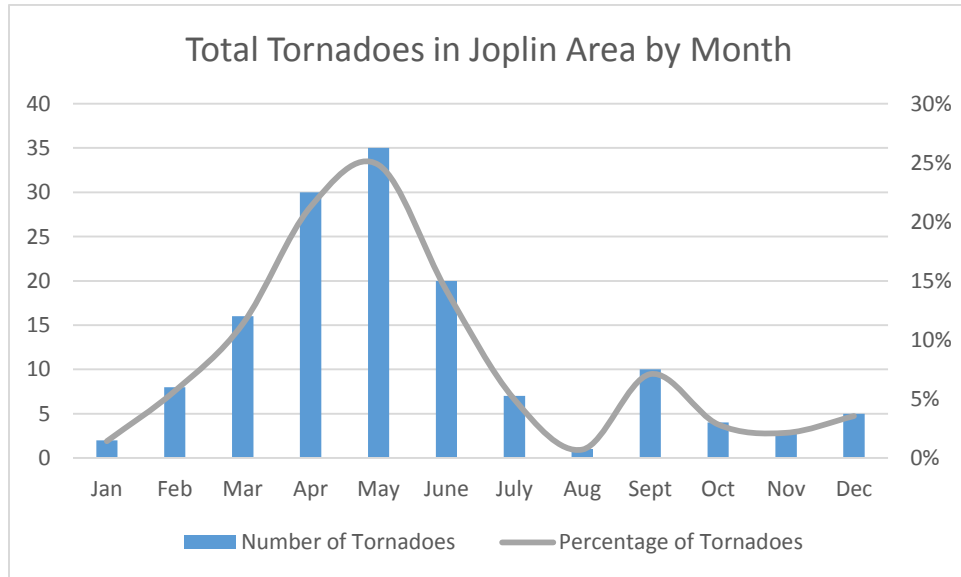


Figure 10

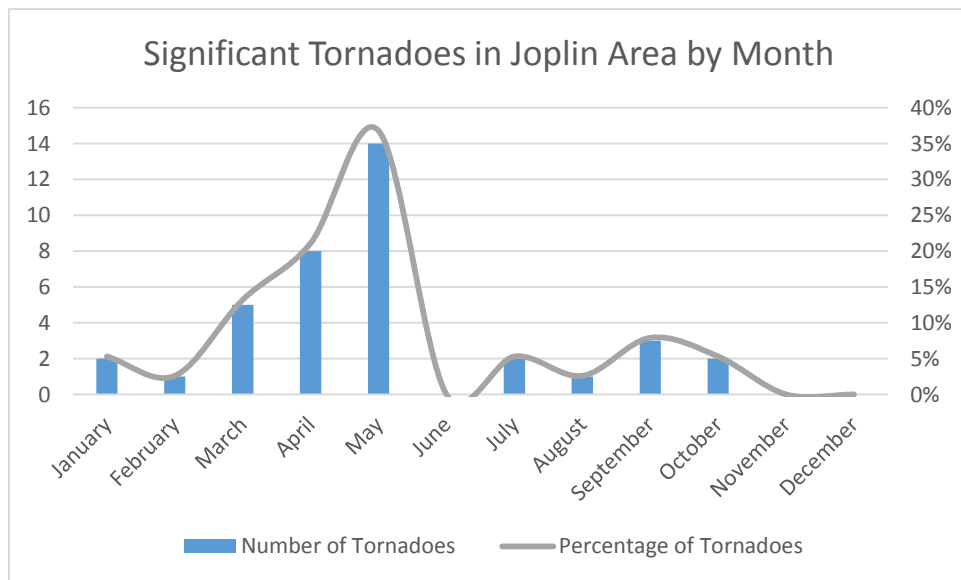


Figure 11

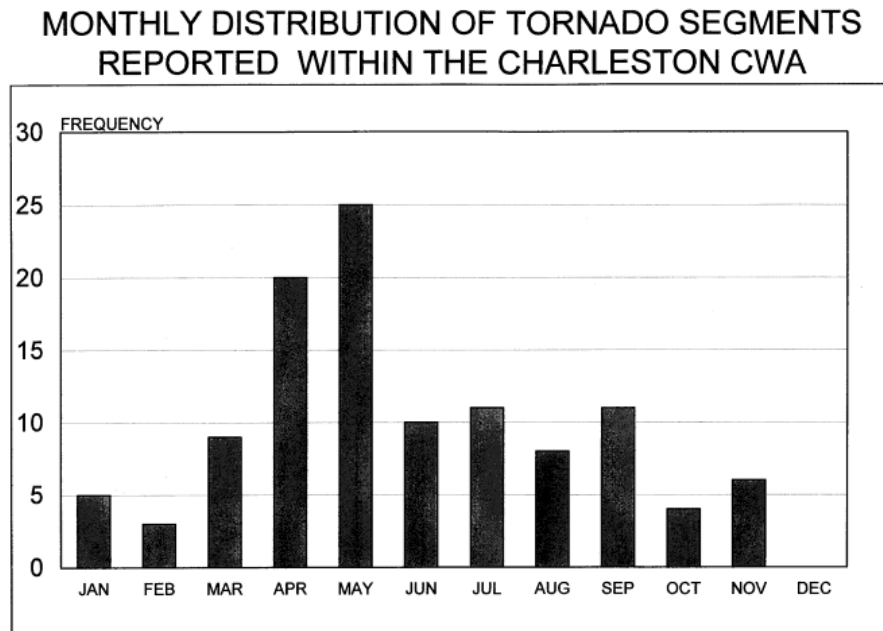
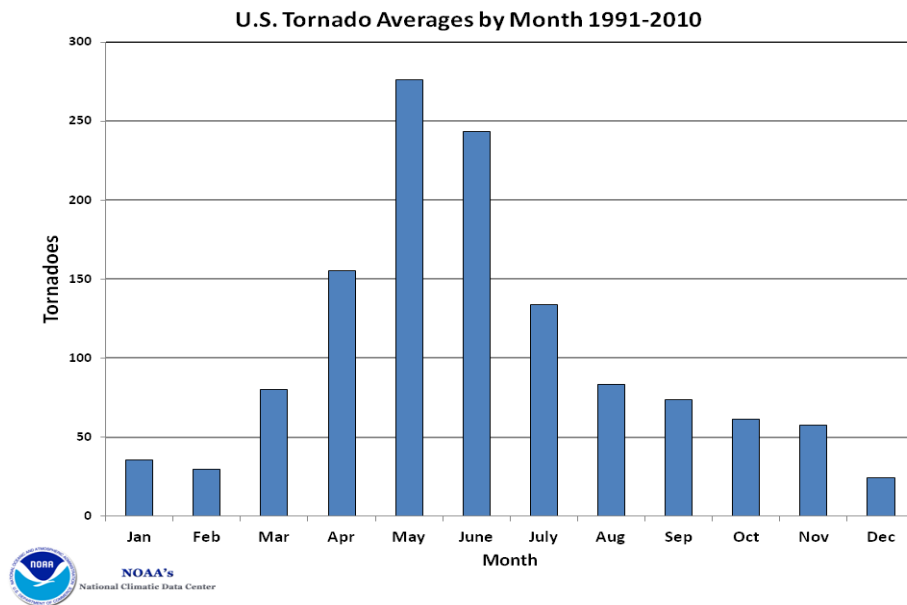


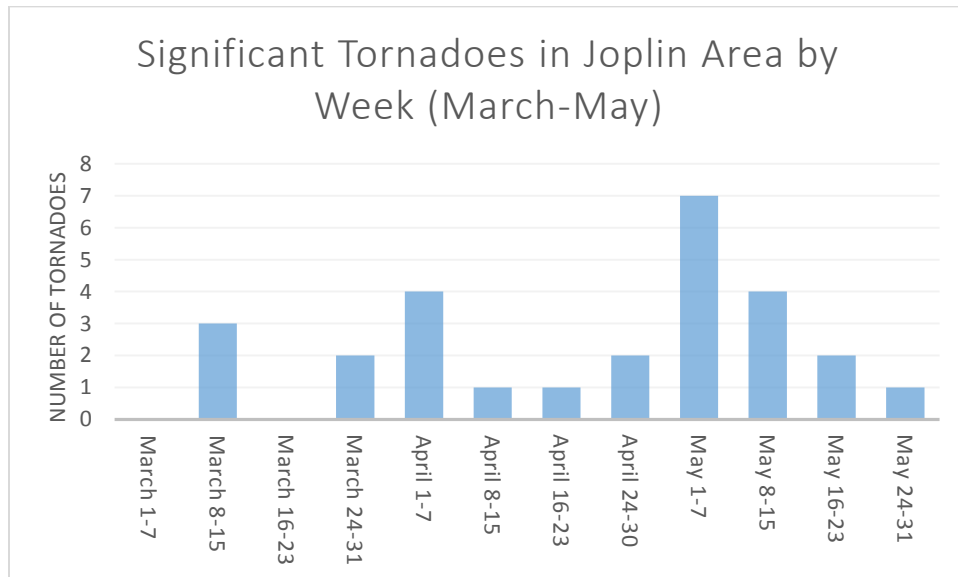
Figure 5. Monthly distribution of all tornado segments reported within the Charleston, SC, CWA during the time period 1950 through 1993. Total tornado segments equal 112.

Figure 12



Since I had found the most significant tornadoes in the Joplin area to occur mostly in March, April, or May, I decided to look closer and find the most common weeks within those months for a significant tornado. Of the 5 significant tornadoes in March, 3 of those occurred between March 12 and March 15. The remaining 2 occurred in the last week of March on the 26th. The first week in April has seen 4 significant tornadoes between the 3rd and the 7th. The second week has seen only one on April 13. The last two weeks have seen 3 tornadoes, one on April 21, one on April 24, and one on April 25. For May, there were 14 significant tornadoes with 6 of those occurring on May 4 or May 5. The second week of May between the 7th and 11th saw 4 tornadoes. The third week saw 3 significant tornadoes between May 15 and May 22, and the remaining tornado occurred on May 31. These results are displayed in Figure 13.

Figure 13



I analyzed the number of tornadoes in the Joplin area by year and found little trend. Figure 14 shows my results for all sizes of tornadoes in the four counties in my study and Figure 15 displays only the significant tornadoes by year. Figure 16 shows results from the NOAA National Climatic Data Center's historic tornado records. Figure 17 comes from the same record from the NOAA, but it involves tornadoes of strength F3, or EF3, and above for the entire United States. My study of the four county area around Joplin, MO consists of tornadoes from 1951 to 2011. The records for the entire United States from the National Climatic Data Center consists of tornadoes from 1954 to 2012. This makes it easier to compare the two results for similar trends. The Charleston, SC study did not include an analysis of tornadoes by year.

Figure 14

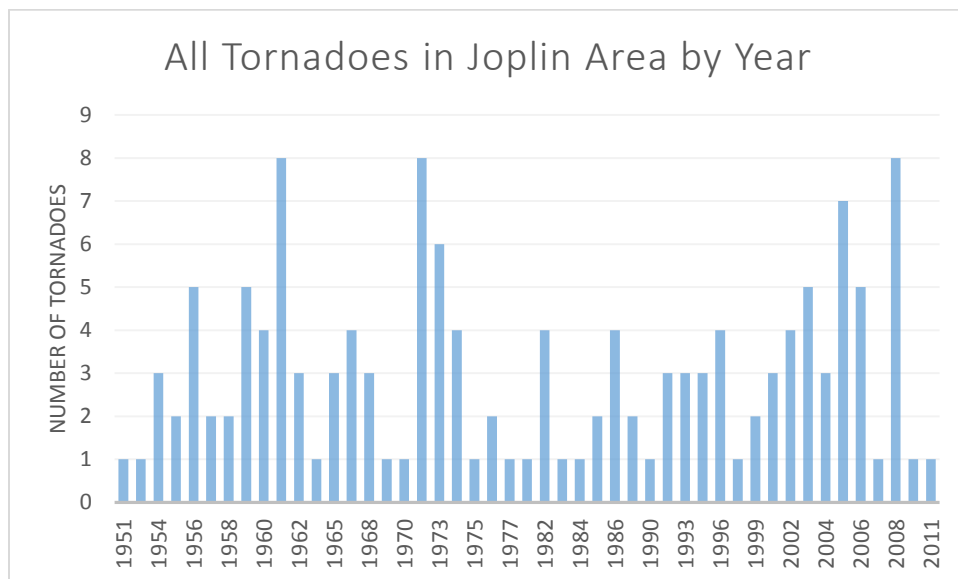


Figure 15

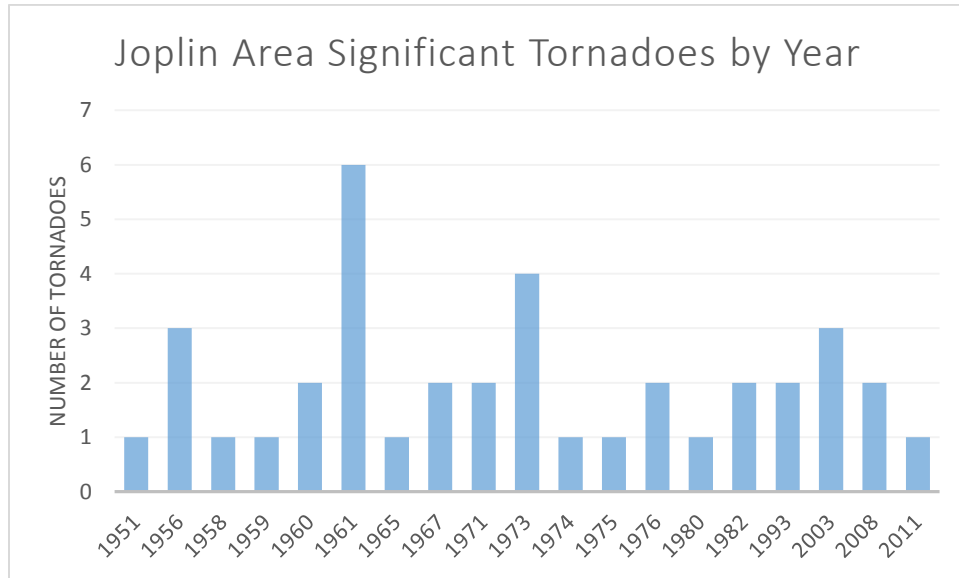


Figure 16

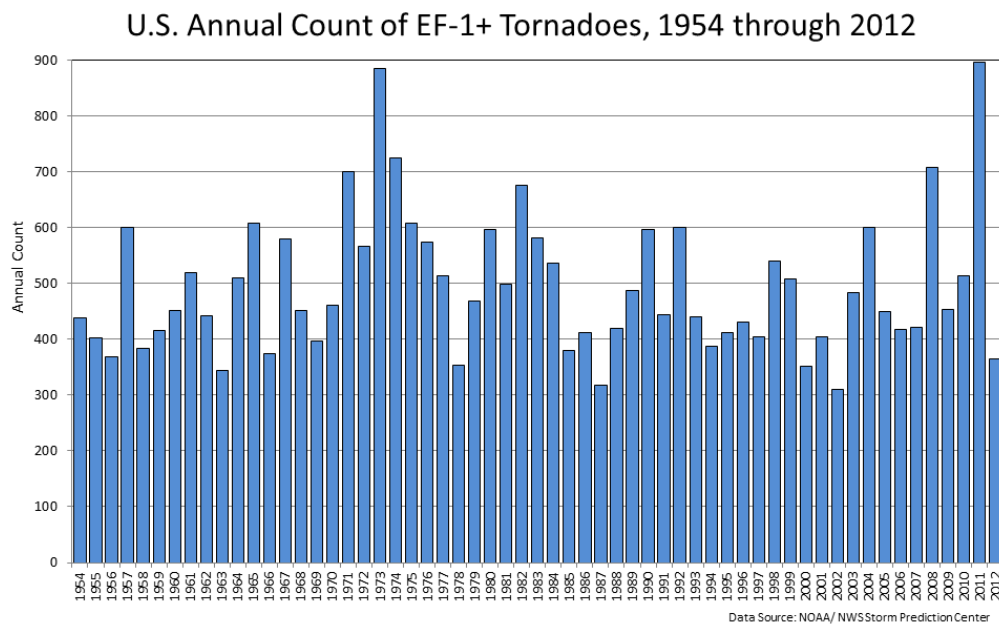
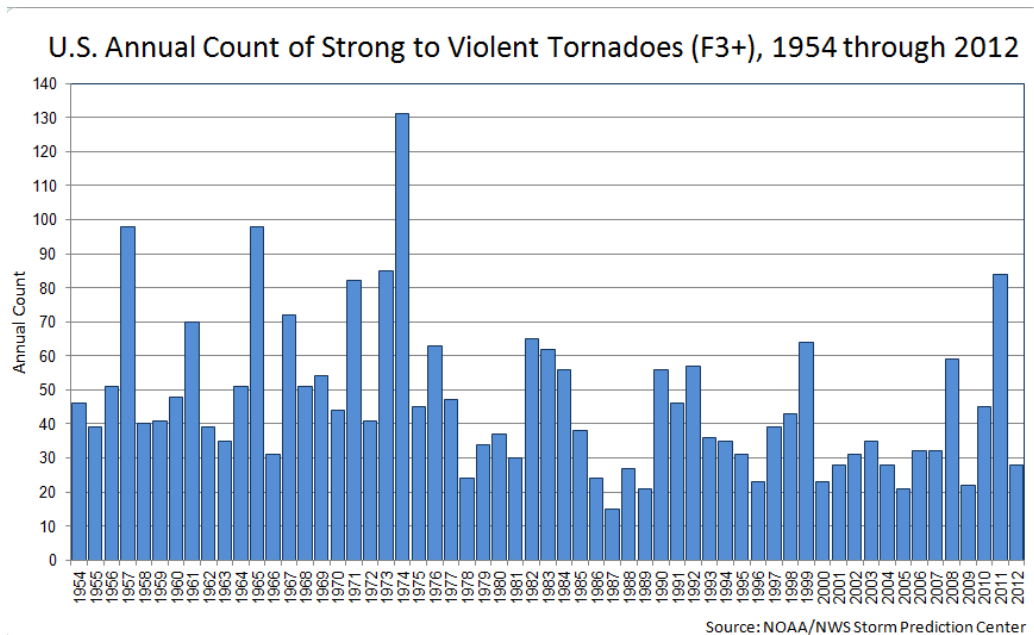


Figure 17



I compared the path length and path width of each tornado to its size based on the Fujita, or Enhanced Fujita, scale. I was unable to find a study on the entire United States that included a path length and width analysis. However, the Charleston, SC study contains a couple graphs showing the number of tornadoes in that county warning area that have each path length and width. The Charleston, SC study doesn't compare the path length and width to the tornado size like my study of the Joplin area does. In order to be able to compare the total number of tornadoes associated with each path length and width from my study to the Charleston study, I organized my data into the same categories used by the Charleston study. Figure 18 shows my results for the Joplin Area in terms of path length and Figure 19 shows the results from the Charleston area. The categories for the path lengths are organized by PL0 through PL5 in miles. Figure 20 displays my results for the four counties around Joplin in terms of path width and Figure 21 displays the results for the Charleston area. The path width categories range from PW0 to PW5 in yards.

The statistical analysis I completed using SPSS shows a significant correlation between the Fujita scale of a tornado and the path length and width of the tornado. Figure 29 displays the correlation between tornadoes of all sizes on the Fujita scale and the path length and width. The relation between the Fujita scale and the length of the tornadoes is $r(N=137)=.584$, $p=.000$. The relation between the Fujita scale and the width of the tornadoes is $r(N=137)=.460$, $p=.000$. Figure 31 displays the correlation between significant tornadoes of size F2 or larger and the path length and width. The Pearson correlation between the Fujita scale and the length of the significant tornadoes is $r(N=38)=.562$, $p=.000$. The Pearson correlation between the Fujita scale and the width of the significant tornadoes is $r(N=37)=.413$, $p=.011$. These strong correlations suggest that as the Fujita scale of the tornado increases, so does the path length and width. Figure 28 shows the mean length and width of all tornadoes to be 2.99 miles by 144 yards. Figure 30 shows the mean length and width of significant tornadoes to be 7.495 miles by 298.32 yards.

The correlation analysis I completed using SPSS also displayed a significant correlation between the path length and width of the tornadoes and the maximum gust speed of the wind, as well as the number of injuries and fatalities associated with each tornado. The results from the analysis are displayed in Figures 29 and 31. These correlations suggest that as the maximum gust speed increases, the path length and width increase, along with the number of injuries and fatalities. This leads to a correlation between the maximum gust speed and the Fujita scale of tornado and the number of injuries and fatalities. So, as the maximum gust speed increases, the Fujita scale of the tornado increases and causes more injuries and fatalities. The correlation analysis from SPSS confirms this by showing a strong correlation, in Figure 31, between the maximum gust speed and the Fujita scale, $r(N=17)=.506$, $p=.038$, for the significant tornadoes in the Joplin area. This correlation was expected because the Fujita scale was created to rate tornadoes by how strong the winds are.

Figure 18

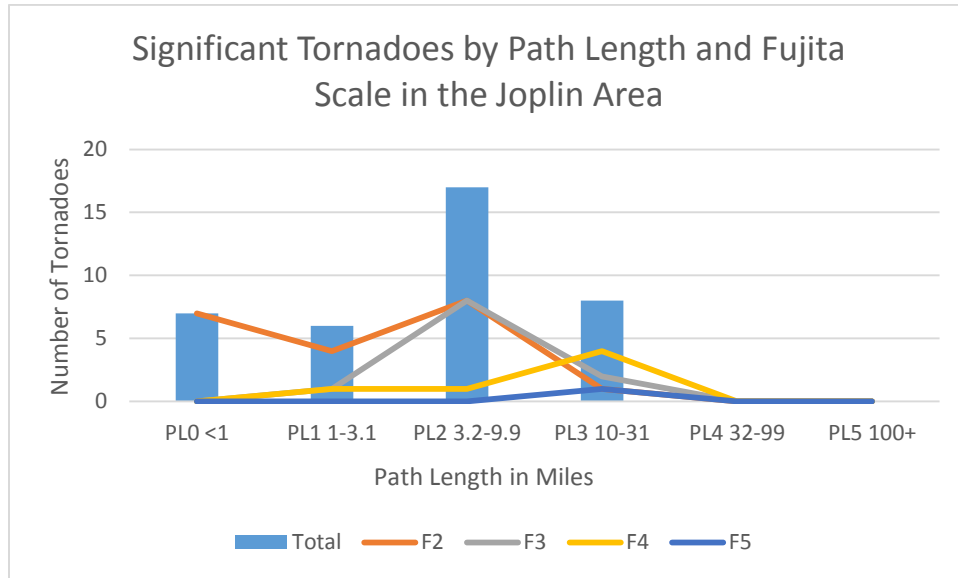


Figure 19

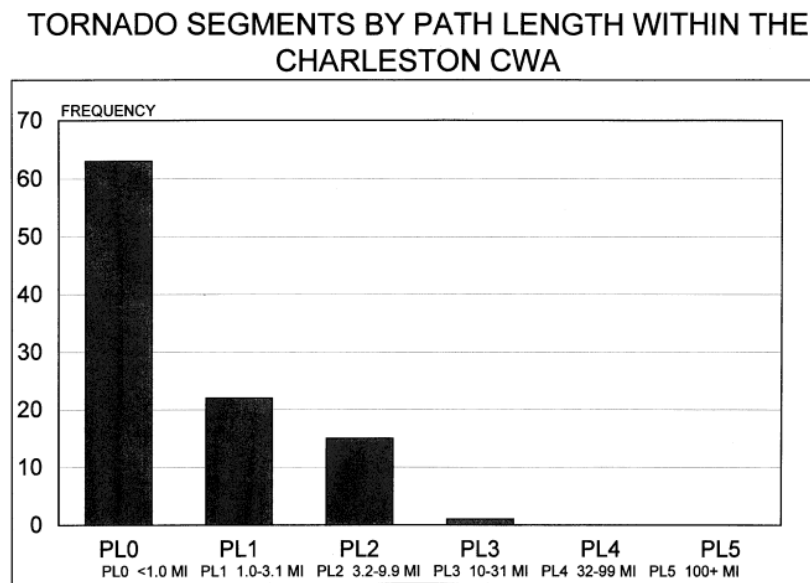


Figure 9. Tornado segments by path length (miles) within the Charleston, SC, CWA.

Figure 20

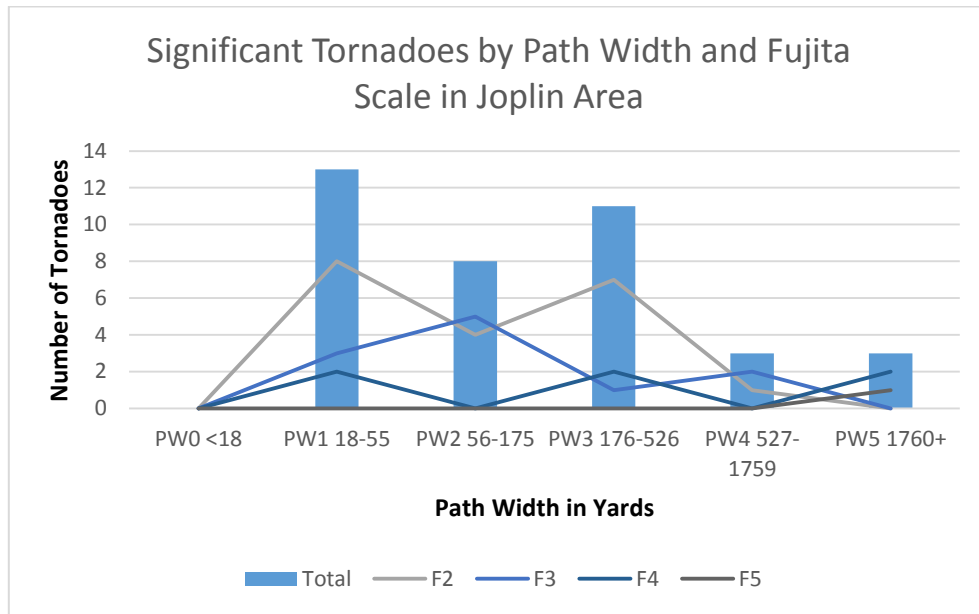


Figure 21

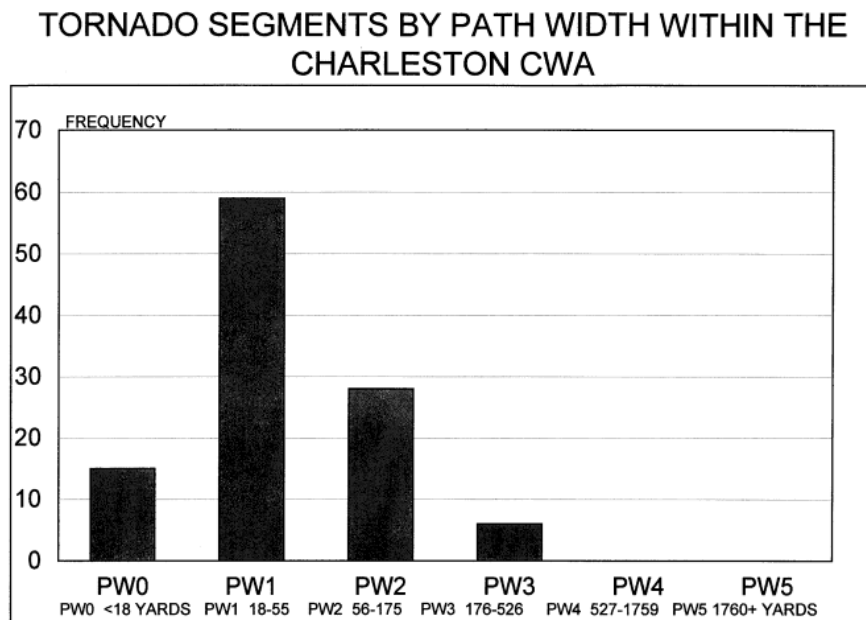


Figure 10. Tornado segments by path width (yards) within the Charleston, SC, CWA.

The next analysis I completed on my data of the significant tornadoes in the four counties surrounding Joplin, Missouri was a comparison of weather conditions to the size of the tornadoes. I started with the maximum temperature recorded on each day of each significant tornado. Figure 22 shows the relationship between the maximum temperature and the size of each tornado based on the Fujita or Enhanced Fujita scale, using only significant tornadoes of size F2, or EF2, and larger. I also compared the dew point and the average humidity from each tornado day to each significant tornado size. Figure 23 shows the relationship between the dew point and the tornado size based on the Fujita or Enhanced Fujita scale. Figure 24 shows the relationship between the average humidity and the tornado size based on the Fujita or Enhanced Fujita scale. I was able to find a maximum temperature for every significant tornado day in the Joplin area. However, some significant tornado days were too far in the past to have recorded dew points and average humidity levels. I used only the significant tornado days that I could find data for. I was unable to find previous studies or studies for the entire United States that showed the same comparisons between weather conditions as I did. So, I was unable to compare my results to the results of others.

I also completed a statistical analysis to find correlations between the weather conditions and the significant tornadoes, using SPSS. Figure 31 displays a strong correlation between the average humidity and the dew point, which is common with every day weather. I also found a correlation between the maximum gust speed of the wind and the maximum temperature to be $r(N=17)=.523$, $p=.031$. This suggests that on the days that a significant tornado occurred in the Joplin area, the higher the temperature was, the higher the maximum gust speed was. This could lead to a small correlation between the temperature and the Fujita scale of a tornado, but my statistical analysis using SPSS didn't show this correlation.

Figure 22

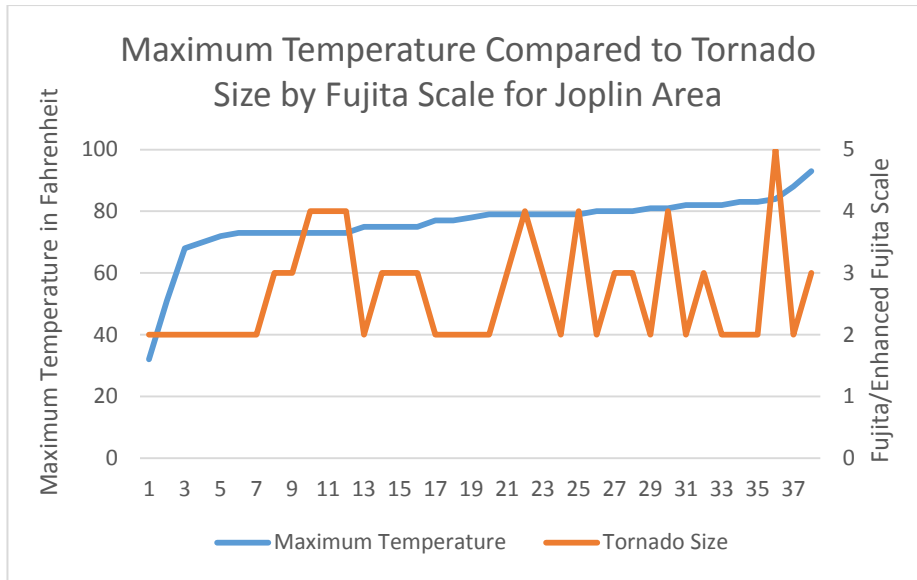


Figure 23

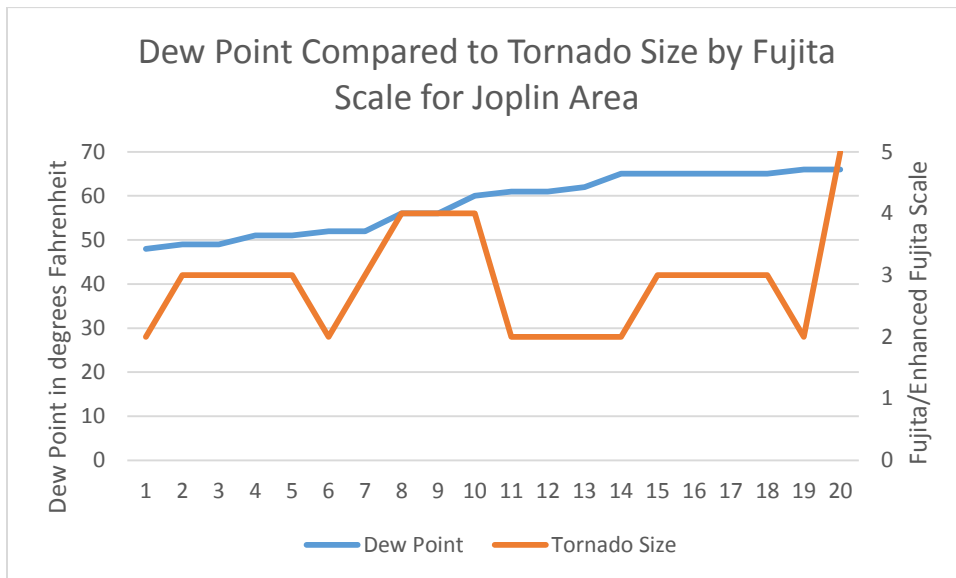
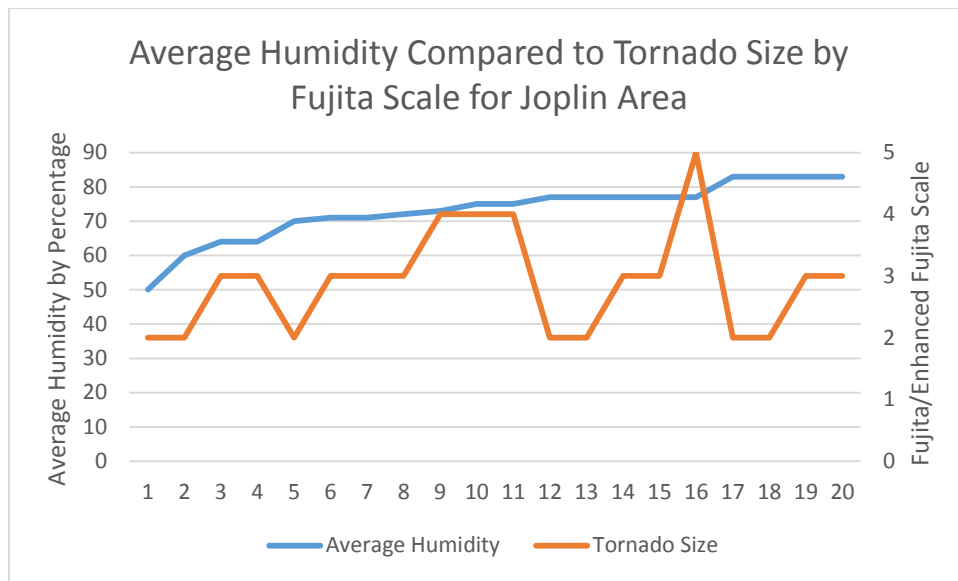


Figure 24



I decided to include a comparison of injuries and fatalities to significant tornado size. The climatology study on Charleston, SC also includes an analysis of tornado injuries and fatalities. My analysis only includes injuries and fatalities associated with tornadoes of size F2, or EF2, and larger in the four counties surrounding Joplin, Missouri. The Charleston analysis breaks down the injuries and deaths by month. I chose to compare injuries and deaths to tornado size instead of month because the majority of tornado injuries and deaths come from the extremely powerful F5, or EF5, tornado that tore through Joplin on May 22, 2011. So a graph of injuries and deaths by month for Joplin would result in one very large bar for May and very small bars for the remaining months with injuries or deaths. Comparing injuries and fatalities to tornado size shows exactly what the Fujita, or Enhanced Fujita, scale should show. The stronger the tornado, or the higher the Fujita or Enhanced Fujita scale, the more injuries and fatalities will occur. Figure 25 shows the results for my study on the Joplin area. Figure 26 shows the results for the climatology study on Charleston, South Carolina.

As I mentioned before, my statistical analysis using SPSS shows a strong correlation between the Fujita scale of the tornadoes and the number of injuries and fatalities. Figure 29 displays the Pearson correlation between the Fujita scale and the number of injuries to be $r(N=137)=.442, p=.000$. The correlation between the Fujita scale and the number of fatalities is $r(N=137)=.407, p=.000$, for all tornadoes. Figure 31 displays the Pearson correlation for only the significant tornadoes in the Joplin area between the Fujita scale and the number of injuries to be $r(N=37)=.550, p=.000$. This confirms that as the Fujita scale of a tornado increases, the number of injuries and fatalities increase.

Figure 25

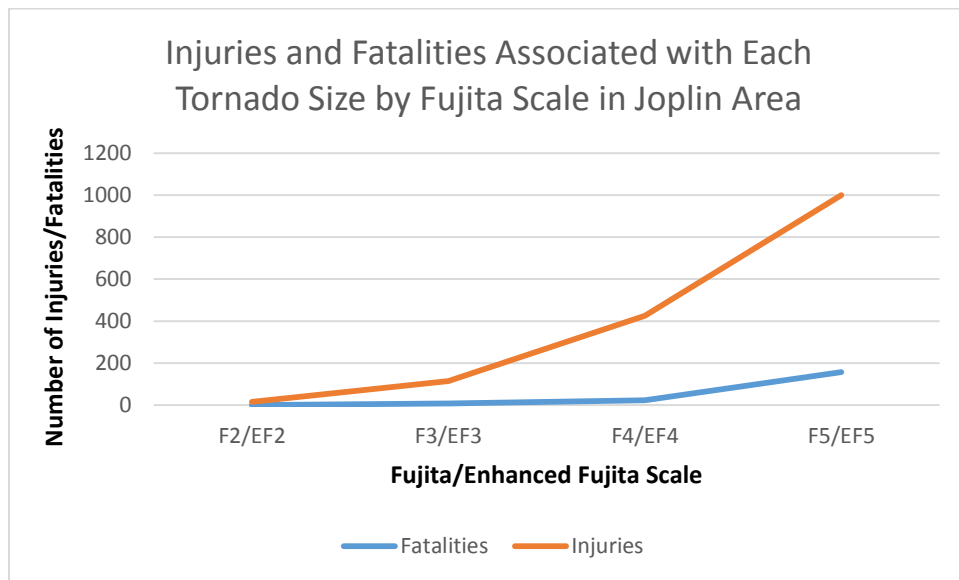


Figure 26

TOTAL DEATHS AND INJURIES CAUSED BY TORNADOES WITHIN THE CHARLESTON CWA

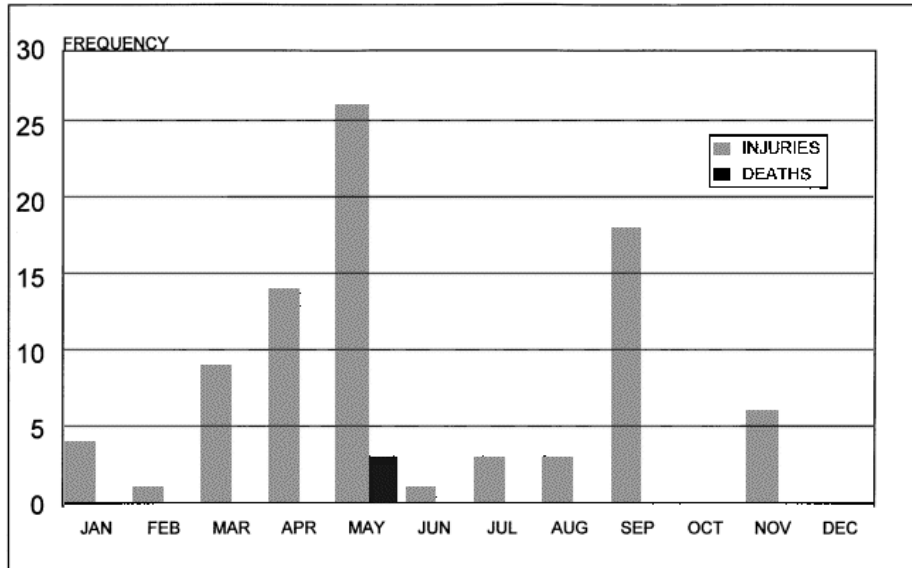


Figure 6. Total deaths and injuries caused by tornadoes within the Charleston, SC, CWA during the time period 1950 through 1993. The lighter shading represents total injuries reported (85). The darker shading represents total deaths reported (3).

My statistical analysis using SPSS showed a few more significant correlations, they are displayed in Figure 31. A correlation was found between the sea level pressure and the wind speed, $r(N=20)=-.723$, $p=.000$. Also, the sea level pressure was related to the maximum gust speed of the wind, $r(N=17)=-.497$, $p=.042$. Again, the sea level pressure was related to the time of the tornado during the day, $r(N=15)=-.524$, $p=.045$. I also found correlations involving the month in which the significant tornado occurred. The month and average humidity correlation is shown by $r(N=20)=.689$, $p=.001$. The month and sea level pressure correlation is shown by $r(N=20)=.457$, $p=.043$. The month and maximum temperature correlation is shown by $r(N=38)=.459$, $p=.004$. The month and the dew point correlation is shown by $r(N=20)=.589$, $p=.006$. These significant correlations are not surprising. The weather conditions will naturally be correlated to each month because of the seasons. The correlations involving sea level pressure are mostly common weather occurrences. A slight correlation between the sea level pressure and the wind speed and gusts, as well as the time of the tornado, could be associated with the tornado event. However, these correlations are too small and the change in pressure is not large enough for meteorologists to be able to see the change and warn the public of an increased risk of a tornado.

Discussion

Beginning this project, I had hopes of finding something interesting about the tornadoes that have occurred in or around Joplin, Missouri. I believe I was successful. For the beginning of my results, I broke down the tornado occurrences by each of the four counties. This was strictly for informational purposes. Jasper County, Missouri has had the most tornado occurrences out of all four counties and it tied with Ottawa County, Oklahoma for most significant tornado occurrences. Again, I would like to define my use of the word significant. Throughout this study, the term “significant tornado” refers to a tornado of size F2, or EF2, or larger. F2 refers to the Fujita scale, which as of 2007 has been updated to the Enhanced Fujita scale, or EF2. The scale ranges from F0-F5 and EF0-EF5. The scale represents the intensity of the tornado and each tornado is categorized after an examination of the damage it caused. Significant tornadoes of F2 or larger cause the most damage. The wind speeds associated with each scale of tornadoes is displayed in Figure 27.

Figure 27

F refers to the Fujita scale and EF refers to the Enhanced Fujita scale. The wind speeds are listed in miles per hour.

| | 0 | 1 | 2 | 3 | 4 | 5 |
|----|-------|--------|---------|---------|---------|---------|
| F | 40-73 | 74-112 | 113-157 | 158-206 | 207-260 | 261-318 |
| EF | 65-85 | 86-110 | 111-135 | 136-165 | 166-200 | >200 |

The results of my study show that 50 percent of all the significant tornadoes in the four counties between 1951 and 2011 occurred between 4 p.m. and 8 p.m. The next time with the greatest occurrence of a significant tornado is midnight. My results are similar to the results from the NOAA for the entire United States. Figure 8 shows that most tornadoes of all sizes in the United States occur

between the hours of 3 p.m. and 8 p.m. Brueske, Plourd, and Volkmer (1998) found that most tornadoes of all sizes in the Charleston, SC county warning area occur between the hours of 2 p.m. and 5 p.m.

South Carolina will be slightly different than Missouri in terms of tornadoes due to many reasons. To name a few, South Carolina is next to the Atlantic Ocean and can receive tornadoes from hurricanes.

South Carolina also sits to the east of the Appalachian Mountains, which can have an effect on air flows.

The fact that all three studies resulted in tornadoes most likely occurring in the middle to late afternoon gives meteorologists a great idea of when to expect a tornado. For Joplin, Missouri, meteorologists will have less hesitance when sounding a tornado warning between the hours of 4 p.m. and 8 p.m. because of the knowledge that those are the hours of most occurrence for significant tornadoes.

After looking at the months of the tornado occurrences in the four counties, I found that tornadoes are more likely to occur in the months of April and May around Joplin, Missouri. Brueske, Plourd, and Volkmer (1998) came to the same conclusion for tornadoes in Charleston, SC. The NOAA National Climatic Data Center shows in Figure 12 that most tornadoes of any size occur in the months of May and June for the entire United States between the years of 1991 and 2010. My study, as well as the Charleston study, use data from approximately 50 years. From Figures 9, 10, 11, and 12, I can conclude that most tornadoes occur in the month of May. Concannon, Brooks, and Doswell (2000) confirm my conclusion because their climatology study of the entire United States showed that most tornado touchdowns occur within 2 weeks of May 1. Including their results, I feel confident stating that most tornadoes occur in the months of April and May.

I also looked at my data by week and found that most significant tornadoes occur between May 1 and May 7. However, three of those seven significant tornadoes occurred on May 4, 2003 from the same thunderstorm. Stating that significant tornadoes around Joplin, MO are most likely to occur the first week of May would be accurate, but meteorologists shouldn't only expect a significant tornado during that week. The very violent EF5 that tore through Joplin on May 22, 2011 occurred in the third

week of May. I would rather tell meteorologists that significant tornadoes are most likely to occur in the months of April and May between 4 p.m. and 8 p.m.

I performed a frequency analysis on my data by year and found no pattern of occurrence. Figures 16 and 17 from the NOAA also show no pattern of occurrences. Figure 14 shows my results for all tornadoes in the four counties for 60 years and Figure 16 shows the NOAA results for the entire United States for roughly the same 60 years and for tornadoes larger than EF1. Figure 15 shows my results for the four counties for only significant tornadoes and Figure 17 shows the NOAA results including tornadoes of size EF3 and above. This makes it easy to compare the two results. The years that saw the most tornadoes in the Joplin area also show a high number of tornadoes for the entire United States. Concannon, Brooks, and Doswell (2000) were able to come to the conclusion that the maximum frequency of strong tornadoes of size F2 and larger to be once every 2 or 3 years in any location of the United States. I was unable to come to the same conclusion for the Joplin area.

My analysis of the path lengths and widths for the significant tornadoes in the Joplin area found that most of the significant tornadoes are of average size. By average size, I mean that most significant tornadoes are between the path lengths of 3 and 10 miles, and between the path widths of 18 and 526 yards. Brueske, Plourd, and Volkmer (1998) found mostly smaller tornadoes for the Charleston, SC area. The Charleston study didn't compare the path lengths and widths to the Fujita scale of the tornadoes. I analyzed the lengths and widths against the Fujita scale to see if the path length and width increased as the intensity of the tornado increased. Figures 18 and 20 show little correlation between the Fujita scale of a significant tornado and the path length and width of the tornadoes for the Joplin area. However, the statistical analysis using SPSS shows a strong correlation.

The next part of my data analysis included weather conditions on the days of the significant tornadoes in the Joplin area. I used the maximum temperature, dew point, and average humidity for

each day. However, I was unable to find data for the dew point and average humidity for every significant tornado day. Data from the 1950s and 1960s is limited because of the lack of records kept from those years. I used the data I was able to find to look for a correlation between the weather conditions and the size of the tornados based on the Fujita or Enhanced Fujita scale.

My hopes for comparing the weather conditions to the Fujita/Enhanced Fujita scale of the tornadoes was to find an increase in the size of the tornado along with an increase in the condition. For the maximum temperature of each tornado day, there wasn't a constant correlation between the increase in temperature and the increase in the size of the tornado. My statistical analysis using SPSS also did not show a significant correlation between the Fujita scale of a tornado and the maximum temperature of the day, Figure 31. However, one tornado of size F2 occurred on a day with a maximum temperature of 32 degrees Fahrenheit and another tornado of size F5 occurred on a day with a maximum temperature of 83 degrees Fahrenheit. This would seem to prove my hypothesis, but after adding in the other significant tornadoes it is shown that an F2 tornado can also occur on a day with a maximum temperature of about 83 degrees Fahrenheit. I was able to conclude that significant tornadoes occur mostly on days with a maximum temperature between 75 and 80 degrees Fahrenheit. Figure 30 displays the mean maximum temperature for the significant tornadoes to be 76.03 degrees Fahrenheit, which resulted from my statistical analysis using SPSS. I would like to further this section of my study to include every tornado occurrence in the four counties instead of only the significant tornadoes.

The dew point analysis and the average humidity analysis had similar results to the maximum temperature analysis. A correlation could not be concluded from the data. Figure 31 shows the fact that no significant correlation was found between the Fujita scale of the tornado and the dew point or the average humidity from my statistical analysis using SPSS. The dew point frequency analysis shows that an F2 tornado occurred on a day with the lowest dew point and an F5 occurred on a day with the

highest dew point, but there is not a steady increase of the size of the tornado with the increase of the dew point. This is shown by Figure 23. Figure 24 shows the same kind of result in the average humidity analysis. Like the analysis of the maximum temperature, an F2 occurred on a day with an average humidity of 50% and an F5 occurred with an average humidity of 78%. However, looking at every significant tornado day with available data, there is no strong correlation between the average humidity and the size of the tornado. Figure 31 shows the results from the correlation analysis using SPSS, which agree that no significant correlation exists. I was able to conclude that most significant tornadoes in the Joplin area occur with an average humidity between 70 and 80 percent and a dew point between 50 and 65 degrees Fahrenheit. Figure 30 shows the mean average humidity to be 73.10 percent and the mean dew point to be 58.25 degrees Fahrenheit. Gaffin and Parker (2006) found significant tornadoes in the southern Appalachian region to occur during dew points of 58 and 70 degrees Fahrenheit, 85% of the time. This is very similar to my results. The slight difference could be accounted for due to the geographical differences between the Appalachian region and the Joplin, Missouri area.

The last analysis I completed on my data involved the number of injuries and fatalities association with each intensity of the tornadoes. I found that the number of injuries and fatalities increase with the increase of the size of the tornado by Fujita/Enhanced Fujita scale. Figure 25 shows my results. Figure 29 shows the results using SPSS, which proves that a significant correlation exists between the Fujita scale of the tornado and the number of injuries and fatalities that occurred. The Pearson correlation between the Fujita scale and the number of injuries is $r(N=137)=.442$, $p=.000$. The Pearson correlation between the Fujita scale and the number of fatalities is $r(N=137)=.407$, $p=.000$. Figure 31 shows the same results, but only using significant tornadoes of size F2 or larger, $r(N=37)=.550$, $p=.000$. It is important to note that the May 22, 2011 tornado of size EF5 was the cause of over 1000 injuries and 158 fatalities, the majority of the total number of injuries and fatalities from all significant tornadoes in the Joplin area. Brueske, Plourd, and Volkmer (1998) completed an analysis of injuries and

fatalities, but they didn't compare them to the size of the tornado. Figure 26 shows that they found most of the Charleston, SC county warning area injuries due to tornadoes to occur in the month of May. An analysis of the injuries and fatalities from significant tornadoes for the Joplin area by month would result in the majority of the injuries and fatalities occurring in May, due to the May 22, 2011, EF5 tornado.

Conclusion

The results from my tornado climatology study of the Joplin area show interesting information that can contribute to the field of atmospheric science. Meteorologists will be able to benefit from the knowledge found in my report. My conclusions will hopefully bring science closer to finding a solution that will help warn the public of a tornado in the Joplin area faster, in order to save more lives. My study can be continued and I intend to complete a further analysis of my data. The tornado climatology of the Joplin area, including the four counties of Jasper and Newton Counties in Missouri, Cherokee County in Kansas, and Ottawa County in Oklahoma, can be expanded further and conclusions can be made in much more detail than what I have completed with this report. I was able to complete the basic analysis in order to compare my results to other studies. My data collection was limited slightly due to the large selection of data and the early years used. If I could work with the NOAA or the National Weather Service directly, I might be able to find sufficient data in the amount of detail needed to complete a more in depth analysis of the tornadoes in and around Joplin, Missouri. For now, my study was successful in completing the analysis that I had planned to complete. I found that a significant tornado will most likely occur in the Joplin area in the month of April or May between the hours of 4 p.m. and 8 p.m. with a maximum temperature of roughly 76 degrees Fahrenheit, a dew point around 58 degrees Fahrenheit, and an average humidity of about 73 percent.

Results from Correlation Testing using SPSS

Figure 28

Descriptive Statistics determined by SPSS involving all 141 tornadoes that have occurred in the four counties for the past 60 years, ranging from F0 to F5.

| Descriptive Statistics | | | |
|-------------------------------|--------|----------------|-----|
| | Mean | Std. Deviation | N |
| MONTH | 5.3972 | 2.45787 | 141 |
| F | 1.14 | 1.072 | 137 |
| FATALITIES | .23 | 1.343 | 140 |
| INJURIES | 4.24 | 22.022 | 140 |
| LENGTH | 2.9918 | 5.12596 | 140 |
| WIDTH | 144.02 | 268.631 | 140 |
| COUNTY | 93.16 | 47.019 | 140 |

Figure 29

Correlations determined by SPSS involving all tornadoes from size F0 to F5.

| | | Correlations | | | | | | |
|------------|---------------------|--------------|--------|------------|----------|--------|--------|--------|
| | | MONTH | F | FATALITIES | INJURIES | LENGTH | WIDTH | COUNTY |
| MONTH | Pearson Correlation | 1 | -.142 | -.043 | -.042 | -.062 | -.127 | -.026 |
| | Sig. (2-tailed) | | .098 | .614 | .619 | .467 | .135 | .756 |
| | N | 141 | 137 | 140 | 140 | 140 | 140 | 140 |
| F | Pearson Correlation | -.142 | 1 | .407** | .442** | .584** | .460** | .071 |
| | Sig. (2-tailed) | .098 | | .000 | .000 | .000 | .000 | .412 |
| | N | 137 | 137 | 137 | 137 | 137 | 137 | 137 |
| FATALITIES | Pearson Correlation | -.043 | .407** | 1 | .923** | .625** | .742** | .085 |
| | Sig. (2-tailed) | .614 | .000 | | .000 | .000 | .000 | .320 |
| | N | 140 | 137 | 140 | 140 | 140 | 140 | 140 |
| INJURIES | Pearson Correlation | -.042 | .442** | .923** | 1 | .673** | .738** | .106 |
| | Sig. (2-tailed) | .619 | .000 | .000 | | .000 | .000 | .212 |
| | N | 140 | 137 | 140 | 140 | 140 | 140 | 140 |
| LENGTH | Pearson Correlation | -.062 | .584** | .625** | .673** | 1 | .683** | .128 |
| | Sig. (2-tailed) | .467 | .000 | .000 | .000 | | .000 | .131 |
| | N | 140 | 137 | 140 | 140 | 140 | 140 | 140 |
| WIDTH | Pearson Correlation | -.127 | .460** | .742** | .738** | .683** | 1 | .067 |
| | Sig. (2-tailed) | .135 | .000 | .000 | .000 | .000 | | .432 |
| | N | 140 | 137 | 140 | 140 | 140 | 140 | 140 |
| COUNTY | Pearson Correlation | -.026 | .071 | .085 | .106 | .128 | .067 | 1 |
| | Sig. (2-tailed) | .756 | .412 | .320 | .212 | .131 | .432 | |
| | N | 140 | 137 | 140 | 140 | 140 | 140 | 140 |

** . Correlation is significant at the 0.01 level (2-tailed).

Figure 30

Descriptive statistics involving only significant tornadoes of size F2 or larger.

Descriptive Statistics

| | Mean | Std. Deviation | N |
|--------------------|---------|----------------|----|
| F | 2.68 | .842 | 38 |
| LENGTH | 7.495 | 8.1736 | 38 |
| WIDTH | 298.32 | 429.276 | 37 |
| max temperature | 76.03 | 9.871 | 38 |
| dew point | 58.25 | 6.688 | 20 |
| average humidity | 73.10 | 8.478 | 20 |
| sea level pressure | 29.7250 | .14609 | 20 |
| wind speed | 13.95 | 3.859 | 20 |
| max gust speed | 35.88 | 8.536 | 17 |
| MONTH | 5.0000 | 2.23002 | 38 |
| INJURIES | 15.03 | 41.255 | 37 |
| BGN_TIME | 1415.97 | 792.946 | 33 |

Figure 31

Correlations involving only significant tornadoes of size F2 or larger.

Correlations

| | | F | LENGTH | WIDTH | max temperature | dew point |
|--------------------|---------------------|--------|--------|--------|-----------------|-----------|
| F | Pearson Correlation | 1 | .562** | .413 | .180 | .051 |
| | Sig. (2-tailed) | | .000 | .011 | .280 | .832 |
| | N | 38 | 38 | 37 | 38 | 20 |
| LENGTH | Pearson Correlation | .562** | 1 | .726** | .090 | .194 |
| | Sig. (2-tailed) | .000 | | .000 | .591 | .413 |
| | N | 38 | 38 | 37 | 38 | 20 |
| WIDTH | Pearson Correlation | .413 | .726** | 1 | .098 | .144 |
| | Sig. (2-tailed) | .011 | .000 | | .563 | .557 |
| | N | 37 | 37 | 37 | 37 | 19 |
| max temperature | Pearson Correlation | .180 | .090 | .098 | 1 | .253 |
| | Sig. (2-tailed) | .280 | .591 | .563 | | .281 |
| | N | 38 | 38 | 37 | 38 | 20 |
| dew point | Pearson Correlation | .051 | .194 | .144 | .253 | 1 |
| | Sig. (2-tailed) | .832 | .413 | .557 | .281 | |
| | N | 20 | 20 | 19 | 20 | 20 |
| average humidity | Pearson Correlation | .169 | .287 | .200 | -.185 | .772** |
| | Sig. (2-tailed) | .476 | .220 | .411 | .436 | .000 |
| | N | 20 | 20 | 19 | 20 | 20 |
| sea level pressure | Pearson Correlation | -.279 | -.367 | -.436 | -.396 | .046 |
| | Sig. (2-tailed) | .234 | .111 | .062 | .084 | .847 |
| | N | 20 | 20 | 19 | 20 | 20 |
| wind speed | Pearson Correlation | .190 | .211 | .248 | .233 | .080 |
| | Sig. (2-tailed) | .421 | .372 | .306 | .323 | .737 |
| | N | 20 | 20 | 19 | 20 | 20 |

| | | | | | | |
|----------------|---------------------|--------|--------|--------|------|-------|
| max gust speed | Pearson Correlation | .506 | .702 | .795 | .523 | .109 |
| | Sig. (2-tailed) | .038 | .002 | .000 | .031 | .677 |
| | N | 17 | 17 | 16 | 17 | 17 |
| MONTH | Pearson Correlation | -.086 | -.028 | -.040 | .459 | .589 |
| | Sig. (2-tailed) | .606 | .866 | .816 | .004 | .006 |
| | N | 38 | 38 | 37 | 38 | 20 |
| INJURIES | Pearson Correlation | .550** | .706** | .812** | .097 | -.046 |
| | Sig. (2-tailed) | .000 | .000 | .000 | .566 | .853 |
| | N | 37 | 37 | 37 | 37 | 19 |
| BGN_TIME | Pearson Correlation | -.114 | -.057 | .131 | .286 | -.100 |
| | Sig. (2-tailed) | .529 | .753 | .476 | .106 | .724 |
| | N | 33 | 33 | 32 | 33 | 15 |

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Correlations Cont.

| | | average humidity | sea level pressure | wind speed | max gust speed |
|--------------------|---------------------|------------------|--------------------|------------|----------------|
| F | Pearson Correlation | .169 | -.279 | .190 | .506* |
| | Sig. (2-tailed) | .476 | .234 | .421 | .038 |
| | N | 20 | 20 | 20 | 17 |
| LENGTH | Pearson Correlation | .287 | -.367 | .211 | .702** |
| | Sig. (2-tailed) | .220 | .111 | .372 | .002 |
| | N | 20 | 20 | 20 | 17 |
| WIDTH | Pearson Correlation | .200 | -.436 | .248 | .795** |
| | Sig. (2-tailed) | .411 | .062 | .306 | .000 |
| | N | 19 | 19 | 19 | 16 |
| max temperature | Pearson Correlation | -.185 | -.396 | .233 | .523 |
| | Sig. (2-tailed) | .436 | .084 | .323 | .031 |
| | N | 20 | 20 | 20 | 17 |
| dew point | Pearson Correlation | .772** | .046 | .080 | .109 |
| | Sig. (2-tailed) | .000 | .847 | .737 | .677 |
| | N | 20 | 20 | 20 | 17 |
| average humidity | Pearson Correlation | 1 | .050 | .005 | .013 |
| | Sig. (2-tailed) | | .834 | .983 | .962 |
| | N | 20 | 20 | 20 | 17 |
| sea level pressure | Pearson Correlation | .050 | 1 | -.723** | -.497* |
| | Sig. (2-tailed) | .834 | | .000 | .042 |
| | N | 20 | 20 | 20 | 17 |
| wind speed | Pearson Correlation | .005 | -.723** | 1 | .377 |
| | Sig. (2-tailed) | .983 | .000 | | .136 |
| | N | 20 | 20 | 20 | 17 |
| max gust speed | Pearson Correlation | .013 | -.497* | .377 | 1 |
| | Sig. (2-tailed) | .962 | .042 | .136 | |
| | N | 17 | 17 | 17 | 17 |

| | | | | | |
|----------|---------------------|------|-------|-------|-------|
| MONTH | Pearson Correlation | .689 | .457 | -.420 | -.133 |
| | Sig. (2-tailed) | .001 | .043 | .065 | .611 |
| | N | 20 | 20 | 20 | 17 |
| INJURIES | Pearson Correlation | .113 | -.189 | .047 | .692 |
| | Sig. (2-tailed) | .646 | .437 | .848 | .003 |
| | N | 19 | 19 | 19 | 16 |
| BGN_TIME | Pearson Correlation | .093 | -.524 | .374 | -.267 |
| | Sig. (2-tailed) | .741 | .045 | .169 | .402 |
| | N | 15 | 15 | 15 | 12 |

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

Correlations Cont.

| | | MONTH | INJURIES | BGN_TIME |
|--------------------|---------------------|--------|----------|----------|
| F | Pearson Correlation | -.086 | .550** | -.114 |
| | Sig. (2-tailed) | .606 | .000 | .529 |
| | N | 38 | 37 | 33 |
| LENGTH | Pearson Correlation | -.028 | .706** | -.057 |
| | Sig. (2-tailed) | .866 | .000 | .753 |
| | N | 38 | 37 | 33 |
| WIDTH | Pearson Correlation | -.040 | .812** | .131 |
| | Sig. (2-tailed) | .816 | .000 | .476 |
| | N | 37 | 37 | 32 |
| max temperature | Pearson Correlation | .459** | .097 | .286 |
| | Sig. (2-tailed) | .004 | .566 | .106 |
| | N | 38 | 37 | 33 |
| dew point | Pearson Correlation | .589** | -.046 | -.100 |
| | Sig. (2-tailed) | .006 | .853 | .724 |
| | N | 20 | 19 | 15 |
| average humidity | Pearson Correlation | .689** | .113 | .093 |
| | Sig. (2-tailed) | .001 | .646 | .741 |
| | N | 20 | 19 | 15 |
| sea level pressure | Pearson Correlation | .457** | -.189 | -.524 |
| | Sig. (2-tailed) | .043 | .437 | .045 |
| | N | 20 | 19 | 15 |
| wind speed | Pearson Correlation | -.420 | .047 | .374 |
| | Sig. (2-tailed) | .065 | .848 | .169 |
| | N | 20 | 19 | 15 |
| max gust speed | Pearson Correlation | -.133 | .692** | -.267 |
| | Sig. (2-tailed) | .611 | .003 | .402 |
| | N | 17 | 16 | 12 |

| | | | | |
|----------|---------------------|-------|-------|-------|
| MONTH | Pearson Correlation | 1 | -.019 | .087 |
| | Sig. (2-tailed) | | .909 | .631 |
| | N | 38 | 37 | 33 |
| INJURIES | Pearson Correlation | -.019 | 1 | -.073 |
| | Sig. (2-tailed) | .909 | | .690 |
| | N | 37 | 37 | 32 |
| BGN_TIME | Pearson Correlation | .087 | -.073 | 1 |
| | Sig. (2-tailed) | .631 | .690 | |
| | N | 33 | 32 | 33 |

** . Correlation is significant at the 0.01 level (2-tailed).

* . Correlation is significant at the 0.05 level (2-tailed).

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