5-2018

Dixie tornadoes : a spatial analysis of tornado risk in the U.S. south.

Joshua L. Sherretz
University of Louisville

Recommended Citation

Sherretz, Joshua L., "Dixie tornadoes : a spatial analysis of tornado risk in the U.S. south." (2018). *Electronic Theses and Dissertations.* Paper 2948.
https://doi.org/10.18297/etd/2948

DIXIE TORNADOS:
A SPATIAL ANALYSIS OF TORNADO RISK IN THE U.S. SOUTH

By

Joshua L. Sherretz
B.S. University of Louisville, 2012

A Thesis
Submitted to the Faculty of the
College of Arts and Sciences of the University of Louisville
in Partial Fulfillment of the Requirements
for the Degree of

Master of Science
in Applied Geography

Department of Geography and Geosciences
University of Louisville
Louisville, KY

May 2018

DIXIE TORNADOS:
A SPATIAL ANALYSIS OF TORNADO RISK IN THE U.S. SOUTH

By

Joshua L. Sherretz
B.S. University of Louisville, 2012

A Thesis Approved on

April 11, 2018

by the following Thesis Committee:

____

Thesis Director
Dr. Charlie Zhang

____

Dr. Jason Naylor

____

Dr. Jian Du-Caines

ACKNOWLEDGEMENTS

This thesis would not have been possible without the assistance of Dr. Charlie Zhang, Associate professor of Geography and Geosciences at the University of Louisville. I sincerely thank Dr. Zhang for his contribution to this thesis and for all the assistance he provided for me throughout the thesis writing process. Your encouragement and support were invaluable.

I would also like to thank the other members of my Thesis Committee which includes:

Dr. Jason Naylor, Assistant Professor of Geography and Geosciences at the University of Louisville and Dr. Jian Du-Caines Associate Professor of Atmospheric Science at the University of Louisville for their assistance with this thesis without which it would not have been possible.

I would also like to thank my family for their continued support and assistance with this thesis as well. My father and mother, both have earned doctoral degrees, lent their professional advice and supportive assistance which was and remains highly valued and appreciated.

ABSTRACT

DIXIE TORNADOS: A SPATIAL ANALYSIS OF TORNADO RISK IN THE U.S. SOUTH

Joshua L. Sherretz

April 25, 2017

Throughout the years tornados were a feared and respected phenomenon. This phenomenon was traditionally associated with the high plains of the United States for very good reason. More tornados occur in the American high plains than anywhere else in the world, hence the term: Tornado Alley. However, the American Deep South was and remains prone to many tornados too. So much so that parts of the Deep South were and still are referred to as Dixie Alley. The major focus of this study was how the two areas compared as far as risk is concerned.

This study used both geographic and statistical methods to compare the risk of tornado disasters in Dixie Alley to that of Tornado Alley. Several factors to include population density, forest cover, and poverty rate were analyzed. In addition, the overall tornado density was analyzed. This allowed for a final comparison of the statistical difference between the two regions which tested the theory that Dixie Alley has comparable risk levels to Tornado Alley.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

INTRODUCTION

Weather is a natural phenomenon that awed humanity since time immemorial. Weather had an impact on everything on Earth. It both sustained and destroyed life on Earth. For example, spring rains renewed life by filling reservoirs, helping plants bud, and providing fresh water for humans and animals to drink. Water sustained all life as we know it. Weather was and is at times extremely beautiful thanks to phenomena like rainbows. However, weather can take away life as well. Hurricanes, tornados, lightning, and other severe weather events killed thousands of people, animals and plants every year and across the globe as well as causing massive destruction to cities and towns (Chan 2015). So it is no wonder humanity has had a love/hate relationship with the weather. Humans both appreciate and fear the weather. That relationship was why humans always keep an eye on the weather conditions and forecast in the past and humans continue to do so now.

Primitive agricultural societies tracked seasonal changes in the weather, but those societies often trusted in their pantheon of gods to send rain on their fields. They prayed and worshipped in belief that they would find favor from their many gods and the result would produce an abundance of crops. Ancient civilizations believed the gods provided the rain that caused their crops to grow. They also believed the gods withdrew their favor when severe weather occurred. When severe weather caused destruction and death to people, structures and fields, the ancient people believed it was necessary to offer types of ritual sacrifices to appease their angry gods.

Modern societies rely more on technologies like radar and satellites to forecast weather conditions and issue early warnings when severe weather is expected. People have learned to trust official weather reports and forecasts that continue to become more and more accurate. Nevertheless, sudden, unexpected changes in the weather can still surprise even the most experienced forecaster. Therefore, weather remains both an appreciated and feared phenomenon that impacts all of us.

Tornados are a classic example of severe weather that is both amazing and dreadful. On average around 1200 tornadoes touchdown in the United States each year (Edwards, 2017 Accessed 3/14/17). Tornadoes touchdown all over the United States each year, but the most common occurrences are in the high plains and Deep South in the United States. In these areas, tornados killed dozens of people annually despite modern advances in early warning systems and improved storm forecasts. For example, the 1974 a super outbreak of tornadoes was responsible for 330 deaths in all (Fuhrmann et. al. 2015). As such, tornado research is of critical importance both now and in the future.

Tornados in the southern United States were of particular concern because the South is much more densely populated than the high plains. This means the likelihood for destruction of property and human death was statistically greater as a result of tornados which occurred in the South. The primary cause of tornados across southern states was due to the fact that warm, moist air from the Gulf of Mexico collides with cooler, drier air coming across the Great Plains of the United States during spring and summer months. However, it should be noted that Florida differs from the other southern states in that most of its tornados were from waterspouts. The other states see most of their tornados spawned from frontal systems passing through the region. Also large tornado outbreaks were common in this region such as the super outbreak on April 26-27, 2011, which spawned over 200 tornados in the deep South (Lietz 2016). Furthermore, the 1974 super outbreak spawned many tornados in this region as well.

The part of the South that most frequently experienced tornados is known as Dixie Alley (Dixon et. al. 2011). Although no exact definition of Dixie Alley existed it is generally believed to contain a large area extending from Eastern Texas to West Georgia and north to Central Tennessee and it included large portions of Louisiana, Mississippi, and Alabama as well. This region demonstrated a high risk for tornados on par or nearly on par with what is known as Tornado Alley (Agee et. al. 2016). In addition, Boruff et. al. (2003) revealed that the tornado density was increasing in the South relative to the plains and that the mean center of tornados has moved southeast since the 1950's. Tippet et. al. (2016) added to this line of thought in literature by pointing out the fact that extreme outbreaks were getting more intense as storm relative helicity increased in the South. This means that more people were put at risk for tornados in any given year. Worse yet is the fact that there are many large cities in the South with larger footprints that logically put more people at risk. As these cities grow the target grows, this is the expanded "bulls-eye effect", and is a major part of tornado risk estimations (Ashley et. al 2014). Combined with what we know of Dixie Alley which experiences a greater number of night time tornadoes and a higher poverty rate all this means there remains a greater risk for a significant disaster to occur again (Ashley 2007). That is why research into this area was and is so important right now.

LITERATURE REVIEW

Research on the topic of tornados began in the late 1940s, but didn’t achieve much public attention until the 1960s. One of the early pioneers in tornadic research and forecasting was Dr. Keith Browning. He sought to identify the various life stages of a tornadic storm in order to discover when or in what stage a tornado is most likely to develop. Browning (1965) proposed an addition to the three known stages of storm life cycle at the time (i.e., Cumulus, Mature, and Decaying) - a fourth stage called Severe Right (SR) Mature. Later, this type of storm was dubbed a supercell by Browning. Different from other storm types by their rotating updraft, called a mesocyclone, supercells contain strong, stable updrafts compared to traditional thunderstorms (Browning, 1965).

As a rule of thumb a supercell thunderstorm consists of a forward flank downdraft, rear flank downdraft, and an updraft (Lemon and Doswell 1979). These components are shown in Figure 1. As air is sucked into the storm from the updraft it cools down then falls downward via the front flank downdrafts. Due to the large amount of wind shear present in supercell environments, the updraft rotate. The rotating air pulls hydrometeors around the rear side of the updraft creating a so-called hook echo on a radar. The air in the hook echo descends to the surface creating the rear flank downdraft. A vortex then forms in the rain free area along the right flank of the system at the notch between the rear downdraft and the updraft, where the tornado generally forms.

Dr. Ted Fujita, a renowned meteorologist, demonstrated how tornados were linked to hook echoes within a supercell storm through analysis of events from the 1974 super outbreak (Fujita 1975). Also Markowski (2002) extensively discussed hook echoes.

Markowski classified hook echoes based on their shape. In addition, both authors reaffirmed prior studies that indicated how hook echoes were an indication of rotation within the system since they were the result of precipitation wrapping around the mesocyclone due to strong rear flank updraft. However, a hook echo does not mean that a storm is tornadic, merely that the storm has a mesocyclone.

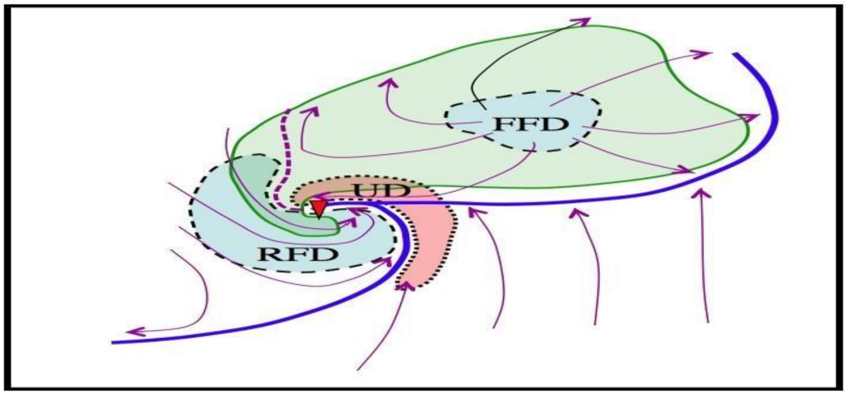


Figure 1: Diagram of supercell thunderstorm adapted from Doswell 2009. On the role of columnar convective vortices within the atmosphere. Green shaded area is the radar return. Blue shaded area shows the downdrafts. The red shaded area shows the updraft and the red triangle denotes the likely location of a tornado.

By the 1990s research into vortices had advanced enough to be able compare tornadic vortices to non-tornadic vortices also known to exist. To that end, Doswell and Burgess (1993), examined a series of different vortices and mesocyclones in an attempt to better quantify existing classifications of thunderstorms. Doswell and Burgess reviewed previous literature on supercells and proposed three divisions: low precipitation supercells, classic supercells, and high precipitation supercells. These categories were distinguished by the amount of rainfall in each category. They found that the low precipitation supercells were least likely to produce severe weather due to a lack of a deep cold pool that typically develops with precipitation. Classic supercells were most commonly associated with large tornado outbreaks. High precipitation supercells were the most common type, but generally produce fewer tornadoes than classic supercells due to the strong cold pools created by the large amounts of rainfall. Markowski et al. (2002) studied the impact of cold pool strength on tornado development. They found strong tornadoes were most likely to develop when cold pools are only slightly negatively buoyant. When air parcels in the cold pool were too negatively buoyant, they cannot be lifted by the updraft and tornado development was less likely.

The first step in tornado research was to understand how thunderstorms develop. Tornadic storms are the product of four elements: moisture, shear, instability, and a triggering effect that can cause tornados. Instability, as it pertains to weather, is defined as the tendency of air parcels to rise through the environmental air mass. In an unstable environment an air parcel displaced upwards became warmer than the air surrounding it, thus making the parcel positively buoyant. This positive buoyancy means the parcel will continue to rise through the atmosphere to great heights unabated by the surrounding air. In a stable environment, a displaced air parcel was cooler than the surrounding air. This makes the parcel negatively buoyant resulting in it being unable to rise. In a stable environment air parcels were unable to reach the lifting condensation level (LCL) defined as the point at which a parcel reaches the dew point and condensed into clouds.

In an unstable environment the parcel may be forced to rise, if there is a triggering mechanism present, to the LCL allowing it to turn with other air particles to form clouds. When the atmosphere was very unstable air parcels could rise quickly resulting in a rapid development of storm systems.

Moisture refers to the amount of water vapor in the atmosphere. Although measured in a variety of ways, relative humidity remains the most well-known moisture variable. The definition of Relative humidity is the amount of moisture in the air relative to the maximum possible moisture content. For example, a relative humidity of 60 percent indicates the local atmosphere currently contains 60 percent of its maximum possible content of water. Maximum content depends largely on temperature. Warm air has a higher saturation vapor pressure compared to colder air. In other words, an air mass at 70 ° can have a higher water vapor content before reaching saturation than an air mass at 30 °F temperature. Moisture is the fuel for all tornadic storms because without moisture storms do not occur. After all, clouds are made mostly from water vapor as well as small amounts of ice and dust depending on the elevation of the cloud.

The dew point is the temperature at which the relative humidity reaches 100 percent and water vapor condenses into liquid water. A very high dew point means water will condense at relatively warm temperatures. A very low dew point means air must be cooled a substantial amount before water condenses. Large dew point temperatures contribute to severe weather because they cause lower cloud bases which were shown to be associated with tornadic supercells (e.g., Thompson et al. 2003), and they were shown to be associated with larger instability in the atmosphere. But the triggering event causes the air mass to rise to the dew point.

Thermal triggers are the most common form of initiator. In these scenarios thunderstorms are prompted when a moist air mass is rapidly warmed up by solar radiation. As air warms up it becomes less dense and therefore positively buoyant. Positively buoyant air masses continue to rise until the air mass reaches the dew point and begins to condense into clouds. If the heating is sufficient these clouds will likely build into thunderstorms. A great example of these would be the pop up thunderstorms that are very common in the summer months in many areas of the United States. However, thunderstorms generated in this manner were generally little more than standard air mass storms since those storms form in environments with little to no wind shear. Consequently, storms produced in this manner are less likely to cause severe weather problems for people and property.

There are several different types of triggering events which could result in the formation of a thunderstorm: orographic, thermal, and frontal. Mountains, hills, or any other sharp rise in land elevation are known as Orographic triggers. When an air mass meets a mountain range, prevailing winds force the air mass up over the mountains. As an air mass rises over an orographic trigger it will cool and condense into clouds. These clouds then start to produce rain that falls on the windward side of the mountain. Oftentimes, such storms can produce tremendous amount of rain on the windward slope of the mountains. The main concern of these storms are flash floods and lightning strikes.

Lastly and most importantly are frontal thunderstorms. When separate air masses collide it can cause a very unstable environment. This happens when a warm air mass collides with cold air mass and the direction the air masses are moving does not matter much.

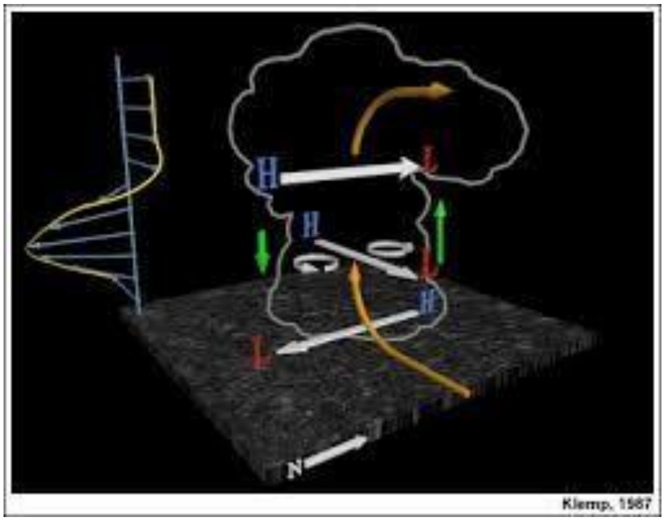
The collision of air masses results in the less dense air rising over the denser air. Thunderstorms formed in this manner were responsible for severe weather destruction and remain so because the conditions that create frontal thunderstorms also generate a lot of wind shear in addition to the instability in the atmosphere and moisture already present.

However it is important to point out the presence of all three elements previously mentioned does not necessarily mean a severe storm occurred. That is because there are three distinct types of thunderstorms: a single cell, a multi cell, and a supercell. A single cell storm is the most basic type of thunderstorm. Single cell storms consist of a single nonrotating cell and typically result from thermal heating. Single cell storms remain most common in the summer months when strong summer heat can rapidly rise and heat an air mass. However, single cell storms occur in environments with little to no wind shear, and generally dissipate in less than an hour. Therefore, single cell storms very rarely produce severe weather conditions.

A second type of thunderstorm is known as a multi-cell storm. As the name implies, this type of storm consists of two or more single cells. A multi-cell storm can develop in several different ways. It can develop when multiple cells in close proximity to each other merge together. But the most common way that these storms formed was when a preexisting cell spawns a new cell within the same system. Multi-cell systems were usually stronger and lasted longer than single cell storms. Multi-cell storms produce a substantial amount of severe weather in the form of flash flooding, straight-line winds, hail, and occasional weak tornados. Stronger and more organized variations of multi-cell storms such as squall lines are more likely to produce severe weather. A squall line forms along a front and consists of a series of many storms merged into a single line that can stretch over one hundred miles. Squall lines typically form in frontal systems when a series of many storms develop in close proximity along or just ahead of the main front. These tend to be rather fast moving and very strong storms. Squall line storms are the type that is most commonly associated with straight line winds since the downdrafts from the different cells in the storm often combine to produce a very strong outflow. The outflow can be detected by weather radar in the form of a bow echo. These storms do at times spawn tornados, but the tornados were not as frequent nor as severe as the supercell storms described below.

So what causes supercells to become tornadic? The primary conditions include the presence of a deep pool of cold air at the base of the thunderstorm and strong surface level rotation of the storm. Vertical rotation is the first component of tornado development. In an environment with strong vertical wind shear the air has a horizontal rotation. Think of it like a plastic tube rolling across the ground. However, vertical wind shear is what causes tornadic storms to develop. As a storm develops and begins to move, pressure gradients begin to build in the storm as wind comes from different directions. The following illustration from Klemp (1987) in figure 2 is a great example. Say an environment has low level winds out of the north, and upper level winds out of the west. In this scenario a storm would have high pressure on the east side at low levels, south side at mid-level, and west side at an upper level. Thus it would also have low pressure on the west side, north side at the mid-level, and east side at the upper level.

Since air moves from high pressure to low pressure, an upward directed force would be created on the east side of the storm that further strengthens the updraft in that region.



Klemp, 1987

Figure 2: Illustration of the effect of wind shear on thunderstorm adapted from Klemp (1987) Dynamics of Tornadic Thunderstorms.

As Markowski and Richardson (2009) note, all storms have air beneath them which is cooler than the surrounding environment. That is because the rain falling from the storm acts as a natural air conditioner by cooling the air as it passes through. The intensity of this cold air pool is largely dependent on the original height of the air and the amount of rainfall in the downdraft, with more intense rain producing more intense cold pools. Cold air pools at the base of the storm are important because the cold air makes the base of the storm negatively buoyant since cold air is heavier than warm air. This tilts the horizontal rotation downwards. When this is combined with and updraft that is strong enough to lift the cold pool and the updrafts tendency to tilt the rotation upwards you get a stretching of the rotation. As the rotation stretches it increases in speed like an ice skater twirling faster as she tucks in her arms. A very-stretched rotation generally means strong tornados. Once a tornado is formed its strength is measured by the damage its causes.

Tornados ratings occur on a six-part scale ranging from EF0 to EF5 which was based on the type of destruction caused by the tornado. This scale is known as the Enhanced Fujita Scale, a modified version of the scale developed by Dr. Ted Fujita in 1974. Unlike the original Fujita Scale, the enhanced version uses 28 different indicators to calculate a tornado rating (WSEC 2006). These rating indices range from softwood trees to high rise buildings and each has its own unique damage scale. The Enhanced Fujita Scale also recognized how wind speed can do different levels of damage to different buildings depending the quality of construction. Table 1 below explains the EF scale very well.

Table 1: Table showing EF scale wind speeds and damage indicators taken from Brown (2012) How tornado damage is rated.

Enhanced Fujita Scale damage and windspeed estimates

Damage	Little Damage	Minor Damage	Roof Gone	Walls Collapse	Blown Down	Blown Away
EF5	X	X	X	X	X	X
EF4	X	X	X	X	X	
EF3	X	X	X	X		
EF2	X	X	X			
EF1	X	X				
EF0	X					
Estimated windspeed (mph)	65-85	86-110	111-135	136-165	166-200	200+

For example, EF0 damage consists of broken branches, shingles blown of roofs, and other minor property damage. At the other end of the scale is EF5 damage which means large well-built buildings were destroyed and blown away. Events at the higher end of the scale are rarer than events at the lower end of the scale. However, the Fujita

Scale is not a direct measure of intensity and should not be used as one (Doswell and Burgess 1988). This is because the Fujita Scale is based purely on damage. As such it is possible for a violent tornado to earn a weaker EF rating if it does not contribute to any appropriate damage indicators. This is why it remains important for weather experts to advise people to take necessary safety precautions for all tornados.

Thompson et. al. (2003) provided an extensive review of tornado parameters. The article found all of these to be indicative of supercells, but in different ways. The review included mention of a mixed layer convective available potential energy (MLCAPE), a mixed layer lifting condensation level (MLLCL), a 0-6 km vector shear, and a storm relative helicity (SRH).

Convective Available Potential Energy (CAPE) is a measure of the buoyancy of an air mass relative to the surrounding air and is a great measure of instability. A high CAPE indicates that the air mass is extremely unstable and updrafts that develop in the environment became very strong. Thompson et. al. (2003) found that MLCAPE was an important indicator of extreme events. Also, the authors found evidence showing the MLLCL was also important since the LCL is the level at which moisture condenses into clouds. The authors found that a very low LCL was conducive to thunderstorm development since it meant that such storms could form faster and more efficiently.

Wind related factors such as 0-6 km vector shear and SRH were also found to be good predictors of supercell events. The 0-6 km vector shear is a measure of vertical wind shear in the environment, which turned out to be a big player in the development and intensification of the rotation. Thompson et. al. (2003) found that supercells became more likely when the 0-6 km vector increased. Furthermore, the authors also found a link to SRH, which was a direct measurement of the potential for cyclonic updraft rotation. The SRH was helpful to distinguish between significant tornadic supercells and non-tornadic supercells, particularly at the 0-1 km value. As SRH increased the likelihood of a supercell increased.

As mentioned before tornados recorded weather history has shown the spring months remain the most common period for tornados to occur in the United States. But the exact timing varies. Based on latitude the states in the southern United States experienced an earlier peak tornado season compared to other regions. Gagan et. al. (2010) found that there were distinct patterns of tornado activity in the United States. For much of the Deep South from the Gulf coast of Texas to South Carolina, the peak tornado season was shown to occur during March through May with the highest frequency of tornados happening during April. For the Great Plains, Ohio Valley, and Mid-Atlantic regions tornado the primary tornado season was determined to be April through June with peak activity in May (NOAA 2017, Last Accessed 3/21/17). For the Northeast and Great Lake regions tornado season was shown to be May through July with peak activity in June.

After peak season, tornado activity declines through summer months until autumn at which time activity spikes at a much lower level than in the spring in the south and lower plains. Finally, according to weather research the winter months saw activity decline to negligible levels for all regions except in the South where activity levels bottom out at low to moderate risk during the winter. Interestingly, the South has the highest tornado risk from October through March. The High Plains have the highest level of activity from April through September. The farthest western states were the only region without a significant tornado threat as it is not uncommon for some western states to go years without a single tornado.

This quantitative study sought to analyze tornado reports in Dixie Alley as compared to tornado reports from Tornado Alley. Geographic information systems (GIS) were used to analyze distribution and density of tornados in those two regions. GIS technology was used to perform kernel density mapping in both regions. The study results show us a rough picture of the distribution of tornados in each region. The kernel density method was chosen for its accuracy and reliability. The kernel density mapping used the planar method. The parameters of the kernel density analysis were as follows: the areal unit was in square miles and the cell size was set at 1 square mile. This was done for both Dixie Alley and Tornado Alley. The states researched included those in Dixie Alley and the states in Tornado Alley. As previously mentioned each data point included point of origin, path width and length, F scale rating, casualties, an assessment of deaths and injuries, financial damage estimates, and time and date of the tornado.

METHODOLOGY

The next table shows data which was used in my study. The National Oceanic and Atmospheric Association (NOAA) has an exhaustive database available to the public. This paper only used data found in the NOAA which was from 1980 to present for this study. Table 2 shows a sample of data from a NOAA dataset. There is one entry for each event in the table.

According to the dataset each confirmed tornado was measured. The measurements included a point of origin, a path length, a path width, F-scale rating, casualties such as death and injuries, financial damage estimates, and measurements for time and date. Point of origin explained where the tornado touched down. Path length was measured from the point on which the tornado makes first contact with the ground to the point where the tornado last makes contact with the ground. Path width was measured as the maximum width obtained rather than the average width.

F-scale rating was measured as the maximum obtained intensity instead of average intensity. Damage costs were measured as the cumulative total expense of the destruction caused by the tornado. Time and date were measured for when the tornado occurred. Additional demographic data was used from the census bureau. Most of the NOAA data pertained to storm reports gathered by storm spotters and submitted to NOAA. A sample of which can be seen in table 3 below. This dataset included all confirmed tornadoes, nearly two thirds were either EF0 or EF 1. Normally this would not be considered an issue. However, the number of reported tornadoes increased significantly in the last 20 years. The increased frequency over the past two decades was the result of the reported inclusion of low end tornadoes.

Table 2: Sample of d*ata* from NOAA Storm Prediction Center.

Touchdown Latitude	Touchdown Longitude	Date	Fujita	Fatalities	Injuries	Width	Length
32.97	-87.08	8-Mar-80	1	0	0	73	6.1
31.2	-85.63	8-Mar-80	2	0	5	40	16
31.7	-87.78	17-Mar-80	1	0	0	50	0.2
31.65	-87.7	17-Mar-80	1	0	0	50	0.5
33.42	-87.2	20-Mar-80	1	0	0	50	0.1
33.17	-86.25	20-Mar-80	2	0	6	50	3.8
31.03	-86.1	12-Apr-80	2	0	1	150	31.1
30.88	-88.27	13-Apr-80	1	0	0	50	0.1
31.07	-88.03	13-Apr-80	1	0	0	17	0.1
30.68	-88.2	13-Apr-80	1	0	0	20	0.3
30.88	-87.78	13-Apr-80	2	0	0	50	0.1
30.7	-88.08	13-Apr-80	1	0	0	30	0.1
32.6	-85.45	13-Apr-80	2	0	13	440	11.3

A low end tornado is one which barely meets the requirements for classification as a tornado. A low end tornado has slow circulating wind speeds, typically less than 70 mph. Low end tornadoes were recorded in the past two decades due to the introduction of improved radar technology and partly because of the expansion of population centers throughout the United States. The sheer number of low end tornadoes relative to the number of severe tornadoes was recognized because it could skew my data collection. This is because tornadoes rated EF1 or less make up 70% of all tornadoes. If those were included in my data collection that could cause an inherent bias in the dataset. Therefore, I decided not to include the low end tornadoes in my dataset for the purpose of this research.

In addition, data form the United States Census Bureau was collected to provide information on the factors of population density and poverty rate for both Dixie Alley and Tornado Alley. Furthermore, data on forest cover percentages was collected from the National Forest Service Database. The data was then geocoded using the coordinates given for tornado touchdown longitude and latitude. That was done using the geocoding tool in ARCGIS. Two fields, touchdown latitude and touchdown longitude, were matched to geographic locations using an address locator comprised of geographic coordinates. In other words, when I imputed the touchdown coordinates the locator searched for matching coordinates in the database. Where there was a match the data was assigned a point on the matching coordinates. For the small percentage that did not return a match in the database, a more extensive review was conducted. Most of the mismatches were tornadoes that touched down outside the study area and then moved into the study area. Those mismatched samples were disregarded. The few data points within the study that did not get matched were coded by hand.

Research Analysis of Data Collection

The results of this study looked at how population density, poverty rate, and line of sight affect tornado risk for Dixie Alley and then Tornado Alley. Analysis of the tornado counts, population density, poverty rate and casualties were gathered. Maps for each risk factor were drawn based on the data. These maps were overlaid on top of each other to produce an overall risk map for each area. From the overall overlay a risk index was assigned at the county level for both of the regions. Finally, a T test was completed to determine the statistical significance and difference between the frequency and patterns of tornadic activity which compared Dixie Alley to Tornado Alley?

In order to do that I determined the statistical test or tests to use and calculated risk level. Since risk is a combination of factors it behooved me to use a statistical test that calculated statistics for multiple data sets so a p-value was needed. The lower the p-value the better. Ideally, a p-value of 0.05 or lower proved the best result since its results are very unlikely caused by chance. In such a test overall tornado counts were used as the test statistic since all other statistics were dependent on the tornado count because without it, we could not get statistics like fatalities, property damage, and F-scale rating. As a matter of fact, raw count was used as the test statistic for all tests simply because of how dependent the other variables are on tornado count.

But keep in mind this is a risk assessment and thus other factors must be included to get a proper analysis of risk. Risk has two parts to it considered in this study. The first is the likelihood of a dangerous event occurring in a given area. That is probability. The second part is the number of people and property effected by a dangerous event. The first half of the equation was easier to quantify since those factors change at a much slower pace than the other half of the equation. To calculate the chance of an event occurring is sometimes as easy as calculating the average for a given area. However, this is not ideal for all situations. This is particularly true when extreme values in the dataset skew the average. In such situations the median was used as an adequate solution. The use of the median proved best when the dataset was large and/or over one hundred. The median was much more consistent in large samples since a single addition to a dataset did not change the median much. Conversely, adding a value to a small dataset can significantly change the median relative to the size of the data points. Keep in mind this method for calculating probability is only useful for situations in which the dependent factor is only dependent on one independent factor. However, more complex calculations required a completely different solution to the problem.

When one decides to calculate the probability of something occurring which uses many different factors, then a researcher should consider all separate factors first, and afterward consider the separate factors as a group. Technically, the laws of probability state that in order to calculate the probability of one event happening based on another event one must divide the number of events in Group B by the grand total of Group C. For example, if one were to calculate the probability of an EF5 tornado causing casualties one would divide the number of EF5 tornadoes that caused casualties by the total number of EF5 tornados. For each additional factor the researcher further divides by the total for the factor. In this manner a researcher can calculate the probability of any event happening given a series of factors. After a researcher knows the probability of an event happening he/she has one half of the equation solved. The other half of the problem must determine the amount of people and property affected by a tornadic event.

The people and property affected by a given tornadic event was the often overlooked half of the risk equation. This was unfortunate since this is the part we should all be concerned about. Logically, locations with a greater population have a higher potential impact from any given tornadic event. In addition, the larger a population center area is, the larger potential impact. This describes what is known as the bullseye effect. The reality of the bullseye dilemma is narrow when compared to all the acreage in the rural areas. Thus, it is logical to assume the chance of any event striking a bullseye is very low. As an example, a strong tornado striking a major urban area is the worst case scenario for a tornado event, but the odds of a tornado striking a major city have proved slim according to historical records. This may in part be the reason we have the unfortunate myth which suggests tornadoes do not strike large cities. Incidentally, tornadoes have hit major cities ranging from Miami to Minneapolis. However, population is not the only factor involved in risk.

Another risk we must consider is vulnerability to the effects of a tornado. As stated in the literature review section certain aspects of a population can make them more vulnerable to a tornado than they otherwise might be. The most prominent of these vulnerabilities was the percent of a population considered below the poverty level. This was important because poor people tend to live in homes that are more easily destroyed by an oncoming tornado. For example, mobile home residents are typically among the disproportionately poor in a population. Storm studies have shown how mobile homes are not safe in tornados and can be death traps since strong tornadoes can easily pick up and throw mobile homes. In addition, poorer people are more likely to dwell in poorly built homes or homes without a basement or storm shelter. Poverty may have the biggest impact on vulnerability but it is not the only factor considered in this study.

Factors of Data Collection

Another factor considered was a person's ability to see the tornado coming. A striking difference between noticed in Dixie Alley which contrasts with Tornado Alley has to do with the line of sight for a tornado. The South and the Midwest are different in this regard because the Midwest has far more space where the land relatively is flat with few trees. Such conditions often allow a person in Tornado Alley the opportunity to see an on-coming tornado from miles away. However, that is not the case in much of the South where the land is heavily forested and the topography has high and low terrain. As a consequence, tornadoes in the South are often not visible and advance notice is not often possible (Ashley 2007). This means the person in the South probably has significantly less time to react safely, particularly when the person has no other warning.

A third factor considered when tornadoes hit. A tornado that strikes sometime in afternoon is generally going to cause less casualties than a storm that strikes in the middle of the night. As figure 3 shows tornadoes are most common in the afternoon hours for both regions. But Dixie Alley has consistently higher rates of nighttime tornadoes by several percentage points. This is concerning since nighttime tornadoes are more dangerous than daytime tornadoes. Why? It is because most people are asleep at night making them completely unaware of the approaching tornado. Conversely, people are more likely to be aware of a tornado during the day since they are up and active.

So how do we calculate how many people are at risk in a given area? Well, first collect demographic data on population distribution. But is raw total population data the best distribution metric? The answer is unlikely because a raw population dataset may not evenly distributed over geographic area.

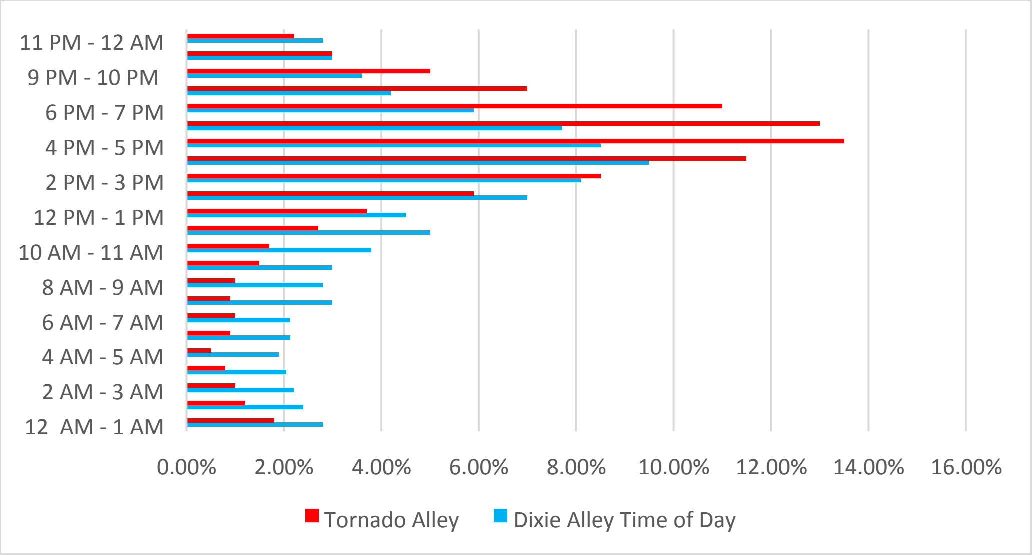


Figure 3: Graph of time of day each sampled tornado occurred at in both Tornado Alley and Dixie Alley. Tornado Alley is in red and Dixie Alley is in blue. created using NOAA data

This was particularly true when the study area was very large. For example, the state of Georgia has a population just over 10 million but it very unevenly distributed with very high densities in the greater Atlanta area. Moderate density was seen along the fall line, particularly in the cities of Columbus, Macon, and Augusta and low density in the northern Appalachian foothills and Southern swamplands. For example it's very likely that a tornado would cause more damage when it hits downtown Atlanta or one of the fall line cities, than a tornado would do if it hit the rural areas in the north and south of the state. In order to properly quantify density for our study a density map was required for the study area. This was done with kriging techniques in order to provide an accurate depiction of population density throughout the study area as well as all the other factors in order to calculate an accurate estimate of all values for the study area. Kriging is a method of estimating values for each pixel in a raster using a form of triangulation to estimate the value of individual pixels based on the known values of nearby cells. The known points were county centroids. As an example, let’s say there is a dataset with ten data points some of which are duplicates that can be illustrated like this: 1, 1, 2, 3, 4, 6, 7,.3 7, 9, 10. A simple line graph of this data set would give values of 0 for 5 and 8. However, in a real life situation there was almost always at least a data points with those values. That shows a more representative dataset to work with. With kriging working as reliable estimate of density, population, and other factors, the work began on combining everything together.

Logically, risk is assumed to be highest where population density and tornado occurrences are both high. Thus, the simplest way to figure out risk was to combine population density with tornado occurrences. However, this was a very simplistic view of risk. After all population is not the only factor to consider, just the most obvious. For example, persons in poverty are usually at a higher risk than wealthy people since the poorest people often do not have access to proper shelter. Forest cover can also be an issue to since it can obscure a person’s view of an oncoming tornado. Keep in mind poor people in heavily forested, rural areas might not have reliable TV, radio or cell phone reception to provide adequate tornado warnings and not every town has tornado sirens.

As such these factors were discussed, but are also part of the analysis. The analysis used kriging to generate maps for all factors. Each data point for each layer was assigned an index value raging from zero to ten based on the presence of that risk factor in the cell. High numbers indicated a strong presence of that risk factor. Once all indexes were calculated the index values of factor had to be averaged out to create a total risk index with higher numbers.

That was done by overlaying a map of population density with a map of tornado occurrences. However, a problem with that is it would only provide a general idea of the risk. In order to get an exact number statistical tests were run to give a much more accurate analysis of risk for tornadic areas. This why a supplement was used with the overlay for statistical analysis. Given that the dataset goes back to 1980 it was prudent to look at risk trends from 1980 through 2015. Excluded years were 2017 and 2016 since 2017 had not been completed and removing 2016 gaves us an even dataset. For the research period of time analysis the tornado counts, population density, poverty rate, forest cover, and casualties were considered and calculated. Finally, statistical tests were run on an index to determine first if the two are statistically different, then later to determine which if any was of a higher risk. Specifically, t-tests were performed on the overall index to asses if Dixie Alley had a significant difference from Tornado Alley. This was used to either prove or disapprove the null hypothesis that there was no difference between the two regions. Furthermore, t-tests have also been performed on population and tornado count data to analyze the differences shown for the distribution in these factors and to analyze if differences in how these affected the overall risk.

RESULTS

The first part of the results section looked at risk results for Dixie Alley. Analysis of tornado counts from 1980 to 2016 indicated the area of highest tornado density is a broad overall density; most of the state was fairly low with areas of moderate density in northeast and southeast Georgia as seen in Figure 4.The highest tornado count densities were in a region extending northeast from southwestern Louisiana to southeastern Tennessee. Other hotspots included central Arkansas and north central Tennessee. The very lowest densities were in the Appalachian Mountains of eastern Tennessee. These numbers were not a surprise; previous research revealed mountainous regions were less likely to experience tornados

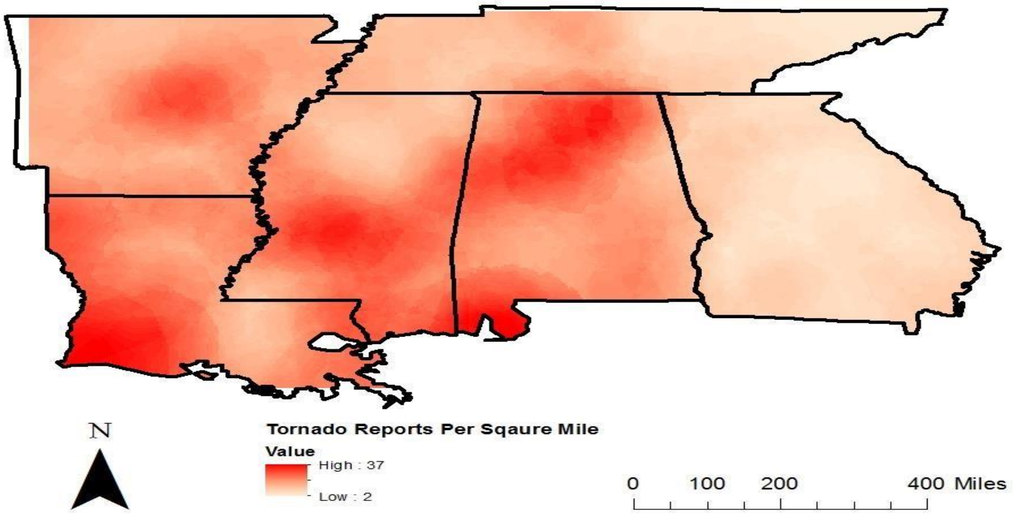


Figure 4: Map of tornado density in Dixie Alley Created in ARCGIS using NOAA Data.

The high density areas aligned with historical records and scientific research about Dixie Alley. The only real surprise on this map was it shows low densities throughout much of Georgia and east Tennessee.

How did these tornado densities compare to population density throughout Dixie Alley? As illustrated the lowest densities were located in rural areas. Figure 5 shows population density in the South. Obviously, population densities reflected highest in large metro areas like Atlanta, Nashville, and New Orleans. Thus these remain the areas of highest concern for tornado risk.

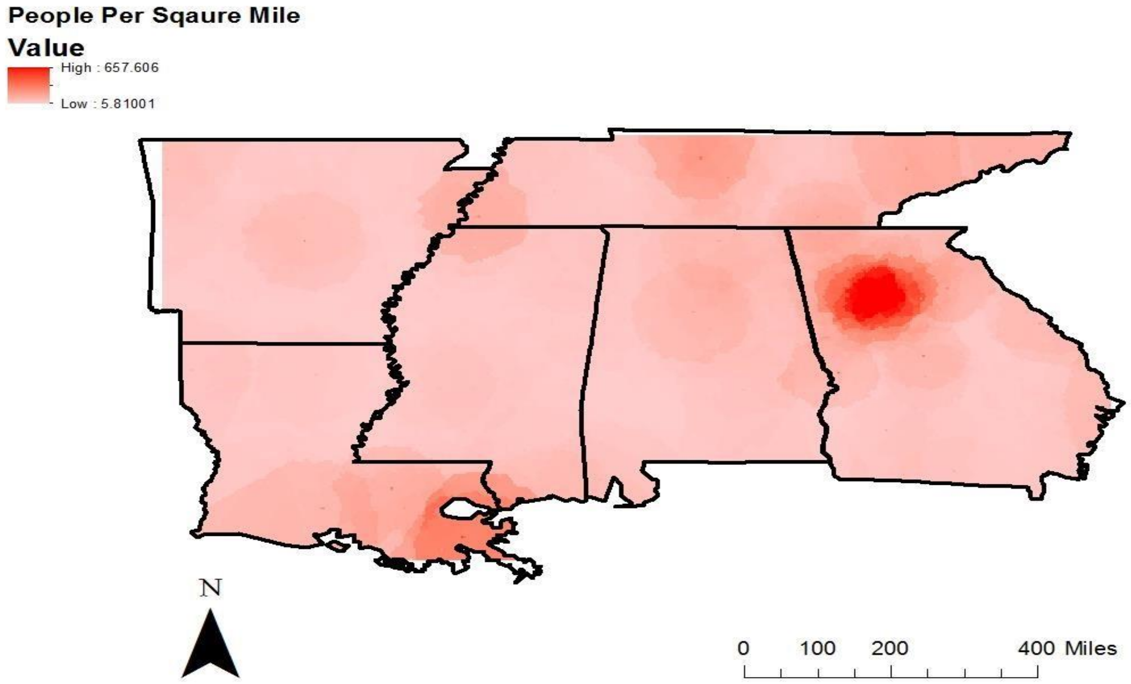


Figure 5: Map of population density in Dixie Alley created using NOAA data.

Figure 5 highlighted the major urban areas in Dixie Alley. Atlanta stands out very clearly. Nashville, New Orleans, Memphis, and Birmingham. Little Rock, Mobile, Huntsville, Knoxville, and Chattanooga all appear too. These areas should be of concern in Dixie Alley. Atlanta, the largest metropolitan area in Dixie Alley, has a population of over 5.5 million. Nashville, New Orleans, Memphis, and Birmingham have populations in the 1 to 2 million range. Little Rock, Mobile, Huntsville, Knoxville, and Chattanooga are in 300K to 500K population range. Of these cities only Birmingham, Huntsville, and Chattanooga lie within the belt of highest Tornado density in Dixie Alley. Indeed, tornados struck all those cities multiple times in their history. According to the Tornado History Project, there were 88 tornados since 1950 which touched down in Jefferson County, Alabama, where Birmingham is located. That is an average of 1.2 tornados per year. The number of tornados that touched down in Huntsville were 61 since 1950 and in Chattanooga there were 26 tornados that touched down. Dixie Alley has 12 cities in the 100K to 300K range including, Athens GA, Columbus GA, Augusta GA, Savannah GA, Murfreesboro TN, Clarksville TN, Montgomery AL, Jackson MS, Baton Rouge LA, Shreveport LA, Metairie LA, and Lafayette LA. We hope those do not get hit by a tornado under any circumstances because it would impact a lot of people and their property.

Poverty was another tornado risk factor studied. The large swaths of very rural areas included the Appalachian Mountains of East Tennessee, North Georgia, and Northeastern Alabama, the Mississippi Valley Region of Mississippi, Arkansas, and Louisiana, and the swamplands of southern Georgia and Alabama. While those regions still have low populations they were considered more likely to have poor and sparse populations.

Poverty rates were and remain high in Dixie Alley, particularly research indicated the higher poverty areas tend to be located where African American minorities were the majority of the population particularly in some counties. The poverty region in the South where many African Americans live was demonstrated geographically by a broad crescent shaped region running through southern Georgia, southern Alabama, and up the Mississippi valley in Mississippi and Louisiana. The map in Figure 6 shows poverty as a major issue in Dixie Alley. There were areas identified with high poverty rates along the Florida/Georgia border, much of Northern Louisiana, and in the Ozark Mountains of Northern Arkansas. Many African Americans reside in those areas. Notice Tennessee does not seem to fit with the trend evident in the rest of Dixie Alley. This was consistent with the concentration of high poverty counties along the Kentucky border and in the southwest portion of the Tennessee. This pattern was much like the pattern evident throughout the entire Appalachian region of the United States.

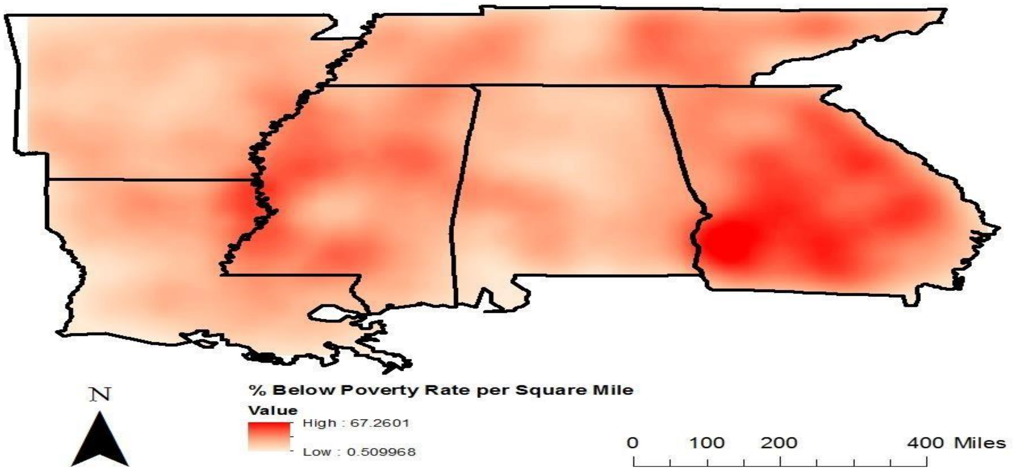


Figure 6: Percent of population below poverty line per square mile in Dixie Alley. Data provided by the US Census Bureau

Remember poor populations consistently experience greater vulnerability to natural disasters than their wealthier population groups due to a lack of proper shelter and usually to a lack of tornado warning in sufficient time to safely react.

> That leads to the next point. Line of sight was considered a tornado risk factor too.

Line of sight, in this case, means an ability to see the tornado coming. In the Tornado Alley this was not as big of an issue as in Dixie Alley since the land in Tornado Alley remains generally flat and treeless. Obviously, that allows people to see the tornados from miles away. However, the terrain in Dixie Alley was very different from Tornado Alley. As seen in Figure 7, Dixie Alley has more forest cover and hills. In addition, storms in Dixie Alley tend to produce a higher number or rain rapped tornados. Hence heavy rain blocks the view of tornados.

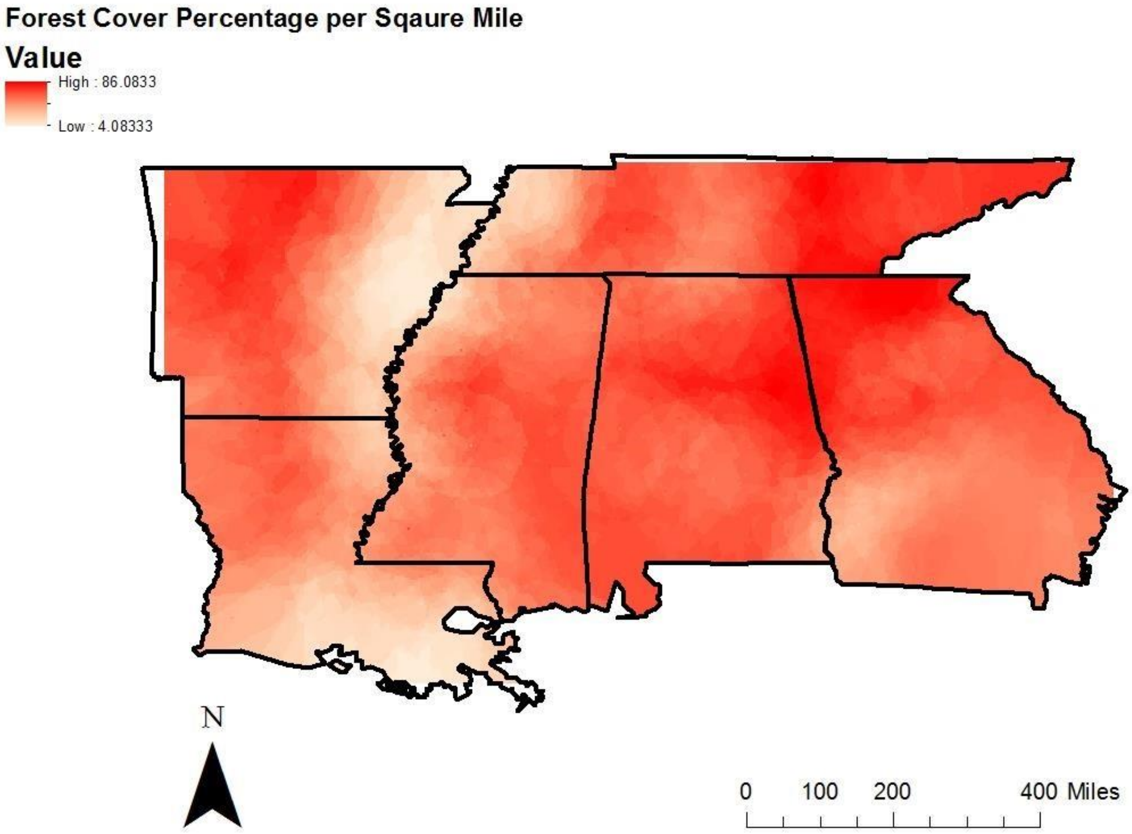


Figure 7: Map of forest cover percentage per square mile

All the above mentioned obstructions make it significantly hard to detect a tornado, and with less access to warning systems the people in Dixie Alley are at a greater risk. One could reasonably expect this to be a problem for rural, poor people, especially for those who do not live where tornado sirens provide warnings and for those who may lack TV, radio and cell phone warnings. Therefore, forest cover was a risk factor worthy of analysis. So how does Tornado Alley Look in for these factors, particularly tornado count?

The distribution of tornado counts in tornado alley follows a pattern where the highest distributions are in the cetral plains of Kasas, Oklahoma, and Central Texas as seen in the Figure 8. Missori has low numbers of tornado reports through relatively speeking.

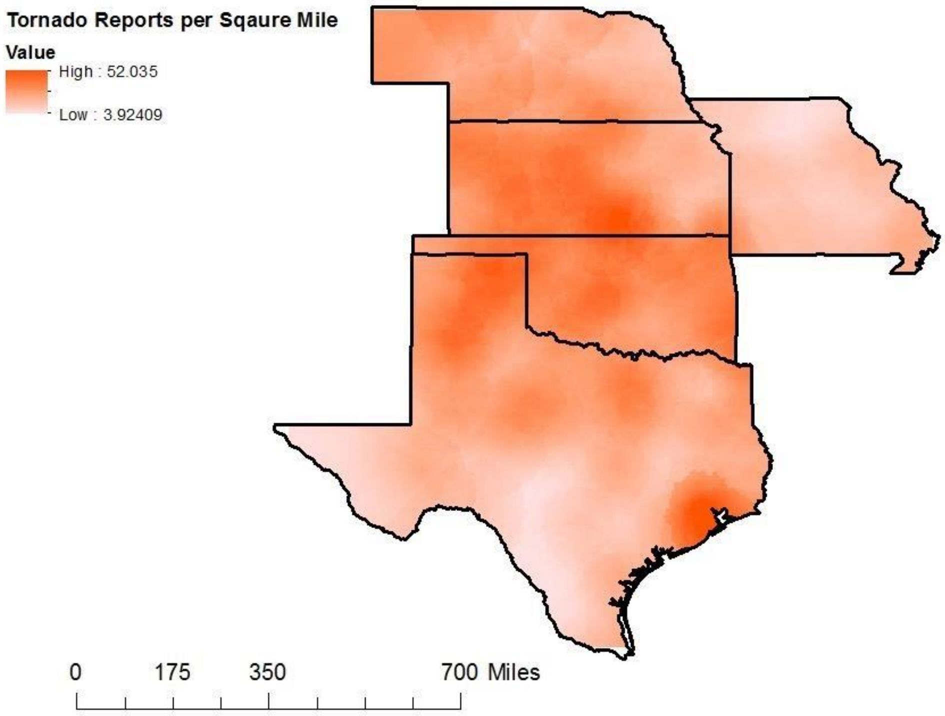


Figure 8: Map Showing tornado reports per square mile in Tornado Alley

Southern and western Texas also have low numbers as well. East Texas and much of Nebraska have moderate levels of tornado counts relative to the rest of Tornado Alley. The Houston area also stands out for its high number of tornado reports. However, how do the other factors appear in tornado alley.

Figure 9 demonstrates how populations in Tornado Alley were much more concentrated in major cities like Dallas, Houston, St. Louis, Kansas City, and

Omaha. However, the western areas of these states were very sparsely populated. In Tornado Alley the population density follows a pattern similar to Dixie Alley where there is one core urban county surrounded by several rings of suburban counties and then very rural counties after that.

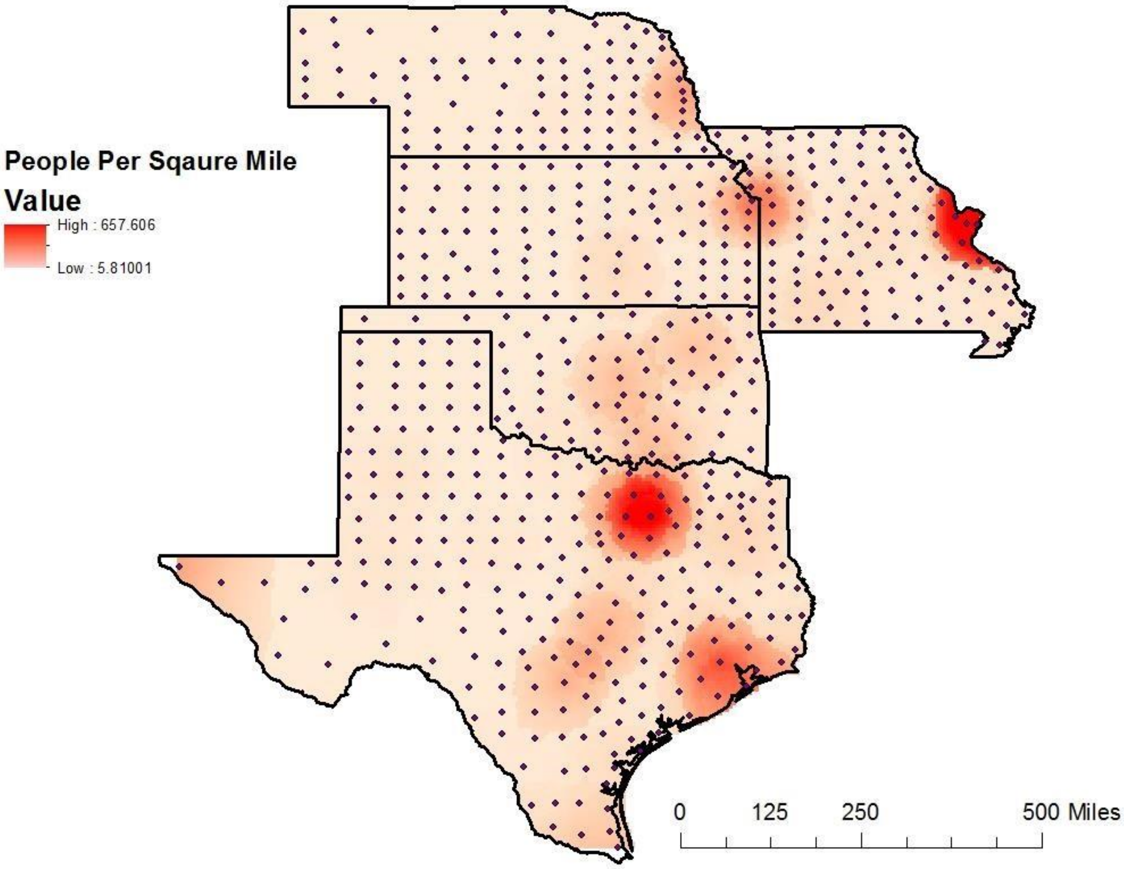


Figure 9: Map of population density in Tornado Alley measured as people per square mile.

However, some of the lowest population densities in the United States are found in the western high plains of Tornado Alley. The map in Figure 10 clearly highlights a difference in population density for Tornado Alley as compared to Dixie Alley. What stands out is how fast the population density declines in Tornado Alley when moving to the west. That was not so in Dixie Alley. Also population densities in Dixie Alley remain higher than the very low levels seen in western areas of Tornado Alley.

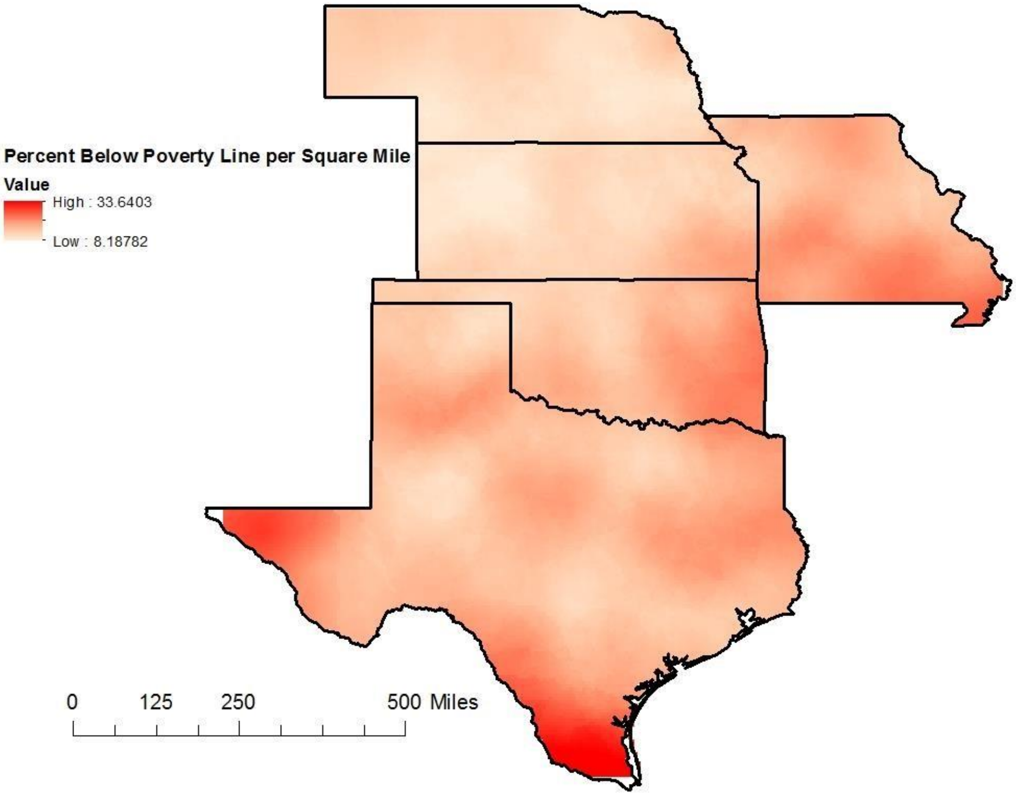


Figure 10: Map of poverty rate in Tornado Alley

As seen from this map the areas of Tornado Alley suffering from high poverty remain along the border with Mexico in Texas and to lesser extent in some rural areas of east

Oklahoma. South Texas has high immigrant populations, primarily Hispanics from Mexico, and in this area poverty is a real concern for the population. Eastern Oklahoma, unlike south Texas, has a poor Caucasian population.

So due to all the aforementioned risk factors it was necessary to combine those and determine the actual tornado risk. Tornado Alley was known to have a higher peak intensity which generally regularly occurred in the months of April and May but the risk steadily declined throughout the year reaching near zero in December and January as seen in Figure 11.

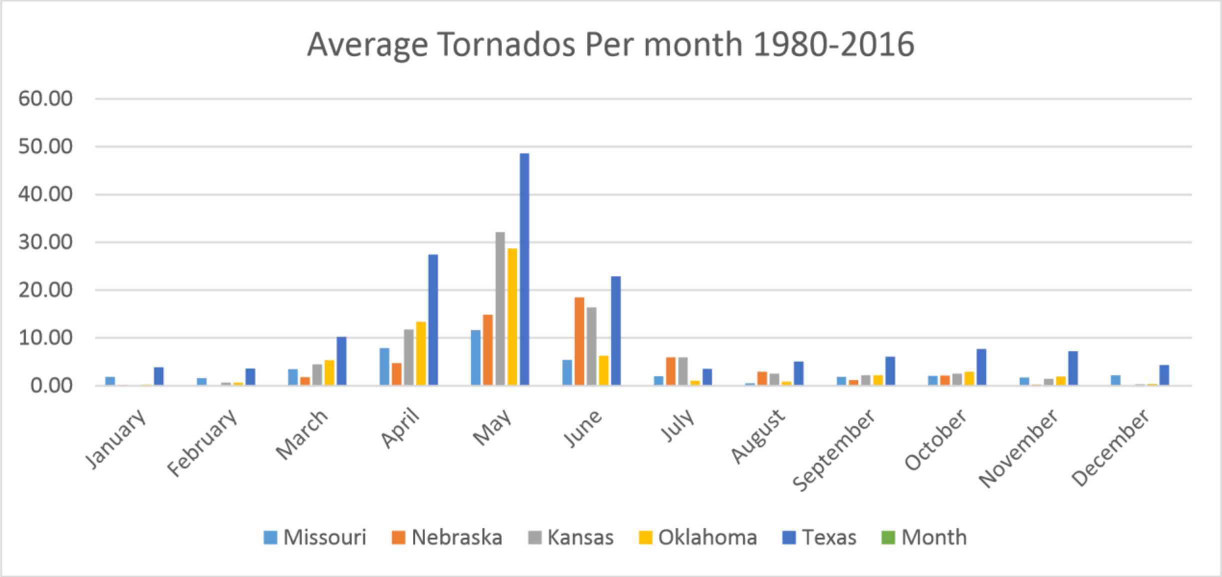


Figure 11: Graph of average tornado count by month for Tornado Alley from 1980 to 2016. Data provided by NOAA

As seen in the chart in Figure 11 the peak month in Tornado Alley is May which produced around 100 tornados across the region on average. Tornado activity begins to sharply decline throughout the region after June. By August the tornado activity reached minimal numbers near zero and remained like that till the next spring with one exception. October had a slight increase in tornadic activity. This slight uptick in October is the autumn tornado season. It is nowhere near as intense as the spring season yet it has a tendency to catch people by surprise since many people do not expect an autumn tornado season. The autumn tornado activity was likely due to a combination of higher altitude and more northerly location.

So how did Tornado Alley compare to Dixie Alley? Figure 12 highlights the monthly tornado activity average for Dixie Alley. There were some striking differences discovered through comparison of Dixie Alley to Tornado Alley.

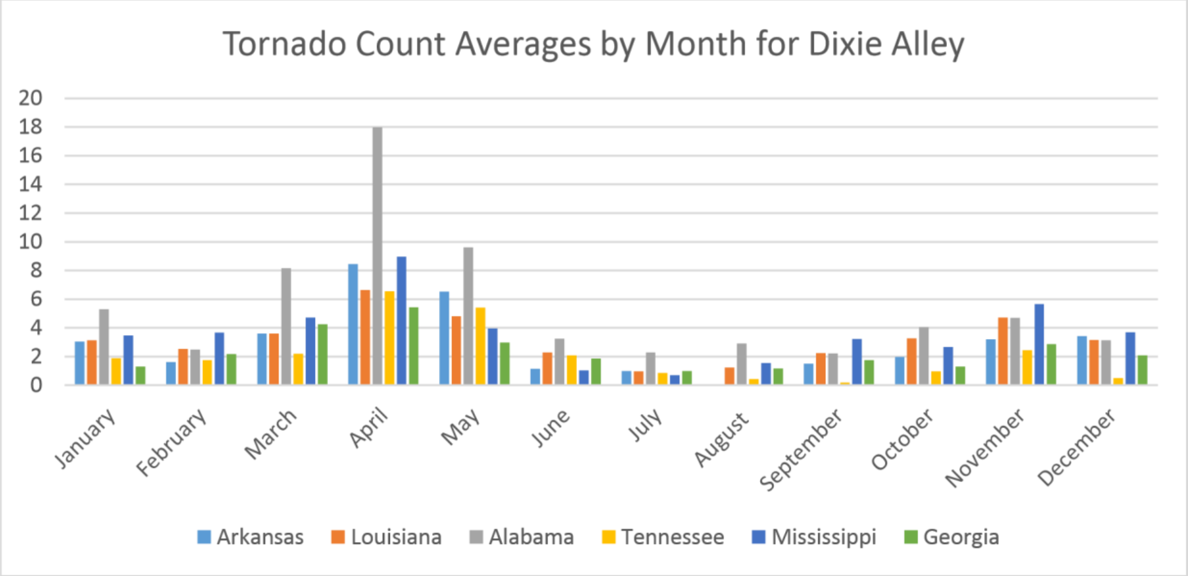


Figure 12: Graph of average tornado count per month for Dixie Alley from 1980-2016. Adapted from NOAA data

The first difference noticed by a comparison of Dixie Alley to Tornado Alley is there were two distinct peaks of tornado activity in the south. The first peak occurred in April which was a month earlier than the peak month in Tornado Alley. The second peak season was in November and is almost as intense as the spring season. The lowest point of tornado activity in Dixie Alley occurred during August. But the lowest point in Tornado Alley occurred in February. Furthermore, with the exception of a summer lull in tornado activity, Dixie Alley remained at elevated tornado activity throughout much of the year. This is further evidence of a point made previously. Although peak tornado activity is higher in Tornado Alley, average tornado activity is greater in Dixie Alley. In fact, tornado activity is higher in Dixie Alley every month from September through

March. For example, every state in Dixie Alley sees at least one tornado in December on average. However in Tornado Alley only Texas and Missouri see December tornados during an average year. But Tornado Alley had higher activity in April through July. Another noteworthy point noticed was the autumn peak of tornadic activity in Dixie Alley was more prominent than it was in Tornado Alley. Thus the risk from a tornado in Dixie Alley during the autumn remains greater than the risk of a tornado in tornado in Tornado Alley.

So what exactly was the total risk? In order to calculate the total risk all the tornado risk factors previously discussed were considered and an index was developed to assess total risk. Each risk factor was assigned an index rating ranging from 1-10 based on raw totals for that factor. Separate index ratings were then combined into a total index for each county within the study area. Once that was done the index ratings were divided between Tornado Alley and Dixie Alley based on their location. Statistical tests were then used to measure the difference between the two. Those tests showed the two data sets were statistically different.

The first tornado count was for Dixie Alley. In the example of Georgia, a county level count of all tornados since 1980 was conducted for the state. The total tornado count in Georgia counties ranged from a high of 19 in Fulton County to a low of two in six other counties. Regions of high activity included northwest Georgia and southeast Georgia. The lowest levels were in the central and northeastern portions of the states. The distribution state wide varied very little when compared to other states in Dixie Alley. Nevertheless Georgia, like Tennessee, had a comparatively lower of tornados than the other four states in

Dixie Alley both in terms raw tornado count and shown in the index.

Alabama had tornado totals ranging from a count of four tornados in Franklin County to 68 tornados in Baldwin County. A string of high count counties extended in a diagonal line from southern Louisiana to northern Alabama. There were also small areas of high tornado counts along the gulf coast of Alabama.

The tornado index used in this research had a range of 1-10 and was assigned based on a count of tornados that have touched down in a county between 1980 and 2016. For example, a rating of 1 represents a count of one to ten tornados and a rating of a 10 represents 100 tornados or more. The tornado index did not include tornados that moved into a county after touching down in another county. The figure 13 highlighted the index ratings for each county in Dixie Alley.

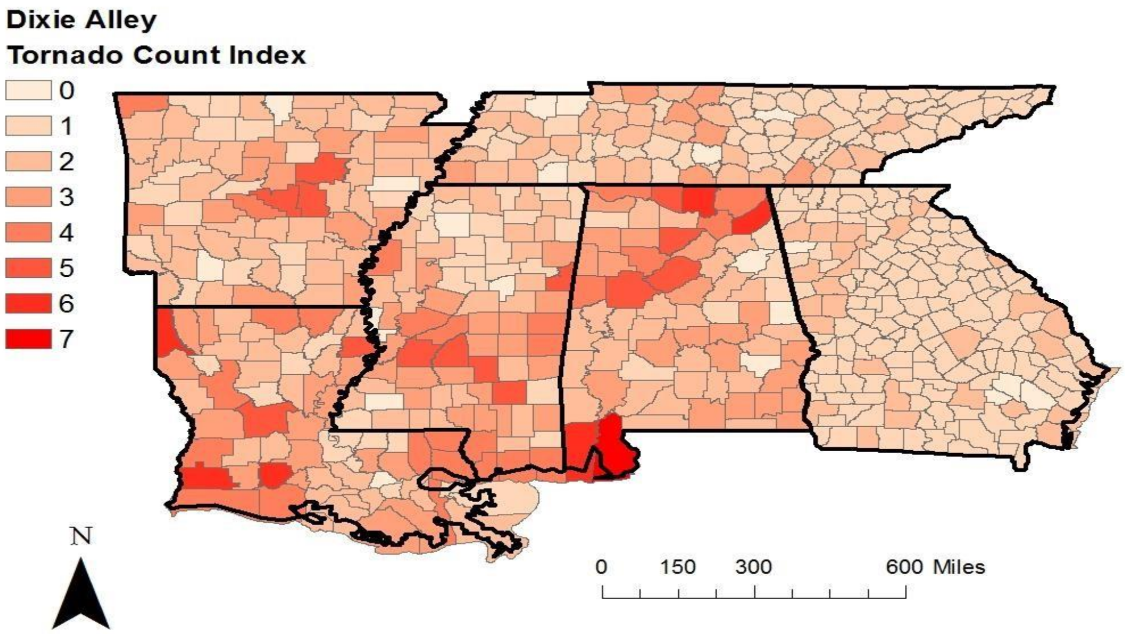


Figure 13: Tornado density index for Dixie Alley created in ARCGIS. Measured as the total number of confirmed tornadoes between 1980 and 2016 where a rating 0 is zero tornados and 7 is 70-79 tornados.

The map of index ratings was very similar to the raw count data except that it did a better at highlighting which areas were considered more vulnerable to tornados. The highest index rating in Dixie Alley was a 7 found in Baldwin County, Alabama. Baldwin County is located along the gulf coast between Mobile County, Alabama and Escambia County, Florida.

Several widely scattered counties received a score of zero. There was also a band of elevated ratings running southwest to northeast from central Mississippi to northeast Alabama. That band of elevated ratings included the cities of Jackson, Birmingham, and Huntsville and a cluster of elevated readings in central Arkansas around Little Rock.

But how did the Dixie Alley tornado raw counts compare to Tornado Alley raw counts? Figure 14 shows Tornado Alley had higher raw tornado count totals at the county level and the

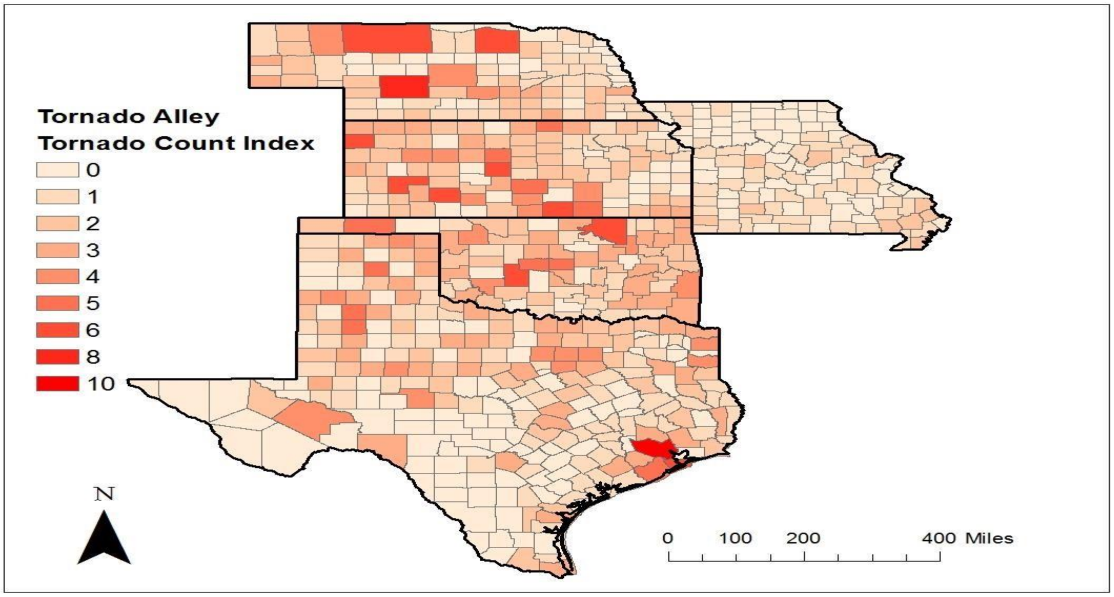


Figure 14: Tornado density in Tornado Alley created using ARCGIS

overall tornado count was much more evenly distributed. Texas was particularly interesting because its state counts ranged from a high of 136 in Harris County, where Houston is located, to a low of zero for Brooks County which is located in the far south near the Mexican border. This extreme variance highlights the great diversity in such a large state as Texas. At the low end was Missouri. Missouri had a relatively low count compared to the other states in Tornado Alley. Northern Missouri had a very low level of tornado activity and compared similarly to west Texas.

So what about the index ratings for those states? Index ratings were determined as less than four for the vast majority of the counties in Tornado Alley. However, Tornado

Alley had the only ten index rating in the study. The one ten index rating was found in Harris County, Texas. Harris County had 136 tornados between 1980 until the present time. That is an average of almost four tornados per year. Interestingly, Harris County tornado count is heavily influenced by tropical storm systems due to its location. A couple of named systems like Hurricane Alicia in 1983 and Tropical Storm Allison in 1991 contributed to the high index rating. Both of those hurricanes produced dozens of tornadoes in the area. The highest index for a county, not affected by tropical systems, was seen in Baldwin County, Nebraska which is located in the southwestern part of state. Other high index ratings remained scattered throughout the study area save for Missouri which had an index rating of three or lower throughout the state. But how did that compare to the other tornado factors?

Researchers suggest population index is a major factor in assessing tornado risk. So what were the population density index ratings for poverty in the study area?

Dixie Alley was studied first. Figure 15 shows population density index for Dixie Alley.

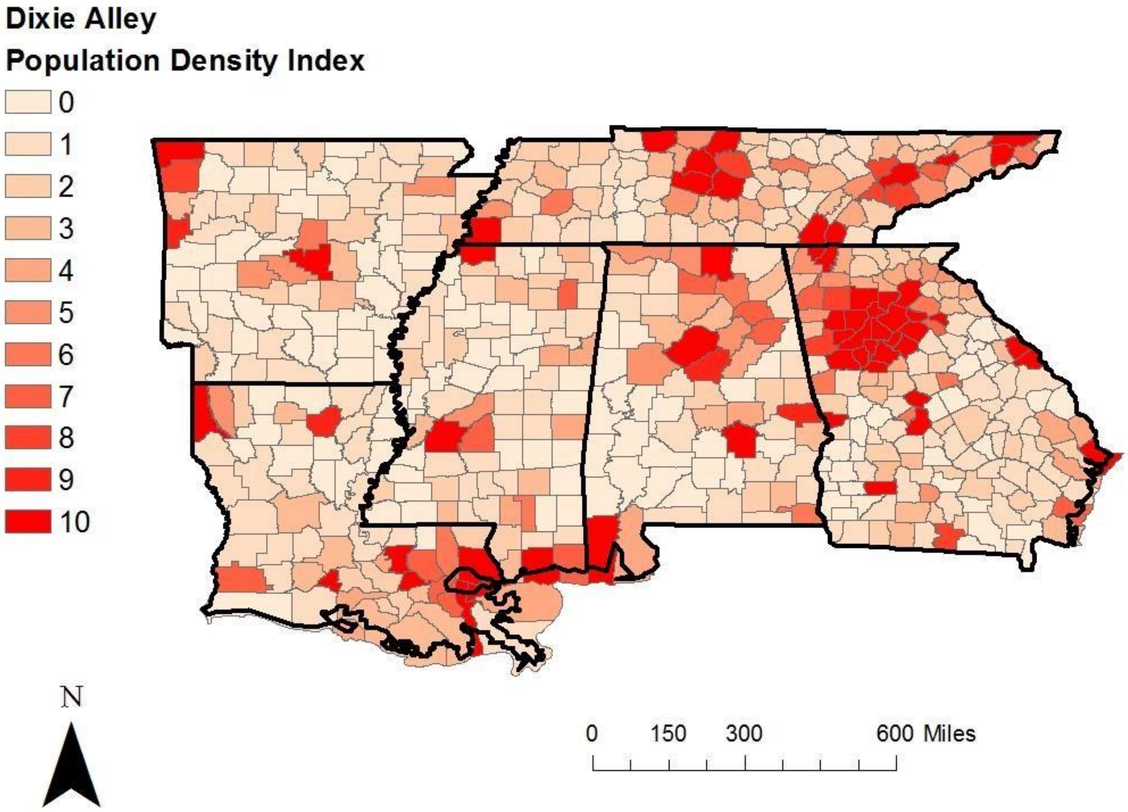


Figure 15: Population density Index for Dixie Alley created in ARCGIS

The average population density index rating for Dixie Alley was 2.73 or 3 when rounded up and the mode was 1 plus a standard deviation of 3.13 giving us a range of 0 to 5.86 or in simplified terms 0-6 for the range. As seen in the map in Figure 15, the urban areas stood out. The urban areas were prominent because high population density index ratings were compared to the rural areas surrounding the cities.

The Atlanta area had an expansive area of high density. There was also a stretch of high density counties along the gulf coast stretching from Mobile to New Orleans and one in eastern Tennessee between Chattanooga and Bristol. Much of Arkansas and Mississippi had very low index ratings for population density as did southern Georgia, central Tennessee, and northern Louisiana. So how did this compare to Tornado alley? Figure 16 shows Population density index for tornado alley.

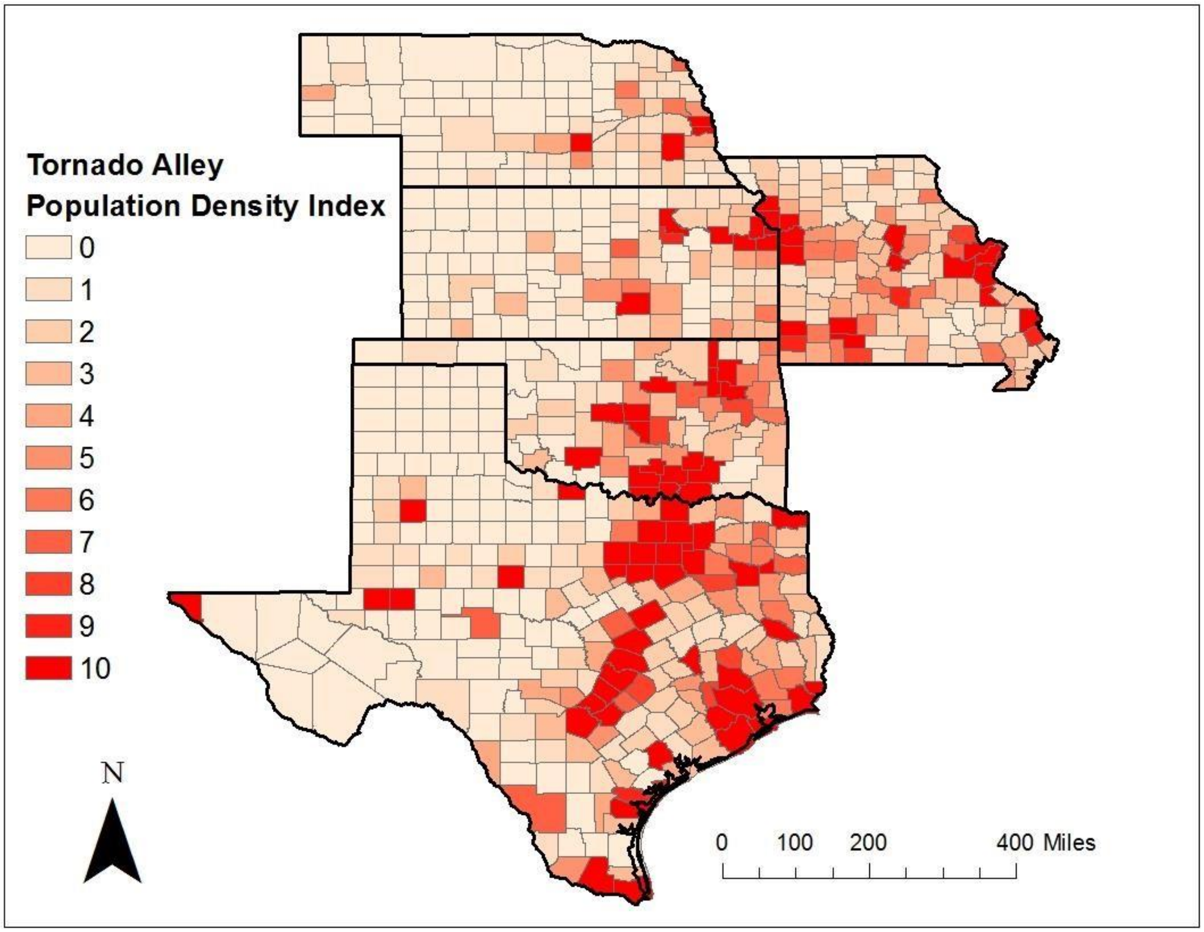


Figure 16: Population density index for Tornado Alley created in ARCGIS.

The statistics for the population density index in Tornado Alley revealed a mean of 2.81 which was statistically identical to Dixie Alley. Notice the distribution of index ratings was heavily clustered in the eastern half of Tornado Alley. The western region was more sparsely populated. The western half of the area was very rural with the exception of a few small cities in west Texas such as Lubbock and Amarillo. Aside from those most of the western counties have populations of only a few thousand or less and tornados that hit those areas often only hit remote farms. How was the poverty index distributed in Dixie Alley? It roughly mimicked the raw poverty percentage as seen from the map of the region. In figure 17 the indicator most prominent was the cluster of high poverty index ratings for the region along the Mississippi River in western Mississippi and northeastern Louisiana.

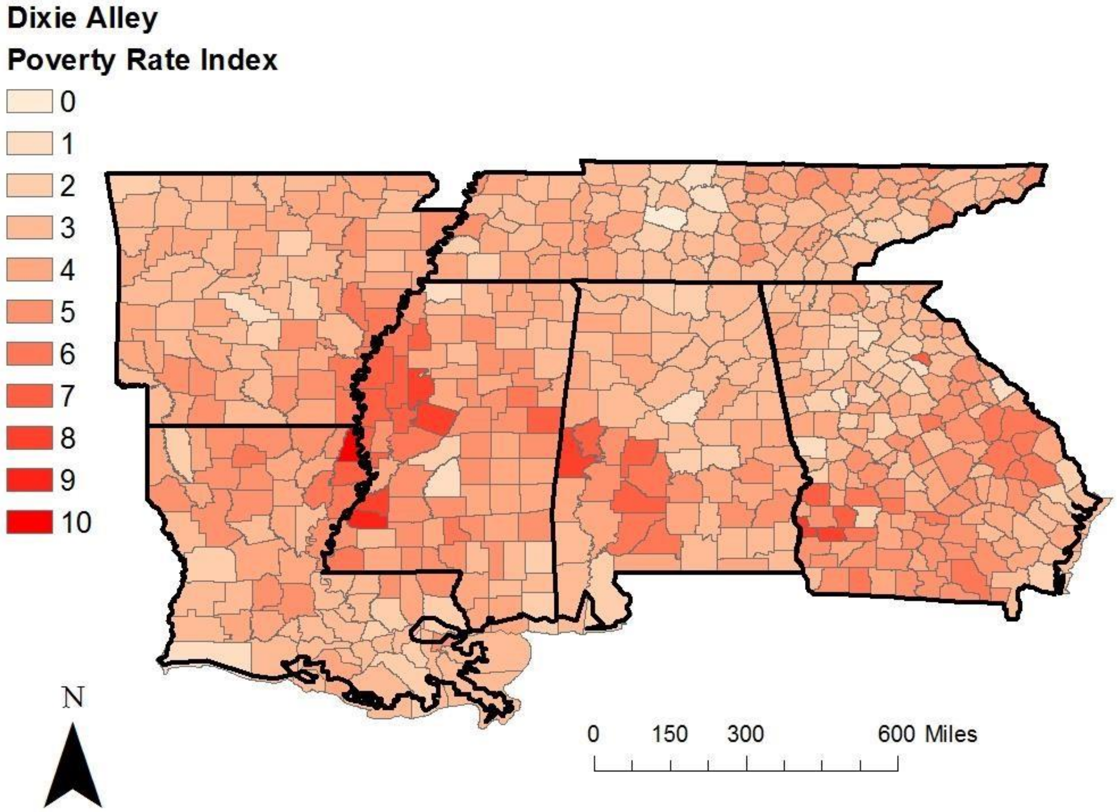


Figure 17: Poverty rate index for Dixie Alley Created in ARCGIS

There were also clusters of high poverty index ratings in southern Alabama and southern Georgia. Those populations were where minority races have a greater representation than the majority race of the state. Also most of the low poverty index ratings were found in the cities like Atlanta, Birmingham, and Nashville. The descriptive statistics read a mean of 3.82, a mode of 3, a median of 4, and standard deviation of 1.33 for a range of 2.49 to 5.05. So how does that compare to the Midwest? Unlike density there was a rather significant difference in the distribution of poverty rates in the Tornado Alley as seen in the Figure 18 which displayed poverty index ratings for the area.

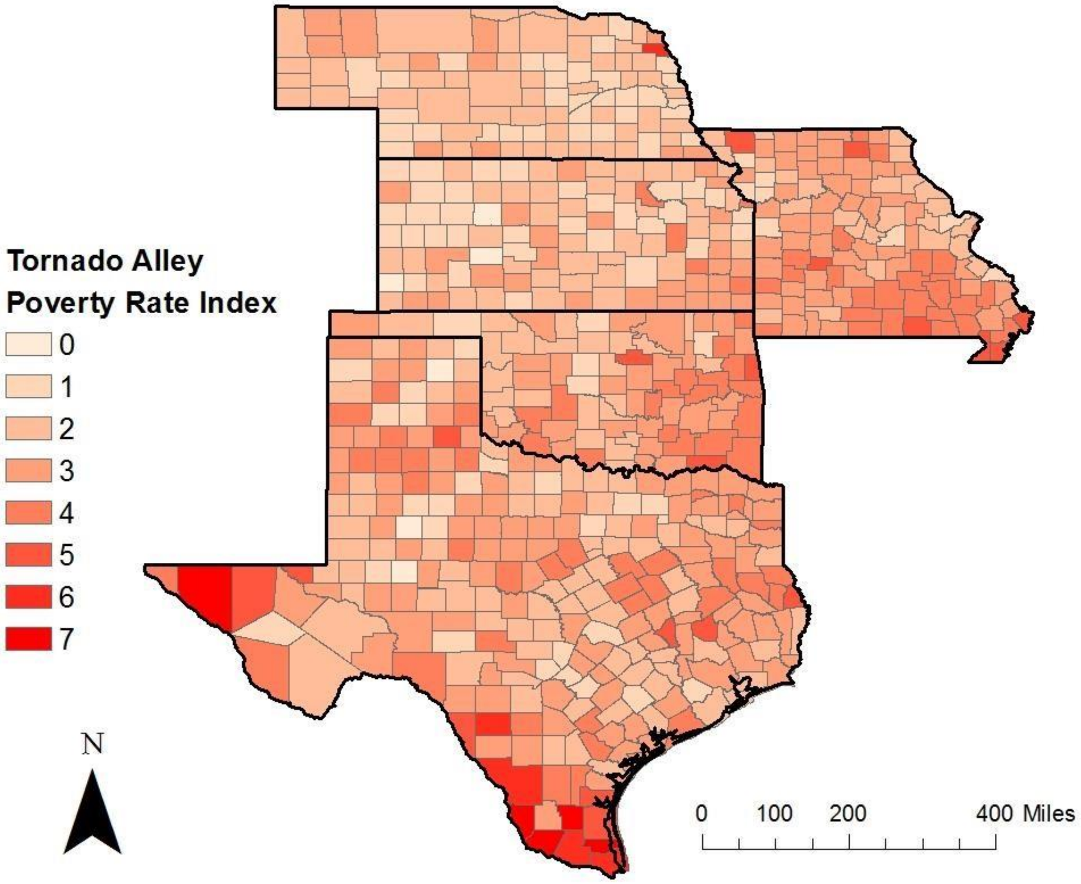
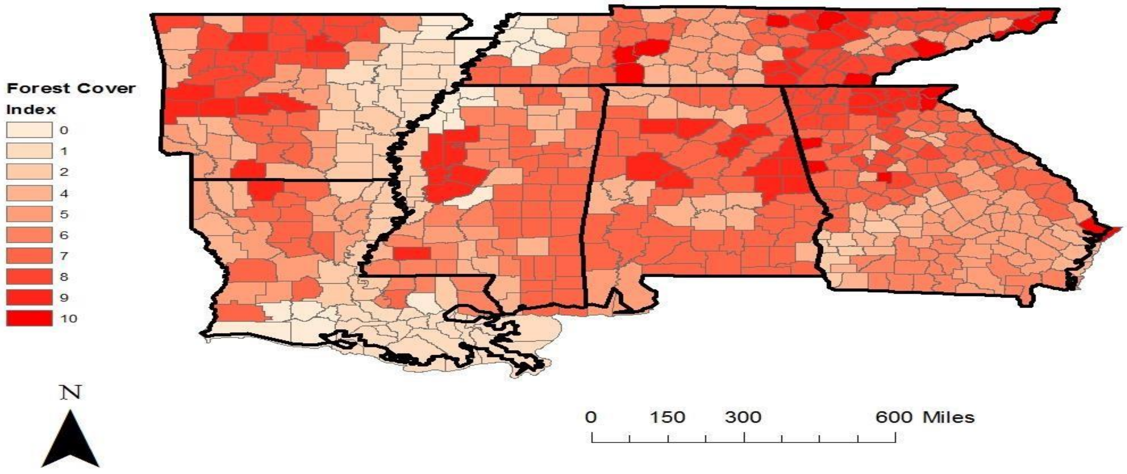


Figure 18: Poverty rate index for Tornado Alley created in ARCGIS

As you can see poverty rates were not as high in Tornado Alley compared to Dixie Alley. The highest index rating was a 7 in parts of Texas along the border with Mexico. The lowest rating was a 0 for several counties in the eastern high plains. The high plains in general had very low index ratings which means poverty rates are low for those counties. There were also clusters of moderate poverty in eastern Oklahoma and southeastern Missouri. The descriptive statistics read a mean of 2.57, a mode and median of 2, and a standard deviation of 1.14 for a range of 1.43 to 3.71. Therefore the poverty ratings for Tornado Alley are statically lower than Dixie Alley.

Next a forest cover index was included. Visibility of tornados has often been looked at when evaluating tornado risk in the United States. Lack of sight of a tornado affects risk and pertains to this study because Dixie Alley has a lot of forest cover as seen in figure 19. As a matter of fact, most of Dixie Alley is covered in forests ranging from the mixed forest of the Appalachian foothills to the pine forests of South Georgia and Alabama. By comparison much of Tornado Alley is on a semi-arid plain which is relatively devoid of tree cover due to the much lower rainfall totals in Tornado Alley. In addition, much of Tornado Alley is very flat save for the Ozark Mountains of southern Missouri and eastern Oklahoma.



. **Figure 19**: Forest cover index for Dixie Alley created in ARCGIS

However, Dixie Alley is very rugged outside of the coastal plain due to the existence of the Appalachian Mountains in the Northeast and the Ozark Mountains in the northwest. In Dixie Alley we saw a very uneven distribution of forest cover index ratings across the entire region. There was a pattern seen in the following map of Dixie Alley. Notice the

Mississippi Valley has very low forest cover for its entire length through Dixie Alley. Like in the Mississippi Valley region, the Coastal Louisiana region also has very little forest cover.

Conversely, the highest index ratings in the Appalachian foothills of North Georgia and Alabama, Eastern Tennessee, and the Ozark Mountains of Northwestern Arkansas

The General rule of thumb noticed was forest cover increased farther away from the Mississippi River. The descriptive statistics showed a mean of 5.66, a mode of 6, a median of 5, and a standard deviation of 2.47. That gave us a range of 3.29 to 8.14.

How did that compare to Tornado Alley? Forest cover in Tornado Alley was sparse as see in Figure 20, but forest cover in Dixie Alley was heavy in many places. See the following map.

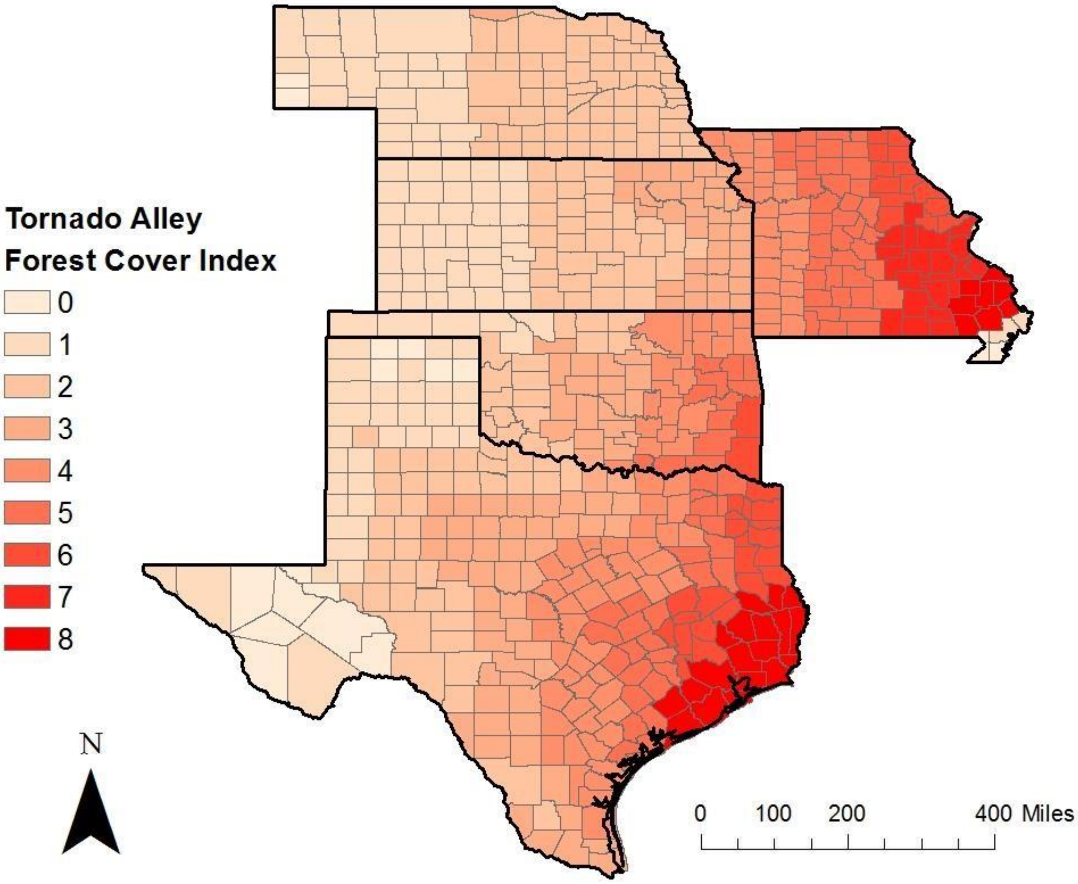


Figure 20: Forest cover index for Tornado Alley created in ARCGIS

The map in Figure 20 made it clear that the farther west you get the less forest cover there is in Tornado Alley. The lowest values occur in the panhandle of west Texas which, a mostly desert area, thus devoid of plant life other than cacti and a few hardy shrubs. The semi-arid high plains of western Kansas and Nebraska also had low values due to the plant life in those areas which is mostly limited to prairie grass and a few bushes. The highest values were along the Gulf coast of Texas and southeast Missouri where moisture is abundant and rain is frequent. The descriptive statistics for this region indicate the mean, median, and mode all equal 2, the standard deviation is 1.92 for a range of .08 to 3.92.

At this point we are moving on to the cumulative index for all the tornado risk factors studied. So what was the total cumulative risk? After determining the total index statistical analysis was done on the datasets. The total index for Dixie Alley was distributed geographically in Figure 21 below.

There did seem to be a pattern to the geographic distribution of values in Dixie Alley. There were consistently low values throughout the Mississippi Valley. There was a band of high values running southwest to northeast from southern Mississippi to northern Georgia.

Much of eastern Tennessee also had high values. Low values existed in southern Georgia. The statistics indicated a mean of 3.52, a median of 3, a mode of 2, and a standard deviation of 1.04 for a range of 2.48 to 4.56. This meant the average county in Dixie Alley had a cumulative index rating of 4.

How does that compare to Tornado Alley? The distribution of cumulative index values for Tornado Alley followed an east-west pattern geographically seen in Figure 21 below. The distribution of high values was mainly concentrated in eastern Texas and Oklahoma with smaller pockets found around St. Louis and Kansas City. Low values existed throughout western parts of the region from Texas to Nebraska where populations were low and obstructions were minimal. Northern Missouri also scored low values for much of the same reasons. The descriptive statistics for this region read a mean of 1.92, a mode and median of 2, and a standard deviation of 1.15 for a range of .73 to 3.07. So

Tornado Alley has an average risk that was 1.6 points lower than Dixie Alley, but is that significant?

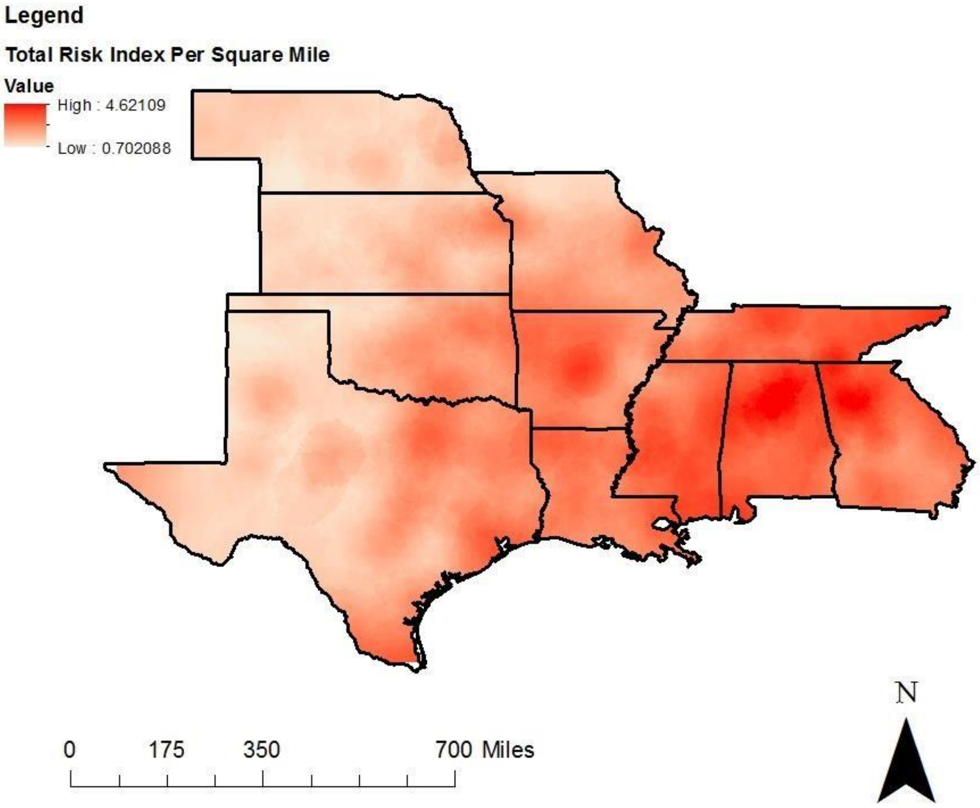


Figure 21: Total index for entire study area created in ArcGIS

Statistical Analysis

The final step of this research determined the overall significance of the total statistical significance for tornado risk. A chart of samples from the Dixie Alley dataset and the Tornado Alley dataset was shown below in Table 4. Remember, the index ratings are the mean of the index ratings for the four factors in this research: population density, poverty rate forest cover, and casualties. The t-tests run on tornado counts and population density statistics were done to determine if there was a significant difference between the two regions in these two key factors. Table 3 shows the t-tests for the tornado count.

Table 3: Results of t-test performed on tornado counts for both regions.

	Tornado Count Dixie Alley	*Tornado Count Tornado Alley*
Mean	19.53077816	23.87941501
Variance	46.43350238	66.40306496
Observations	2583	3624
Hypothesized Mean Difference	0	
Df	6049	
t Stat	-22.82451213	
P(T<=t) one-tail	5.5395E-111	
t Critical one-tail	1.64510557	
P(T<=t) two-tail	1.1079E-110	
t Critical two-tail	1.960356237	

Table 4 revealed Dixie Alley had a lower mean and variance than Tornado Alley. This meant that Dixie Alley had fewer tornados than Tornado Alley, but the number of tornados varies less. In addition, the p-stat was very significant. Why? It was very significant because it is less than .05 for both regions. This meant that the tornado count distributions for the two regions were statistically significant. Why? It was because the t-value and the pvalue are both significant. What does that mean when both are significant? It means they both exceeded the minimum significance level of .05. In other words, we can conclude that these differences are not the result of pure coincidence. This was expected as the two regions have many differences geographically and climatically.

How does the population t-test look for both regions? As seen in the table 5 below Tornado Alley had a slightly higher mean poverty rate than Dixie Alley and the variances are almost the same. These two datasets are very similar in regards to population index.

Table 5: T-test results for population data of the two regions in the study.

t-Test: Two-Sample Assuming Unequal Variances		
	Tornado Alley Population Index	*Dixie Alley Population Index*
Mean	4.025270758	3.315217391
Variance	4.176895307	3.896640316
Observations	277	276
Hypothesized Mean Difference	0	
Df	550	
t Stat	4.155464696	
P(T<=t) one-tail	1.88188E-05	
t Critical one-tail	1.647628817	
P(T<=t) two-tail	3.76377E-05	
t Critical two-tail	1.964286551	

However, this similarity is not the result of coincidence because the p-stat is very significant for this test. Why? This was because the p-stat exceeded the .05 significance level. In other words, there was a 95% confidence that this was not the result of coincidence. This means the two datasets were statistically different from each other.

To test the significance of both datasets it was necessary to run a two tailed t-test with unequal variance assumed. The two tailed t-test showed a statistically significant difference between the two datasets in the cumulative index. Remember that the null hypothesis for this test was no difference between the two data sets.

Table 6 below reveals more information about the datasets. The results of another t- test in Table 6 indicate the mean for the Dixie Alley Total Tornado Risk Index

(Variable 1) was 1.6 points higher than the mean for the Tornado Alley Total Tornado Risk Index

(Variable 2).

Table 6: Table showing results of t-tests performed on the total index datasets from Dixie Alley and Tornado Alley.

t-Test: Two-Sample Assuming Unequal Variances		
	Tornado Alley	*Dixie Alley*
Mean	1.736645963	3.055350554
Variance	0.819743632	0.898963925
Observations	644	542
Hypothesized Mean Difference	0	
Df	1130	
t Stat	-24.35581423	
P(T<=t) one-tail	5.8071E-106	
t Critical one-tail	1.646203208	
P(T<=t) two-tail	1.1614E-105	
t Critical two-tail	1.962065552	

Another t-stat was used to show the significance of the comparison between the two datasets. In Table 6 there was just one t-stat used for both datasets. Interestingly, the t-stat was much higher than the critical t-value. The critical t-value tells the point at which the tvalue becomes significant. This in addition to the extreme low p-value meant the difference in means was significant statistically because it once again exceeded the significance value. Therefore, risk distribution in Dixie Alley was determined as greater than risk distribution in Tornado Alley.

CONCLUSION

Now that it has been shown that Dixie Alley has higher risk than Tornado Alley we need to remember that this is due to a variety of factors involved in this analysis. We know that Dixie Alley has higher population density that Tornado Alley as a whole. We can't actually change anything about that people can't be forced to relocate, plus it would be unethical to do so anyways. Forest cover also cannot be changed as to do so would be exorbitantly expensive and time consuming for all involved. In fact, the only factor we can do something about is poverty. Poverty can be the result of many things, and though I am no expert, the most common cause of poverty is lack of education and/or job opportunities. Therefore, to combat poverty should be the priority in tornado risk reduction. An increase in education and job opportunities is needed to combat poverty. Whatever policy is used to do that is beyond me. Thus another way to help reduce risk is to educate people on what to do in the event of a tornado. Therefore, it would be in everyone's best interest to before some kind of tornado education campaign throughout the South. We need to teach people that in the event of a tornado the safest place to be is in your home's basement. If your house does not have a basement get to an interior room on the ground level of your house, most commonly a bathroom. Do not, under any circumstance, attempt to flee the tornado in your car or other transportation. This important because tornadoes more erratically. They change direction seemingly at random and can speed up and slow at any time as well. As a result, attempting to flee can result in you driving right into the tornado your trying to avoid and a car is no shelter in a tornado given the tornadoes can toss cars around like they were children's toys potentially becoming lethal missiles as any debris can become one. As a matter of fact, most people killed in tornadoes are not killed by the wind but by flying debris which become missiles in a tornadoes high winds. There are documented instances of tornado thrown hay puncturing barn doors and steel I beams getting wrapped around trees. There are even reports of cars getting thrown hundreds of yards by strong tornadoes, even whole house can be lifted of their foundations and tossed about by high end tornadoes.

Many people still believe old myths about tornadoes like the idea that don't hit large cities or that they can't hit mountainous areas. Myths that are simply not true. For example, in 1987 a tornado in Yellowstone National Park travelled up and over a 10,000-foot mountain. In 2008 and EF3 tornado Touched down in downtown Atlanta a severely damaged many of the large buildings there. As such, a proposed education campaign should also focus on dispelling common myths about theses myths using established facts in regards to these beliefs. This is critical because believing in theses myths get people killed every year because people do not adequately prepare for tornado. For example, a lot of people think tornadoes can't cross rivers and yet this happens all time. The great Tri State tornado crossed the Mississippi and Wabash Rivers during its nearly 300-mile-long track and the 1975 Brandenburg Tornado crossed the Ohio River after destroying the town of
Brandenburg. The point is that tornadoes can strike anywhere at any time and no place is truly safe.

So we know that Tornado Alley and Dixie Alley both receive a lot of tornadoes each years and that each has unique properties that effect risk in different ways. Dixie Alleys higher population density is a detriment to risk, yet its raw total number of tornadoes is less than Tornado Alley. Tornado Alley has far fewer obstructions allowing people to see an oncoming tornado sooner than later which is a significant advantage despite having more total tornadoes than Dixie Alley. However, as the data showed, Dixie Alley has a higher overall risk based on several different factors analyzed in this study. That said both areas have very high risk compared to the nation as a whole. People in both areas need to be aware of the danger and plan accordingly for any tornado scenario. Only then can it be said this research has accomplished something.

However, there are limitations to this study that have to be addressed as well. Due to the factors used in this study and the very nature of this study there was a natural bias toward urban areas, particularly in regards to population density and tornado counts. The reason is because tornados are more likely to be reported when people see them or they actually do damage. Because of this, many rural tornados go unreported. This is especially true when these tornados do no damage or occur in an area where no one lives such as west Kansas. Therefore, the results of this study should be taken with a grain of salt knowing that rural areas slightly underrepresented, particularly in western portions of tornado alley and the

Appalachian region of Tennessee, Alabama, and Georgia, where population is very sparse. Because of this it should be noted the rural areas probably are at a slightly higher risk than shown and that urban areas are probably of a slightly lower risk than shown. However, because of the limitations of the data this is the closest we can come to accurately depicting vulnerability until we can accurately record every tornado.

In addition, the implications of this research are profound. The idea that risk can be critically analyzed allow us to tell which counties are statistically most vulnerable. This means we know which counties could potentially see the most damage from a tornado. This would allow local governments in these areas to better prepare their citizens for a disaster by opening shelters when needed, increasing public awareness of safety protocol, and installing early warning systems. This could also affect insurance premiums in these high risk areas primarily through rate modifications based on local risk. Other unforeseen implications are possible to.

REFERENCES

Agee, E., J. Larson, S. Childs, A. Marmo. 2016. Spatial Redistribution of U.S. Tornado Activity between 1953-2013. *Journal of Applied Meteorology & Climatology* 55(8): 1681-1697.

Ashley W. S. 2007. Spatial and Temporal Analysis of Tornado Fatalities in the United States: 1880-2005. *Weather and Forecasting.* 22: 1214-1228.

Ashley W. S., S. Strader, T. Rosencrants, A. J. Krmenec. 2014. Spatiotemporal in Tornado Hazard Exposure: The Case of the Expanding Bullseye effect in Chicago, Illinois. *American Meteorological Society*. 6:175-193.Browning, K. 1965. The Evolution of Tornadic Storms. *Journal of the Atmospheric Science.* 22:664-668.

Brown J. 2012. How Tornado Damage is Rated. *Texas Storm Chasers.* Avialable at http://texasstormchasers.com/2012/12/26/how-tornado-damage-is-rated/. (last accessed 4/10/2017).

Chan, M. 2015. U.N. Study: Natural Disasters have caused 600,000 Deaths over 20 Years. *Time.* Available at http://time.com/4124755/natural-disasters-death-united-nations/ (Last Accessed 4/7/2017

Dixon P.G., A.E. Mercer, J. Choi, J.S. Allen. 2011. Tornado Risk Analysis: Is Dixie Alley an extension of Tornado Alley?. *Bulletin of the American Meteorological Society* 92(4): 433-441.

Doswell, C. A., D.W. Burgess. 1988. On Some Issues of United States Tornado Climatology. *Monthly Weather Review* 117: 495-501.

Doswell, C. A., D.W. Burges. 1993. Tornados and Tornadic Storms: A Review of Conceptual Models. In *The Tornado: Its Structure, Dynamics, Prediction, and Hazards.* Ed. Church C., D. Burgess., C. Doswell., R. Davies-Jones, 161-172. Washington DC. USA. American Geophysical Union.

Doswell C. A. 2009. On the Role of Deep Columnar Convective Vortices within the Atmosphere. Doswell Scientific Consulting. Available at http://www.flame.org/~cdoswell/SuptorRoles/SuptorRoles.html (last Accessed 4/10/2017)

Edwards R. 2017. The online Tornado FAQ. http://www.spc.noaa.gov/faq/tornado/ (Last Accessed 3/14/2017). Fujita, T. 1975. New Evidence from April 3-4, 1974 Tornados. *Ninth Conference on Severe Local*

Storms, American Meteorological Society, Boston, p. 248-255.

Fuhrmann C. M., C. E. Konrad, M. M. Kovach, J. T. McLeod, W. G.Schmitz, P. G.Dixon. 2014. Ratings of Tornado Outbreaks across the United States and Their Climatological Characteristics. *Weather and Forecasting.* 29:684-701.

Housing Assistance Council. 2014. Rural Poverty Decreasing, yet remains Higher Than USA

Average. Available at http://www.ruralhome.org/sct-information/mn-hacresearch/rrn/990-official-poverty-rate-2014 (Last Accessed 10/26/2017)

Gagan, J.P., A. Gerard, J. Gordon. 2010. A Historical and Statistical Comparison of “Tornado Alley” to “Dixie Alley”. *National Weather Digest* 34(2): 145-155.

Lietz, J., (2016) The Tornado History Project. Available at http://www.tornadohistoryproject.com/tornado/2011/4/27/map (Last Accessed 3/13/17).

Klemp, J., 1987. Dynamics of Tornadic Thunderstorms. *Annual Review of Fluid Mechanics.* 19:368-402

Maddox, R. A., M. S. Gilmore, C. A. Doswell III, R. H. Johns, C. A. Crisp, D. W. Burgess, J. A. Hart, and S. F. Piltz, 2013: Meteorological analyses of the Tri-State tornado event of March 1925. *Electronic J. Severe Storms Meteor*.8 (1), 1–27.

Markowski P. M., Y. P. Richardson. 2009. Tornado Genesis: Our Current Understanding, Forecasting Considerations, and Questions to Guide Our Future Research. *Atmospheric Research.* 93: 3-10.

Markowski P. M. 2002. Direct Surface Thermodynamic Observations within the Rear Flank Downdrafts of Non-Tornadic and Tornadic Supercells. *Monthly Weather Review.* 130: 1692-1721.

NASA. 2012. Where the trees Are. Available at https://earthobservatory.nasa.gov/IOTD/view.php?id=76697 (Last Accessed 10/26.2017)

NOAA. 2017. U.S. Tornado Climatology History and Trends. Available at https://www.ncdc.noaa.gov/climate-information/extreme-events/us-tornadoclimatology/trends (Last Accessed 3/21/17)

Thompson R. L., R. Edwards, J. A. Hart, K. L. Elmore, P. Markowski. 2003. Close Proximity Soundings within Supercell Environments Obtained from the Rapid Update Cycle. *Weather and Forecasting.* 18:1243-1261

US Tornados. 2013. Monthly Tornado Averages By State and Region. Available at http://www.ustornadoes.com/2013/03/19/monthly-tornado-averages-by-state-andregion/ (Last Accessed 10/26/2017)

Wordpress. 2012. Population Density of The USA and Midwest available at https://mwlibertyfest.wordpress.com/2009/06/08/population-density-maps-for-usaand-the-midwest/ (Last Accessed 10/26/2017)

WSEC, 2006: A recommendation for an enhanced Fujita scale (EF-scale). Texas Tech University Wind Science and Engineering Center. (Available online at www.depts.ttu.edu/weweb/pubs/fscale /efscale.pdf)

CURRICULUM VITA

NAME: Joshua Lunide Sherretz

ADDRESS: 2 Serenity Street
Eufaula AL, 36027

DOB: Springfield, Missouri – March 17, 1990

EDUCATION & TRAINING:

B.S. Geography
University of Louisville
2009-2012

M.S. Applied Geography
University of Louisville
2013-2018