Tornado Fatality Rates: Variables associated with the increased lethality of cyclonic tornadic activity within the Southeastern United States.

by

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Abstract

This thesis examines and attempts to correlate several potential variables to explain the higher than average death rate due to tornados in the Southeastern United States. The in-depth analysis of variables concentrates on two specific areas. First, tornados that occur while the majority of a population is asleep, defined in the context of this paper as nocturnal tornados. The second variable will be tornados that occur outside of the traditional tornado season in the United States. This paper also examines additional variables and how these factors, in combination with the nocturnal and out of season characteristics of tornados in the Southeast, could contribute to the high death toll. The data used in this thesis will consist of data from the Storm Prediction Center Severe Weather GIS (SVRGIS) which accounts for tornados in the continental United States from the year 1950 to 2014. This study finds that while a nocturnal occurrence of a tornado (0000-0700) is not more likely to produce a fatality in the Southeast, those tornados that do produce a fatality are more likely to produce multiple fatalities. Results from this study indicate support for the expansion of the period of high risk for tornados or "tornado season" to include the month of November, and also highlight the increased likelihood of fatal tornados year round in the Southeast.

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CHAPTER 1 INTRODUCTION

Tornados occur in many countries around the world yet only appear in their ferocity and frequency in North America. The geographic makeup of the United States makes for a perfect breeding ground for supercell storms and linear weather systems that can spawn tornados. The combination of cold dry air from the Artic and warm damp air from the Gulf of Mexico combine in the central plains of the United States to create supercell thunderstorms known for producing the extreme tornadic activity for which the United States is known (Ashley 2007). While much of the research on the topic of tornados is focused on detection and dissemination of tornado warnings, some researchers have indicated the need for the social sciences to look at individual behaviors and risk reduction decision-making as part of the process of communicating weather information to the public (Chaney & Weaver 2010). Individual's reaction to the issue of a tornado warning can have a dramatic impact on their chances of survival. If individuals do not know to seek shelter during an issued tornado warning, increasing tornado warning coverage does not reduce fatality rates. Similarly if individuals knows to seek shelter when a tornado warning is issued, but has no immediate access to a tornado approved shelter the risk of death or injury cannot be reduced.

Individuals may consider purchasing a tornado approved shelter, but someone might only consider this a wise investment if they are aware that they live in an area prone to dangerous tornados. This research hopes to identify vulnerable populations that can be incentivized to prepare for an emergency if they fall into one or several vulnerability categories. Socioeconomic and educational attainment, for example, has shown a direct correlation between preparedness and action upon hearing a tornado warning (Chaney et al 2010). Additionally, factors such as sleep schedule and awareness of the possibility of tornados outside of the defined tornado season could affect an individual's level of preparedness. From a public policy perspective a tornado occurring at night or during the winter would have to be treated differently when it comes to issuing warnings and disaster response.

1.1 Fatality Rates

"We don't name tornados the way we name hurricanes. We remember tornados in the language of tombstones" (Davis 2011 p 2). The justification behind using fatality data for this study lies within the completeness of a record of death. Many aspects of a tornado report may be influenced by the accuracy of the report but deaths attributed to a tornadic event are "likely the most complete aspect of historical record" (Ashley 2007 p 1215). Though the great plains of the United States are known for their tornados, there is an area in the southeastern United States that has a higher rate of death from tornados than any other (Ashley 2007). Alabama has the highest tornado death rate of any state in the United States in the time period of 1950-2014 (SVRGIS 2014).

The history of tornados in the United States will be analyzed for variables related to the tornado death rate. These variables that are identified as having potential impact will be examined in relation to Alabama and why its tornado death rate is the highest in the country. As a comparison, a selection of states within the Southeastern region will be used to examine some basic statistics of statewide tornado variables.

The reasoning behind the significance of the tornado fatality rate and why fatality specifically is being studied, is the finality of the impact of death. Though cost to businesses and injuries sustained by individuals may be high, both monetarily and emotionally, there are few events as damaging to a community as the death of an individual. The death of individuals is a permanent event and has drastically far-reaching consequences both in terms of income earning potential being lost, economic impact to the community from losing a contributing individual, and simply the emotional toll on the family and loved ones of someone who has died due to a tornado. This subject is clearly demonstrated through research into the economic impact and migration from communities affected by natural disasters. Though the economic impact of a disaster may be devastating, the economic impact of those who lost loved ones and moved out of the area can be far more dramatic (Liu, Fellowes, & Mabanta 2006).

1.2 State Level Analysis

Tornados and their impacts have been studied all over the United States. Many studies have shown that the southeast is the most dangerous region in the United States for fatalities due to tornados (Ashley 2007). The problem with region-level studies is the fact that though the southeastern United States may be covered by one region of the Federal Emergency Management Agency (FEMA 2010), the way to enact local change is at the state funding level. Research has revealed several studies calling for state level data to be analyzed in order to better narrow down the vulnerability factors that cause this region to have such a high mortality rate due to tornados (Ashley 2007). The impact of having state level data allows state lawmakers to apply for federal funding to try to change the vulnerability of the citizens of their state.

The discovery that the area most likely to produce fatalities due to tornados is not the same geographic region as the area most prone to the sheer number or tornados is a very important finding in assessing tornado vulnerability. Simply knowing that the Southeastern United States is the most vulnerable region for tornado fatalities is not enough to enact change on the part of state and local governments (Ashley 2007). As the authors state within their research referring to the enhanced vulnerability of the region, “The regional component of the problem suggests that a targeted approach might be more effective than a nationwide response” (Sutter &

Simmons 2010, p 136). Only by having state level data can these factors of vulnerability be addressed with the governmental and bureaucratic funding systems we have in place. Research will allow governors of their states and their Emergency Management Agencies to better prepare for future severe weather events, and the better prepared they are the more lives they can save.

This area of regional fatal tornado activity was first identified by Walker Ashley in his analysis of killer tornado events (Ashley 2007). “The interior South tends to have a larger total number of fatalities and number of killer tornado events than any other region in the country” (Ashley 2007 p. 1221). The area of highest fatality risk as identified in the research is a Northwest to Southeast oblong area centered in Memphis, TN (Ashley 2007). This area of maximum fatal risk encompasses area in Alabama, Arkansas, Mississippi, and Tennessee (Ashley 2007). The study area covered in this paper attempts to look at the regional vulnerability of fatal tornados and uses the states identified as having the most increased risk for fatality. This paper attempted to establish the risks associated with the Southeast and therefore did not include Missouri, Illinois, Kentucky, Oklahoma, or Indiana, all of which are included in part of the area of increased fatality risk. This paper attempts to look only at the area of the most severe risk, identified as areas in Arkansas, Alabama, Tennessee, and Mississippi (Ashley 2007).

1.3 Methodology

Two variables that have not previously been specifically outlined at the state level, nocturnal tornados and out-of-season tornados will be examined. While all the variables are interrelated, the timing of tornados due to increased vulnerability of the resident’s sleep schedule and the likelihood of tornados to occur outside of the documented “tornado season” are both variables that have not been thoroughly explored. In the context of this paper a nocturnal tornado is a tornado occurring between midnight and seven AM. An out-of-season tornado is a tornado occurring during the months of November, December, or January. In combining multiple variables a better overall picture of what the actual tornado risk for the state of Alabama is year-round can be developed. We can then help to change the public perception and lack of preparedness that exists in so many communities in our state. Each of the variables of increased vulnerability does not occur within a vacuum and must be treated within the totality of the situation.

The fatality rates of nocturnal tornados and out of season tornados will be compared with the fatality rates of daytime tornados and in-season tornados. In addition, these rates will be compared with fatality rates from nocturnal and out of season tornados in the state of Kansas. Kansas has both the same rate of tornados (when controlling for square mileage) as the state of Alabama and also has a reputation as being a tornado-prone state in the mind of the public both from pop-culture (Wizard of Oz, Twister, etc.) and in the scientific community (Tornado Alley, VORTEX I & II). The primary purpose of this paper is to show that while Alabama is not traditionally thought of as a place with dangerous tornados, there is an increased risk of fatal tornadoes and the narrative surrounding this risk needs to be changed. By changing public awareness of this fact we can change how both the public and the government approach planning for and reacting to tornados and in the process save lives.

CHAPTER 2 LITERATURE REVIEW

In searching for literature relating to this topic one pressing issue was the lack of statewide data for the state of Alabama. Not a single academic source specifically looked at predictor variables that addressed the high tornado death rate in Alabama. What was found was media speculation as well as academic speculation into why this might be the case. Immediately after the tornado outbreak in Alabama in 2011 a column appeared in the Washington Post that gave some thought to possible explanations as to why so many people died in the 2011 outbreaks. The listed reasons included increased regional vulnerability, mobile home density, and complacency of the public to the threat (Samenow 2011). In early 2015 an article appeared on a popular Alabama news site asking the open-ended question of why more people from Alabama have died due to tornados that any other state (Kazek 2015). This article quoted a NOAA meteorologist who stated "It is likely due to a combination of tornado frequency, population density, and the large number of nocturnal events relative to what you see in the traditional tornado alley in the Plains states" (Kazek 2015). While these articles pointed out some possibilities, neither of them had any data behind their claims. Only within the last ten years has the idea of shifting focus away from the traditional tornado alley taken root. Walker Ashley's work identifying the regional vulnerability of the Southeast in fatal tornado events and his coining of the term "Dixie Alley" has identified the Southeast as an area to focus on regarding tornado research (Ashley 2007).

2.1 Nocturnal Tornados

The study of nocturnal tornado genesis has changed recently as new findings pointed to the climatology of evening and night as being favorable for generation of tornados (Kis and Straka 2010). The traditional thought process was that nocturnal conditions were unfavorable for the formation of tornados in all situations. Under normal conditions in a supercell thunderstorm this is true. When energy is no longer entering the system through sunlight, most supercell thunderstorms weaken and are therefore much less likely to produce a tornado. However, linear weather systems react much differently than supercells. Linear weather systems are not as dependent on sunlight to fuel the energy of their storms. Most of the power associated with storms within a linear weather system has to do with temperature differential, pressure differential, humidity and other factors. Authors such as Ashley, Kis, and Straka have all pointed out that the meteorological communities' understanding and knowledge of nocturnal tornados is slim and research in this area is needed (Kis and Straka 2010).

The possibility of tornados occurring after dark and the destruction they can cause, combined with the vulnerability of having people unable to react due to being asleep is a daunting possibility, as well as one that may prove to be significant for influencing fatality rates (Ashley et al 2008). Multiple incident reports have cited a tornado occurring at night as a contributing factor to the fatality of an event. A report detailing the 22-23 February 1998 tornados in Florida highlights the fact that the midnight occurrence of the tornados in question hampered getting warning out to the residents impacted by the storm (Schmidlin et al. 1998). The report goes on to state that many of the people affected by the storm "watched the late evening news for storm information but did not see any warnings for their county so went to bed" (Schmidlin et al. 1998, p 6). This report highlights the increased vulnerability posed by both the fact that people sleeping are more at risk, and people are more likely to be in vulnerable housing at night than during the day when much of the population would be at their place of employment. Compounding these problems was the challenge of reaching those same residents with a warning after it was issued due to them being asleep. Another study echoes the same message when it comes to watches and warnings not reaching residents due to an after midnight occurrence: "issued after midnight, after primetime television and late local news, so many residents could have gone to sleep unaware of the potential for tornados during the night" (Simmons & Sutter 2007, p 4).

Multiple sources have cited tornados occurring at night as causing increased vulnerability and possibly contributing to the amount of fatalities due to the event. Statistically, tornados that occur during the day (0600 to 1800) have 64% lower expected fatalities than overnight (midnight to 0600) tornados (Simmons and Sutter 2007). The report covering the Groundhog Day tornados in Florida cited the fact that in that tornados occurring at night was one of three risk factors associated with the amount of fatalities due to a tornadic event (Simmons and Sutter 2007). Simmons and Sutter also stated that due to the lateness of the storms that spawned the tornados people in the area may not have heard about the potential for severe weather over night since all watches and warnings were issued after normal television viewing hours (Simmons and Sutter 2007). The spawning of a tornado at night was also cited in a report detailing the 1998 Florida tornados. Just as with the report from Simmons and Sutter these tornados occurred near midnight and residents reported that “Several persons told us they watched the late evening news for storm information but did not see any warnings for their county so went to bed” (Schmidlin 1998 p. 4). These reports as well as other field reports showcase the increased vulnerability due to nocturnal tornados and why addressing this as a variable, changes can be implemented to decrease the risk associated with nocturnal tornados.

A “Nocturnal Tornado” in the terms of this thesis is not defined in the same way as other works. Previous work in this field have yielded results that seem to support the conclusion that tornados that occur after nightfall are more deadly due to a variety of factors. People are more likely to be located in a private dwelling at night, their vulnerability is enhanced due to the decreased awareness of being asleep, and finally the difficulty presented by the darkness making a tornado hard to spot and therefore harder to react to if shelter is not immediately available (Monk et al. 2000, Ashley et al. 2008). Simmons and Sutter (2005) concluded that nocturnal tornados were more likely to cause fatalities. Nocturnal tornados will be examined to analyze group behavior such as the likelihood that a significant portion of a population is asleep at a given time and therefore less able to react to a dangerous situation.

In their work, Simmons and Sutter divided their data into three sections, day (0600 – 1759), evening (1800-2359) and night (0000-0600) (Simmons and Sutter 2005). However, this breakup of the variables appears to be for simplicity sake and not for any particularly scientific reason. The article fails to mention a scientific reason for the breakup into time zones, if there was one (Simmons and Sutter 2005). Sunrise and sunset times have been used in subsequent studies of vulnerability from tornados but this time distinction presented problems (Ashley et al. 2008). In addition to the mathematical calculation of local sunrise and sunset times the calculation and conversion of the SVRGIS database to local times was an additional complicating factor (Ashley et al. 2008). One advantage of separating out state level data is the fact that nearly all of the readings for the state of Alabama are in the central time zone and thus no conversion to local time is needed. There is a small portion of Alabama and a portion of Tennessee that uses Eastern Time, however this geographic area includes only a small portion of the study area, includes few tornadoes and would only affect the results on the time related variables by one hour.

Using a sleep study as a justification for time standards of increased population vulnerability is useful because self-reported sleep and wakeup times have daylight savings times already calculated into them. Because of this fact the justification of a nocturnal tornado for the purposes of this thesis shall be defined as any tornado that occurs between midnight (0000) and seven (0700) in the morning. Midnight to seven in the morning was picked to coincide with average bedtimes and wakeup times reported in a diary sleep study (Monk et al. 2000). This time period was chosen because between these two time periods it can be implied that at least half of a sample of the general population will be asleep. The sleep averages changed depending on a weeknight or weekend schedule thus why close to the average times were used, the true average times being 2348 for average sleep and 0723 for average awake (Monk et al. 2000). This continues a line of questioning in several research papers attempting to find the reasons behind nocturnal tornados being so deadly.

Several studies have shown that more tornados occur at night in the southeast than other parts of the United States. Sutter and Simmons cited that Ashley (2007) found that for 1996-2007 "13% of tornados in the seven Southeastern states occurred between midnight and 6AM, compared with 6% of tornados nationally" (Sutter and Simmons p. 132 2010). During this time period (1996-2007) tornados occurring between midnight and 6AM accounted for 14% of all fatal tornados (Sutter and Simmons 2010). Sutter and Simmons speculated that mobile home fatalities being much more likely to occur from midnight to 6AM combined with the increased likelihood of nocturnal tornados in the Southeast could explain the concentration of mobile home fatalities in region (Sutter and Simmons 2010).

The question being asked in this research is whether tornados that occur between midnight and seven in the morning (when greater than 50% of the population of Alabama can be assumed to be asleep and therefore at an increased vulnerability) is statistically significant in contributing to the increased tornado fatality rate for the state of Alabama. As this literature review has demonstrated, there is much speculation and statistical analysis surrounding this subject but the question itself as to its statistical significance has not been directly addressed. By addressing this variable directly better decisions can be made in regard to a plan of action to reduce the vulnerability of the population of the state of Alabama to fatal tornados.

The implication of nocturnal tornados as an increased factor associated with fatality cannot be looked at as a variable that stands alone. Many reports have cited nocturnal tornados as a factor for increased fatality, yet none of these reports cite nocturnal tornados alone as the sole reason for increased fatality (Simons et al. 2010). In general sunrise and sunset times vary depending on the time of year and whether or not the location observes daylight saving time. However for the purposes of this paper the early sunset times associated with winter months will not affect the nighttime tornado variable as it is based upon sleep patterns and not daylight. Though the clock may change according to the month of the year, residents will still have to be at work at the same time in the morning regardless of daylight saving time. The localized time and respective individual behaviors it would modify should be kept in mind for future research as this study only looks at the sociological perspective of increased vulnerably due to individual behaviors e.g. (the population being asleep and therefore unable to react or to be made aware of warnings in their immediate area) and not the darkness resulting in an approaching tornado being difficult to identify.

None of the variables that will be discussed in this paper exist in a vacuum, they are all interrelated. Sutter and Simmons point out in their research into mobile home fatalities that "mobile home fatalities are concentrated in the Southeastern US, significantly more likely in weaker tornados, and occur disproportionately at night" (Sutter and Simmons p. 125 2010). Thus tornados occurring at night when mobile home residents are at home rather than at work puts them at an increased vulnerability yet this increase is not specifically only because of the time of tornado occurrence, but also because at night more vulnerable housing is occupied than during daylight hours. This interrelated problem is even addressed directly by Sutter and Simmons in their paper on mobile home fatalities; "Mobile home fatalities are also more likely to occur at night, and so the mobile home problem is related to the vulnerability of nocturnal tornados" (Sutter and Simmons p. 126 2009).

2.2 Out of Season

The time of year of a tornado striking has been found to have a direct impact on its lethality. Numerous studies cite this fact yet some disagree with the causality of this variable. The data falls generally into two hypothesis. One hypothesis is that a lack of a focused tornado season in the south could lead to a sense of complacency or lack of understanding of tornado risk (Doswell 2003). The competing hypothesis is that tornados occurring out of season are more likely to occur after dark thus compounding the nighttime tornado variable even further (Brooks et Al. 2003).

Studies of this nature are important for situational awareness of risks associated with local areas. In Gainsville, GA a severe tornado struck in 1936 and killed 203 people in the city. Emergency management officials were caught unaware when a tornado killed several people in the area in March 1998 (Doswell 2003). The lack of understanding of risk can lead to risky behaviors that places individuals in dangers they may not even realize. The Southeast is not commonly thought of as a tornado prone area, when as recently as 2011 tornados ripped through Tuscaloosa and other southern cities (Davis 2011).

The lack of a focused tornado season is well documented for the Southeastern United States. For example, when examining the probability of danger due to tornados, the greatest area of risk in February includes areas of Alabama (Brooks et Al. 2003). This research goes on to show graphically the areas of enhanced vulnerability with areas of Alabama being included in the graphical analysis of February, April, as well as November (Brooks et Al. 2003). Another way to look at the lack of a defined tornado season specifically is when it comes to risk of loss of life. While the amount of tornado outbreaks is seven times greater in the Spring, the distribution of the power and destructive capability of the tornados are nearly identical across every month of the year in Alabama (Galway and Pearson 1981). Thus, though tornados are less likely to occur in the winter months, the risk associated from these outbreaks is nearly identical from those during the established "tornado season". This risk of increased fatality due to tornados occurring outside of an established "tornado season" was documented in a report looking at the effectiveness of tornado warning lead times. The research found that expected fatalities were 15% lower for tornados occurring within the established "tornado season" as opposed to those occurring outside of it (Simmons and Sutter 2007).

2.3 Vulnerable Housing

Tornado fatalities due to residents residing in mobile homes is a well-researched topic and some data does exist for specific parts of Alabama, but these reports are mainly compromised of survey data collected after a fatal tornado event (Cheney et al 2010, Cheney et al 2011). Many reports agree around the fact that risk of a fatality increases by as much as ten times or more for those residing in a mobile home as compared to a permanent home structure (Sutter et al. 2010). A regression analysis performed by Simmons and Sutter revealed that for each percent increase of mobile homes in a county fatality rates increase six percent (Simmons and Sutter 2007). In another more recent paper on tornado fatalities in mobile homes from 1996-2007, 44.3% of fatalities in Alabama were located within mobile homes (Sutter and Simmons 2010). However, it should also be noted that during this same time period 43.2% of fatalities in Alabama were residing in permanent structures, resulting in tests that were not statistically significant (Sutter and Simon 2010).

The general consensus of researchers is well stated in an article by Sutter and Simmons, “mobile home fatalities are concentrated in the Southeastern US, significantly more likely to occur in weaker tornados, and occur disproportionately at night” (Sutter and Simmons 2009 p. 125). This quote highlights the interconnectedness of these variables as vulnerable housing as well as nocturnal tornados and even out of season weak tornados could be a contributing factor.

In combination with vulnerable housing, a lack of shelter opportunities for those who reside in vulnerable housing is a contributing factor to vulnerability of those residents as well as a factor in shelter seeking behavior. In Huntsville, where the local government has petitioned the National Weather Service to not remove their local Doppler radar station, only around 1000 out of the area’s 90,000+ households have installed storm shelters (Potok 1996). The report of the 22-23 February 1998 Florida tornados also documented that the residents of the mobile home communities struck by the tornados had no access to underground shelter (Schmidlin et Al. 1998). The same recommendation is made over and over again for the need of mobile home parks to have available underground shelter (Shmidlin et Al. 2009, Miller and Lestina 1996, Schmidlin and King 1995). Yet there are still no laws or tax incentives in Alabama for owners of mobile home parks to provide any kind of underground shelter for their residents. As with all rental property owners, only with the passage of laws or by making the provision non-cost prohibitive will any changes be made. Many assessments performed by state and federal government agencies after deadly tornado events cite a general lack of storm shelters for mobile home residents as a contributing factor to the fatality of tornados (Prevatt et Al. 2012). Several reports detail the disastrous results of residents of mobile homes not having access to shelter.

A nationwide report on fatalities in mobile homes due to tornados was completed and its findings are important (Sutter et al 2010). However, the data for Alabama states that the rate of tornado fatalities of those residing in mobile homes was not statistically significant when compared to individuals residing in permanent housing (Sutter et al 2010). Therefore while mobile homes may be a contributing factor the research contained within this paper will not strictly focus on it as the only vulnerability.

While mobile homes receive a lot of attention as a culprit behind deaths in tornados they are not the only factor, if a permanent structure is not built well or properly to code the occupants may fare no better than those residing in mobile homes (Prevatt et al 2011). As shown in the 2011 tornados that tore through Tuscaloosa, even permanent wood frame housing will not stand up to an F5/EF 5 category storm and this factor needs to be taken into consideration when considering building codes for a state directly in the path of such strong storms (Prevatt et al 2011). Several other reports and even the Department of Commerce service assessment cited a lack of availability of shelters and safe rooms as a contributing factor for the high death toll in the April 2011 tornados (DOC service assessment 2011). Compounding this fact was the lack of public awareness of the available public storm shelter options in and around the Tuscaloosa area (DOC service assessment 2011). In analyzing the April 2011 tornados, better recommendations can be made to plan for a worst-case scenario (Hayes et al 2011). One of these recommendations found in a damage assessment study points to a need for interior safe rooms to be constructed (Prevatt et Al. 2011). During most tornados (EF3 and below) an interior room of a wood frame structure generally provides enough protection to survive the event; however, the same cannot be said for EF4 or EF5 events. In the most extreme events (EF4-EF5) wood frame structures are reduced to their foundation. Researchers concluded that including a “safe room” in building plans would increase resident’s survivability in strong (EF4 – EF5) tornados (Prevatt et Al. 2011).

The increased vulnerability of mobile homes in weaker tornados is a topic that has been researched and some startling findings were revealed in reference to the EF scale of a tornado and mobile home fatalities. "Mobile home fatalities occur disproportionately in the F1, F2, F3 tornados, consistent with greater vulnerability of these structures to less powerful tornados" (Sutter et al. 2010 p 129). This study goes on to state that "it is only a slight exaggeration that F1 and F2 tornados are potentially lethal only for residents of mobile homes" (Sutter et al. 2010 p 136). While this is not a completely true statement, it shows the increased vulnerability of mobile homes. A tornado that might slightly damage a permanent house could potentially cause a fatality if it struck a mobile home. Approximately 82% of fatalities due to tornados hitting mobile homes were rated as an F3 or lower which lends credence to the theory that improving mobile home construction standards could potentially go a long way towards saving lives (Sutter et al. 2010). In a striking example of how construction standards can influence survivability, a report details examples of mobile homes that were built to the new improved construction standards adopted by the state of Florida following Hurricane Andrew (Simmons and Sutter 2007). Damage levels assessed by the Lake County Tax Assessor's office were reduced by 60% in mobile homes built to the post Hurricane Andrew standards thus leading to the conclusion that increased manufacturing requirements could help save lives among those residing in vulnerable housing (Simmons and Sutter 2007).

One problem with increasing the survivability of mobile homes is that first and foremost those improvements can only be applied to new mobile homes and not retroactively applied to those that are already at risk. A second problem is that a mobile home is already built as economically as possible and any safety improvements would cause the cost of manufacturing to go up, which would in turn be passed on directly to the consumer, most of whom do not have much disposable income (De Alessi 1996).

2.4 Tornado Warning Systems

While the forecast of tornados has improved dramatically in the past 40 years, very little improvement has occurred regarding changing the ways warnings are received by the public (Sorensen 2000). The most fundamental change has occurred within the past five years in regard to mobile alerts being sent to smartphones. Mobile alerts and text alerts that mobile phone users can receive still require that the warning be taken seriously by the population that receives it. There is no comprehensive warning system to alert the public of the threat of tornados. Although tornado watches and warnings are disseminated from the National Weather Service, the process of disseminating to the individuals located in the area designated by the alert could be the responsibility of a local, county, or even a privately owned corporation (Sorensen 2000).

Interestingly, until 1938 broadcast of tornado warnings was banned as it was widely considered that the panic that ensued would cause more harm than good (Coleman et Al. 2011). Only when the broadcast of weather data was transferred from the U.S. Army Signal Corps to the U.S Weather Bureau (the predecessor to the National Weather Service) was the ban lifted (Coleman et Al. 2011). Even after the ban was lifted, not much emphasis was placed on tornado warnings until a tornado hit Tinker Air Force Base in 1948, resulting in the loss of multiple airplanes and damaging the readiness level of the Air Force (Coleman et Al. 2011). The warning systems were greatly expanded following the 1974 Tornado Super Outbreak, which received national attention (Coleman et Al. 2011).

One of the most common methods of warning the general public has awareness of is the “air raid” style siren warning system common in many populated areas. Many rural communities do not have the funds to erect a tornado siren nor would they consider it an effective means of warning locals who do not live in a concentrated area (Coleman et Al. 2011). The effective radius of these outdoor sirens is approximately one mile. The primary purpose of outdoor tornado sirens is to warn those who are outdoors to seek shelter, not to awaken people at night (Rice 2012). Compounding the incorrect use of these sirens as a wake up alarm for danger is the fact that many communities do not have sirens, even if the population might assume that sirens are present (Simmons and Sutter 2007, Schmidlin et al. 1998). In the case of the Groundhog Day tornados in Florida, many residents were not originally from the area and assumed the Lake County had tornado-warning sirens (Simmons and Sutter 2007). This lack of hearing a siren to confirm a tornado warning has resulted in increased risk when tornado warnings were not taken seriously and some reports have found that as many as 30% of residents who knew what a tornado warning meant still did not take shelter when a warning was issued for their area (Liu et Al. 1996).

Research shows that individuals that reside in an area that has tornado warning sirens are more likely to receive warning that those in areas that do not have sirens (Liu et al. 1996). However, the reliance on sirens as the main form of public warning is flawed. Research has consistently shown that a NOAA Weather Radio is the most reliable way to receive weather warnings and information, but the use of these life-saving devices is notoriously low (Schmidlin and King 1995, Chaney and Weaver 2010, Chaney et al. 2013). Thus, one of the most effective means of communicating danger is also the least utilized. Not only is a NOAA Weather Radio the most specific in terms of area affected by a warning, but it also has the ability to wake up those who are asleep and would otherwise be unaware of the imminent danger they are currently experiencing.

2.5 Variable Overlap

Many of the variables previously mentioned overlap and cause enhanced vulnerability when an individual falls into more than one category. One example is the overlap of enhanced vulnerability lies within the regional vulnerability of the southeast and vulnerable housing stock. Approximately 54% of mobile home fatalities due to tornados took place in the southeastern United States (Sutter et al. 2010). The combination of the increased occurrence of nocturnal tornados in the southeast further complicates this problem of enhanced vulnerability. Mobile home fatalities due to tornados are at an increased risk at night, as Sutter et al. states

> "Mobile home fatalities are especially likely to occur at night, particularly from Midnight to 6AM. Thus mobile homes might explain much of the lethality of nocturnal tornados, and the prevalence of night time tornados in the Southeast might explain the regional concentration of the mobile home problem" (Sutter et al. 2010 p 136).

Another example of variable overlap is that of out of season tornados and nocturnal tornado occurrence. While this research looks at nocturnal tornados as defined by the time when the risk is greatest to the population (Midnight to 700 AM) other research is more primarily focused on the darkness aspect of the risk of tornados. For these reports, tornados occurring out of season or during the cool and transition seasons are likely to occur during the time of year when the length of daylight is shortest, providing for more chance of tornados occurring after sunset (Ashley 2007). The limited use of NOAA Weather Radios is a compounding factor in nocturnal tornados as traditional "air raid" sirens are not meant to wake up those in the path of an oncoming tornado but only to alert those outside to seek shelter. If more NOAA Weather Radios could be utilized, more effective warnings could be given and those in the path of a tornado could seek shelter even when they would normally be asleep. Combine the use of NOAA Weather Radios with severe weather mobile apps and additional access to underground shelter for those in vulnerable housing and giving them the ability to have time to get into their shelter and many lives could be saved. The cost of all of these systems being upgraded and installed must be weighed against the cost of the lives of Alabama's most vulnerable residents.

CHAPTER 3 RESEARCH QUESTIONS

This intent of this research is to explore factors that could be impacting the tornado fatality rate in the Southeastern United States. The variables that have been identified to investigate further come from statements and observations made about the unique nature of storms and tornadoes in the Southeastern United states. In this region the likelihood that these tornados will occur overnight is much higher than in other portions of the United States. This research will investigate whether or not fatalities caused by tornadoes occurring between midnight and seven a.m. (Nocturnal Tornados) are statistically significant compared to tornados occurring during the day. If a tornado occurring during this timeframe is statistically significant to its likelihood of either causing a fatality or in the magnitude of the fatalities it produces, then the nocturnal occurrence could be a factor in the high tornado fatality rate for this region.

Additionally, tornadoes in the Southeastern United States occur year round, with many fatal storms occurring outside of the traditionally documented tornado season. Tornadoes also occur in the Southeast during periods in which most of the United States has a very low risk or tornado occurrence (November – January). This research will investigate whether or not fatalities caused by tornados occurring in the months of November, December, and January are statistically significant. If a tornado occurring during this timeframe is statistically more likely to produce a fatality, then this variable could influence the high tornado fatality rate for the Southeast.

If this time period is significant for a tornado to produce fatalities, does the data support the expansion of the defined tornado season to a more regionally defined tornado season for the Southeast to include additional months of high vulnerability not associated with other regions?

CHAPTER 4 DATA AND METHODS

The variables this study will address are varied and complex yet interrelated as they all potentially could have an impact on the fatality of tornados. The data for tornados in Alabama will be compared against data from surrounding Southeastern states to examine the geographic variability associated with storms in the Southeastern United States. A binary logistic regression model as well as a linear regression model will be used to examine the statistical validity behind several variables in question.

The high rate of tornados at night in the Southeast has been speculated as a contributing factor in the higher than average tornado death rate (Ashley 2007). Another potential factor that has been cited as contributing to the high death rate has been the high level of vulnerable housing stock (Ashley, Krmenec, & Schwantes 2008). The combination of nulnerable housing stock (mobile homes and trailers) with the timing of nocturnal tornados hitting when people would be residing in the vulnerable housing stock, as in sleeping at home, would lead to an enhanced vulnerability (Ashley et Al. 2008). Vulnerable housing stock is a well-documented problem when it comes to causing high levels of tornadic fatalities and has been thoroughly researched in other publications. In fact, a large portion of fatalities in Alabama occur within single family permanent homes (Sutter et Al. 2010). For this reason vulnerable housing stock will be addressed as a contributing factor, but not the focus of this research.

Tornados occurring outside of the normal tornado season for the United States have the added danger of the public not being aware of the potential for dangerous storms. The fact that tornados are fairly likely all year round in Alabama has been listed as a potential contributing variable in multiple sources (Ashley et Al. 2008). There is also the occurrence of what is referred to as a secondary tornado season in the Southeastern United States in the winter (NWS Birmingham). The seasonality of a secondary spike in tornado activity as well as the increased threat from tornados year-round in the Southeast will be examined to determine if the tornado season needs to be expanded regionally or if the increased danger of tornados year round could mean a defined tornado season for the Southeast actually hurts awareness of the risk when tornados could occur at any time of the year. Finally the tornado warning systems in place or lack of warning systems in place in Alabama to warn people of potential dangers of approaching storms will be examined in conjunction with their viability when it comes to addressing and warning the public of impending danger.

The data used for this project was collected from multiple sources and combined layer by layer in ArcGIS for analysis. The majority of the data is from the Storm Prediction Center Severe Weather GIS (SVRGIS) office at the National Oceanic and Atmospheric Administration (NOAA). The primary data that was used included a shapefile of the continental United States showing state boundaries and within those boundaries county boundaries. A shapefile is a geocoded layer that shows the outline and geographic boundaries on a map. This shapefile was also used as the basis for the analysis of the other data in this project.

The Storm Prediction Center Severe Weather GIS (SVRGIS) provided data that included all known tornados from 1950-2014 for the continental United States. This file was in the form of polylines with data attached that included locations, time, fatalities, and other important data from the cyclonic event. This tornado data is the basis for many of the observations discussed within this paper.

To analyze the data provided by the Storm Prediction Center Severe Weather GIS (SVRGIS) the data must be layered into ArcGIS and then processed to form smaller data sets from which tests can be run. The county data also included state boundaries and was of the same projection as the other data from SVRGIS, which was Lambert Conformal Conic.

The first step in the analysis was to add the tornado data to the shapefile of the United States. The nationwide scope of the data could be visualized with all tornados from 1950-2014 being displayed at the same time. This type of analysis was shown to be of value in tracking the paths of severe storms in several publications by Chaney (Chaney et al 2011).

Variables were also calculated for "Significant Tornados" which is any tornado with a value of F2/EF2 and stronger or that has caused a fatality (Edwards 2017). Or as the NOAA tornado frequently asked questions clarifies, "A tornado is considered "significant" if it was rated EF2 or greater on the Enhanced F scale, or at least F2 on the old F scale. Grazulis (1993) also included killer tornados of any damage rating in his significant tornado database" (Edwards 2017).

Tornados occurring at night present different situations both in terms of the dangers they present as well as where the majority of a population is located. Some research has examined tornados occurring at night as a function of darkness, which causes tornados to be harder to spot on the ground. For this research the difference in population variables is the most important. At night people are more likely to be at home in their residence than at work or in a retail location. Additionally people who are asleep are either unable or less likely to react to approaching severe weather. Night tornados were defined in this research as tornados occurring after 12:00 AM to 7:00 AM, these times were selected based on a sleep diary study performed at the University of Pittsburgh over a 10 year period (Monk et al. 2000). The purpose of the sleep study was to establish a baseline for research studies involving sleep data. The variable time2 refers to tornados occurring between 0000 and 0700. Additionally a secondary variable time3 included refers to the data from 2100 to 0700 hours and was expanded to include hours in which people would be at home, but not necessarily asleep to see if the sleep portion of the variable truly was significant.

A binary logistic regression model was used to determine what variables had an impact on whether or not a tornado produced a fatality. The binary nature of this analysis has its limits. While the identified variables would be examined for the impact they played in causing an individual tornado to become a fatal tornado, no analysis would be done on the magnitude of those fatalities. All fatal tornados would be treated as equals, regardless if they produced one fatality or several hundred. Analysis of the data led to the conclusion that while a binary logistic regression would be useful for determining what variables had an impact on the likelihood of a tornado producing a fatality but not how many fatalities that tornado produced.

To explore the extent to which variables influence the magnitude of the fatality of a tornado, a linear regression model needed to be used. The liner regression model by its nature cannot analyze data that includes zeros, therefore only the tornados with fatalities of one or greater could be examined using this method. The linear regression model examines the fatal tornados and how variables influence the magnitude of the fatalities they produce.

These two separate and distinct models illustrate different aspects of the danger posed by a tornado. The binary logistic regression model examines which variables influence whether a tornado produces a fatality or not while the linear regression model examines what variables influence the number of fatalities a fatal tornado produces. These two statistical tests were run on the data in order to derive two separate conclusions about the variables. The binary logistic regression measured whether or not a variable was statistically significant in determining if a tornado produced a fatality or not. This test did not determine to what extent or how fatal the variables were to a tornado but only if a fatality was produced. The linear regression test was used to determine if specific variables were statistically significant in the number of fatalities they produce.

In changing the scope of the model, additional steps to clean up the data were needed to ensure data quality. A test for skewness was run on the fatality data and it was determined that the fatality variable for fatality was skewed. To solve this problem the natural log of the fatality data was calculated in order to reduce the effect of the skewness of the data.

CHAPTER 5 RESULTS

The results of this study are divided between the two statistical tests that were used: binary logistic regression model and linear regression model. The binary regression model was used to determine if variables were statically significant in a tornado becoming fatal, that is if a tornado produced a single fatality it became a fatal tornadic event. The linear regression model used a fatality variable that allowed the extent of how many fatalities the tornado produced to be evaluated and not just the strict nature of if a tornado was fatal or not. In running the descriptive statistics of the fatality variable for the linear model a test of skewness determined that the variable was skewed and therefore a logarithm had to be applied to address the skewness of the data. The data for these two models also only includes information from the Southeastern states of Alabama, Tennessee, Mississippi, and Arkansas.

5.1 Binary Logistic Regression Model

The first dataset that is used for the binary logistic regression involves all tornados within the area of study. This resulted in a data set of 6762 tornados. The first test used was a binary logistic regression on several variables to determine if they were correlated on if a tornado produced a fatality. The dependent variable for all binary logistic regression tests is the binary variable fatal2, with 1 being the tornado caused a fatality and 0 the tornado did not cause a fatality. This dataset was also limited to the states selected from the Southeastern United States; this data being limited to Alabama, Tennessee, Mississippi, and Arkansas.

The variable officialSeason (Mar-May) was used in the model in order to establish a baseline for significance if tornados occurring during the officially recognized tornado season would be statistically significant.

Using the original variables of time2, significantTornado, dopplar1974, stateTN, stateMS, stateAR, and season a binary logistic regression analysis was run. This first run produced only two significant variables, one from magnitude and one from geographical location. The first was significantTornado, this variable indicates that a tornado being an F/EF-2 or greater has a statically significant impact on if a tornado produces a fatality (Table 1). This is a rather obvious conclusion with the knowledge that most F/EF-0 and F/EF-1 tornados do not regularly produce a fatality. The second significant variable in this analysis is stateTN. This result indicates for this original binary logistic regression analysis that some factor associated with the regional geography of Tennessee played a factor in determining if a tornado produced a fatality.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	time2	-.025	.152	.027	1	.869	.975	.724	1.313
	significantTornado	3.008	.163	342.147	1	.000	20.247	14.721	27.848
	dopplar1974	.123	.120	1.053	1	.305	1.131	.894	1.431
	stateTN	.520	.159	10.721	1	.001	1.681	1.232	2.295
	stateMS	-.191	.157	1.479	1	.224	.826	.607	1.124
	stateAR	.078	.151	.268	1	.605	1.081	.804	1.455
	season	-.072	.130	.309	1	.579	.930	.720	1.201
	Constant	-4.778	.205	540.783	1	.000	.008		

a. Variable(s) entered on step 1: time2, significantTornado, dopplar1974, stateTN, stateMS, stateAR, season.

Table 1 - Binary Logistic Regression Test 1

The binary logistic regression was run a second time while changing the time variable from time2 (0000-0700) to time3 (2100-0700) to account for individuals being in their residence but not necessarily asleep. The changing of the time variable did not alter the results of the binary logistic regression test, the same two variables that were significant in the first test significantTornado and stateTN were the same variables that were significant in after this test was run (Table 2). This test indicates that neither the time period when the majority of the population is asleep nor the time period when individuals are at their primary residence is statistically significant in determining if a tornado will produce a fatality or not, this same assumption will be put to the test using linear regression in the second round of testing.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	significantTornado	3.005	.163	341.175	1	.000	20.187	14.675	27.768
	dopplar1974	.124	.120	1.066	1	.302	1.132	.895	1.432
	stateTN	.518	.159	10.656	1	.001	1.679	1.230	2.292
	stateAR	.085	.151	.314	1	.575	1.088	.809	1.464
	stateMS	-.195	.157	1.533	1	.216	.823	.604	1.120
	season	-.075	.130	.334	1	.563	.927	.719	1.197
	time3	.055	.123	.198	1	.656	1.056	.830	1.345
	Constant	-4.796	.207	538.548	1	.000	.008		

a. Variable(s) entered on step 1: significantTornado, dopplar1974, stateTN, stateAR, stateMS, season, time3.

Table 2 - Binary Logistic Regression Test 2, time change

The binary logistic regression was run a third time while changing the time variable back to the original time2 and the season variable from season (Nov-Jan) to officialSeason (Mar-May) in order to establish a baseline for significance if tornados occurring during the officially recognized tornado season would be statistically significant. The results from this test revealed that in addition to the two statistically significant variables already identified (significantTornado, and stateTN) a third statistically significant variable was identified. The variable officialSeason was identified as statistically significant in a tornado producing a fatality. This relationship is not strong as the other two variables but is still statistically significant. This revelation holds up to the logic that if a tornado occurs within the officially defined tornado season it is more likely to be in a springtime storm and therefore more powerful. This finding seems to indicate that in addition to the official season corresponding to the number of tornado events it is also possible that the official season could correspond to the potential of a tornado to become a fatal event. This finding will be evaluated later in the linear regression portion of testing.

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
time2	-.035	.152	.053	1	.818	.966	.717	1.300
significantTornado	2.991	.163	338.480	1	.000	19.907	14.475	27.377
dopplar1974	.120	.120	1.006	1	.316	1.128	.892	1.427
stateTN	.500	.159	9.903	1	.002	1.648	1.207	2.250
stateAR	.067	.152	.193	1	.661	1.069	.794	1.439
stateMS	-.179	.158	1.289	1	.256	.836	.614	1.139
officialSeason	.239	.114	4.413	1	.036	1.269	1.016	1.586
Constant	-4.908	.213	533.354	1	.000	.007		

a. Variable(s) entered on step 1: time2, significantTornado, dopplar1974, stateTN, stateAR, stateMS, officialSeason.

Table 3 - Binary Logistic Regression Test 3, official tornado season

The binary logistic regression was run a fourth time while changing the officialSeason variable to the monthNov variable in order to test if a regional secondary season was by itself statistically significant in having a tornado produce a fatality. This fourth run resulted in the same results as the original test with the only statistically significant variables being significantTornado and stateTN. The month of November by itself is not statistically significant enough to warrant merit in this testing environment.

Variables in the Equation

	B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
							Lower	Upper
time2	-.029	.151	.037	1	.848	.971	.722	1.307
significantTornado	3.006	.163	341.998	1	.000	20.198	14.688	27.775
dopplar1974	.122	.120	1.028	1	.311	1.129	.893	1.428
stateTN	.524	.158	10.921	1	.001	1.688	1.237	2.303
stateAR	.079	.151	.271	1	.603	1.082	.804	1.456
stateMS	-.193	.157	1.497	1	.221	.825	.606	1.123
monthNOV	-.060	.179	.112	1	.738	.942	.663	1.338
Constant	-4.787	.205	547.051	1	.000	.008		

a. Variable(s) entered on step 1: time2, significantTornado, dopplar1974, stateTN, stateAR, stateMS, monthNOV.

Table 4 - Binary Logistic Regression Test 4, November

The final binary logistic regression test examined the incorporation of the monthNov variable into the officialSeason variable in order to test the statistical significance of adding the secondary season associated with the Southeast to the official tornado season. The variable monthSeason (Mar-May, Nov) was added in this run to test if the expansion of tornado season in the Southeast to include November was a statistically significant in having a tornado produce a fatality. The results from this fourth run show that while significantTornado and stateTN continued to remain statistically significant, monthSeason was also a statically significant variable when it came to a tornado producing a fatality. While this in itself may not be a significant finding it does mean that expanding the traditional tornado season to include months associated with the secondary season is an argument with some merit. If a month not traditionally associated with tornados has a statistically significant impact on a tornado producing a fatality then the inclusion of that month into the public awareness campaign of risk should be considered. This finding could also indicate that tornado season is often defined by frequency of tornadic event and is not a fatality risk based metric.

Variables in the Equation

		B	S.E.	Wald	df	Sig.	Exp(B)	95% C.I.for EXP(B)	
								Lower	Upper
Step 1[a]	time2	-.036	.152	.058	1	.810	.964	.716	1.298
	significantTornado	2.986	.163	336.774	1	.000	19.799	14.393	27.235
	dopplar1974	.114	.120	.907	1	.341	1.121	.886	1.418
	stateTN	.511	.159	10.382	1	.001	1.667	1.221	2.274
	stateAR	.075	.152	.245	1	.620	1.078	.801	1.451
	stateMS	-.180	.158	1.308	1	.253	.835	.613	1.137
	monthSeason	.239	.121	3.904	1	.048	1.270	1.002	1.611
	Constant	-4.931	.217	515.552	1	.000	.007		

a. Variable(s) entered on step 1: time2, significantTornado, dopplar1974, stateTN, stateAR, stateMS, monthSeason.

Table 5 - Binary Logistic Regression Test 5, extended tornado season

While the binary logistic regression model could determine the statistical significance of if a variable had any influence on a tornado producing a fatality, the binary nature of fatalities does not give a complete picture of risk. In the binary logistic regression analysis a tornado that produced 1 fatality was weighted the same as a tornado that produced 50+ fatalities. Weighting all fatal tornados equally gives a one-dimensional assessment of risk, and proves much of what we already know, that weak tornados are less likely to cause fatalities. From various points of view a simple binary fatality risk based assessment could be good enough, however since the data exists a linear regression model of the data could yield more insights into which variables are more influential when it comes to major tornado events and a holistic risk based approach.

5.2 Linear Regression Model

By moving to a linear regression model for the remainder of the analysis new issues with the data must be addressed. A check for skewedness of the fatality variable needed to take place in order to determine if the data could be used in its current form. With this only tornados within the study area that also produced a fatality were included in the data set. This resulted in a much smaller dataset of 383 tornados. A descriptive statistics readout of the fatality variable (fat) indicated a skewness statistic of 4.530 which indicated that this variable was skewed and therefore needed to be transformed in order to not bias the results (Table 6). The skewedness of the variable passes a logic check as well, as many fatal tornados produce less than five fatalities, and on the rare occasion a large tornado can produce many more. To nullify any problems presented by the skewedness of the fatality variable, the variable was transformed via a logarithm to produce the new fatality variable "logfat".

Descriptive Statistics

	N	Minimum	Maximum	Mean	Std. Deviation	Skewness	
	Statistic	Statistic	Statistic	Statistic	Statistic	Statistic	Std. Error
fat	383	1	72	4.64	8.734	4.530	.125
Valid N (listwise)	383						

Table 6 - Skewness of fatality variable

After the logarithm was applied to address the skewness of the fatality variable the other variables were analyzed using a linear regression model. By changing the emphasis of the analysis from looking as simply if a fatality occurred or not, to the totality of the fatality variable changed the scope of the question and the results it presented.

The first linear regression model was run using the original variables identified. The time variable (time2) was the original time variable supported by the sleep study and included only the times from midnight to seven in the morning (0000-0700). The significant tornado variable was unchanged from the binary logistic model (F/EF-2 to F/EF-5). The state variables for Arkansas, Mississippi, and Tennessee remained the same. The season variable refers to the out of season variable first identified as November, December, and January.

In the first run of this linear regression model it is immediately clear what a drastic change looking at the fatality variable as a whole makes. In the binary logistic regression models multiple variables were modified in order to explore if the modifications would make them statistically significant, and as stated earlier usually that was not the case. However, in the first run of the linear regression model four original variables are statistically significant with no modifications (time2, significantTornado, stateAR, and Season). While the significantTorando variable is expected to be statistically significant since we are looking at fatality as a whole, and the Arkansas state variable is a component of geography, the two variables upon which this research started are also statistically significant.

The time variable for this run of the regression model reflects the time identified in which at least 50% a general population of adults would be asleep, and therefore less able to react to a severe weather event such as a tornado. With a significance value of .027 the variable time2 shows that for the Southeastern United States fatalities occurring within the time period of midnight and 7 AM are statistically significant (Table 7). This fact reinforces the need to stress to the public the use of weather radios and mobile cell phone alerts. If there is a heightened risk of fatality during these hours then the way information is transmitted needs to take into account the fact that many members of the public will be asleep. This increased time period of risk also highlights another known fact that weather radio usage is very low in this area despite the increased danger and need for warning (Chaney et. Al. 2011).

The season variable for this run of the regression model reflects the months of November, December, and January. Times in which the majority of the country has a very low threat of tornados. To further illustrate this fact, during the time period covered by the data (1950-2014) not a single fatality has occurred due to a tornado in the state of Kansas for the months of November, December, and January. By contrast the state of Alabama has had fatal tornado events on Thanksgiving Day, Christmas Day, and around the New Year. In this run of the linear regression model the season variable holds a significance value of .007 and reveals that the months of Nov-Jan are statistically significant when it comes to the risk of a fatality due to a tornado (Table 7).

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.451	.175		2.573	.010	.106	.795
	time2	-.299	.134	-.110	-2.227	.027	-.562	-.035
	significantTornado	.749	.154	.244	4.878	.000	.447	1.051
	stateAR	-.330	.134	-.147	-2.465	.014	-.594	-.067
	stateMS	-.072	.140	-.030	-.512	.609	-.348	.204
	stateTN	-.158	.139	-.068	-1.135	.257	-.431	.116
	season	-.313	.115	-.134	-2.732	.007	-.538	-.088

a. Dependent Variable: logfat

Table 7 - Linear Regression Model Test 1, original variables

In the binary logistic model the time variable was modified since the original time was not statistically significant, however in the linear regression model the original time variable was statistically significant with no modifications and therefore only one run of the linear regression model answers the research question regarding that variable. Because of this the time variable will not be modified or altered further and all additional analysis will focus on the season variable and defining if the secondary spike in tornado activity should result in the Southeast redefining its tornado season in order to better inform the public in regards to the year-round risk of death to do hazardous tornados.

In the second linear regression test, the season variable was replaced with only the month of November. November was the month picked for further analysis for two reasons. First, early research indicated a spike in tornado activity in the state of Alabama as indicated by the National Weather Service in Birmingham, AL (NOAA 2017). Secondly a frequency of tornados by the month variable was examined and a large spike in fatal tornado activity can be seen in the month of November (Table 8). This same spike in activity can be seen with all tornados for the area of study are examined (Table 9).

mo

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	27	7.0	7.0	7.0
	2	46	12.0	12.0	19.1
	3	71	18.5	18.5	37.6
	4	121	31.6	31.6	69.2
	5	37	9.7	9.7	78.9
	6	6	1.6	1.6	80.4
	8	2	.5	.5	80.9
	9	2	.5	.5	81.5
	10	6	1.6	1.6	83.0
	11	41	10.7	10.7	93.7
	12	24	6.3	6.3	100.0
	Total	383	100.0	100.0	

Table 8 - Frequency of Month Variable, fatal tornados in the study area

mo

		Frequency	Percent	Valid Percent	Cumulative Percent
Valid	1	454	6.7	6.7	6.7
	2	509	7.5	7.5	14.2
	3	835	12.3	12.3	26.6
	4	1532	22.7	22.7	49.2
	5	993	14.7	14.7	63.9
	6	309	4.6	4.6	68.5
	7	190	2.8	2.8	71.3
	8	171	2.5	2.5	73.8
	9	319	4.7	4.7	78.6
	10	319	4.7	4.7	83.3
	11	711	10.5	10.5	93.8
	12	420	6.2	6.2	100.0
	Total	6762	100.0	100.0	

Table 9 – Frequency of Month Variable, all tornados in the study area

The second linear regression test in which the season variable was replaced by the November variable (monthNOV) to test if the spike in tornado activity in the Southeastern United States was statistically significant in the terms of fatalities produced. Test 2 revealed that the month of November and the increased frequency of tornado activity by itself was not statistically significant in terms of producing fatalities. In the results the November variable (monthNOV) was not a statistically significant variable (Table 10). This however does not mean that in the increased tornado activity during this month should be ignored. Test 1 clearly indicated the time period of November-January as being statistically significant for a tornado producing a fatality.

If the time period was significant in a tornado producing a fatality it should also be significant in examining that same variable for the magnitude of fatality.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	95.0% Confidence Interval for B	
		B	Std. Error	Beta			Lower Bound	Upper Bound
1	(Constant)	.401	.175		2.287	.023	.056	.746
	time2	-.312	.135	-.115	-2.307	.022	-.577	-.046
	significantTornado	.740	.155	.241	4.782	.000	.436	1.044
	stateAR	-.328	.135	-.146	-2.426	.016	-.593	-.062
	stateMS	-.073	.142	-.030	-.513	.608	-.351	.206
	stateTN	-.138	.140	-.059	-.985	.325	-.413	.137
	monthNOV	-.195	.159	-.060	-1.224	.222	-.508	.118

a. Dependent Variable: logfat

Table 10 – Linear Regression Model Test 2, November only

To examine the month variable further and to ensure that the traditionally defined tornado season did have statistical significance when it came to fatalities, the season variable was replaced with a variable detailing the official tornado season for most of the rest of the United States March, April, and May. It was determined in the binary logistic regression that while the official season for tornados was statistically significant for a tornado producing a fatality the relationship with risk to the magnitude of fatalities could not be established due to the binary nature of the model. To try and establish the magnitude the Linear Regression Model Test 3 replaced the November variable with the variable representing the Official Season (officialSeason).

Test 3 results indicate a very strong and highly significant relationship between the number of fatalities a tornado produces and the official tornado season in the Southeastern United States. The correlation of the official tornado season and magnitude of the fatalities indicates that while the official tornado season deals is defined by the increased likelihood of a tornadic event occurring, it also covers the time with the most risk of fatalities due to a tornado. The official tornado season variable has a significance value of .003 and is statistically significant in relation to a tornado producing fatalities if it occurs within the officially defined tornado season (Table 11).

Coefficients[a]

Model		Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t	Sig.	95.0% Confidence Interval for B Lower Bound	95.0% Confidence Interval for B Upper Bound
1	(Constant)	.223	.181		1.230	.220	-.134	.580
	time2	-.301	.134	-.111	-2.248	.025	-.564	-.038
	significantTornado	.702	.154	.229	4.571	.000	.400	1.004
	stateAR	-.323	.134	-.144	-2.417	.016	-.586	-.060
	stateMS	-.023	.141	-.009	-.159	.874	-.301	.256
	stateTN	-.150	.139	-.065	-1.084	.279	-.423	.122
	officialSeason	.300	.101	.148	2.966	.003	.101	.499

a. Dependent Variable: logfat

Table 11 – Linear Regression Model Test 3, official tornado season

The final test of the Linear Regression Model is to test if incorporating the month of November along with the other months defined in the officially defined tornado season is still statistically significant. The officialSeason variable is replaced with the monthSeason variable which includes the months of March, April, May, and November. Test 4 is to see if by including November the newly defined "season" continues to have statistical significance and if so what the implications of that could be as to how to warn the public of the increased danger of this expanded season.

Test 4 clearly shows that the expanded and newly defined "season" that includes the month of November is a statistically significant factor in a tornado producing a fatality if it occurs within the time frame (Table 12). With a significance factor of .021 the variable monthSeason which accounts for March, April, May, and November is a statistically significant in tornado fatality.

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients			95.0% Confidence Interval for B	
		B	Std. Error	Beta	t	Sig.	Lower Bound	Upper Bound
1	(Constant)	.226	.187		1.213	.226	-.141	.594
	time2	-.309	.134	-.114	-2.296	.022	-.573	-.044
	significantTornado	.699	.155	.228	4.524	.000	.395	1.003
	stateAR	-.312	.134	-.139	-2.325	.021	-.576	-.048
	stateMS	-.037	.142	-.016	-.262	.793	-.316	.242
	stateTN	-.144	.139	-.062	-1.032	.303	-.418	.130
	monthSeason	.253	.109	.116	2.321	.021	.039	.467

a. Dependent Variable: logfat

Table 12 – Linear Regression Model Test 4, expanded tornado season

This finding lends credence to the idea that by having a normally defined tornado season, even though there are notable areas of increased risk outside of that season, you are confusing the public at large. If the normally defined tornado season clearly demonstrates a time in which there is an increased risk of tornado occurrence or of a tornado fatality, then logically any time outside of that clearly defined season should be a time of less risk. This clearly not the case in the Southeastern United States. By indicating that there is a time with an increased risk you inadvertently give people a false sense of security if a storm system is occurring in a time period outside of the defined tornado season.

Unlike hurricane season, which has the ability to be adjusted and the public warned when an event takes place outside of its bounds, tornado season and the preparedness with which it brings or the complacency with which the other months are treated is not something that can be changed with a simple warning from the local weather station. If the public is not aware of the heightened risk due to tornados in the other parts of the year all the warnings will fall on deaf ears.

CHAPTER 6 DISCUSSION

The results show that by breaking down particular factors and time periods the data can be analyzed in new and different ways. By redefining what a nocturnal tornado is and how it is classified to incorporate the sleep schedules of the general public we change the way the data is looked at, and therefore can change public policy on how forecasters disseminate tornado warnings or approach how to warn the public of impending danger. This analysis showed that the data surrounding tornados is complex and need detailed analysis to understand our environment. The data clearly shows how a simple question of what causes a tornado to be deadly does not have a simple answer.

For the study area the results of this study indicate that while a tornado occurring between midnight and 7 A.M. is not statistically significant in whether or not it will cause a fatality, it is statistically significant in the number of fatalities that tornado produces. This fact logically holds true in the sense that normally at night storms will not be as strong and therefore they should occur with less intensity and frequency, except for those front driven storm systems that do not require sunlight in order to maintain their destructive energy. However, of those storms that do produce tornados at night, if those storms have the intensity they would catch the majority of the population asleep and unable to react as quickly. Therefore, while a tornado occurring at night is not more likely to produce a fatality, those tornados that do produce a fatality at night are more likely to produce multiple fatalities.

This information can be used in two ways: first the knowledge that strong tornados occurring while the majority of the general public are asleep has a statically significant likelihood for producing more fatalities can change the way forecasters deliver their warnings. If tornado producing storms are predicted overnight a pre-warning alert can be issued to inform the public of the potential for danger in the overnight hours. Many weather apps and weather services already issue these alerts, along with alerts for the potentially for floods, lightning, and winter precipitation. These alerts do not have to meet the strict standards of tornado watches but allow for the public to be aware of the potential time of a need for increased alertness. If individuals know that storms will be in the area at a specific hour they can then prepare, and not have to rely on scrambling to shelter when the imminent alert is issued and it may already be too late if shelter is not immediately available.

Secondly, if severe weather is forecasted during the night, forecasters can change the way alerts are delivered. Local targeted alerts sent via mobile devices and weather radios will be the most effective means for communicating danger to the public at night. The air-raid outdoor sirens were neither designed to wake people from their sleep nor are they effective at doing so. Also as documented in multiple reports, the public can overly rely on the outdoor weather sirens and if they are unable to hear them assume there is no danger, this may not be the case as sirens are not installed in some locations, some are hard to hear when weather is approaching, or they may be malfunctioning (Simmons et. Al. 2007).

Tornados are multi-faceted and unique in their scope and ferocity. They vary depending on what type of storm system spawns them, the time of day, the temperature, and even the month in which they form. What we may classify as a tornado varies so dramatically in damage that those who experience them may disagree with the scientific classification. A weak F0 tornado that snaps a couple of trees bears very little resemblance to the mile-wide path of destruction that has decimated countless towns through the years.

By focusing the analysis of tornados on the frequency of the event, forecasters may be missing the point. While it holds true that the frequency of events and the likelihood of a tornado to produce a fatality are statistically significant, if we focus the same level of urgency on a radar indicated center of rotation that never touches down as a mile wide path of destruction that we know is on the ground, individuals cannot make a complete risk assessment of the situation. Weak tornados generally do not cause fatalities yet we assign the same level of urgency to a weak tornado, or even cloud rotation and “radar indicated tornados” as we do an established EF-5 on the ground. This lack of clarity causes many false warnings and causes the public to not take severe warnings seriously. While more detailed polygons and warning areas that are not just county wide have helped reduce false alarms dramatically there is still a lot of room for improvement. As of this moment we are limited by technology to give a real-time determination of a tornado’s likelihood to cause damage, or even its wind speed. However as technology progresses it is not unreasonable to think that in the near future this data would not be as difficult to collect and therefore if it can be collected in real time the warning system must be updated to focus on the severity of the threat. A combination of automation, drone-flight times, and onboard sensor size could make real time weather collection a reality in the not so distant future. An EF-0 radar indicated rotation should not receive the same focus as a tornado sited on the ground that is producing destruction and once real time analysis is available the warning system must take this information into account. By looking at “significant tornados” as shown in the analysis as statistically significant during every test we can determine that the intensity of a tornado has a statistically significant impact both on if a tornado produces a fatality as well as the magnitude of those fatalities it produces.

Additionally by focusing how we define tornado season on the frequency of events, an incomplete picture of risk is established. While tornados are more likely to occur during tornado season (Mar-May) and that time period is statistically significant for both the likelihood of a tornado to produce a fatality as well as the magnitude of the fatalities it produces, other time periods also showed statistically significant results in terms of either likelihood of producing a fatality or the magnitude of those fatalities.

While an increased awareness of the danger due to tornados during tornado season when the likelihood of the storms in increased, in the Southeast this can create a false sense of safety outside of the defined tornado season. The study results clearly showed that while the official season of March-May was statistically significant in terms of both likelihood of a tornado to produce a fatality as well as the magnitude of those fatalities, by including the month of November (March, April, May, November) the expanded season was still statistically significant both in terms of likelihood of a tornado producing a fatality as well as the magnitude of those fatalities. Additionally, while the original out-of-season variable was not statistically significant in the likelihood of a tornado to produce fatalities, the time period of November-January was statistically significant in the magnitude of fatalities produced by a tornado occurring during that time in the study area.

The increased fatality variables of tornados in various parts of the year in the Southeast raises the question if having a defined tornado season for this region is warranted, or if by designating a tornado season you create a false sense of security for any month outside of that clearly defined parameter. The traditional way of defining the season by frequency of storm also does not hold true since there is a spike in tornado activity throughout the southeast in the month of November (NOAA 2016). The seasonality of tornados and tornado producing storms needs to be re-evaluated using the frequency of a tornado to occur, and rating all tornados equal in severity. The public is not receiving a clear picture of the risk associated with these storms. As our understanding of these storms evolves so too should our assessment of the risk they incur and our public response to them as a threat to the safety of individuals.

CHAPTER 7 CONCLUSION

The two areas of interest for increased fatality of the Southeastern United States were nocturnal tornados and out of season tornados. Both areas of interest produced results that merit further inquiry.

Nocturnal tornados were defined as being related to human behavior patterns and not a function of the amount of sunlight as has been defined previously. Nocturnal tornados were related to sleep patterns and the increased risk posed by individuals being asleep when a tornado strikes. In the Binary Logistic regression there was no statistically significant relationship between a tornado occurring between the hours of midnight and seven and if a tornado produced a fatality. Even when the time period was expanded to include any time a person could be at their place of residence (2100-0700) rather than at work or another location, a statistically significant relationship could not be established in regards to the likelihood of a tornado producing a fatality.

However, when examining the relationship between tornados and how many fatalities they produce a statistically significant relationship was discovered within the linear regression model. Therefore while human behavior of sleep patterns may not be related to if a tornado produces a fatality or not, it is related to the number of fatalities produced by a tornado.

Examining when the risk of a tornado producing a fatality occurs throughout the year is a multi-layered and complicated question. The original out-of-season variable of Nov-January was not statistically significant in determining if a tornado would produce a fatality, however the linear regression model showed that it was statistically significant to the number of fatalities a tornado produced during that part of the year. In looking at the official tornado season as defined by April-May the official season variable was statistically significant both in if a tornado would produce a fatality as well as significant in how many fatalities that tornado would produce if it occurred within the official season.

The spike of tornado occurrences in the Southeast during the month of November is enough to cause alarm for forecasters. If only tornados occurring during the month of November are examined, this time period is not by itself significant for either a tornado producing a fatality, or in the relationship with how many fatalities a tornado would produce. If the tornados that occur in the month of November are included in the data along with the official season a statistically significant pattern emerges. By expanding the tornado season to include March, April, May, and November if a tornado will produce a fatality is a statistically significant variable, and also the number of fatalities a tornado produces if it falls within that time period is also holds a statistically significant relationship.

There were several noteworthy issues with the data used for this project. For some tornados the magnitude was unknown and therefore missing. Though missing data was rare in the area of analysis there were some holes that if filled would give a more reliable and complete picture of the risk associated with this area. The database itself includes the number of fatalities a tornado produces but gives no indication where along the path of the tornado the fatalities occur, or if they were in the same structure, or within what structure type. Mobile home percentages by county were known, but the inferred implications of a simple percentage by county would not have held much validity in the specifics of this study. For fatal tornados a simple count of how many fatalities occurred within mobile homes and how many within permanent structures would have been useful. This data exists outside of the SVRGIS database but having all the data collected in one place would aid further research.

Several additional data points that would be useful in the data but would require time and money to collect are post disaster interview questions such as if those affected by the storm had a weather radio, if they had immediate access to tornado approved shelter, and how long before the tornado struck did they receive a warning. All of these data points are available in reports but they are for very specific tornado events and do not reflect the totality of the data across the entire Southeastern United States.

Future research on this topic that merits work would be to expand the analysis of the increased risk to the Eastern United States by including those areas identified by Walker Ashley as having an increased risk of fatal tornados (Ashley 2007). By expanding the analysis to include all areas covered by the polygon and not just those states including the most severe risk a better overall picture of risk can be established. The expanded polygon would include parts of Missouri, Illinois, Indiana, Kentucky, Oklahoma, and others.

Furthermore, by specifying the level of analysis to the county level rather than the state level a more targeted approach could focus in on where exactly the risk is greatest. A country wide analysis of tornados indicates some areas that a tornado event is so rare it represents an outlier in the range of more than 50 years' worth of data. By including whole states large geographic regions are included, not all states have the same risk of tornados equally distributed. In a state where not all of the geographic region has an increased vulnerability to tornados you skew the data geographically and potentially reduce the magnitude of the risk by including areas that are not at the same level of danger. By reducing the level of analysis to counties, you allow the data to drive the analysis rather than using arbitrary geographic distinctions such as state lines to determine your analysis. The county designation is not perfect, but by reducing the areas you get a more localized and more accurate representation of tornado risk in an area.

A more complete picture of fatal risk could be established with this data by including geo-coded fatality markers. By indicating where a fatality occurred along a tornado's path more precise analysis of the damage and indication of risk in the area can be established. While this is a touchy subject it is necessary in order to better understand the locality of risk associated with tornados, and while it can be accomplished it will be very labor intensive and must be approached with tact and sensitivity.

Another area of geo-coded analysis that could be of merit would be to historically examine the paths of tornados to determine if any local avenues of damage paths are statistically more likely to be hit multiple times and therefore have increased risk. On top of determining historical likely paths of tornados and the risk based upon owning a home in various areas of historical tornado activity, research could also be done to see if any geographic features have any effect on tornado paths.

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APPENDIX 1 ILLUSTRATIONS

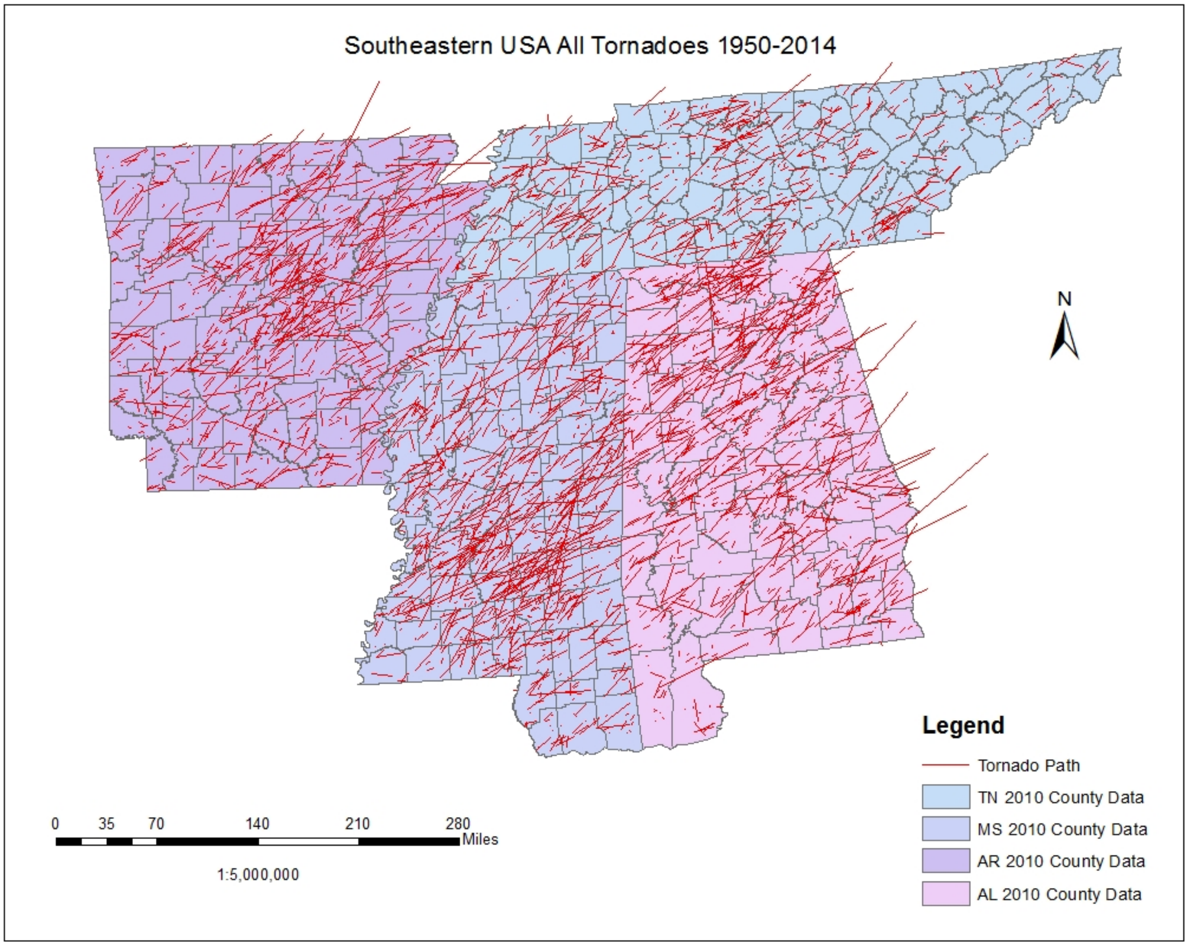

Illustration 1 – All tornados in study area 1950-2014

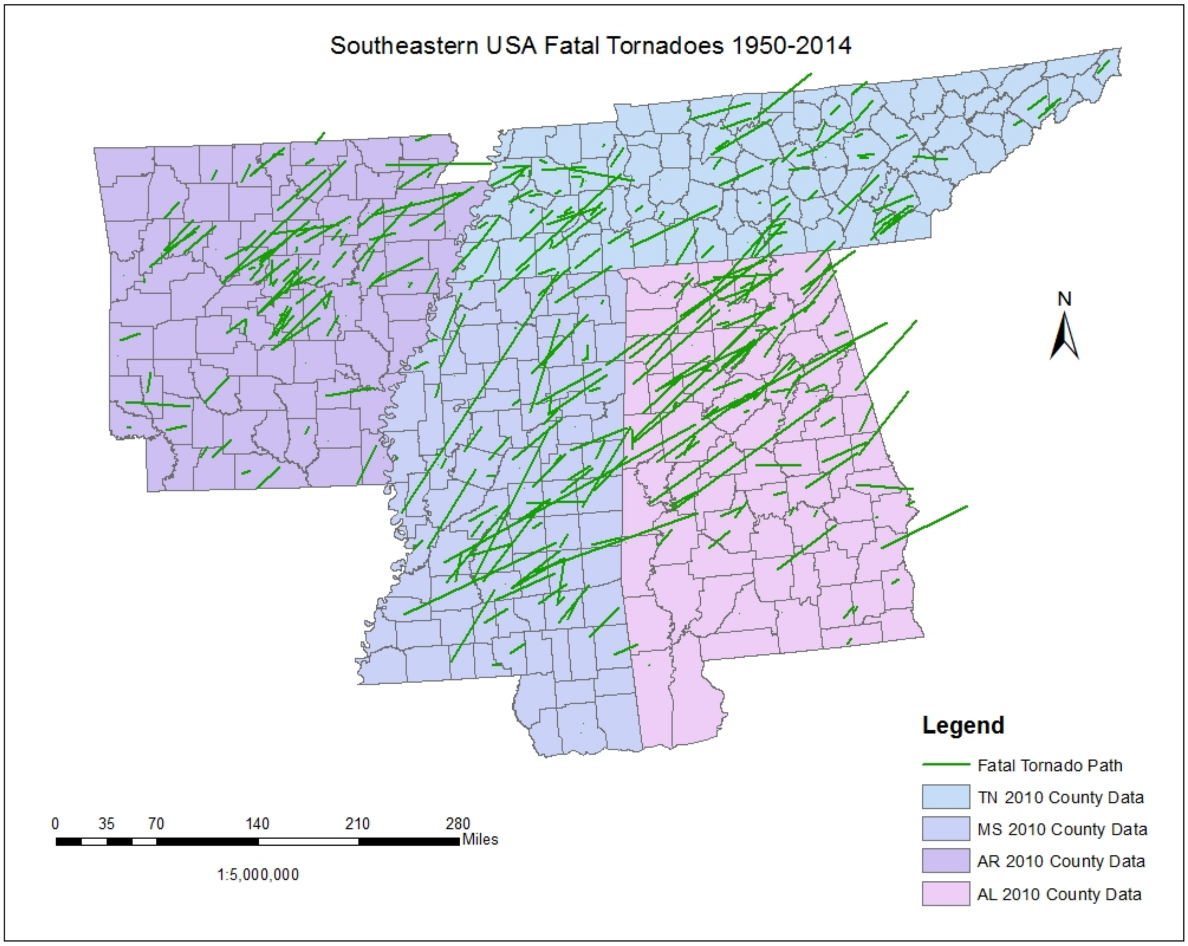

Illustration 2 – Fatal tornados in study area 1950-2014

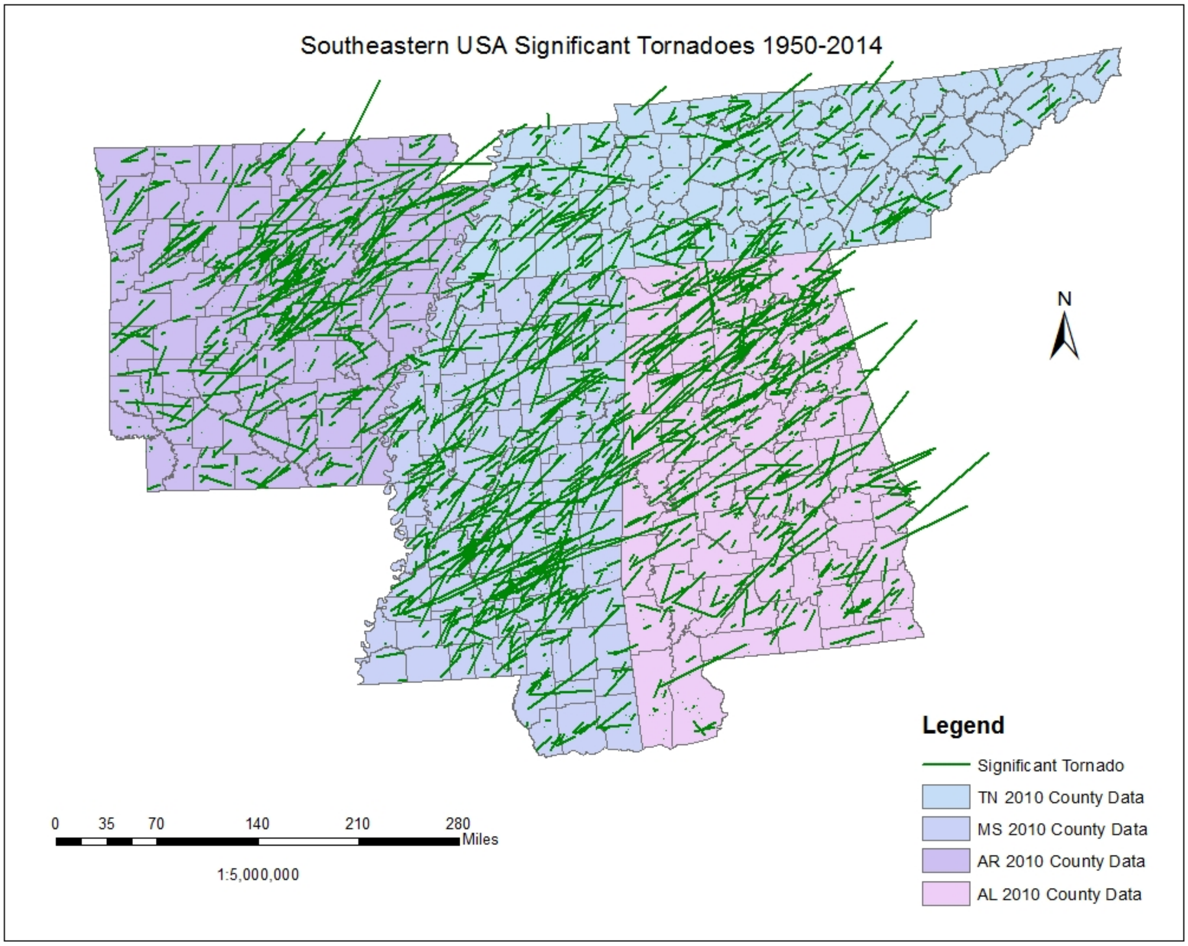

Illustration 3 – Significant (F/EF-2 and stronger) tornados in study area 1950-2014

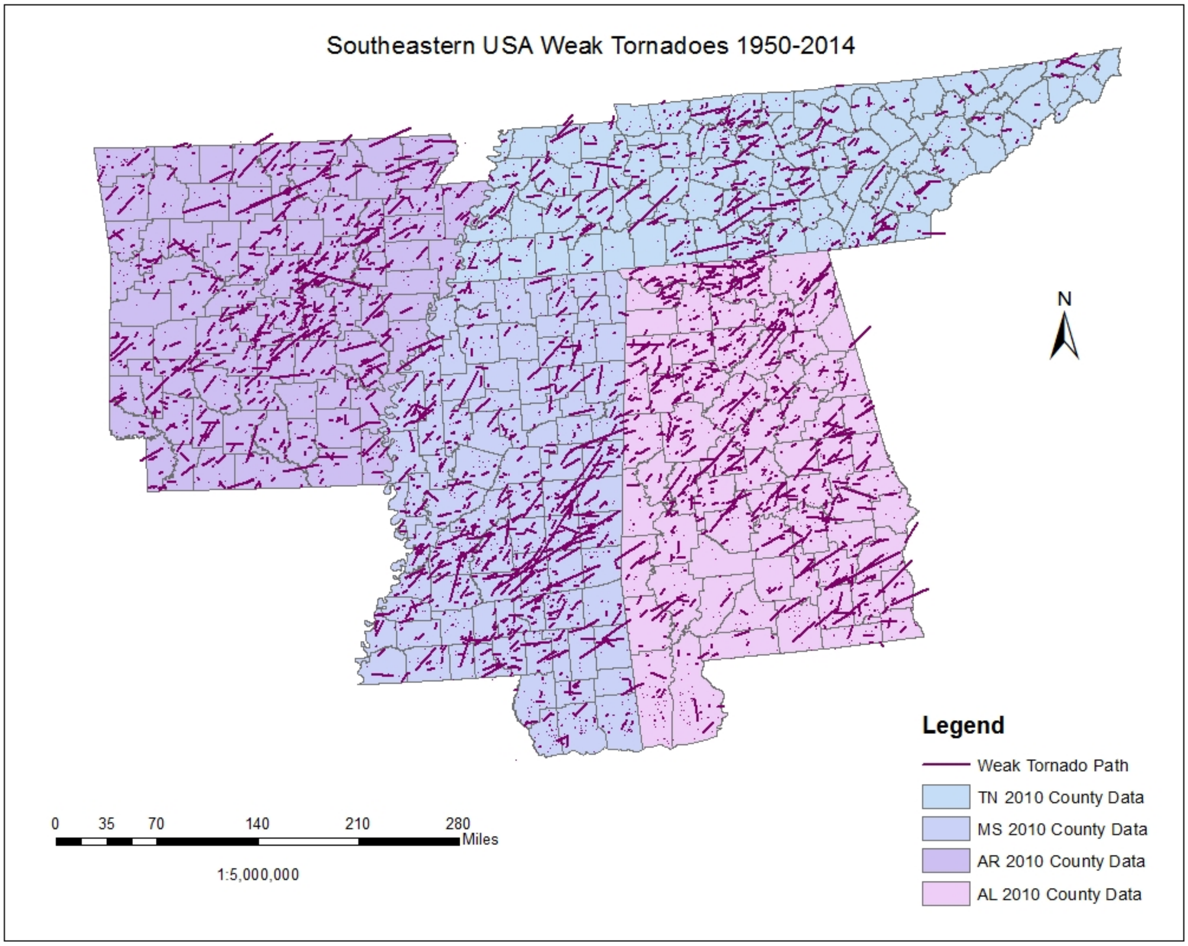

Illustration 4 – Weak (F/EF-0 and F/EF-1) tornados in study area 1950-2014

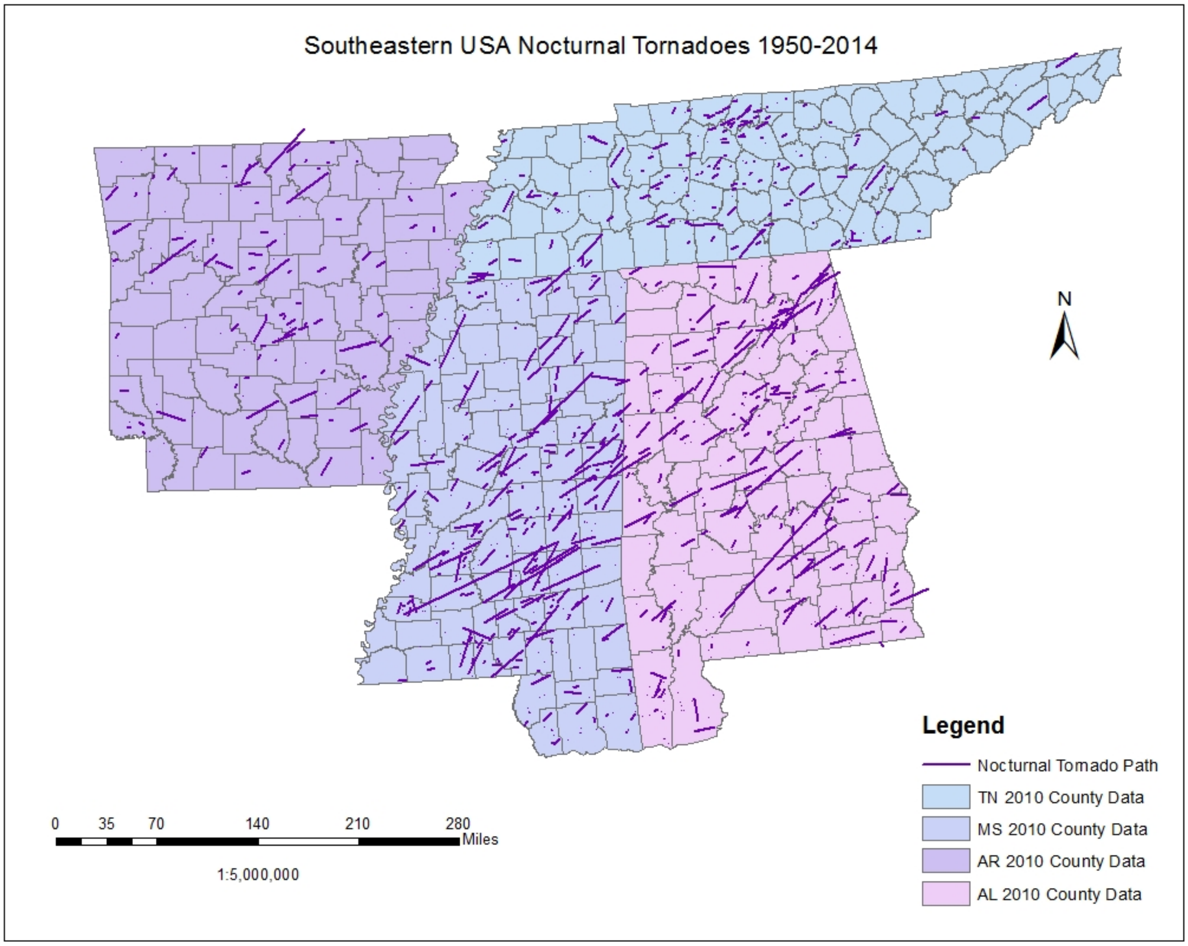

Illustration 5 – Nocturnal tornados (0000-0700) in study area 1950-2014

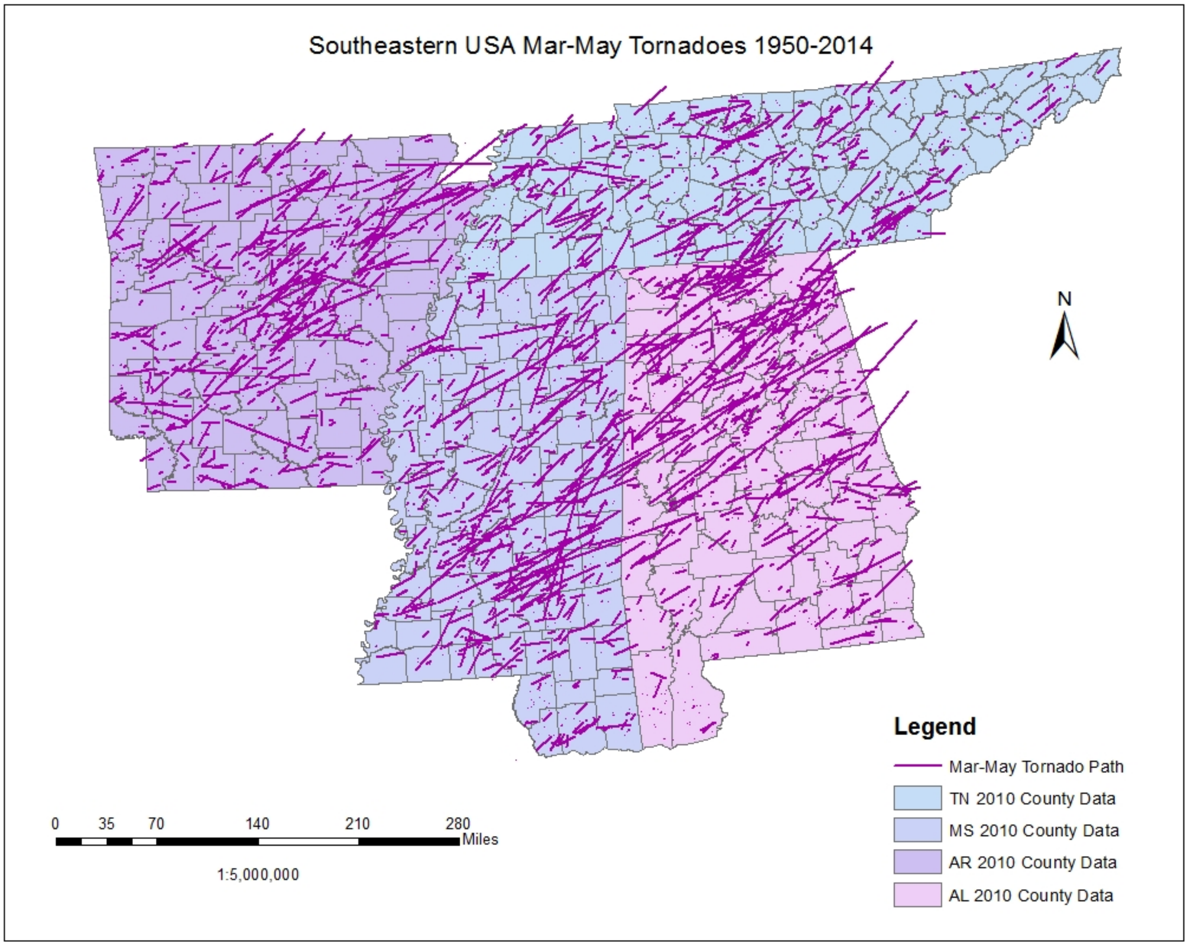

Illustration 6 – Official season (Mar-May) tornados in study area 1950-2014

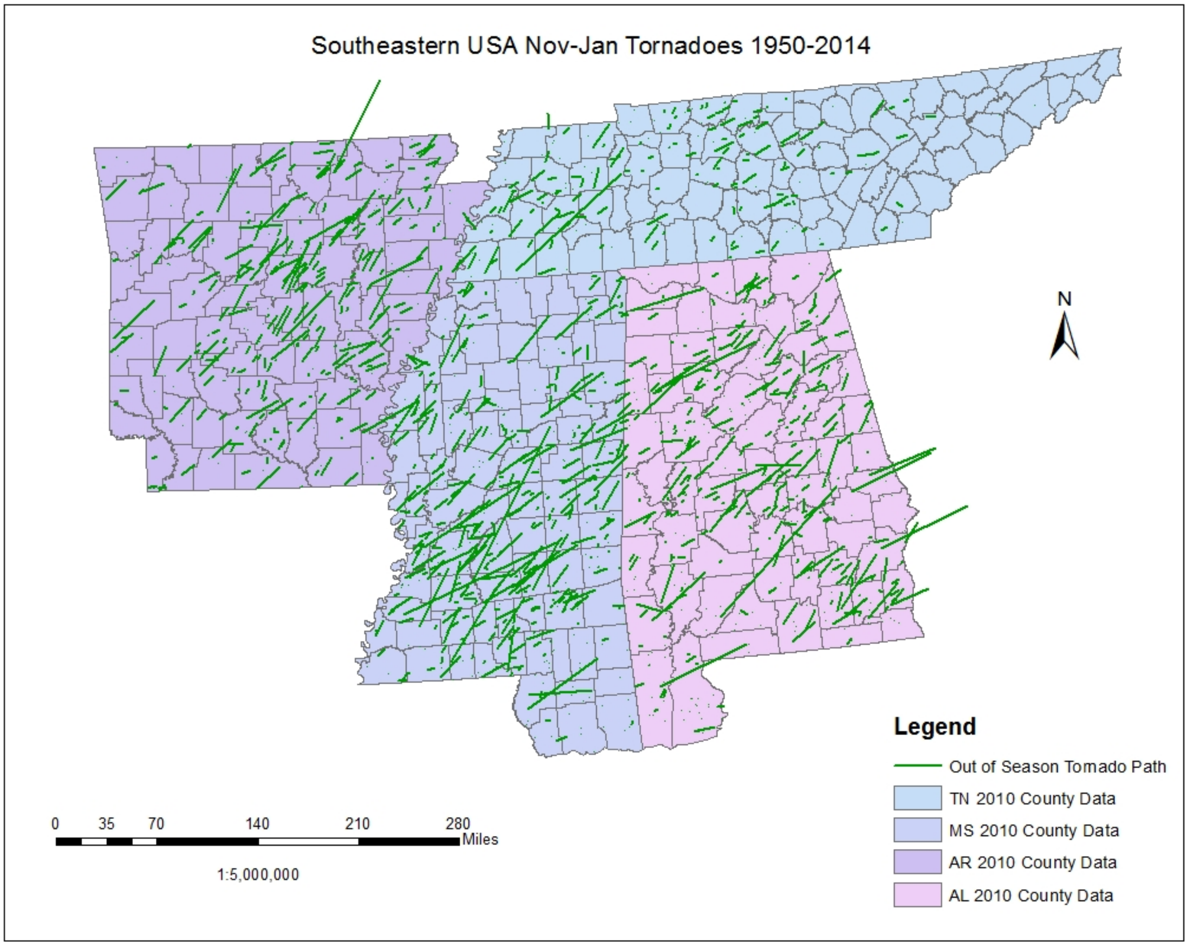

Illustration 7 – Out-of-season (Nov-Jan) tornados in study area 1950-2014

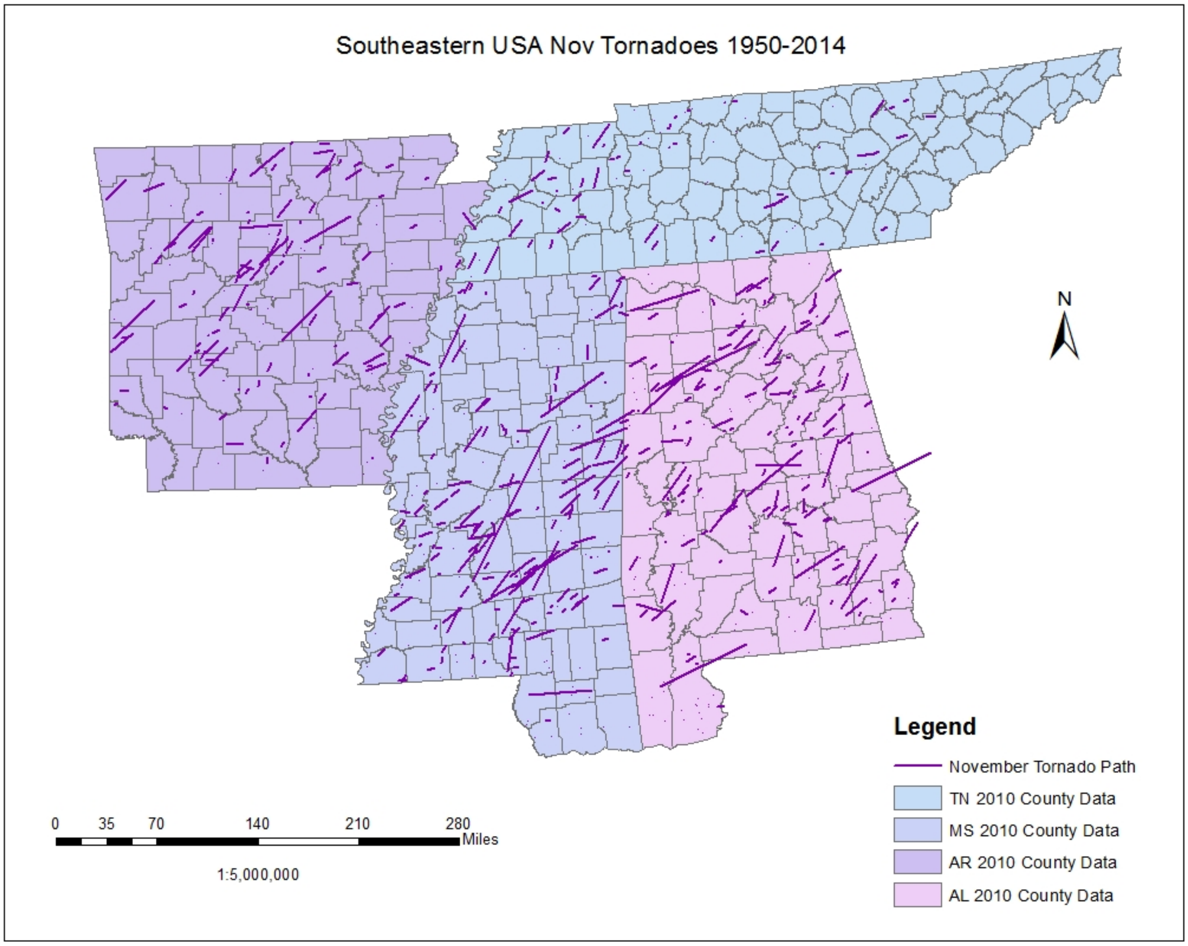

Illustration 8 – November tornados in study area 1950-2014

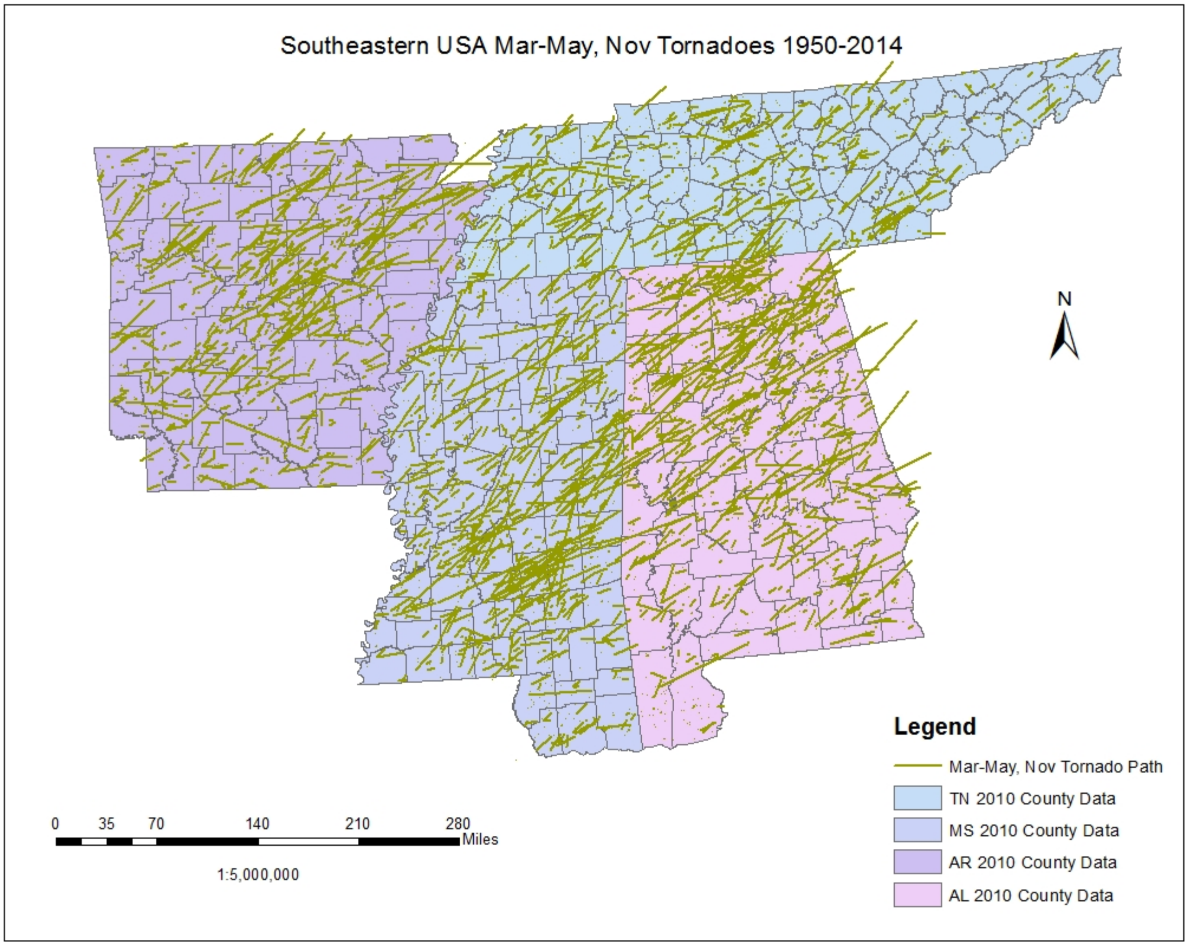

Illustration 9 – Extended season (Mar-May, Nov) tornados in study area 1950-2014

APPENDIX 2 LIST OF VARIABLES

1. fat = How many fatalities a tornado produced, numerical value
2. fatal2 = Binary yes/no to a tornado producing a fatality (fat = 0, fat ge 1 = 1)
3. logfat = logarithm of fatality variable (ln(fat))
4. time = timestamp of when the tornado occurred
5. time2 = time between 0000 and 0700
6. time3 = time between 2100 and 0700
7. mag = magnitude of tornado either in F-scale or EF-scale
8. significantTornado = magnitude greater or equal to F/EF-2
9. year = year tornado occurred
10. dopplar1974 = Binary variable if a tornado occurred before or after Doppler radar was used to issue tornado warnings (year < 1974 = 0, year ge 1974 = 1)
11. st = state in which tornado occurred (Touchdown)
12. stateTN = Tennessee
13. stateMS = Mississippi
14. stateAR = Arkansas
15. mo = Month in which tornado occurred
16. season = Month of November, December, and January
17. officialSeason = Month of March, April, and May
18. monthNOV = Month of November
19. monthSeason = Month of March, April, May, and November

APPENDIX 3 DEFINITIONS

For this paper the following terms are defined as follows:

1. Nocturnal Tornado – A tornado touchdown occurring between midnight (0000) and seven (0700) in the morning. When at least 50% of a generalized population can be expected to be asleep and therefore less able to react to a tornado and also unable to be warned by conventional means (Local Radio station, Local TV news, outdoor sirens).
2. Vulnerable Housing Stock – Any manufactured or mobile home of any configuration that does not have a permanent foundation. (US Census Definition)
3. Manufactured/Mobile Home – housing units manufactured and moved to a site rather than being built on site. These two terms represent the same type of housing. The industry that produces these homes has sense moved from calling these units mobile homes to manufactured homes, however in tornado research these terms are both used and are interchangeable (Sutter and Simmons 2010).
4. Out of Season Tornado – A tornado touchdown occurring from 1 November through 31 January of any year in the database.