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Spatial and Temporal Analysis of the 27 April 2011 Tornado Outbreak in Central Alabama

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Abstract

This study investigates the spatial and temporal patterns of the 27 April 2011 tornado outbreak in Central Alabama. Disasters, and vulnerabilities to such events, vary across space and time. The 2011 Super Outbreak was the largest, most costly, and one of the most deadly tornado outbreaks ever recorded in U.S. history. In this study, the results of 29 documented tornado tracks (889 data points total) in Central Alabama reveal findings related to complex topography and its effects on tornado intensity. The temporal pattern s of this particular outbreak are - consistent with other studies' evidence that suggests a small peak in nocturnal tornado activity in the Southeast U.S. These are a few of the many factors that contribute to tornado vulnerability in the Deep South.

Tornado; Outbreak; 27 April 2011; Alabama; GIS; Spatial; Temporal; Damage; Vulnerability

Introduction

Tornadoes are nature's most violent windstorms, and are a significant threat to life and property all across the United States (Ashley, 2007). Although tornadoes tend to occur more frequently in what is commonly known as Tornado Alley, not a single state in the country is immune. The ideal combination of moisture, instability, and lift can be enough to fuel supercell thunderstorms to produce violent tornadoes capable of unimaginable amounts of damage. This fuel is often found in the Midwest and the Southeast, where warm, moist air is swept up from the Gulf of Mexico. The spatial and temporal distributions of tornadoes in the United States have been documented in numerous studies (Ashley, 2007; Boruff et al., 2003; Suckling and Ashley, 2006; Hall and Ashley, 2008; Brooks, Doswell, and Kay, 2003). However, there has been very little formal research on tornado activity in the Deep South, despite three southern states leading in terms of killer tornadoes (Ashley, 2007, p. 1216). Many studies have shown tornado-related vulnerabilities are higher in southern states, leading to higher casualty rates from tornado outbreaks (Elsner and Fricker, 2017). Some attribute this difference to the lag in advancing technology and warning systems, as well as to discrepancies in housing type and quality.

Hazard mapping is a useful tool for decision makers to better understand how the human environment interacts with the natural environment. The integration of new tools and technology has transformed hazard mapping into more effective and efficient methods to gather, organize, and manipulate geospatial data. Yuan, Dickens-Micozzi, and Magsig (2002) utilized Geographic Information Systems (GIS) technology, along with remote sensing technology, to analyze tornado damage tracks from the 3 May 1999 tornado outbreak. The study ultimately found that GIS methods are useful for tornado verification and damage assessments. Boruff et al. (2003) analyzed tornado hazard frequency by mapping tornado data on a digital map, analyzing property and crop damages, as well as the number of fatalities. Curtis and Mills (2012) analyzed a spatial video collection within a GIS of how a post-disaster landscape returns to normalcy following the deadly EF4 tornado that ripped through Tuscaloosa, Alabama, in order to support ongoing recovery efforts following the historical outbreak. The study concluded that the visible aspects of recovery can be mapped and analyzed with the advance of spatial technology (Curtis and Mills, 2012). The objective of this case study is to analyze spatial and temporal patterns of the 27 April 2011 tornado outbreak in Central Alabama using GIS. Major advances in GIS technology, as well as the growing requirement of a standard operating procedure for GIS-based damage assessments have made the process more efficient and the results ultimately more accurate (Crawford, 2014). This study investigates the spatial and temporal patterns of the April 27th tornado outbreak in Central Alabama using GIS, followed by a case study of the Tuscaloosa tornado. Using survey points by the National Oceanic and Atmospheric Administration (NOAA) National Weather Service (NWS), taken from 28 April to 2 May 2011, our goal is to find patterns based on a number of factors, including tornado intensity, frequency, elevation, temporal distribution and type of structures that received damage.

Historical Tornado Outbreaks in the United States

There have been several major tornado outbreaks throughout U.S. history that have resulted in hundreds of deaths and billions of dollars in property loss. The 1925 Tri-State tornado outbreak was one of the most deadly and catastrophic tornado outbreaks in U.S. history. The outbreak claimed approximately 695 lives, injured over 2,000, and left over $16.5 million in damages (Brodt, 1986). After inflation adjustments, that is about $225 million today. The event affected the states of Missouri, Illinois and Indiana, and produced one of the longest continuous single tornado tracks ever recorded (Galway, 1981; Maddo, Gilmore, Doswell, Johns, Crisp, et al., 2013; Stimers & Paul, 2017).

21-22 March 1932, commonly known as the “Deep South Outbreak”, was another deadly and destructive outbreak, with over 30 confirmed tornadoes and over 300 fatalities. This was the most fatal outbreak in a 24-hour period until 2011 (NOAA, n.d.; Knupp et al., 2014). The event affected much of the Southeast, but Alabama was by far the hardest hit, with more than 250 fatalities (Grazulis, 1993). The outbreak spawned ten F4 and F5 tornadoes, eight of which occurred in Alabama alone (Grazulis, 2001).

One of the most significant tornado outbreaks in the United States since 1950 is the 3-4 April 1974 “Super Outbreak”. This event spawned 148 tornadoes in less than 24 hours, with 30 of those ranked as F4 or F5. The outbreak claimed 335 lives, and injured more than 6,000 (Cordifi, 2010). These tornadoes ripped through thirteen states, with a total path length of 3,241 kilometers (~ 2014 miles) (Locatelli et al., 2002).What made the April 1974 outbreak unique was the large number of long-track, violent tornadoes over a short amount of time (Furhmann et al., 2014, p. 697).

The significance of an outbreak depends on several factors. A few studies rank tornado outbreak significance by a meteorological factor known as ‘Destruction Potential Index’ or DPI (Thompson and Vescio, 1998; Doswell et al., 2006; Shafer and Doswell, 2010; and Knupp et al., 2014). DPI is the product of tornado area and F/EF-scale, plus one (1). This calculation complements the Fujita (now Enhanced Fujita) scale by attempting to standardize damage scores in sparsely populated areas that may lack manmade structures, an aspect on which the F/EF-scale is heavily dependent. The DPI methodology was adjusted in 1994 to consider a tornado's maximum width instead of mean width when calculating area, which then introduces a requirement to adjust DPI values from outbreaks prior to 1994 to make a fair comparison. Additionally, there is a requirement to adjust F/EF-scale for outbreaks prior to the newly operational EF-scale in 2007. According to Knupp, 2014, the 27 April 2011 outbreak is the strongest outbreak on record in terms of DPI, with a value of 21,980.

Judging tornado significance by economic loss can be highly biased without taking inflation into account. Additionally, costliness is biased by population trends and urbanization that continue to increase each year, which lead to more damages and losses. According to the NWS Storm Prediction Center (SPC) (2015), the most expensive tornado since 1950 was the Joplin, Missouri tornado in May 2011, with an adjusted-inflation amount of $2,921,780,000. This was followed by the Tuscaloosa, Alabama tornado from 27 April 2011, with an adjusted rate of $2,556,550,000 (SPC, 2015).

The 2011 Super Outbreak

The 2011 Super Outbreak, which occurred from 25 April to 28 April, was the largest (in number of tornadoes), most costly, and one of the most deadly tornado outbreaks ever recorded in U.S. history (Knupp et al., 2014). 27 April was the most active day of the event, with almost 200 confirmed tornadoes. The outbreak stretched over the southern, midwestern, and northeastern states, but its effects echoed across the country, and still linger to present day. With 62 confirmed tornadoes in Alabama, the outbreak holds the record for the most tornadoes in Alabama in a 24-hour period, claiming 243 lives (Graettinger et al., 2012). For the month of April, insurable losses from tornadoes exceeded US$11 billion, while the total loss was estimated at around US$15.5 billion (Knupp et al. 2014; Simmons, Sutter, and Pielke, 2012). Many of these tornadoes tracked across regions of complex topography, which makes this outbreak a good case study to get a better understanding of how substantial variations in topography may affect tornado structure and primarily intensity.

Spatial and Temporal Tornado Patterns in Alabama

Alabama is located in the southeastern United States, in the heart of a region colloquially known as Dixie Alley. Whereas Tornado Alley encompasses most of the Great Plains, where the topography is generally flat, the southeastern states are comprised of more complex terrain from the neighboring Appalachian Mountains. This hilly terrain often hides funnels clouds that may reach the ground, making it difficult for trained storm spotters to make ground truth determinations. Additionally, tornadoes in Dixie Alley are more likely to be rain-wrapped, embedded in shafts of heavy rain from the neighboring downdraft. Most of these storms also occur in the late afternoon and early evenings of especially warm, humid days, according to the National Weather Service (NWS, n.d.). However, relatively high nocturnal tornado probabilities may be another factor contributing to the relative maximum of tornado vulnerability in the Deep South (Ashley, Krmenec and Schwantes, 2008). Using a sun angle algorithm to determine sunrise and sunset, Coleman and Dixon (2013) determined that almost half (48.6%) of all southeastern tornadoes between 1973 and 2011 occurred at night (night is considered from sunset to sunrise). Looking from month-to-month, Alabama's severe weather season has two peaks – the primary peak from March to May, and the secondary peak in November and December (See Figure 1).

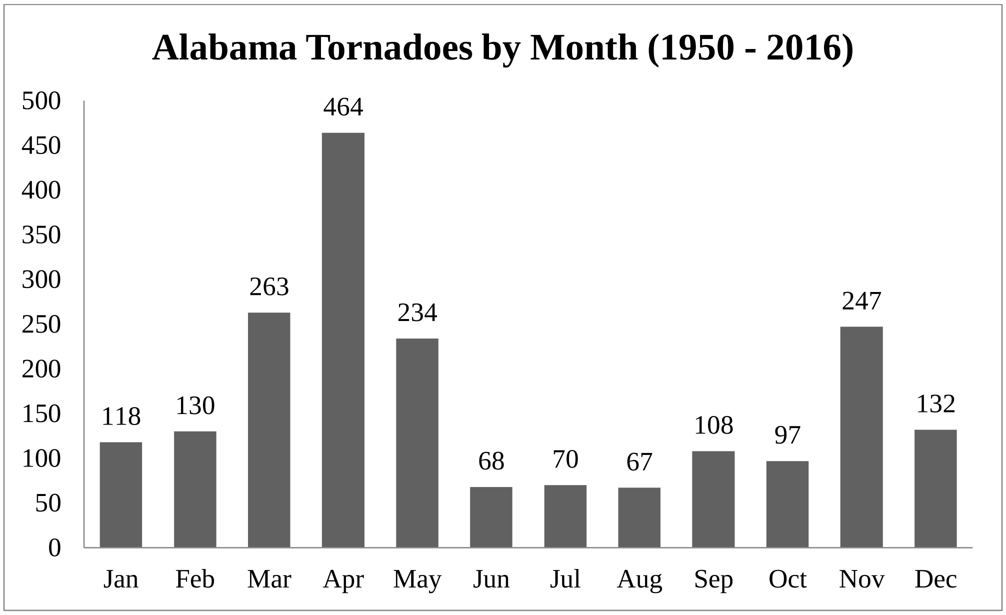

Figure 1: Alabama tornado frequency by month (Adjusted bar graph from the NWS Birmingham, Alabama and SPC)

Alabama has experienced its share of strong tornadoes, leading with the state of Oklahoma in terms of the highest number of EF5 tornadoes with eight since 1950 (NOAA, n.d.; Kazek, 2015). Eight may not seem like an impressive number, but EF5 tornadoes are extremely rare, with sustained winds of over 200 mph. An interesting observation of these eight documented tornadoes is that all of them occurred in the western half of Alabama, with the exception of two that dissipated in extreme North Alabama. Additionally, the majority of the confirmed EF4 tornadoes since 1950 also occurred in the western half of Alabama. Typically, these severe weather systems develop in Arkansas and Louisiana, and then travel into Mississippi in the morning hours and cross the Alabama state line during the afternoon/late evening hours based on the historical tornado activity. It is common for isolated cells ahead of a quasi-linear convective system (QLCS), or squall line, to spin up tornadoes during the middle to late afternoon. Once the system enters the eastern half of Alabama, these storms often weaken as the sun sets and the heat of the day diminishes, making the atmosphere more stable.

Spring of 2011 was one of the most active tornado seasons in the modern tornado record, with about 758 confirmed tornadoes across the United States (Knupp et al., 2014; NOAA, 2011; and Simmons, Sutter, and Pielke, 2012). According to the National Weather Service (2016), the highest number of tornadoes occurred in the state of Alabama on 27 April 2011 (62), followed by 45 on April 15th of the same year.

Data and Methods

GIS data were obtained from the National Weather Service in Birmingham website, which was produced and extracted from the National Weather Service Damage Assessment Toolkit (U.S. Department of Commerce, NOAA, National Weather Service, 2016). Although the website reports the links contain information for all 62 tornadoes whose damages were surveyed across the State of Alabama, the dataset “All Survey Points” contains detailed information for 29 confirmed tornadoes (with 889 data points) that traveled through Central Alabama on 27 April

2011. All of the data points were imported into the ArcGIS software and were spatially referenced using the Universal Transverse Mercator (UTM) projection. These points were plotted to show each of the 29 identified tornadoes. Digital Elevation Model (DEM) data at 1/3 arc-second (approx. 10 meter) resolution were obtained from the USGS National Elevation Dataset[1] and integrated into the GIS system. Of the 29 identified tornadoes in the NOAA dataset, the number of data points for each tornado varies with a wide range (2-177). Twelve of the 29 tornadoes have fewer than 10 data points, and seven of these have five or fewer points. Only eleven tornadoes within the dataset contain 20 or more data points. Although this dataset came with EF rating for all 29 confirmed tornadoes, we collected additional damage information from the NOAA Storm Events Database[2], which contains number of fatalities, injuries, damage estimates and other event-specific information and provides a holistic view of tornado damages for a particular location.

Classification of NOAA Storm Events/Damage Data - Damage Category

The damage narrative on the NOAA Storm Events Database seemed to be very subjective. Therefore, we quantified the narrative using the following criteria. If there is a death involved or heavy damages to property, it is designated as 'high’; if there is no death involved, but some property damage, it falls under ‘medium’; and if there are only few property damages or trees uprooted, it is categorized as 'low’. Upon quantifying the data, we assigned ‘high’ with a value of three (3), ‘medium’ with a value of two (2), and ‘low’ with a value of one (1). In case of no information available, we assigned a value of zero (1).

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[1] USGS National Elevation Dataset: https://viewer.nationalmap.gov/basic/

[2] NOAA Storm Events Database: https://www.ncdc.noaa.gov/stormevents/

Results and Discussion

Because of its incredible strength and ephemeral nature, a tornado’s intensity is nearly impossible to measure. An EF rating is determined after its impact through a series of damage surveys. The NOAA damage assessment from the 27 April tornado outbreak was conducted from 28 April to 2 May 2011 through which EF ratings were assigned. Figure 2 shows 29 identified tornado tracks with 889 data points depicting the EF ratings over a 1/3 arc-second DEM.

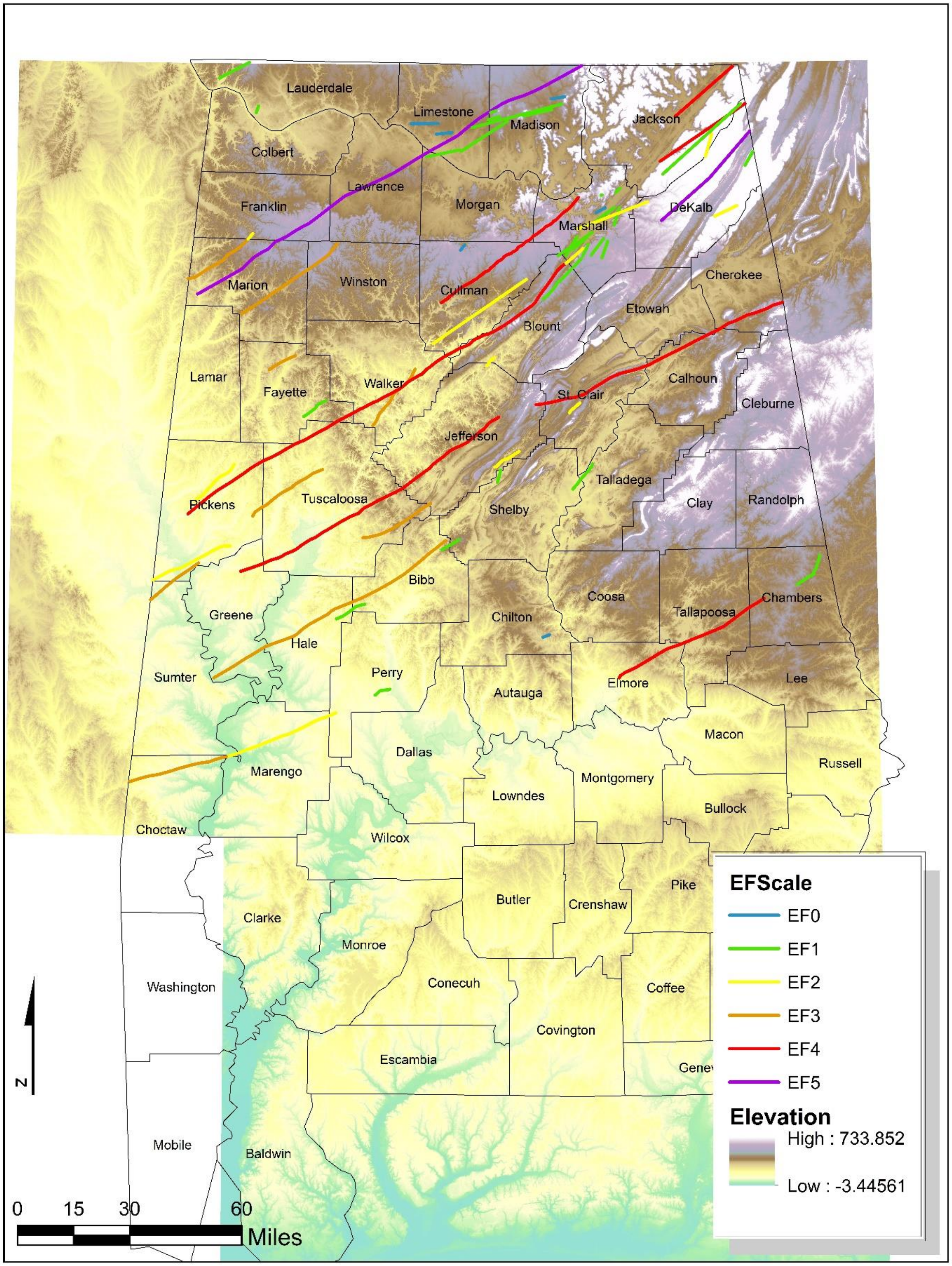

Figure 2: Surveyed Alabama tornado tracks normalized by EF-Scale with 1/3 arc-second DEM from the USGS National Elevation Dataset

There have been a number of studies in the past that have analyzed the effects of complex topography on tornado activity. A few of these studies have found that varying topography may influence a tornado’s motion (Ahmed and Selvam, n.d; Selvam, Strasser, Ahmed, Yousef, and Ragan, 2015), and translational speed (Karstens, Gallus, Lee, and Finley, 2013). Moreover, there has been evidence noted in previous studies that show higher damage totals related to higher elevation (Ahmed and Selvam, 2015; Selvam, Strasser, Ahmed, Yousef, and Ragan, 2015). Researchers at the University of Alabama at Huntsville (Lyza and Knupp, 2014) have found that topography is one of the many factors attributed to a tornado’s strength. In many cases, (NWS) maps showing previous outbreaks depict the tracks reaching peak strength adjacent to higher elevations.

As shown in Figure 2, all tornado tracks in our study area from 27 April 2011 generally had a southwest to northeast movement, which is the dominant direction of thunderstorms in the region (Klockow, Peppler, and McPherson, 2014). However, we found some correlation between tornado intensity and elevation as depicted by Figure 3, where NOAA data points by EF-scale are plotted into different elevation groups. The histogram shows that tornado data points with high intensity i.e. EF4 and EF5 are higher in higher elevation, while data points with low to medium intensity i.e. EF0 to EF3 are in abundance (especially EF3) in lower elevation. The Pearson's R or Pearson Product-Moment Correlation Coefficient (PPMCC) in IBM SPSS Statistics determines a significant correlation ($p < 0.05$) between elevation and the total number of EF4 and EF5 data points. We also found a significant negative correlation between elevation and EF3 data points ($p = 0.026$), which implies a strong relationship of EF3 and elevation, when elevation is decreasing. These findings can be critical in land use planning or mitigation decision-making to take protective measures against high intensity tornadoes.

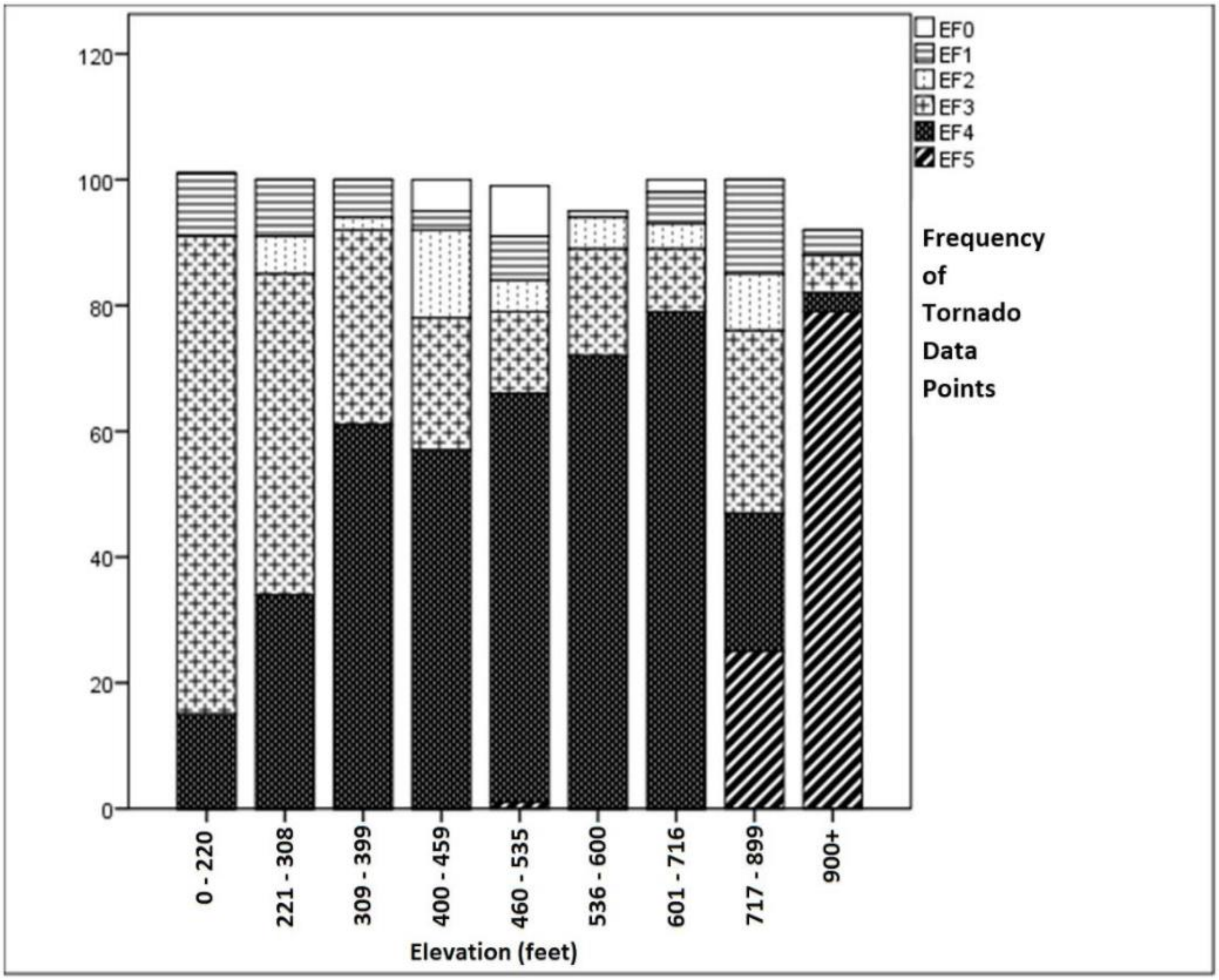

Figure 3: NOAA data points of April 27th tornadoes in EF-Scale in different elevation groups

We also analyzed the relationship between elevation and tornado damage ratings measured from the NOAA Storm Events Database. Table 1 shows the cumulative damage categories in each elevation group (e.g. summation of high, medium and low damage ratings). The totals are relatively close for each elevation group, which indicate the damages from tornadoes are consistent in all elevations. This is probably due to heavy damages from a high number of EF3 data points at lower elevations as well as EF4 and EF5 data points from mid- to higher elevations, as shown in Figure 3. The Pearson's R coefficient also reflects this finding as it determines there is no significant correlation ($p = 0.154$) between elevation and damage category.

Elevation (feet)	Cumulative Damage Category
0-220	181
221-308	186
309-399	145
400-459	142
460-535	153
536-600	191
601-716	167
717-899	194
900+	228

Table 1: Cumulative damage categories in different elevation groups

We also investigated the temporal pattern of these tornadoes. Based on temporal data from NOAA's National Centers for Environmental Information Storm Events Database, from 0000 CDT 27 April 2011 to 0000 CDT 28 April 2011, there were two peaks of tornado activity (See Figure 4). The first peak occurred in the early morning hours from 0300 CDT to 0600 CDT, and the second occurred in the afternoon hours from around 1400 CDT to 2000 CDT. This is consistent to previous studies' assessments of the nocturnal peak in tornadoes in the Southeast (Sims and Baumann, 1972; Ashley, 2007; Ashley, Krmenec, and Schwantes, 2008; Kis and Straka, 2010). Looking at the 27 April event, the nocturnal tornadoes are also in agreement with those findings that note consistencies between QLCS (squall line) and nocturnal tornadoes. The early morning hour tornadoes that occurred on 27 April were the product of a QLCS with increasing wind shear.

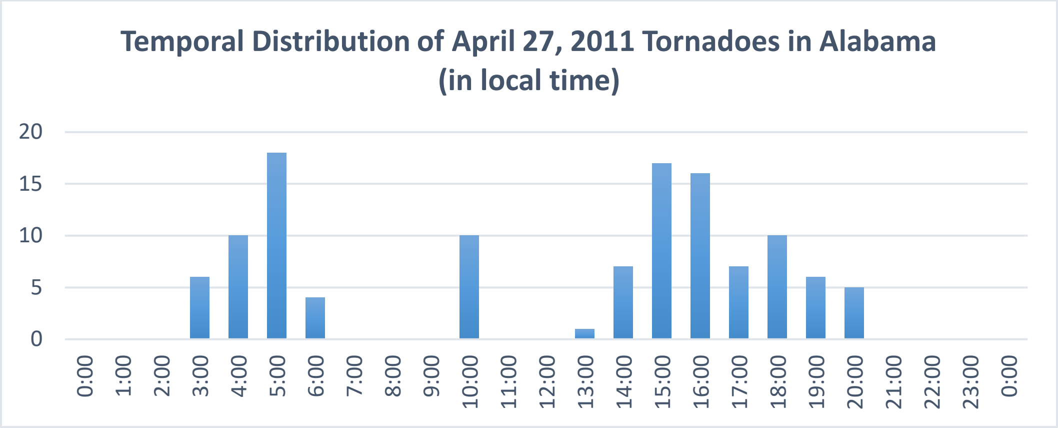

Figure 4: Temporal Distribution of 27 April 2011 Tornadoes in Alabama, based on temporal data (in Central Daylight Time) from NOAA's National Centers for Environmental Information

Case Study – The Tuscaloosa Tornado

On 27 April 2011 at approximately 22:00 UTC, a supercell thunderstorm spawned a tornado southwest of the City of Tuscaloosa, AL. The tornado crossed I-359 and tracked across the residential areas of Tuscaloosa. A hardened room in a neighborhood was the only structure remaining after debris was cleared[3] (FEMA, 2013). The tornado then passed over the intersection of 15th Street and McFarland Boulevard, one of the busiest intersections in the city, leaving a trail of destruction approximately a half of a mile wide. The storm continued into Jefferson County and finally dissipated in northeast Birmingham before entering St. Clair County. In addition to the hundreds of millions of dollars in damage in Tuscaloosa County alone, 44 lives were claimed, and more than 1500 were injured. Following damage assessments, the tornado was designated as an EF-4. Figure 5 shows the survey points following the track in Tuscaloosa, crossing McFarland Boulevard. With this particular tornado, we utilized GIS to investigate the specific damage of the built infrastructure and its relationship to elevation.

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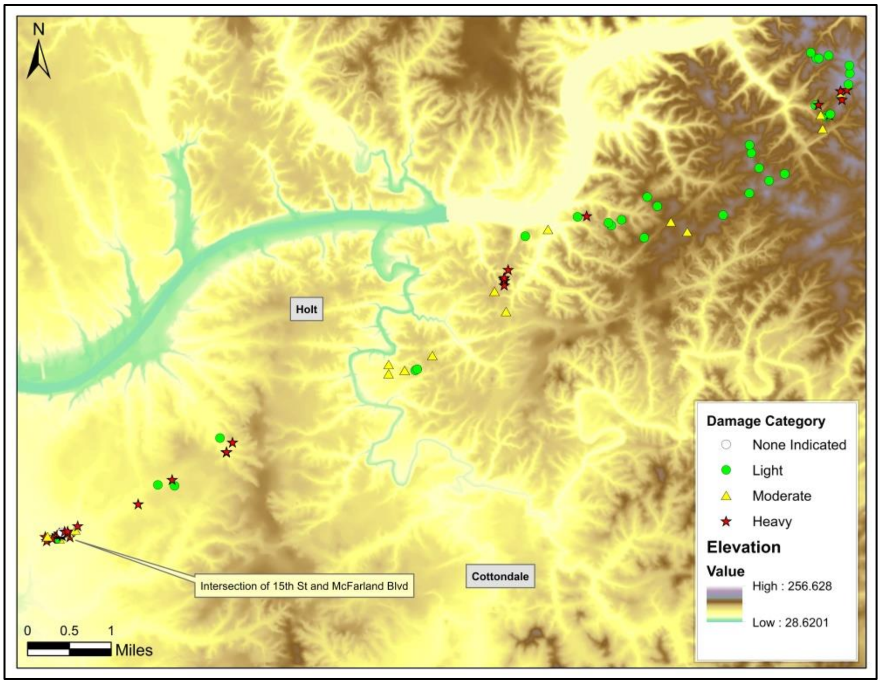
[3] More information on the "hardened structure" can be found in FEMA's publication, *FEMA P-908, Mitigation Assessment Team Report – Spring 2011 Tornadoes: April 25-28 and May 22 (2012)*



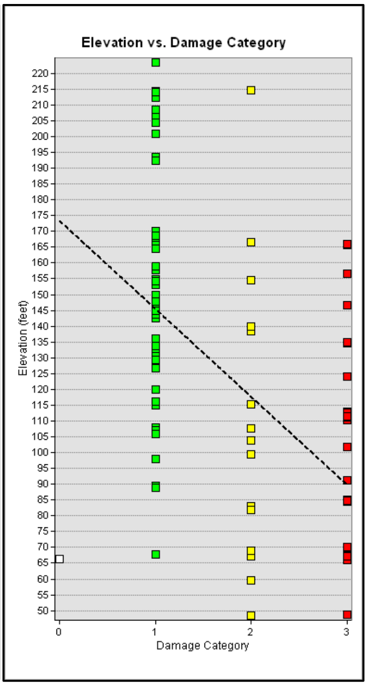


Figure 5: Tuscaloosa-Birmingham tornado track (based on NOAA data points) normalized by damage category over a 1/3 arc second DEM in the City of Tuscaloosa

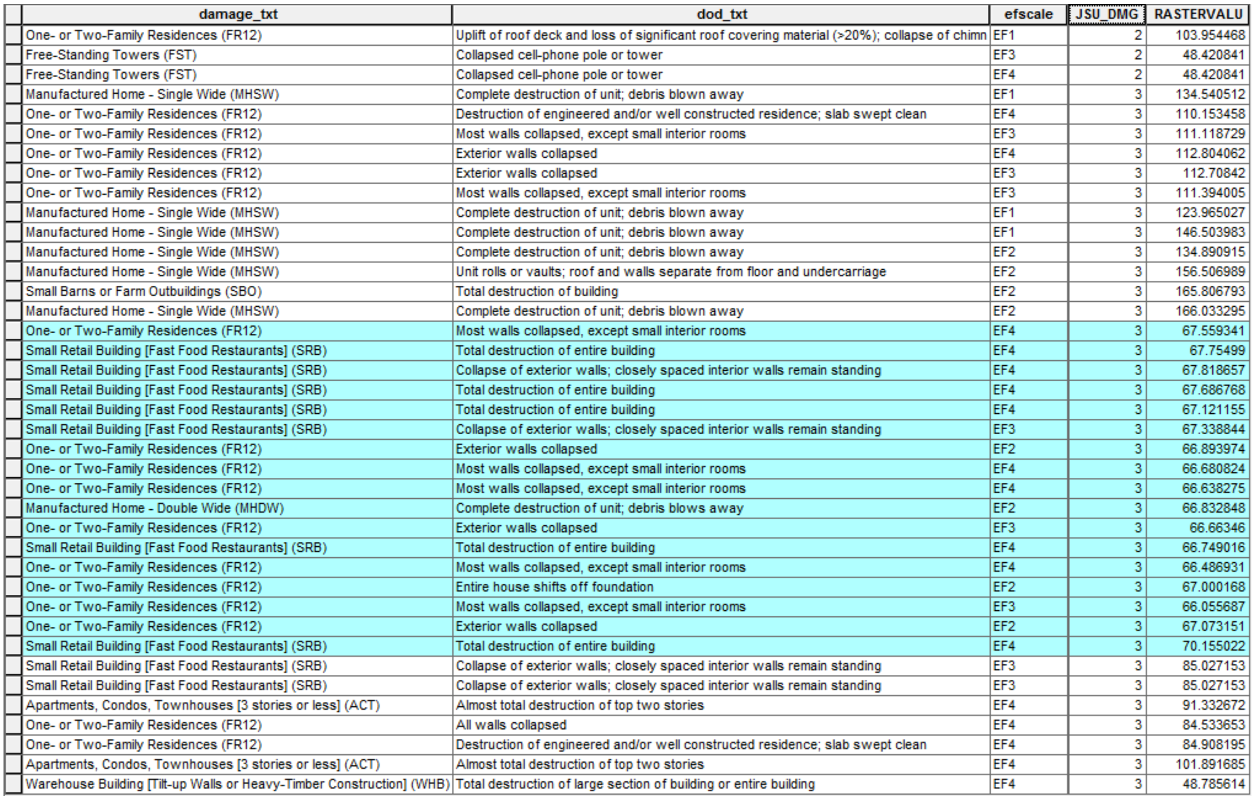
Figure 6: Scatterplot of Elevation vs. Damage Category

The survey points were imported into ESRI's ArcGIS' ArcMap program, and spatially referenced using the Universal Transverse Mercator (UTM) projection. Points that were part of the Tuscaloosa-Birmingham tornado track were selected and exported to separate it from the tracks layer. The track of survey points was then clipped to the Tuscaloosa County boundary. The points were normalized by damage category (see *Damage Classification* section for more details) and coded based on damage classification (see map legend in Figure 5).

A USGS NED 1/3 arc-second (approx. 10 meter) Digital Elevation Model (DEM) of Alabama, including Tuscaloosa County and a few surrounding counties from the National Elevation Dataset, was imported into ArcMap along with the Tuscaloosa tornado track, normalized by damage category. We extracted the elevation values from the DEM based on the damage category using the Spatial Analyst tool, extract values by points. This also appends the RASTERVALU (elevation) value to the new points in the table. This enabled us to graph the relationship between elevation and damage. The scatterplot in Figure 6 shows that most of the survey points designated with a damage category of 3 (heavy damage) were found to occur in lower elevations. Figure 5 shows where the tornado produced slightly less damage as it advanced toward higher elevations.

Out of the 109 data points associated with the Tuscaloosa-Birmingham Tornado track in Tuscaloosa County, 36 (33.0%) were designated as heavy damage (damage category = 3). Of those 36 points, 23 (63.9%) were taken at an elevation below 100 feet. Based on this map depicting the Tuscaloosa-Birmingham tornado track, and the corresponding attribute table of those points given a damage category of 3, it can be concluded that the majority of the heaviest damage occurred in relatively lower elevations.

Focusing on those survey points in the Tuscaloosa tornado path that were categorized with a damage category of 3, most of the structural damage was to residential homes (one- or two- family residences and manufactured homes), followed by small retail buildings (See Figure 7). The columns highlighted in blue in Figure 7 indicate points located within a half mile radius of the intersection of McFarland Boulevard and 15th Street, one of the busiest intersections in the city surrounded by several businesses, including a mall. This accounts for 17 of the 36 points assigned a damage category of 3, so it is difficult to attribute damage to elevation without also considering the effects of development and urbanization.



damage_txt	dod_txt	efscale	JSU_DMG	RASTERVALU
One- or Two-Family Residences (FR12)	Uplift of roof deck and loss of significant roof covering material (>20%); collapse of chimn	EF1	2	103.954468
Free-Standing Towers (FST)	Collapsed cell-phone pole or tower	EF3	2	48.420841
Free-Standing Towers (FST)	Collapsed cell-phone pole or tower	EF4	2	48.420841
Manufactured Home - Single Wide (MHSW)	Complete destruction of unit; debris blown away	EF1	3	134.540512
One- or Two-Family Residences (FR12)	Destruction of engineered and/or well constructed residence; slab swept clean	EF4	3	110.153458
One- or Two-Family Residences (FR12)	Most walls collapsed, except small interior rooms	EF3	3	111.118729
One- or Two-Family Residences (FR12)	Exterior walls collapsed	EF4	3	112.804062
One- or Two-Family Residences (FR12)	Exterior walls collapsed	EF3	3	112.70842
One- or Two-Family Residences (FR12)	Most walls collapsed, except small interior rooms	EF3	3	111.394005
Manufactured Home - Single Wide (MHSW)	Complete destruction of unit; debris blown away	EF1	3	123.965027
Manufactured Home - Single Wide (MHSW)	Complete destruction of unit; debris blown away	EF1	3	146.503983
Manufactured Home - Single Wide (MHSW)	Complete destruction of unit; debris blown away	EF2	3	134.890915
Manufactured Home - Single Wide (MHSW)	Unit rolls or vaults; roof and walls separate from floor and undercarriage	EF2	3	156.506989
Small Barns or Farm Outbuildings (SBO)	Total destruction of building	EF2	3	165.806793
Manufactured Home - Single Wide (MHSW)	Complete destruction of unit; debris blown away	EF2	3	166.033295
One- or Two-Family Residences (FR12)	Most walls collapsed, except small interior rooms	EF4	3	67.559341
Small Retail Building [Fast Food Restaurants] (SRB)	Total destruction of entire building	EF4	3	67.75499
Small Retail Building [Fast Food Restaurants] (SRB)	Collapse of exterior walls; closely spaced interior walls remain standing	EF4	3	67.818657
Small Retail Building [Fast Food Restaurants] (SRB)	Total destruction of entire building	EF4	3	67.686768
Small Retail Building [Fast Food Restaurants] (SRB)	Total destruction of entire building	EF4	3	67.121155
Small Retail Building [Fast Food Restaurants] (SRB)	Collapse of exterior walls; closely spaced interior walls remain standing	EF3	3	67.338844
One- or Two-Family Residences (FR12)	Exterior walls collapsed	EF2	3	66.893974
One- or Two-Family Residences (FR12)	Most walls collapsed, except small interior rooms	EF4	3	66.680824
One- or Two-Family Residences (FR12)	Most walls collapsed, except small interior rooms	EF4	3	66.638275
Manufactured Home - Double Wide (MHDW)	Complete destruction of unit; debris blows away	EF2	3	66.832848
One- or Two-Family Residences (FR12)	Exterior walls collapsed	EF3	3	66.66346
Small Retail Building [Fast Food Restaurants] (SRB)	Total destruction of entire building	EF4	3	66.749016
One- or Two-Family Residences (FR12)	Most walls collapsed, except small interior rooms	EF4	3	66.486931
One- or Two-Family Residences (FR12)	Entire house shifts off foundation	EF2	3	67.000168
One- or Two-Family Residences (FR12)	Most walls collapsed, except small interior rooms	EF3	3	66.055687
One- or Two-Family Residences (FR12)	Exterior walls collapsed	EF2	3	67.073151
Small Retail Building [Fast Food Restaurants] (SRB)	Total destruction of entire building	EF4	3	70.155022
Small Retail Building [Fast Food Restaurants] (SRB)	Collapse of exterior walls; closely spaced interior walls remain standing	EF3	3	85.027153
Small Retail Building [Fast Food Restaurants] (SRB)	Collapse of exterior walls; closely spaced interior walls remain standing	EF3	3	85.027153
Apartments, Condos, Townhouses [3 stories or less] (ACT)	Almost total destruction of top two stories	EF4	3	91.332672
One- or Two-Family Residences (FR12)	All walls collapsed	EF4	3	84.533653
One- or Two-Family Residences (FR12)	Destruction of engineered and/or well constructed residence; slab swept clean	EF4	3	84.908195
Apartments, Condos, Townhouses [3 stories or less] (ACT)	Almost total destruction of top two stories	EF4	3	101.891685
Warehouse Building [Tilt-up Walls or Heavy-Timber Construction] (WHB)	Total destruction of large section of building or entire building	EF4	3	48.785614

Figure 7: Attribute table of NOAA data points from the Tuscaloosa-Birmingham Tornado track, clipped to Tuscaloosa County, showing only the points with a damage category of 3*(The points highlighted in blue designate points located within half a mile of the intersection of McFarland Boulevard and 15th Street)*

Moreover, as evident from Figures 8 and 9, the Tuscaloosa tornado damage track shows no curvature or deviation in its path. This is consistent to Ahmed and Selvam's (2015) findings that the tornado damage path is almost straight, even though the terrain is hilly (p.5).

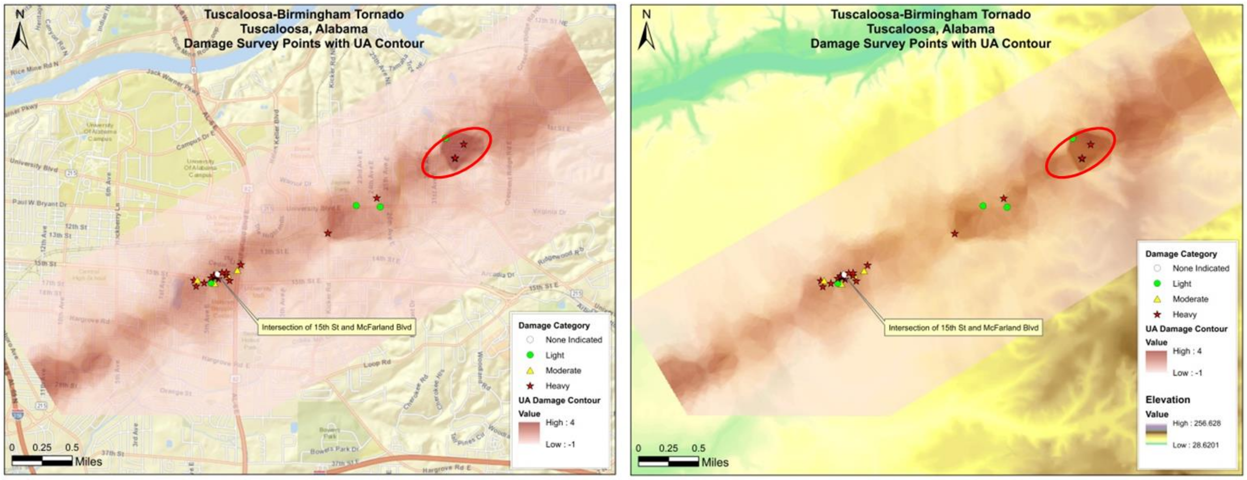


Figure 8 & 9: NOAA Data Points layer with Tuscaloosa Damage Contour (courtesy of The University of Alabama) without (8) and with (9) the DEM

Recent studies from the University of Arkansas (Ahmed and Selvam, 2015; Selvam, Strasser, Ahmed, Yousef, and Ragan, 2015) show tornadoes tend toward higher elevations and cause a greater amount of damage as they ascend uphill. Our case study from the Tuscaloosa-Birmingham tornado in Tuscaloosa County tends to contradict suggestions that tornado-generated damage occurs significantly more often in higher elevations. Our case study shows that the majority of the NOAA survey points that we designated as heavy damage points were taken at relatively lower elevations (compared to the rest of Tuscaloosa County and the rest of Alabama). Additionally, the evidence from our case study also argues suggestions that tornadoes divert from their original path in hilly terrain. The Tuscaloosa-Birmingham tornado shows little to no diversion based on the damage track analyzed in the case study.

Conclusion

This study investigated spatial and temporal patterns of the historical 27 April 2011 tornado outbreak in Central Alabama. The results of 29 documented tornado tracks (889 data points in total) in Central Alabama suggest that higher intensity tornadoes (EF4 and EF5 data points) occurred in relatively higher elevations and there is a significant relationship between EF3 data points and lower elevations. However, further investigation of tornado damages that include fatalities and injuries based on NOAA Storms Events Database show that significant damages can occur at any elevation as the cumulative damage is almost similar across all elevation groups and there is no significant relationship between elevation and damage category. Strong tornadoes such as EF3 and EF4 can also occur frequently and cause damage in lower elevations. Our case study on Tuscaloosa-Birmingham tornado also shows that heavy damages occurred at relatively lower elevations and argues suggestions from other studies that tornadoes divert from their original path in hilly terrain as we found little or no diversion based on the tornado track. Additionally, the temporal trends of this particular outbreak are consistent with other studies' evidence that show a small peak in nocturnal tornado activity in the southeastern U.S. The findings from this research may be useful to the emergency management community, planners and the weather enterprise in that it shows the variation of vulnerability over space and time in the context of natural hazards.

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