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# Vulnerability due to Nocturnal Tornadoes

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**NORTHERN ILLINOIS UNIVERSITY**

# Vulnerability due to Nocturnal Tornadoes

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# HONORS CAPSTONE ABSTRACT

This study investigates tornado fatalities that occurred between sunset and sunrise from 1985 to 2020. Previous literature has suggested that nocturnal tornadoes are associated with enhanced vulnerability because they are difficult to spot and occur when tornado warning efficacy is at a minimum. Furthermore, nocturnal tornadoes tend to occur when a majority of the public is asleep in particularly vulnerable housing and potentially unaware of the threat for severe weather. Results echo previous findings that nocturnal tornadoes are deadly, especially in manufactured housing and in the Southeastern United States. From 1985 to 2020, 36.9% of tornado fatalities occurred at night, with 58% of these fatalities occurring in mobile homes. The vulnerability of these weaker structures is further highlighted, as 57.9% of tornado fatalities occurred in either permanent or mobile homes during the day, while these structures were associated with 87.1% of nocturnal tornado fatalities. Spatial analysis reveals that the Southeastern United States continues to exhibit high tornado fatality rates for both daytime and nocturnal events. These findings reveal that nocturnal tornadoes continue to be a problem in the United States and, if injuries and fatalities from tornadoes are to be reduced, a concerted effort focused on mitigating the effects of these nighttime events is needed.

**Introduction:**

The annual number of tornado fatalities has decreased in the United States across the past century (Brooks and Doswell 2002) due to the advancements in radar technology, and improved warning communication to the public. Despite this decrease, tornado related fatalities continue to occur, especially in outbreak events (e.g., April 2011), during the overnight hours, and outside of the traditional severe weather season. Specifically, tornadoes occurring between sunrise and sunset, nocturnal tornadoes, cause a disproportionate number of deaths when compared to their frequency of occurrence (Ashley et al. 2008, Anderson-Frey and Brooks 2019), implying nocturnal tornadoes are more deadly than their daily counterparts (Ashley et al. 2008, hereafter Ashley). This enhanced vulnerability to nocturnal events occurs because nocturnal tornadoes are usually difficult to spot and warn (Brotzge et al. 2010) and present a challenge to forecasters since they can occur in atmospheric environments with ingredients that are not typically considered overly favorable for tornadoes (Kis and Straka 2010). Additionally, most of the public is asleep in weak structures during these events and may rely on technology not designed to wake them to receive warning information (Mason et al. 2018). Furthermore, nocturnal tornadoes are more common in the Southeast U.S., which is a region where extremely wind-vulnerable housing (e.g., weak framed or manufactured homes) is prevalent (Strader and Ashley 2016). This study serves as an update on previous research that has examined the vulnerability due to nocturnal tornadoes, including data from a contemporary period from 1985 - 2020.

**Background:**

Several studies have investigated the vulnerability associated with nocturnal tornadoes or have studied individual components influencing vulnerability considering all tornadoes. Ashley found that from 1950 – 2005, 27.3% of tornado events were nocturnal, with 39.3% of tornado

fatalities, and 42.1% of killer tornadoes taking place at night. A more updated look at this figure comes from Anderson-Frey and Brooks (2019), who used tornado data and fatality information from 2003 – 2017 but did not use the same method for classifying nocturnal tornadoes as Ashley. Findings indicate that that daytime (overnight) tornadoes comprised nearly 48.6% (16.6%) of all tornadoes, and approximately 49.2% (20.4%) of all tornado fatalities, but only 39.1% (24.7%) of all killer tornadoes. Both studies conclude that nocturnal tornadoes account for a disproportionate number of fatalities. Additionally, research has indicated that nocturnal fatalities occur at higher rates in weak framed structures or manufactured housing. Ashley found that 44.8% and 26.2% of tornado fatalities occurred in mobile homes and permanent structures respectively, but more than 60% of mobile home fatalities occurred at night. This is supported by recent work from Strader and Ashley (2016), who found that mobile homes accounted for 54% of all housing related tornado deaths from 1985 to 2017, despite mobile homes representing only 6% of the entire U.S. housing stock.

Anderson-Frey and Brooks (2019) noted northern Alabama, southern and middle Tennessee, and southwestern Missouri as locations for the most frequent occurrences of deadly tornadoes. Similarly, Ashley found the American South to have the highest percentages of nocturnal tornadoes, nocturnal fatalities, and number of nocturnal killer events from 1950 – 2005, compared to all other regions of the U.S. Other work has supported these regional findings or has gone further to investigate the unique vulnerability of the southeast to tornadic events. Besides a higher frequency of nocturnal tornadoes, the prevalence of manufactured housing, high percentages of socioeconomically and demographically vulnerable populations (Strader and Ashley 2018), and lack of resources or community shelters for residents who wish to evacuate wind vulnerable housing (Ash et al 2020) have been suggested as contributors to the southeast's

high fatality rates. Additionally, Brotzge and Erickson (2010) suggest that geographic regions, such as the southeast, with high numbers of weak, linear, or nocturnal tornadoes may experience a higher number of unwarned events (e.g., no tornado warning is issued when there is a tornado on the ground). Unfortunately, other work assessing the changing risk landscape has indicated that tornado disaster potential in the southeast will only increase, as increases in the built environment and population act to amplify the abovementioned vulnerabilities (Strader et al. 2017).

The warning communication process also plays a critical role in nocturnal tornado vulnerability. While there is a chance nocturnal storms may go unwarned, the probability an individual does not receive an issued tornado warning at night is a much greater threat. In a study following the March 2020 Tennessee nocturnal tornadoes, less than half of an interviewed group felt strongly that they would receive a nighttime tornado warning (Ellis et al. 2020). Loss of power, poor cellular coverage in rural locations, lack of NOAA Weather Radios, heavy sleep, and hearing impairments have been cited as barriers to receiving warnings at night (Walters et al. 2020). Individuals tend to rely on social media and television to wake them in the event of severe weather (Mason et al. 2018), listen for outdoor tornado sires although they are not intended to warn individuals indoors of an incoming tornado (Walters et al. 2020), or in the event of receiving a warning will seek out additional information or visual confirmation of a tornado before taking shelter (Mason et al. 2018). These factors combined reveal that there is ample room for improvement in communicating the risk presented by nocturnal tornadoes, as well as improving to nocturnal warning process to help mitigate the vulnerability to nocturnal events.

While the focus of this study does not relate to advancing knowledge in forecasting nocturnal tornadoes, or their convective environments, both factors contribute to the

vulnerability of nocturnal events. Anderson-Frey and Brooks (2019) found nocturnal tornadoes make up a disproportionately high percentage of nocturnal fatalities, but many nocturnal deaths occurred in marginal tornado environments. Others have found the predictability of nocturnal tornadoes to be lower, especially in the southeastern United States (Bunker et al. 2019) with respect to traditional forecasting methods and parameters. This region has a different climatological risk of tornadoes than other areas of the U.S. (Krocak and Brooks 2018), as the diurnal cycle does not play as strong as a role for tornado frequency (Krocak and Brooks 2018, Bunker et al. 2019) as it does in other areas. Overall, many traditional methods for forecasting tornadoes may be misleading in nocturnal situations, and highly relied upon tornado climatologies may be misguiding (Kis and Straka 2010), which could influence warning decisions and communication, and therefore enhance vulnerability.

**Methods:**

This study uses fatality information acquired from the National Climatic Data Center's *Storm Data,* and from historical archives of tornado fatality data provided by the National Oceanic and Atmospheric Administration's (NOAA) Storm Prediction Center. Data included the location of the fatality (e.g., state, county, closest municipality, latitude, longitude), temporal information (e.g., month, day, year, local time), and other demographics (e.g., sex and age). Collected information was verified using google maps, news sources, and warning verification tools such as Iowa State University's National Weather Service Storm Based Warning Verification (https://mesonet.agron.iastate.edu/cow/). Due to differences in reporting techniques between different resources, all fatality times were converted to Local Standard Time (LST). This conversion accounts for differences in time zones and potential observation of daylight savings for solar calculations.

To classify a tornado fatality as nocturnal, local sunset-sunrise calculations were performed using a Python package known as Astral (https://astral.readthedocs.io/en/latest/index.html). The package is based on NOAA's sunrise, sunset, and solar position calculators (https://www.esrl.noaa.gov/gmd/grad/solcalc/calcdetails.html), and uses the methodology from Zimmerman (1981) to account for the effect of refraction, when the sun appears to be higher than its actual position in the sky. Like Ashley, three time periods are defined for analysis: day (local sunrise to local sunset), evening (local sunset to local midnight), and overnight (local midnight to sunrise). Descriptive statistics and spatial analyses were generated using Python and ArcGIS, with specific use of the Albers Equal Area Conic Projection for spatial analysis.

**Results and discussion:**

*a) Temporal Analysis*

From 1985 – 2020, there were a total of 2,370 tornado fatalities in the U.S., with 1,496 (63.1%) of these of these fatalities occurring during the day and 874 (36.9%) attributed to nocturnal events. An average of 94.8 annual tornado deaths occurred over the 25-year period, with 59.8 annual daytime deaths and 34.9 nocturnal deaths occurring across 37 different states. The cool season months of October – March saw a higher proportion of deaths from nocturnal tornadoes (60.2%), while April – September exhibited a lower proportion of nocturnal tornado fatalities (39.8%). All fatalities occurring between 2100 and 0400 LST were classified as nocturnal, and all fatalities occurring between 0700 LST and 1500 LST were classified as daytime. Fatalities occurring between 0400 LST and 0700 LST, as well as 1500 LST and 2100 LST were classified as either nocturnal or daytime, depending on the location of fatality and the time of year. In the first period consisting of the early morning hours, the number of nocturnal deaths per local hour decreased until all deaths were classified as daytime, while the second

period, the early evening hours, the number of nocturnal deaths per local hour increased until all deaths were classified as nocturnal. Approximately 63.1% of tornado fatalities occurred during the day, 23.5% occurred in the evening, and 13.3% occurred in the overnight hours, with daytime fatalities peaking around 1700 LST, and nocturnal fatalities peaking near 2000 LST (**Figure 2**).

These statistics are similar to findings from Ashley for the period of 1950 - 2005. Overall, the proportion of nocturnal fatalities is slightly lower compared to Ashley (36.9% compared with 39.3%). The time periods of day, evening, and overnight show similar proportions to previous work, comparing 63.1% of daytime fatalities to 60.7% (1950 – 2005), 23.5% of evening fatalities to 30% (1950 – 2005), and 13.3% of overnight fatalities to 9.3% (1950 – 2005). The proportion of daytime and overnight fatalities have increased slightly, while the proportion of evening fatalities has decreased. The slight changes in proportions between the two time periods could potentially be explained by the presence of large daytime outbreak events in the current dataset. For example, 2011 saw 553 fatalities of which almost 84% occurred during the day, and nearly 57% from a single outbreak. Additionally, Ashley found cool and transition season months of November – April to have the highest nocturnal fatality proportions.

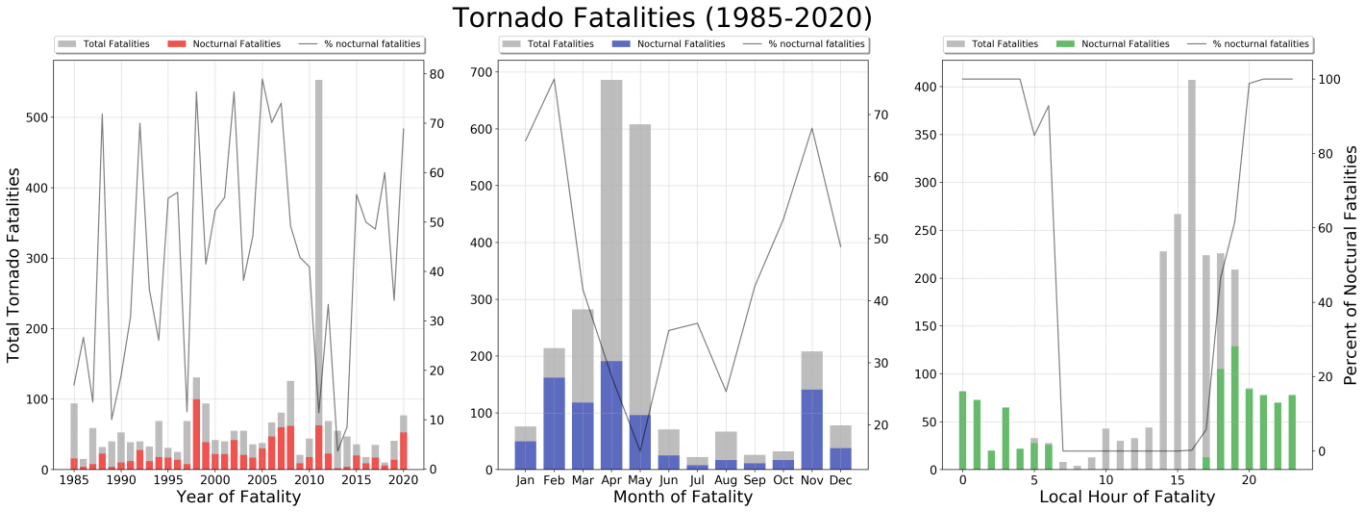


***Figure 2:*** *Yearly (left), monthly (center), and hourly (right) tornado fatalities from 1985 – 2020.*

*b) Spatial analysis*

Tornado fatalities occurred in 37 different states from 1985 to 2020, with 57.2 % of deaths occurring in the southeast region. Similar to previous findings, daytime tornado fatalities exhibited two maxima (**Figure 3**) over southwestern Missouri (14%) and northern Alabama (23%), while the nocturnal fatality maximum (**Figure 3**) was centered over southern Tennessee (19%) and northern Alabama (11%). Although Georgia (10%) and Florida (10%) were not classified as locations for the highest nocturnal tornado fatality frequency, they still exhibited a high proportion of nocturnal fatalities. A similar proportion of nocturnal fatalities occurred in the southeast (58%) when compared to overall fatalities, but daytime fatalities had a slightly different distribution including portions of the Midwest and the entire southern United States.

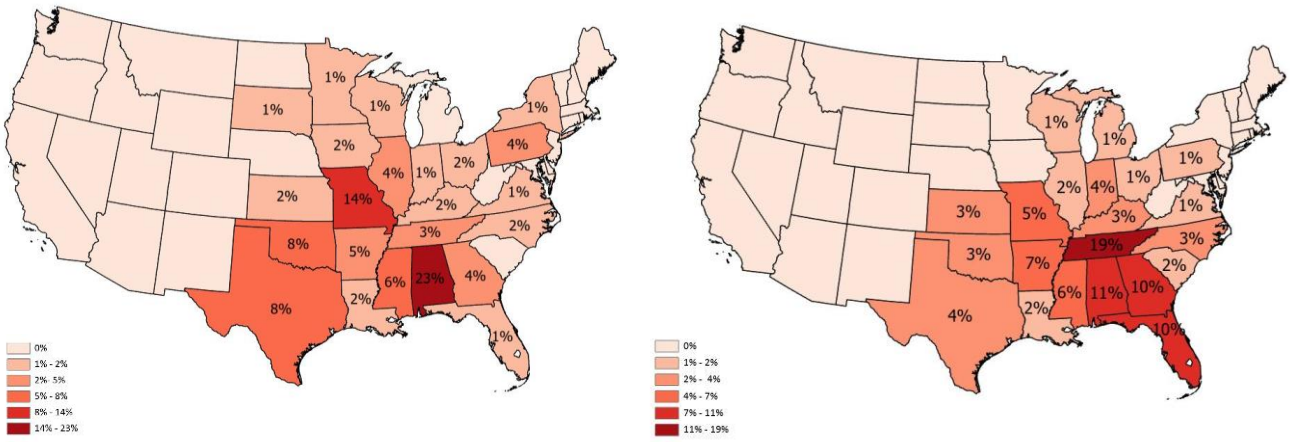


***Figure 3****: Distribution of daytime fatalities (left) and distribution of nocturnal fatalities (right) across the United States.*

A state-by-state comparison of nocturnal fatalities (**Figure 4**) helps identify which states may be especially vulnerable due to exposure, or high prevalence of other factors such as manufactured housing. It is important to compare the total number of fatalities per state to the percent per state that are nocturnal. For example, 100% of the tornado fatalities occurring in New

Mexico were nocturnal, but throughout the 25-year period, the state only had two tornado fatalities occur. On the other hand, 84% of the tornado fatalities occurring in Florida are considered nocturnal, and throughout the 25-year period, the state experienced 104 fatalities, indicating a higher level of vulnerability than New Mexico. The states of Florida, Georgia, and Tennessee display the highest proportion of nocturnal fatalities when compared to the overall count. Other states displaying high counts but low proportions of nocturnal fatalities, such as Missouri and Alabama, tend to experience a high number of daytime fatalities, usually in outbreak events.

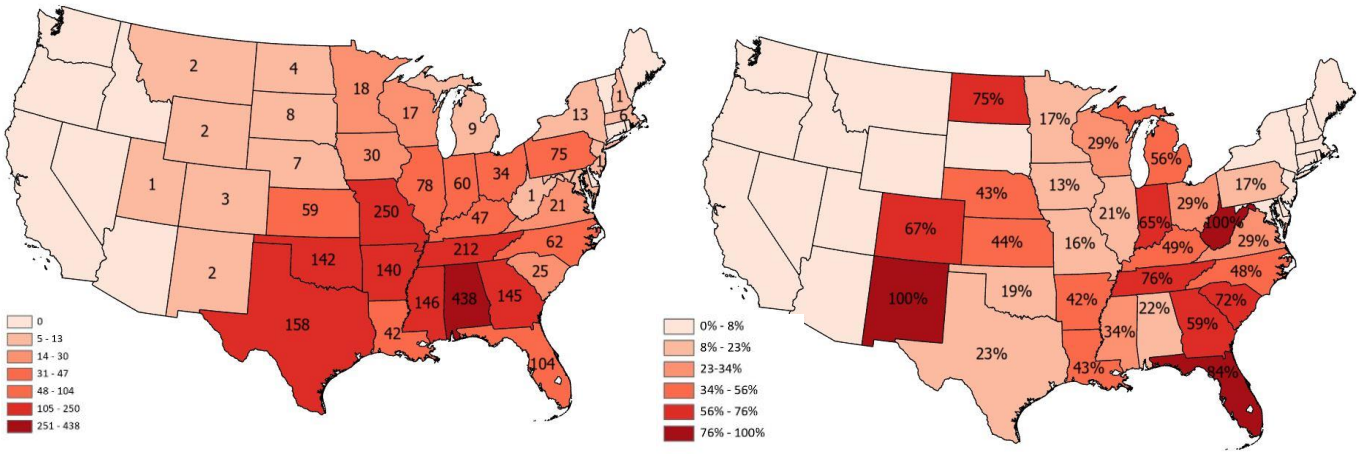


***Figure 4:*** *Count of fatalities per state (left) and percent of fatalities that are nocturnal by state (right). Only states with fatalities (left), or greater than 8% nocturnal fatalities are labeled (right).*

Fatalities occurred across six location types: permanent homes (31.1%), mobile homes (39.7%), permanent structures (8.6%), vehicles (7.6%), in outside or open areas (2.9%), or were unknown (6.1%). Permanent structures are buildings like schools and businesses, that are generally constructed with stronger frames and concrete, when compared to permanent homes (single family homes) or mobile homes. Overall, permanent, and mobile homes contained the highest proportions of deaths with 87.1% (57.9%) of nocturnal (daytime) occurring between these two categories (**Figure 5**). Mobile homes were especially vulnerable at night during this

period, accounting for 58% of all nocturnal fatalities. For the 1950 – 2005 period, Ashley found 60.8% of mobile home fatalities occurred at night. The small difference in these proportions could be explained by a higher number of fatalities occurring in permanent homes or structures during the daytime hours. Despite this, overall findings indicate mobile homes are still particularly vulnerable to nocturnal events. Of the 507 nocturnal fatalities that occurred in mobile homes, 49.1% occurred in the southern states of Arkansas, Mississippi, Alabama, Georgia, and Florida, compared to Ashley's 55.2% across the same five states. However, besides the southeast, many nocturnal tornado deaths occurred in mobile homes in Tennessee and Indiana, suggesting that while the proportions between the Ashley's study and this one may differ, mobile homes continue to remain deadly for nocturnal events but in more areas of the U.S. than just the southeast.

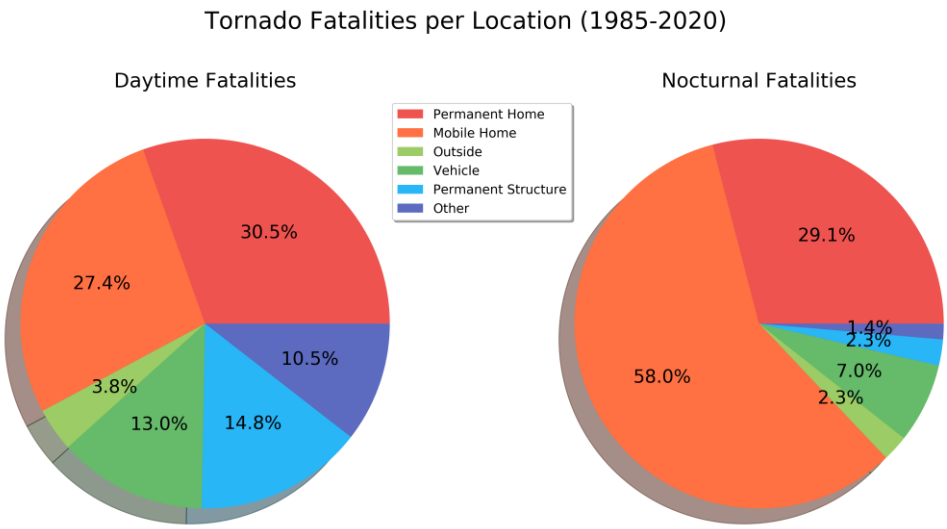


***Figure 5:*** *Daytime (left) and nocturnal (right) fatalities by location in which the fatality was recorded from 1985 – 2020.*

Finally, a brief analysis of demographic factors such as sex and age revealed uniform findings across all categories. Approximately 47.64% of all fatalities in the dataset were female, 48.14% of all fatalities were male, and the sex of remaining proportion of fatalities was

unknown. When examining daytime fatalities, approximately 46% of daytime deaths were male, and 46% of daytime deaths were female. For nocturnal events, approximately 48% of deaths were female, and 50% of deaths were male. Similar themes are seen in an analysis of age. While those aged 40 – 70 account for slightly less than half the dataset, proportions between age groups (**Table 1**) revealed small, if any, differences between total, daytime, and nocturnal fatalities.

| Age | Total Fatalities | % Total | Daytime Fatalities | % Daytime | Nocturnal Fatalities | % Nocturnal |
|---|---|---|---|---|---|---|
| 0 - 10 years old | 184 | **7.76%** | 100 | **6.68%** | 84 | **9.61%** |
| 10 - 19 years old | 123 | **5.19%** | 79 | **5.28%** | 44 | **5.03%** |
| 20 - 30 years old | 188 | **7.93%** | 108 | **7.22%** | 80 | **9.15%** |
| 30 - 40 years old | 241 | **10.17%** | 133 | **8.89%** | 108 | **12.36%** |
| 40 - 50 years old | 314 | **13.25%** | 197 | **13.17%** | 117 | **13.39%** |
| 50 - 60 years old | 338 | **14.26%** | 216 | **14.44%** | 122 | **13.96%** |
| 60 - 70 years old | 319 | **13.46%** | 198 | **13.24%** | 121 | **13.84%** |
| 70 - 80 years old | 260 | **10.97%** | 166 | **11.10%** | 94 | **10.76%** |
| 80 - 90 years old | 171 | **7.22%** | 121 | **8.09%** | 50 | **5.72%** |
| 90 - 100 years old | 40 | **1.69%** | 29 | **1.94%** | 11 | **1.26%** |
| 100 + years old | 1 | **0.04%** | 0 | **0.00%** | 1 | **0.11%** |
| Unknown | 191 | **8.06%** | 149 | **9.96%** | 42 | **4.81%** |

***Table 1:*** *Counts and proportions of all, daytime, and nocturnal fatalities by age group.*

**Conclusion:**

Results echo previous findings that nocturnal tornadoes are deadly, especially in manufactured housing and the Southeastern United States. Nocturnal tornadoes fatalities occur most frequently in the non-peak tornado season (cool season months), in the Southeast, and in weaker housing structures such as permanent and mobile homes. Previous research has theorized

that besides weak framed housing and distribution of nocturnal fatalities, the warning communication process, forecasting challenges related to nocturnal environments, and a changing risk landscape in the United States all contribute to the vulnerability associated with nocturnal tornadoes, and why they continue to be a problem in the U.S. While this study served to update previous findings related to nocturnal vulnerability, future work aims to evaluate these statistics using data related to all tornadoes from the study period, in terms of proportions of killer tornadoes and intensity of tornadoes (E(F) scale ranking). Additionally, a locational analysis and spatial analysis of demographic factors such as sex and age may reveal significant relationships with regards to nocturnal fatalities. Overall, nocturnal tornadoes continue to be a problem in the U.S. and, if injuries and fatalities from tornadoes are to be reduced, a concerted effort focused on mitigating the effects of these nighttime events is needed.

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