

NCAA Football and Cloud-to-Ground Lightning: A Probability Analysis

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Abstract

Large venue events present inherent risks, both natural and man-made, for spectators and players alike. Lightning frequency and location is one of the most difficult hazards to forecast. This research investigates cloud-to-ground lightning strikes that occurred within 15 miles of the 81 NCAA football stadiums within the Southeast region of the United States. The domain of the study covers an area of the Mid-South from the Gulf of Mexico north to southern Illinois and from eastern Texas east to western Georgia. Using the NCAA policy on lightning as a guideline, probabilities of risk from lightning were found at various radii from each stadium during the time of day and year in which NCAA football games are played. Additionally, the average delay time due to lightning and near-stadium strike lead times were investigated. While individual stadium statistics were calculated, entire study area and latitudinal divisions are presented temporally.

Keywords: Lightning; NCAA; Stadiums; Large venue; Hazards

Introduction

Weather related hazards pose a unique risk for spectators and participants at large outdoor venues. In particular, lightning claims the lives of approximately 54 people in the United States every year. 45% of these lightning fatalities occur in open areas such as sports fields [1]. While some fatalities may occur in small isolated fields or stadiums, a lightning strike during an event at a large venue could be devastating on a much grander scale. College football stadiums comprise some of the most popular large venues in the Mid-South and Southeast, which are also areas prone to high numbers of lightning strikes [2]. Therefore, this research focuses specifically on lightning strikes near National Collegiate Athletic Association (NCAA) football stadiums in the Mid-South and Southeast. On average of about 25 million lightning strikes hit the ground in the United States every year [3]. Louisiana, Mississippi, Alabama and Arkansas (four states in the domain of this research) rank within the top five states in terms of average strike density. For instance, Louisiana ranks second in strike density with an average of 19.7 strikes per square mile [4]. Mississippi, Alabama, and Arkansas rank third, fourth, and fifth respectively. Because of these high strike densities, the Mid-South and Southeast regions are also at high risk for lightning related deaths. Using an average taken from 2002 to 2011,

Mississippi is ranked 5th on population-weighted lightning deaths per year. Alabama is ranked 6th and Florida is ranked 8th. All of the states in this research domain are ranked in the top 20 states regarding lightning deaths per year [5]. Using data from the Center for Disease Control's Health Statistics, Adekoya and Nolte found that a total of 374 lightning fatalities occurred between 1995 and 2000; 203 of those deaths took place in the southeastern United States [6]. However, not every lightning strike results in a fatality. The National Weather Service reports that only about 10% of people who are physically affected by lightning die as a direct result. The other 90% are often left with significant disabilities [1]. It is also important to consider that outdoor college football stadiums are not used for sporting events on a regular basis year round. The college football season lasts from late August into November. This partially overlaps with the timing for highest average cloud-to-ground lightning frequency, which is described as being during the months of June, July, and August [7, 8]. When looking at the NCHS data,

Adekoya and Nolte found that 92% of the fatalities took place between the months of May and September [6]. Within those months, 80% of the casualties took place between 10am and 7pm [3]. Therefore, the diurnal lighting and casualty rates maximum coincide with the timing of most football games. Regardless of timing, coastal areas are generally thought to

be more prone to risks from lightning. This is because differential heating and moisture between the land and water surfaces allows for more rising air, convection, and storms near the coast [9]. In a case study looking at locations across Georgia for the 1996 summer Olympics, Livingston et al. found that coastal sites such as Savannah had more lightning strikes because of the local sea breeze [10]. This increase in strikes reached about 50 km inland and paralleled the coast. Further inland, the strikes were more uniformly distributed. The NCAA has universal procedures in place to address the risk of lightning strikes near college football stadiums in the United States during game time. These procedures are the same regardless of the schools' geographic location. Each institution is responsible for tracking local storms and monitoring lightning strikes. The rules for what must be done when lightning is detected within a certain distance of the stadium are as follows: when lightning strikes within 15 miles (24.12 km) of a stadium, on-field officials should be notified; when lightning strikes within 10 miles (16.09 km) of the stadium, officials must use the public address system to notify attendees of the weather situation and suggest they evacuate for a safer environment; when lightning strikes within six miles (9.66 km) of the stadium, the game will be postponed until the time when no lightning has been detected within six miles for at least 30 minutes [11].

Data

This research used data from the National Lightning Detection Network (NLDN) 2001-2011 dataset of cloud-to-ground lightning strikes (Figure 1). The NLDN began complete coverage of the United States in 1989 and is composed of 114 sensors throughout the United States [7]. As described in Orville and Huffines, the accuracy of the NLDN can vary due to the variation in distance between sensors across the United States [7]. Cummins et al. determined the mean accuracy of the NLDN to be within approximately 500m (0.31 miles) of a strike's location [12]. The overall detection efficiency of the NLDN sensors is greater than 90% [13].

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The obtained dataset spatially covers the Mid-South and a portion of the Southeast United States, which defines the chosen study domain. Strikes with signals ranging from 0-15 kA were omitted given that these values are typically associated with cloud-to-cloud lightning [14]. The domain fully encompasses 81 outdoor NCAA Division I-III stadiums (Figure1). The coordinates of each stadium are based on the center-point of the playing surface. The typical NCAA regular football season for all stadiums spans from August 24 to November 30, so the data from that time period were isolated for analysis. During August, September, and October (Daylight Saving Time), the time period 1400-0600 GMT was used. During November (Standard Time), the time period 1500-0700 GMT was used. These times include two hours prior to the earliest game day kickoff and one hour after the end of the latest game to account for all active field time and the time required to clear the stadium after the conclusion of the contest [15].

Methods

For the purpose of this research, all lightning strikes within a 15-mile radius of each stadium center were isolated from the Mid-South and Southeast dataset. This 15-mile distance was chosen based on current NCAA rules, which comes into effect at that radius. Since NCAA rules are outlined in miles, the methods for this research will be conducted using miles as well.

NCAA-based zones

Within each stadium's 15-mile dataset, the lightning strikes were evaluated using two methods. First, NCAA-based zones were defined. According to NCAA policy, strikes 6 - 15 miles from a stadium prompts notification of on-field officials. This zone was defined as the notification zone. The delay zone was also defined by NCAA rules as a 6-mile radius. The 1-mile ring directly surrounding the stadium was isolated due to the dense concentration of tailgaters, spectators, and participants within that area and was defined as the potential disaster zone. The NCAA-based zones were used to examine the probability of different events. First, the probability of a delay was calculated by examining the notification zone for strikes. When a strike occurred in the notification zone then the delay zone would be examined for strikes in the following 30 minutes to calculate a binary answer. If a strike occurred in the delay zone in the following 30 minutes after the notification strike, an answer of yes would be assigned and searching in the delay zone would cease. The probability of a delay was calculated using Eq. 1 where DE is the total number of delay events, NE is the total number of notification events, and PP is the probability of delay.

$$P_p = \frac{DE}{NE} \tag{1}$$

To avoid redundancy from the same storm, strikes within the notification zone initiating a search in the delay zone had to be at least 30 minutes apart. The average lead time between the initial notification strike

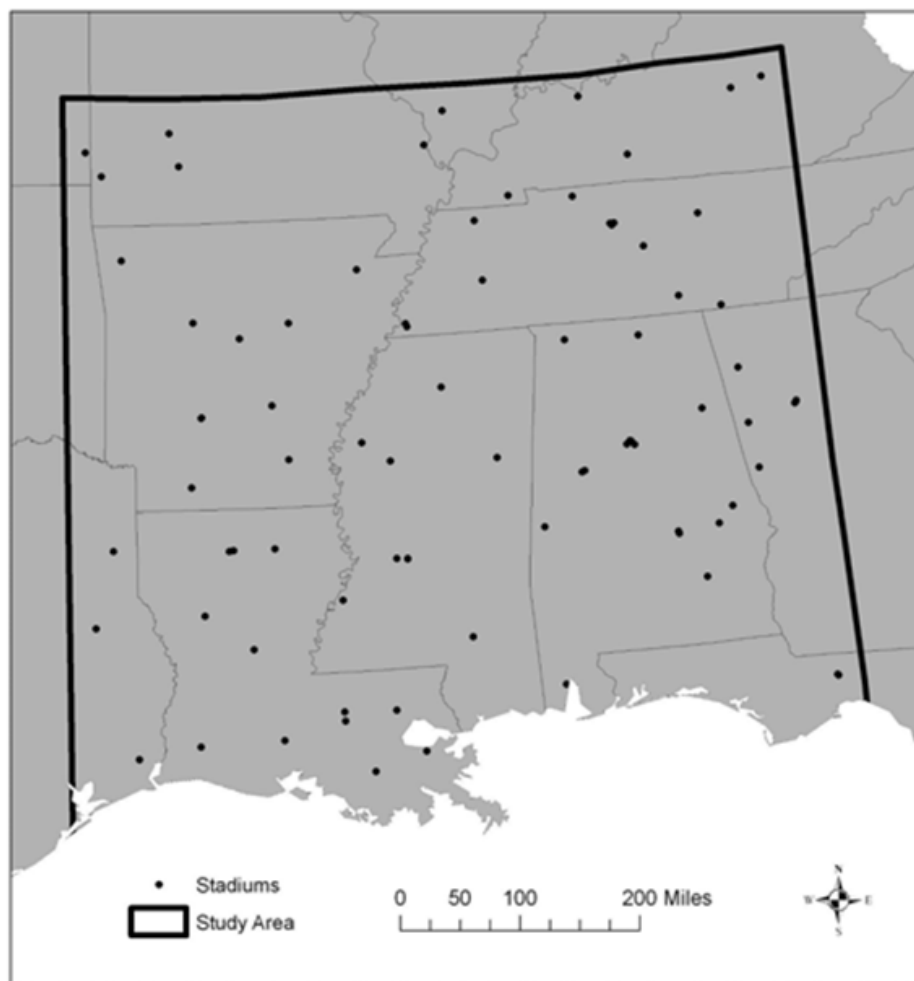


Figure 1: Map of the study area and stadiums used in study



Figure 2: Zones Illustration

and the delay strike (delay zone lead time) was calculated using the times of the events used for determining the probability of a delay.

The probability of a potential disaster strike was calculated in relation to both the notification zone and the delay zone using the same methodology as the probability of a delay. In relation to the notification zone, once a notification strike occurred, the potential disaster zone was searched for the following 30 minutes for a strike. In relation to the delay zone, the delay zone was independently searched, and when a delay strike occurred, the potential disaster zone was searched for 30 minutes. The probability of a potential disaster strike was calculated using Eq. 2 where OE is the total number of outer zone events (either the notification zone or the delay zone), pE is the total number potential disaster events, and PD is the probability of a potential disaster strike.

$$P_d = \frac{pE}{D_e} \quad (2)$$

The average potential disaster zone lead time was calculated for both the notification and delay zone using the same methodology as the delay zone lead time. Statistical significance between zones was examined for the variables described above using 95% confidence intervals.

Individual radii zones

The second method used to analyze lightning strikes near a stadium was a 1-mile radius approach. The 15-mile circular area around the stadium was divided into 1-mile concentric rings (i.e. the 1-2-mile ring, the 2-3-mile ring, through the 14-15-mile ring). In accordance to the methods in section 3.1, the area within one mile of the stadium was defined as the potential disaster zone. The probability of a potential disaster strike (Eq. 2) and the lead time before a potential disaster strike were calculated for each concentric ring. The probability of a delay (Eq. 1) and lead time before a delay strike were calculated for the 6-7-mile through the 14-15-mile concentric rings using the NCAA definition of the delay zone. In addition, the length of the delay events was calculated. Since a game delay lasts for 30 minutes past the

last delay strike, scanning within the delay zone continued until there were no additional delay strikes found for that length of time. The total

delay time in minutes was calculated using Eq. 3 where TF is the time of the last delay strike, TI is the time of the initial delay strike, and DL is the delay length.

$$D_L = (T_f - T_i) + 30 \quad (3)$$

Similar to the NCAA-based zones, statistical significance between individual radii zones was examined using 95% confidence intervals.

Spatial and temporal analyses

The probability of a delay, probability of a potential disaster strike, average lead time before a delay strike, average lead time before a potential disaster strike, and average delay time were analyzed both temporally and spatially using the NCAA-based zones. Through examination of the weekly climatology of lightning strikes, two sub-seasons of the football season were outlined. Season 1 comprised of August and September, while season 2 comprised of October and November. This temporal examination was performed to account for the hypothesized seasonal increase in storm motion as synoptic conditions become less benign later in the NCAA football season. Spatially, the study domain was broken into three regions: the coastal region (Coastal), the deep-south (Deep-South), and the Tennessee, Ohio, and mid-Mississippi valleys (Valley). The split between the Coastal and Deep-South regions occurred at 31° N latitude, and the split between the Deep-South and Valley regions occurred at 35° N latitude. These divisions were made to account for regional phenomenon such as sea breezes in the Coastal region and early season frontal passages in the Valley region. Temporal and spatial comparisons were performed using 95% confidence intervals.

Results and Discussion

The football season was split into one week segments to assess the risk of lightning within the entire study domain (Figure 3). The months of August and September both averaged more than 500,000 strikes per week. October and November averaged less than 500,000 strikes per week. Therefore, a division in the season was established to distinguish the two temporal variations in the number of strikes. In total there were 7,393,252 strikes within the study area for the football season, with 2,136,671 of those strikes (29%) occurring in the first week of the season. This highlights the enhanced lightning risk posed during the last week of August when compared to the rest of the season. When examining the season spatially, a maximum was observed along the coast, just inland of the Gulf of Mexico and southeastern Texas (Figure 4). This is attributed to increased convection due to sea breezes in the area. The other relative maximum that exists across locations such as northeastern Arkansas, southeastern Missouri, and northwestern Tennessee may be largely attributable to the 11-year study period. This short period of observations makes it possible for a series of events to affect the overall climatology. This is also seen in the temporal climatology during the week of September 21- September 27. Splitting the football season into the August and September (early season) and October and November (late season) allowed for comparison of probabilities between the first and second half of the season. No statistically significant differences existed between the two seasons for the probability of a potential disaster strike when the first strike was within six miles or when the first strike was within 6-15 miles. The probability of a delay strike when the first strike was between 6-15 miles also showed no statistically significant differences between the seasons. The lead times for potential disaster when the first strike is within 6 miles or within 6-15 miles and lead time for delay strikes when the first strike is within 6-15 miles show similar results. Like the full season statistics, the interquartile ranges of the lead times for potential disaster strikes are much larger due to the small sample size. Separating the study area into three latitudinally divided regions revealed

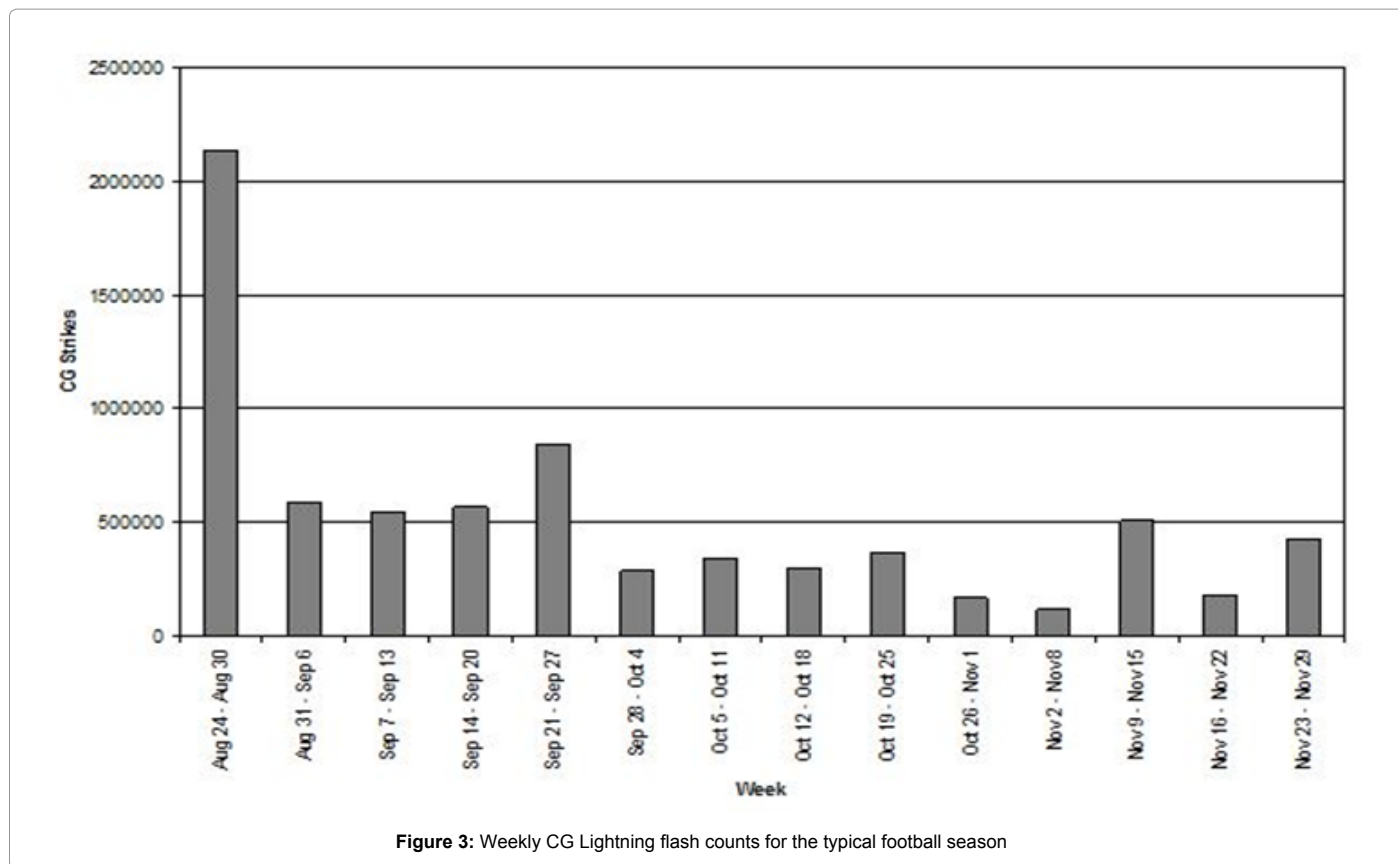


Figure 3: Weekly CG Lightning flash counts for the typical football season

no statistically significant differences between the probability of delay and average lead time to a delay strike for the three regions. Additionally, no statistically significant difference using the same alpha in the probability of a potential disaster strike or lead time to a potential disaster strike existed between the regional divisions. These results show that within the domain of this research, the same NCAA guidelines are justified in being applied to the entire region and season. In order to assess the current NCAA policies, an investigation comparing the 6-15-mile radius notification zone to the 6-mile delay zone was conducted. The probability of receiving a potential disaster strike was statistically significantly greater with an alpha of 0.05 if a strike previously occurred within six miles (median of 10%) of the stadium than if a strike previously occurred within the 6-15-mile

radius (median of 2%) (Figure 5). However, there was no statistically significant difference in lead time for the potential disaster strike using the same spatial definitions, despite the tendency for shorter lead times from strikes occurring within the delay zone (Figure 6). When a strike occurred in the notification zone, there was a median lead time of 18.1 minutes before a potential disaster strike. When a strike occurred within the delay zone, the median lead time was reduced to 13.5 minutes. Therefore, while a strike within the notification zone is less likely to be followed by a strike within the potential disaster zone, it does not necessarily imply a significantly greater lead time should a strike occur. Concentric rings 1-mile in width, emanating from the center-point of the stadium, were also investigated to find the probability of a delay. Based on NCAA's rules for a delay, a strike within any of the 1-6-mile concentric rings would result in a 1.000 probability of delay. Figure 6a depicts the results for the remaining 1-mile wide rings between six and 15 miles of the stadium. As expected, the probability of delay decreases as distance from the delay zone increases. The highest probability of delay, 67.4%, exists when the first strike is

detected within 6-7 miles from the stadium. The probability of delay becomes statistically significantly less at a distance of 8-9 miles from the stadium. The lowest probability, 33.3%, exists within the outermost ring, 14-15 miles from the stadium. Should a delay strike occur, Fig 6b shows the average lead times for each of these instances. The greatest median lead time (12.2 minutes) before a delay strike after notification was located in the outermost ring. To minimize official notifications while maintaining a significant lead time, the radius at which the lead time became statistically significantly was found. A statistically significant decrease occurred between the outer ring and the 9-10-mile radius ring where the median lead time was 9.7 minutes. At the 9 - 10 mile radius, the probability of delay (50.8%) would be significantly greater than the 14-15 mile radius where notification currently occurs. Within the closest ring of 6-7 miles from the stadium, the average lead time before a delay strike is 6.4 minutes.

Beyond just the probability of delay and the amount of time leading up to the delay, the total length of delay is also important to game day operations. The results indicate that regardless of where the initial strike is detected, the average length of a game delay is just over 60 minutes (Figure 6c) and is not affected by storm motion through the delay zone. The interquartile ranges of each of the rings indicate that 95% of the delays will be between 50 and 70 minutes in length. Only 2.5% of game delays will be longer than 70 minutes, depicting the rarity of long game delays and postponements.

The probability of a potential disaster, like the probability of delay, also decreases with increasing distance from the stadium. The highest probability, 29.7%, exists when a strike occurs in the 1-2-mile radius ring. The probability of a potential disaster strike becomes statistically significantly different from this value at the 5-6-mile radius ring, where the probability drops to 14.5%. The lowest chance of a potential disaster strike,

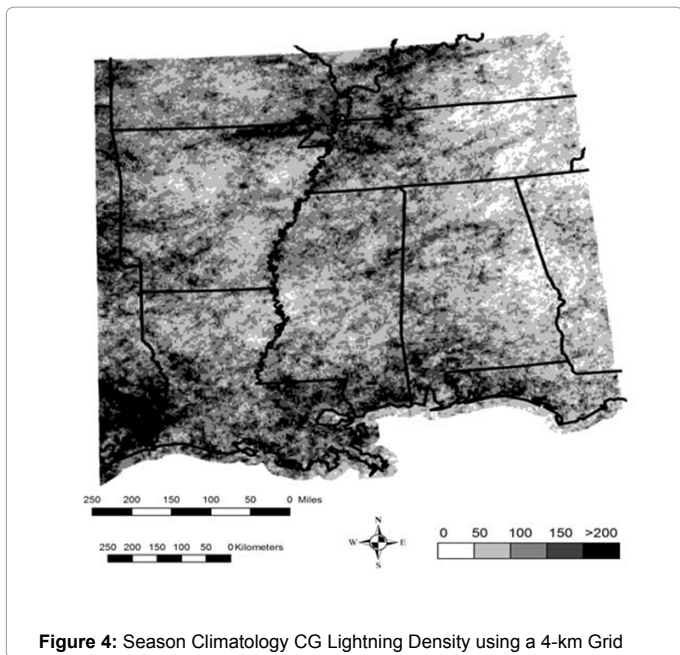


Figure 4: Season Climatology CG Lightning Density using a 4-km Grid

(3.7%), exists when the initial strike occurs within the 14-15 mile ring. This result indicates the current NCAA policy of delay games when a strike occurs within 6- miles of the stadium is the best practice. When a potential disaster strike occurred, the lead time ranged from about seven minutes in the 1-2-mile radius ring to around 17 minutes for the 11-12-, 12-13-, and 14-15-mile radius rings (Figure 7). The small number of potential disaster events in the dataset resulted in a larger variability of potential disaster lead times within individual radii when compared to other variables. There is not a statically significant decrease from the 17-minute lead time until the 3-4-mile radius ring. Although the greatest lead time exists in the 11-12-mile radius ring, this is likely a result of the small sample size and large variability. While the longer lead time from a strike in the 11-12 mile radius ring would be beneficial in an evacuation scenario, the low probability of a potential disaster strike actually occurring (5.2%) means there would be many false alarms and an evacuation may not be the most viable option.

Conclusion

The results justify the effectiveness of current NCAA lightning guidelines. Initial lightning strikes within a 6-mile radius of the stadium resulted in a higher probability of potential disaster than did initial strikes between 6-15 miles. Additionally, no statistically significant differences occurred either temporally or spatially, justifying the same set of rules for the entire study domain; more lightning strikes occurring within an area did not necessarily equate to a greater risk of delays or potential disaster. Future research may look to expand upon the area of the domain used in this study and attempt to justify temporal and spatial divides in other regions. Across the domain of this research, it is important to note that the risk associated with playing football games during the last week of August is much higher than any other week in the season. This is mainly due to the numerous pulse thunderstorms that occur across the area in late summer. Most of these thunderstorms are short-lived but can still produce frequent cloud-to-ground lightning. Regardless of the time of season, the authors emphasize the use of a meteorologist or a trained person to monitor lighting in real time to help minimize the risk of disaster. The greatest concern to a NCAA football game in regards to lightning is in fact the potential for strikes within the potential disaster zone. The probabilities of potential disaster strikes presented in this research may seem relatively low, but the actual area encompassed within one mile of the center-point of the stadium is also quite small. Additionally, the results, like NCAA guidelines, do not take into account storm motion relative to the stadium. Therefore, there are many ways a storm could pose no risk to the stadium, but would affect an area within 15 miles of the stadium. These instances could include storms that form on the leeward side of the stadium or storms that only partially clip the periphery of the 15-mile radius ring. The methods used in this research found an average delay time of just over 60 minutes. Most (95%) delays are between about 50 and 70 minutes. These delays are long enough that a stadium evacuation would seem warranted to spectators and is justified to minimize risk of life. This also highlights the rarity of lightning being the cause for postponements in NCAA football, with only 2.5% of delays lasting longer than about 70 minutes. This study used only cloud-to-ground lightning data due to the threat it poses to human life. NCAA rules do not specify that a lightning flash must be cloud-to- ground; therefore delays will be more frequent and longer in reality than in the study. Some universities use trained meteorologists who observe real-time cloud-to-ground lightning data while other universities may only have an

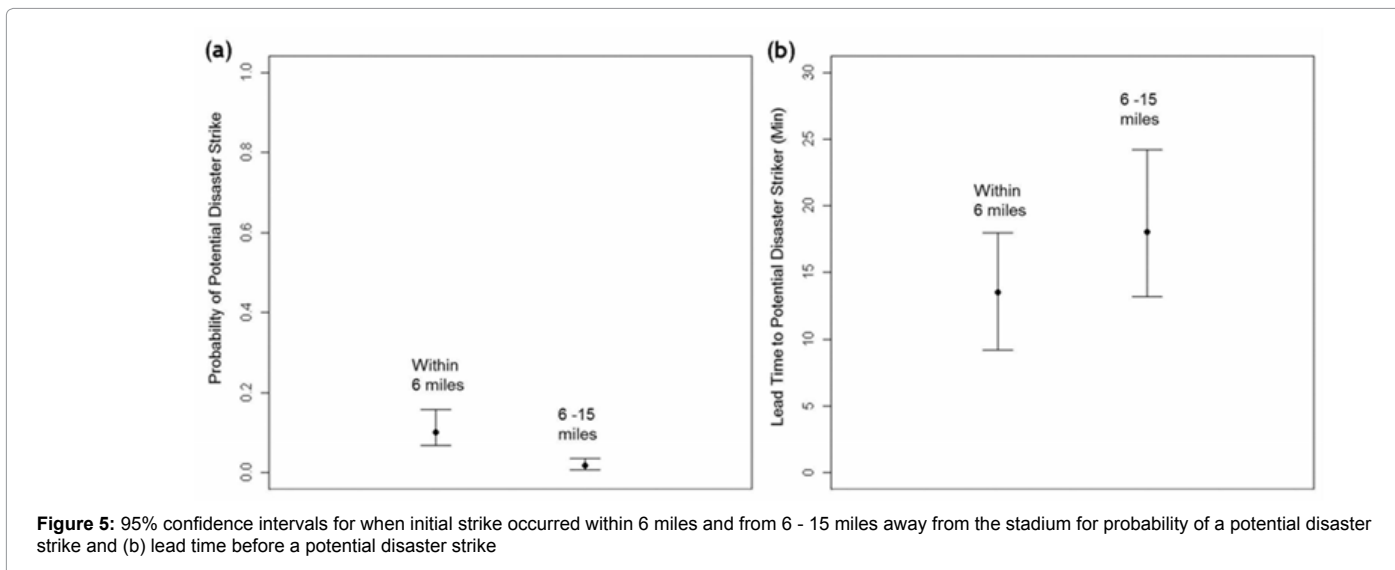
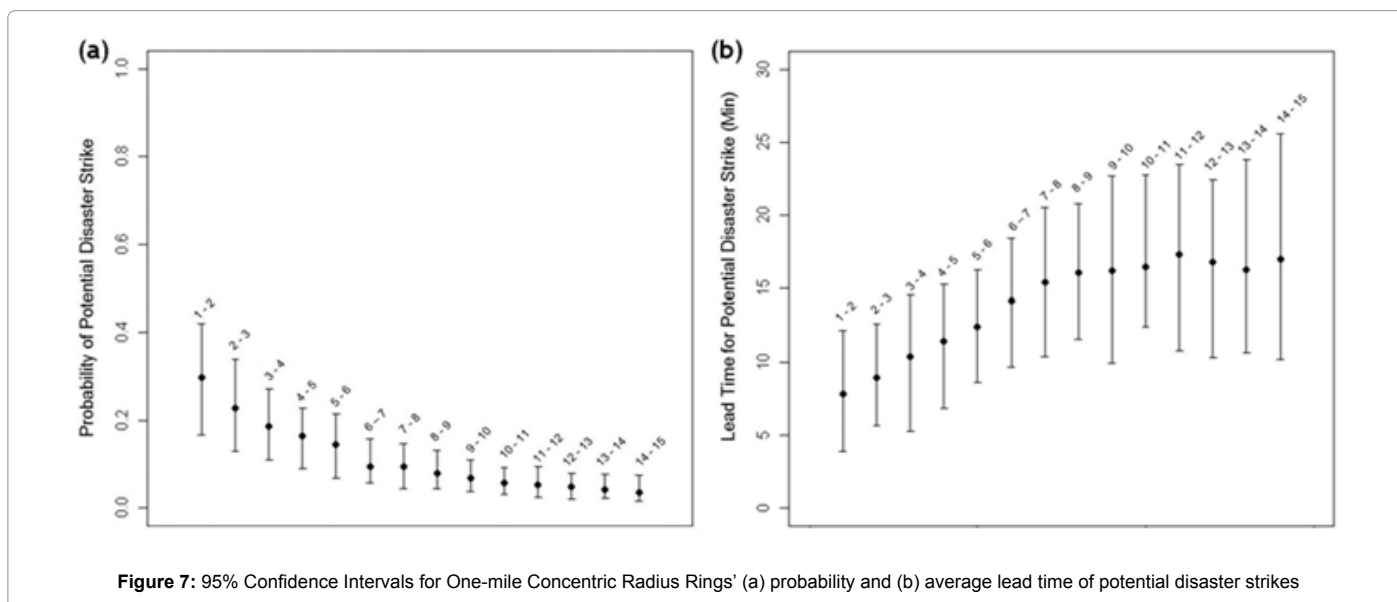
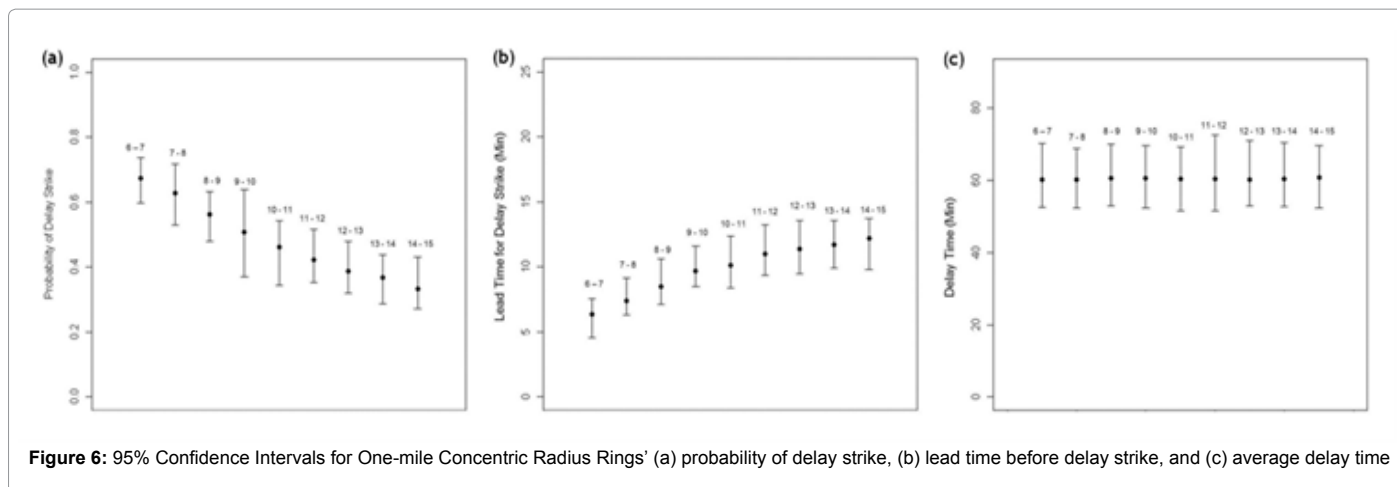


Figure 5: 95% confidence intervals for when initial strike occurred within 6 miles and from 6 - 15 miles away from the stadium for probability of a potential disaster strike and (b) lead time before a potential disaster strike



observer watching the skies.

Future work may look at expanding the domain not only in the United States but also into other portions of the world. Similar methods could be implemented to investigate the lightning risk to other sports, both professional and collegiate, as well as other outdoor venues such as concerts and fairs. The policies associated with these other outdoor activities may not be strictly defined, giving further justification for understanding the related lightning risk.

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References

1. NWS (2002) Updated AMS Recommendations for Lightning Safety.
2. Gratz J, Noble E (2006) Lightning safety and large stadiums. *B Am Meteorol Soc* 87: 1187-1194.
3. Walsh KM, Cooper MA, Holle R, Rakov VA, Roederl WP et al. (2013) National Athletic Trainers' Association position statement: lightning safety for athletics and recreation. *J Athl Training* 48: 258-270.
4. Vaisala (2012) Cloud-to-Ground Flashes by State.

5. Vaisala (2012) Lightning Fatalities by State.
6. Adekoya N, Nolte, KB (2005) Struck-by-lightning deaths in the United States. *J Environ Health* 67: 45 - 50.
7. Orville RE, Huffines GR (2001) Cloud-to-Ground Lightning in the United States: NLDN Results in the First Decade, 1989-98. *Mon Weather Rev* 129: 1179-1193.
8. Holle RL, Cummins KL (2010) Monthly distributions of US NLDN cloud-to-ground lightning. 21st International Lightning Detection Conference.
9. Hodanish S, Sharp D, Collins W, Paxton C, Orville R E (1997) A 10-yr monthly lightning climatology of Florida: 1986-95. *Weather and Forecasting* 12: 439-448.
10. Livingston E S, Nielsen-Gammon J W, Orville R E (1996) A climatology, synoptic assessment, and thermodynamic evaluation for cloud-to-ground lightning in Georgia: A study for the 1996 summer Olympics. *B Am Meteorol Soc* 77(7): 1483-1495.
11. NCAA Policy or book.
12. Cummins K L, Murphy M J, Bardo E A, Hiscox W L, Pyle R B, et al. (1998) A combined TOA/MDF technology upgrade of the U.S. National Lightning Detection Network. *J Geophys Res* 103: 9035-9044.
13. Cummins K L, Cramer J A, Biagi C J, Krider E P, Jerauld J, et al. (2006) The US National Lightning Detection Network: Post-upgrade status. 2nd Conference on Meteorological Applications of Lightning Data, Am Meteorol Soc.

14. Biagi C J, Cummins K L, Kehoe K E, Krider E P (2007) National Lightning Detection Network (NLDN) performance in southern Arizona, Texas, and Oklahoma in 2003-2004. J Geophys Res 112.
15. Frey B (2013) MSU Gameday Operations. Mississippi State University, USA.