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Lightning Impacts on College Football Games

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***Abstract*—Lightning safety policies influence all types of sporting events, including collegiate football in the United States, which overlaps the end of the lightning season. The economic impacts of these policies can be large. Cloud-to-ground and in-cloud data from the National Lightning Detection Network (NLDN) are analyzed for 136 mostly college football games from 2010 through 2015 that were modified by lightning. The effects include complete cancellation, termination partway through the game, or delays before or during the game. NLDN data are composited around the locations and times of the impacts on games using the approach of Lengyel et al. [2005]. Results indicate that some games are affected when massive amounts of lightning are in the area, some have steadily moving storms crossing the stadia, and many are affected by moderate or weak storms. While difficult to assess after the fact, many games are managed well to avoid lightning.**

Keywords*—football, game delays, game postponements, sports, advance lightning warnings, NLDN data.

I. Introduction

The National Collegiate Athletic Association (NCAA) first published a lightning safety policy in 1997 [Bennett et al., 1997]. This was the initial codification of guidelines for affecting sporting events since understanding that is more recent had developed of lightning safety issues [Bennett, 1997, 2000; Walsh, 1997]. During prior years, increasing attention had been called to the deleterious effect of lightning on football games [Maggied, 2002; Walsh and Bennett, 1996]. Since the NCAA Lightning Safety Guideline 1d had no well-defined precedent, it can be considered as the beginning of the current impetus for cancelling, stopping, or suspending football and other collegiate sporting events in the United States. The NCAA has subsequently published periodic updates to the lightning safety guidelines in its annual Sports Medicine Handbook such as Bennett et al. [2006]. The National Athletic Trainers' Association has also published longer statements than the brief NCAA guidelines [Walsh et al., 2000, 2013]. The 2013 statement specifically addressed the criteria for postponing and resuming games, as well as how to plan for spectator evacuation at large venues. These considerations led to the concept of studying past cancelations, suspensions, and delays that are reviewed in the present paper. The American Meteorological Society also published lightning safety guidelines that were more general than for sporting events only [American Meteorological Society, 2003; Cooper et al., 1999]. The American Medical Association issued similar recommendations [Cooper et al., 1999].

An individual case was examined by Holle and Krider [2006], and an overview of policies is described by Walsh et al. [1997] and Walsh [2013]. Reagan et al. [2013] examined the probability of the lightning threat within a 15-mile radius for various football stadia. The expenses associated with these events can be large, as indicated by a university paying the visiting team $975,000 for appearing for a football game that was never played due to lightning (https://www.sbnation.com/college-football/2014/9/3/6090801/florida-idaho-game-canceled-terminated-schedule).

This summary concentrates primarily on university and college football games during the autumn in the United States from 2010 to 2015. A few National Football League (NFL) games are included to increase the sample size. It is likely that many more games were affected to some extent by lightning but they were not reported to major media sites, and they are therefore not included in this dataset. Additional impacts of lightning on autumn sports include at least 1) an average of 15 states with at least one high school football game affected per year, 2) an average of at least 20 university and high school soccer contests affected per year, and 3) other autumn sports at colleges and high schools such as soccer, cross country, golf, and tennis. These lists do not include school-based baseball and softball games that are played in the spring, golf tournaments, or impacts of lightning on other international sporting events such as soccer (football), and cricket.

Lengyel et al. [2005] composited lightning data around the times and locations of lightning-caused deaths, injuries, or other events. In most cases, the locations were well known while the times were less precise. The lightning data leading up to the event for 60 or 90 minutes were plotted as a function of distance out to 20 or 50 km from the incident location, as well as the same time and distance afterward. It was found that a portion of the cases consisted of adequate advance warning as a storm approached so that action could be taken to avoid the lightning threat. Other events had minimal or no lightning leading up to the event such that action was more difficult to justify. This methodology will be applied to 136 football games in this current study.

II. DATA

A. Lightning data

The National Lightning Detection Network (NLDN) provides both cloud-to-ground (CG) and in-cloud pulse (IC) data. A CG flash has one or more return strokes; the average is four to five cloud-to-ground strokes per cloud-to-ground flash [Rakov, 2016]. The estimated NLDN CG flash detection efficiency (DE) for the contiguous 48 United States has been at least 90% since 2000 [Cummins et al., 2006; Cummins and Murphy, 2009; Nag et al., 2014, 2015; Murphy and Nag, 2015]. Cloud-to-ground stroke DE is about 70%. Recent assessment by Murphy and Nag [2015] indicate a 95% or higher CG flash DE following an NLDN upgrade in 2013. Polarity identification of CG strokes is made in the present study; NLDN reports with positive peak currents <15 kA have been excluded. Prior to 2013, the NLDN reported cloud pulses for 15-25% of cloud flashes. Following the 2013 upgrade, detection increased to about 50% [Nag et al., 2014; Murphy and Nag, 2015]. More details about the temporal evolution of NLDN performance before 2012 are provided in Koshak et al. [2015]. Definitions and context for these lightning performance measures are in the extensive summary by Nag et al. [2015].

B. Football game identification

An original list of 150 football games affected by lightning was developed for 2010 through 2015 at East Carolina University. Information was collected by calls to the game operations staff at larger colleges. A few more reports were subsequently identified, but some cases were also eliminated due to a lack of reliable data. The final dataset from 2010 through 2015 is 136 cases (Table I). It is likely that more games were affected by lightning, but were not reported and therefore not included in this dataset.

Additional games affected by lightning in 2016 and 2017 have not been analyzed at this time. Nearly all of these incidents were obtained from web-based reports from the universities involved in the game, from university game operations personnel, or from local news reports in cities near the stadium. It was possible to accomplish all of this data collection by careful searching of web reports that generally stay online for many years after the event. Some of the major delays resulted in very extensive news coverage because of their impacts on the activities of tens of thousands of people traveling to attend in person, as well as changing television, radio, and web reporting in real time. However, many of the events were mostly inconveniences that resulted in minor delays.

The location of the stoppage was usually clear, since it was at the stadium located on the campus of the college or university. However, some games were played off-campus at other stadia and in a few cases were at neutral sites. These locations were readily identifiable from Google Earth.

The time of the event was much more difficult to determine. NLDN lightning data are time-stamped to better than a millisecond. However, the time of the event during a game is affected by many factors:

- The nominal start time of the game is generally not the actual kick-off moment, but several minutes later due to pre-game activities and media impacts. The actual kick-off time could be identified clearly in only a few cases.
- After the game starts, the time of a delay, postponement, or cancellation is not usually stated in the reports according to external time, but in terms of the game's play clock.
- When only the play clock time is identified, the following sequence was used. The average length-of-game as reported by the NCAA ranges from 3 hours, 12 minutes in 2010 to 3 hours, 23 minutes in 2014. For the National Football League, the game duration was 12 minutes shorter in 2014 than the 2014 college game.
- This play clock time was then apportioned from the start of the game assuming a 20-minute half and five-minute quarter breaks. The quarters therefore are assumed 45.75 minutes long in 2014. This apportionment is the primary source of uncertainty for timing. Although the timing error is not likely to be too large, it is estimated to be as long as ten minutes. This interval affects the event timing relative to the very accurately detected lightning.

III. OVERVIEW OF 136 GAMES IN SAMPLE

Table I indicates the five types of impacts that are analyzed in this study. Six games never started due to lightning. Another set of 34 games started late but were eventually completed. An additional 18 games were suspended due to lightning at some point during the course of play, and never resumed. Twelve games had a lightning delay causing the start of the second half to be delayed. The largest group was 66 games that were stopped at some time but were eventually completed.

TABLE I. FIVE CATEGORIES OF LIGHTNING IMPACTS ON GAMES

Games	Type of lightning impact		
		College	**NFL**
6	Never started	6	0
34	Started late	30	4
18	Suspended and not restarted	17	1
12	Halftime delays	12	0
66	In-game delays	61	5
136	Total	126	10

The number of games per year affected ranged from 17 in 2011 to 38 in 2014. The year-to-year variation may be due to meteorological factors affecting lightning occurrence during the football season, more awareness in recent years, and variations in the data collection system that was based on personal contacts and web searches.

The lengths of delays for games that were resumed after an interruption are shown are shown in Fig. 1. The shortest delay occurred for 21 minutes in two cases, while the longest was 348 minutes. There were only four games with an exactly 30-minute delay, although this is often the recommended wait time for games to be resumed.

IV. Times and Locations of Affected Games

A. Time of year of lightning impacts

In-season football is played primarily during the autumn months from late August to early December in the United States. In this study of 136 cases from 2010 through 2015, the most frequent time of year with delays or postponements is the first week of September (Fig. 2).

A primary factor to consider is that CG lightning in the contiguous United States is much more frequent in September than in subsequent months, and is continually decreasing through September until it occur much less often in October (Fig. 3). As a result, the overlap of the start of the football season with the occurrence of lightning continuing from the summer into September results in a distinct maximum of lightning delays in early September (Fig. 2). Note in Fig. 2 that game delays continue to occur at a lower rate into December.

B. Time of day of lightning impacts

Games are scheduled to start between late morning and the evening hours. The times of day of lightning delays for the 136 events in this study are shown in Fig. 4. There is one group at 1400 to 1500 local time for afternoon games, and another grouping from 1900 to 2000 for evening games. Note that a few of the in-game delays begin late in evening due to prior lightning-caused delays.

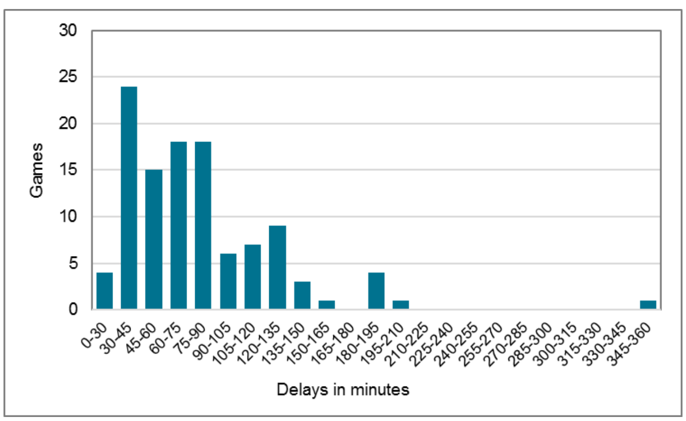

Fig. 1. Lengths of delays in minutes.

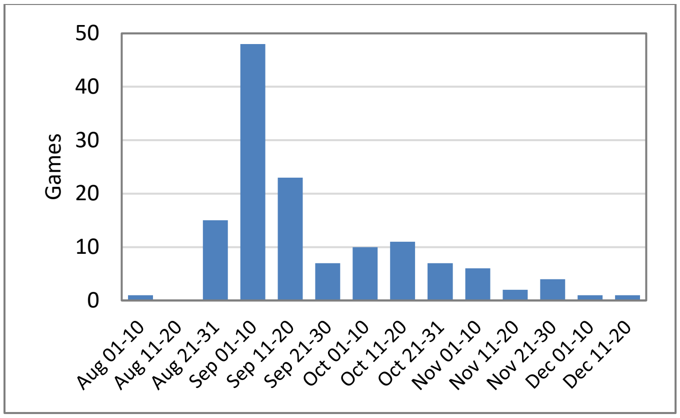

Fig. 2. Portions of months when 136 primarily collegiate football games impacted by lightning in the United States from 2010 through 2015.

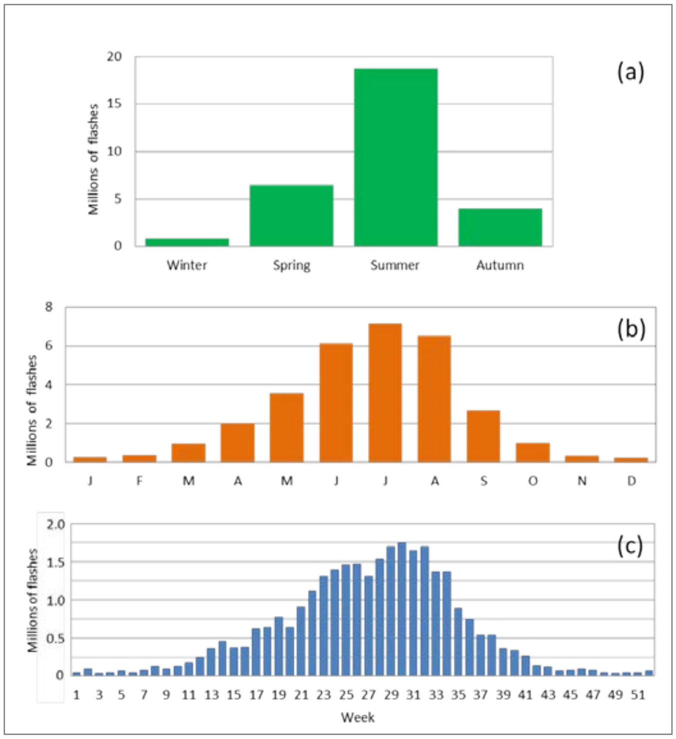

Fig. 3. CG flashes by (a) season, (b) month, and (c) week from 2005 through 2014 for the United States and adjacent areas from the NLDN [Holle et al., 2016].

The occurrence of CG lightning in the contiguous United States is much more frequent in mid-afternoon to evening (Fig. 5). As a result, the delays of starts or in-game progression is not the same as the time of day of lightning presence. Instead, there is a clustering around the scheduled game times in Fig. 4.

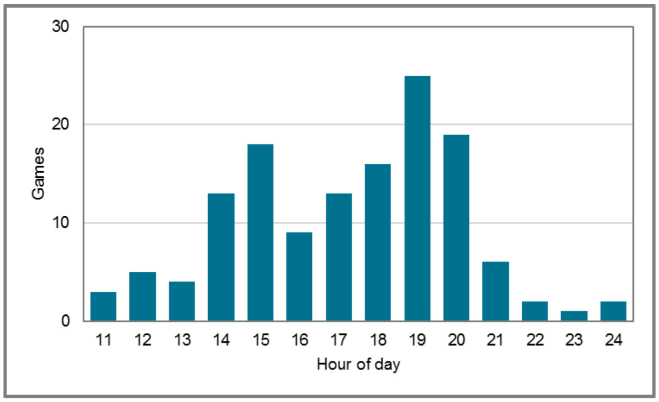

Fig. 4. Time of day in local time of 136 primarily collegiate football games impacted by lightning in the United States from 2010 through 2015.

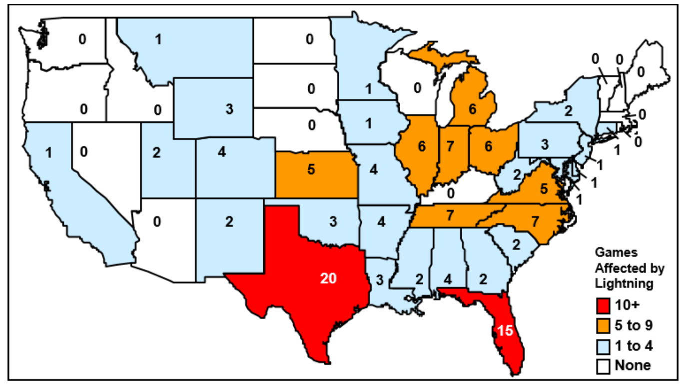

Fig. 6. States where 136 primarily collegiate football games were affected by lightning in the United States from 2010 through 2015.

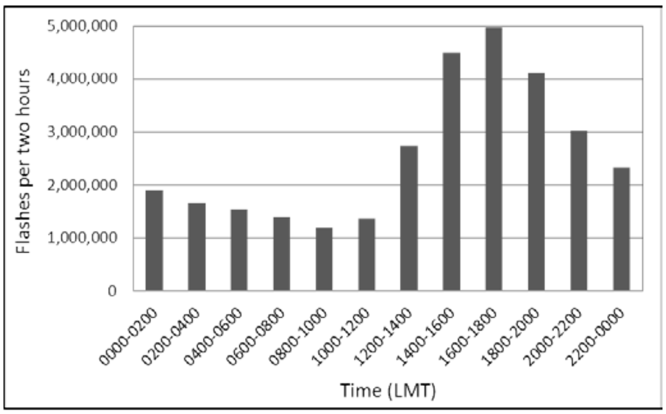

Fig. 5. CG flashes in two-hour periods in local mean time (LMT) from 2005 to 2012 for the contiguous United States and adjacent areas from the NLDN [Holle, 2014].

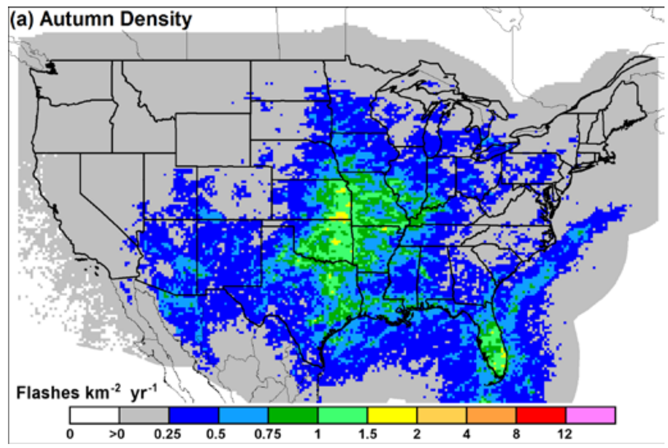

Fig. 7. Cloud-to-ground flash density during autumn from 2005-2014 [Holle et al., 2016].

C. *States with lightning impacts*

The locations where the 136 games are affected are shown in Fig. 6, while Fig. 7 shows the NLDN-detected flash density in the autumn months of September, October and November [Holle et al., 2016]. Two states are dominant in the football game sample - Texas and Florida have frequent lightning and their college football games are affected in September and October. Other states shaded in orange in Fig. 6 indicate regions with a sizable number of game impacts. It is apparent from Fig. 6 that lightning has affected collegiate football games in nearly all parts of the country during this six-year period.

V. Analysis Method

A sample of the analysis approach is shown by the example in Fig. 8, similar to that used by Lengyel et al. [2005]. This game started at 1535 local time, and had two unspecified delays attributed to rain during the third quarter. It was suspended at 1905 local time before the end of the third quarter, and never restarted. This game is in the third category of 18 suspended games in Table I. The zero time is a vertical line in the center of the diagram when the suspension began, and the zero distance is the location of the stadium. The following lightning features are apparent in Fig. 8:

- Prior to the cancellation time, negative cloud-to-ground strokes (orange minus signs) and in-cloud pulses (blue squares) were detected by the NLDN to be 25 km away at -3600 seconds (one hour) before suspension.
- Lightning came closer until at 30 minutes (-1800 seconds) before suspension it was nearly overhead.
- Within a few minutes after suspension, an additional cluster of negative cloud-to-ground strokes was located within five km of the stadium, and quickly ended.
- One hour after the suspension, another storm moved steadily toward the stadium and reached directly overhead at 2700 seconds (45 minutes) after suspension.
- This V shape is indicative of a steadily approaching storm, reaching overhead, and then leaving the stadium.
- A few positive cloud-to-ground strokes (green triangles) are present during this storm, but none occurred earlier.
- This later storm slowly moved away, but by that time, the decision was made to terminate the game.

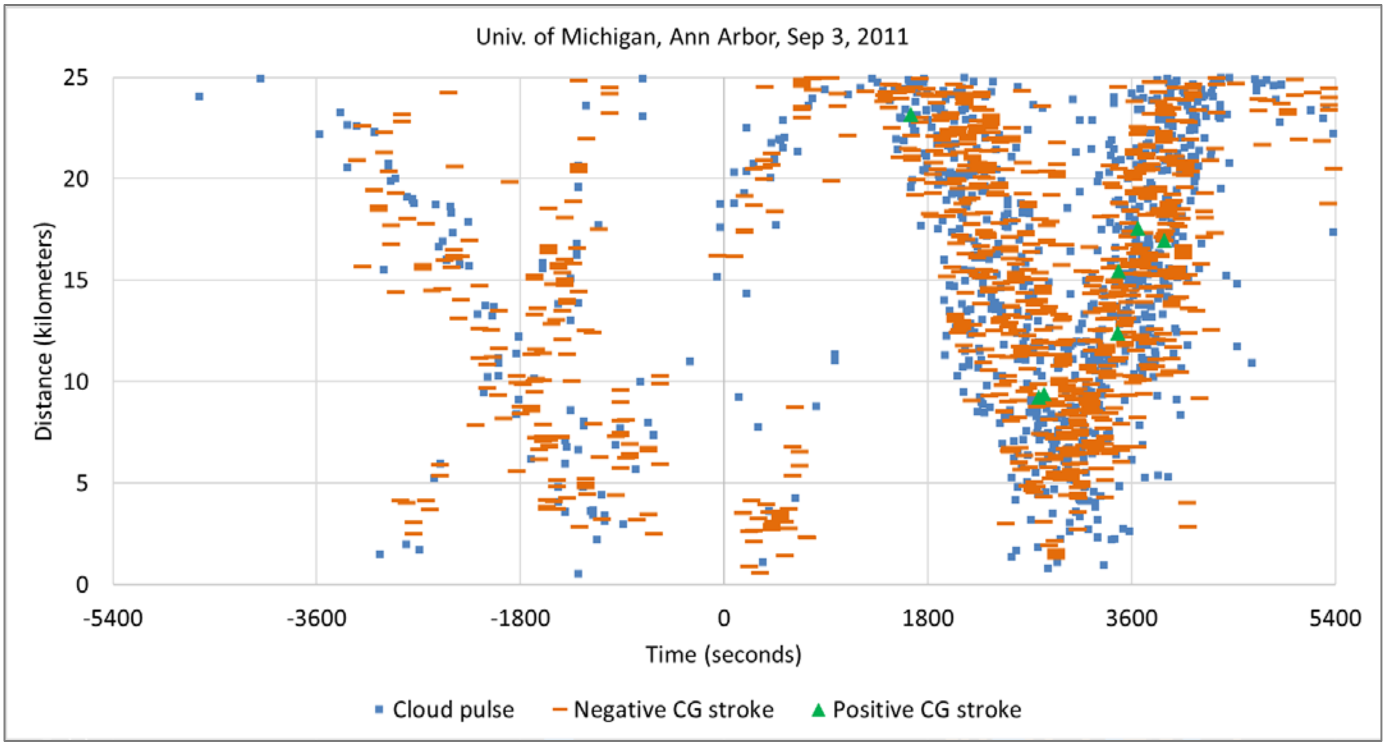

Fig. 8. Time of suspension is labeled as zero in vertical centerline. Horizontal scale: times before and after suspension time are labeled in seconds up to 90 minutes before (-5400) to 90 minutes after (5400). Vertical scale: km away from the stadium located at zero. Blue squares are in-cloud pulses, orange minus signs are negative cloud-to-ground strokes, and green triangles are positive cloud-to-ground strokes [after Lengyel et al., 2005].

VI. Six Games That Never Began

Six games never began on the scheduled day due to the detection of the presence of lightning (Table I, first line). Five of them, in the Midwest states of Illinois, Kansas, Michigan and Missouri, were postponed to the next day. The 30 August 2014 event at the University of Florida was cancelled and never played. All were scheduled to begin between 1800 and 1930 local time. Fig. 9 shows an analysis of lightning for each of the six cancelled events, where the format is that of Fig. 8. The following are features associated with these games in Fig. 9:

- Top left Fig. 9, Coffeyville Community College: Substantial lightning activity started at least 90 minutes in advance of the scheduled game time (left side of shading) out to 25 km from Coffeyville and slowly diminished as game time approached. Another series of infrequent, mainly in-cloud pulses began shortly after the scheduled time and continued within 20 km for over 20 minutes (1200 sec). Apparently, the preceding very active lightning was reinforced by the recurrence of nearby lightning at the scheduled time, and the game was canceled. It is not known how the decision was made.

- Top center Fig. 9, University of Florida: This cancellation was mentioned in the Introduction as resulting in a large expense. Lightning began within 25 km about 45 minutes before the scheduled time, the game was delayed, a very active storm continued overhead and near the stadium for the next 90 minutes and the game was canceled.

- Top right Fig. 9, University of Illinois: Lightning appeared at a distance shortly before the scheduled start, then a massive storm persisted nonstop over and near the stadium for 90 minutes after that time, resulting in cancellation.

- Lower left Fig. 9, Eastern Michigan University: This event is from a stadium located only 17 km east of the University of Michigan event in Fig. 8. The lightning sequence is remarkably similar to Fig. 8, except this game never started. Both games were scheduled to start at 1900.

- Lower center Fig. 9, Missouri State: A storm is apparent in the diagram when it is leaving at 1800 seconds (30 minutes) before the scheduled game start but then another storm approaches with a less well-defined V shape persisting nearby for 90 minutes to cancel the game.

- Lower right Fig. 8, Washburn: This game was not called by lightning since the only events are six cloud pulses long after the cancellation. Instead, the game was cancelled due to "severe weather" and lightning was apparently not a factor. The National Weather Service publication *Storm Data* indicates a series of severe thunderstorm events including one tornado and numerous reports of high winds and hail upwind to the west of Topeka, Kansas prior to the game. Note that many of the lightning delays are termed "weather delays" during the delay on the stadium scoreboard and in media. This is misleading, since most other cases in this study are lightning delays. In the present case, it was a severe thunderstorm delay, not lightning, although lightning was mentioned in the news reports.

The six games that were never started are summarized by general categories in Table II according to their lightning activity. Some games are in more than one category, and these types of lightning activity will be used in subsequent categories of lightning impacts, as follows:

- Classic V shapes, indicative of steadily moving storms, are shown in Fig. 8 and the lower left storm in Fig. 9.
- Massive storms are apparent in the top panels of Fig. 9.
- Medium intensity storms are indicated in the lower two left events in Fig. 9.
- Weak storms.
- Very few strokes are in lower right Fig. 9. Similar difficulties are found in other events that were identified in the media as due to lightning but were accompanied by other meteorological factors, in this case by severe weather. In fact, it appears that in some cases to be discussed later, lightning may have been used as an excuse to stop play during highly undesirable conditions although the lightning threat itself as demonstrated with NLDN data is not significant enough to cancel the game.

TABLE II. FIVE TYPES OF LIGHTNING ACTIVITY AFFECTING SIX GAMES THAT NEVER STARTED

Games	Lightning presence for games that never started
1	Classic V shape for steadily moving storm
3	Major storm before, during or after decision time
2	Medium intensity storm with strokes at varying distances
0	Weak intensity storm with small amount of strokes
1	No lightning, or very few strokes

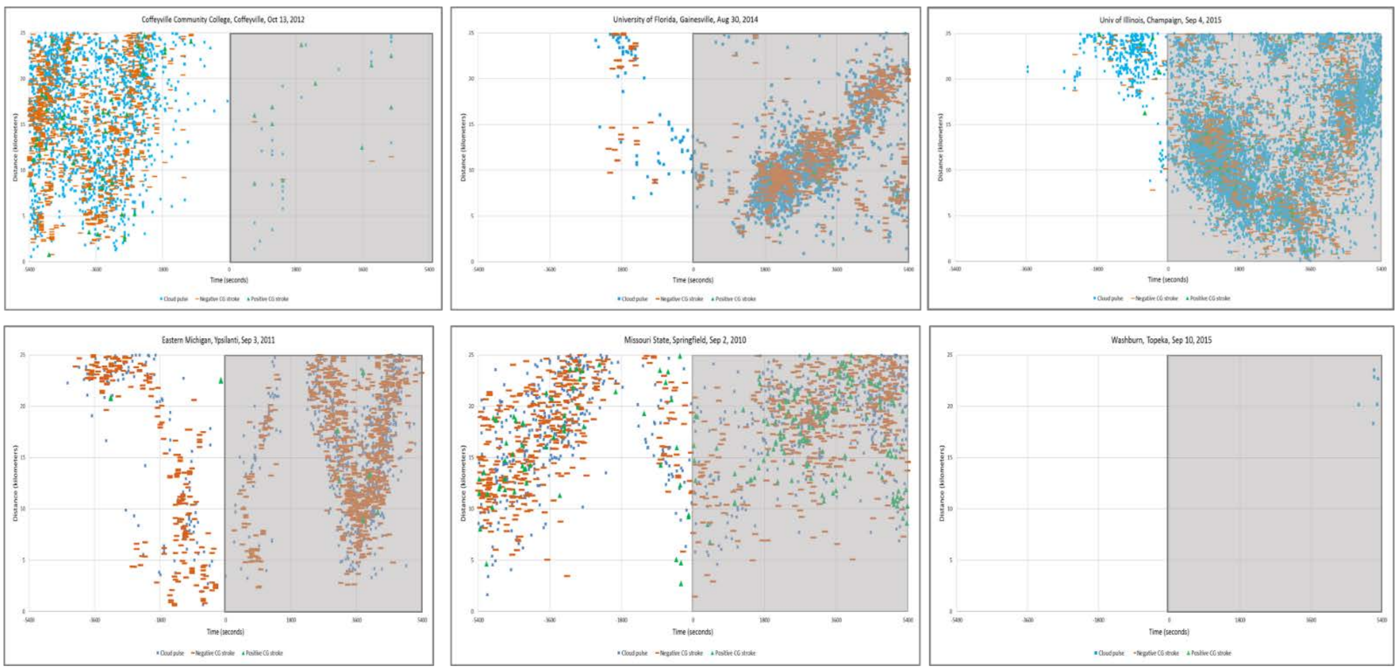

Fig. 9. Same as Fig. 8 for six games that never started. Gray shading overlays lightning after the event had been suspended at time zero.

VII. 34 GAMES THAT STARTED LATE

There were 34 games that started late but were eventually played in their entirety (Table I). Of this total, 30 were collegiate and four were NFL games. Nearly half of them, 16, were in the first ten days of September. In addition, 15 had scheduled start times of 1800 or 1900 local time, so they were early evening games that were affected by lingering late-afternoon thunderstorms in the area. Texas and Florida accounted for 12 of the games.

Analyses were made of lightning relative to the late starts using the same format as Fig. 8. Results in Table III show that the classic V shape for a moving storm was only present in four games that started late. Seven games had major thunderstorms at or around the time of the late start, while 14 games were associated with medium intensity thunderstorms, six were weak and five had almost or no lightning.

The conclusion is that the most common scenario is a thunderstorm near the stadium in time and space that is of medium intensity but does not have the classic V shape of a moving thunderstorm. Such a situation is not especially well defined since some activity is at varying distances and times. In addition, as mentioned earlier, several games with no lightning were associated with severe weather yet little or no lightning actually occurred within 90 minutes and 25 km of the stadium.

The extreme case in the entire dataset is shown in Fig. 10. The game at McMurry University in Abilene, Texas was scheduled to begin at 1400 local time, but did not start until 1948 local time, a delay of 348 minutes. The graphical representation shows lightning beginning during the hour before the scheduled game start, and then persisting at all distances for two and a half hours. After a 30-minute break, another traveling storm arrived, as indicated by a partial V shape. About 30 minutes after that event left, the game started, although a few positive strokes persisted nearby.

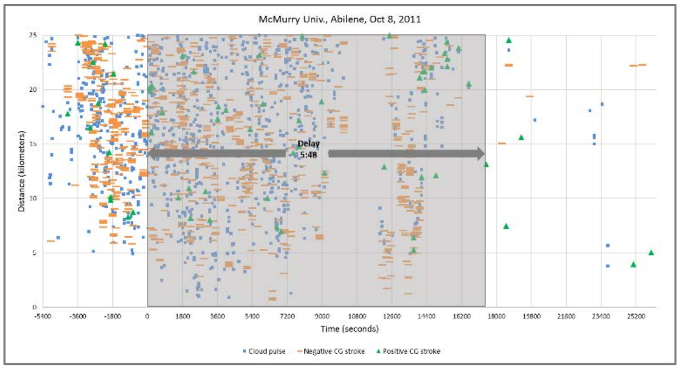

Fig. 10. Same as Fig. 8 for game delayed five hours and 48 minutes by lightning at McMurry University on 08 October 2011.

TABLE III. FIVE TYPES OF LIGHTNING ACTIVITY AFFECTING GAMES THAT STARTED LATE

Games	Lightning presence for games that started late
4	Classic V shape for steadily moving storm
7	Major storm before, during or after decision time
14	Medium intensity storm with strokes at varying distances
6	Weak intensity storm with small amount of strokes
5	No lightning, or very few strokes

VIII. 18 GAMES SUSPENDED AND NOT RESTARTED

There were 18 games that started, but lightning stopped the games and the contests were never resumed. These games were widely dispersed from Florida to Texas and as far north as Connecticut. Ten of them were during the first ten days of September. The times of suspension ranged from noon to midnight. Results in Table IV show that quite a few games had weak amounts of lightning or no lightning at all. These are sometimes difficult to reconcile with lightning data alone, and reconstructing the decision process after the fact is not feasible.

An example is a nighttime game at the University of Arkansas that was never restarted after a delay, as shown in Fig. 11. Note that most of the lightning was in-cloud, together with more positive cloud-to-ground strokes than negative cloud-to-ground strokes. The in-cloud pulses were overhead for about 15 minutes after the suspension time, and persisted within 10 km for 90 minutes after the suspension. It is possible that the visual appearance of the in-cloud lightning after dark led to a very conservative response in this case. There had also been a 66-minute delay earlier in the game, and the home team had a large lead, so the decision may have been more expedient than objective.

Because of such limitations in reconstructing the situation afterward, it could be suggested that the decision process be documented during the game and archived. Many of the games appear to be impacted by stoppages at reasonable times and places by examination of the lightning data. However, it is unclear how some of the delays or cancellations were determined based on lightning data only.

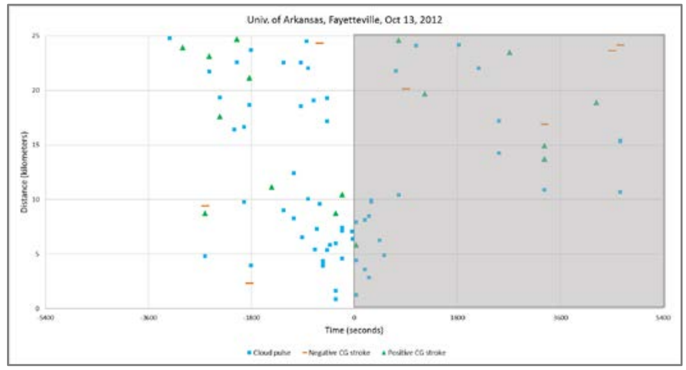

Fig. 11. Same as Fig. 8 for game suspended and never restarted at the University of Arkansas on 13 October 2012.

TABLE IV. FIVE TYPES OF LIGHTNING ACTIVITY AFFECTING GAMES SUSPENDED AND NOT RESTARTED

Games	Lightning presence for suspended games that were not restarted
5	Classic V shape for steadily moving storm
6	Major storm before, during or after decision time
4	Medium intensity storm with strokes at varying distances
10	Weak intensity storm with small amount of strokes
5	No lightning, or very few strokes

IX. 12 GAMES WITH HALFTIME DELAYS

Games were delayed at halftime on 12 occasions. The 20-minute halftime period was long enough for a storm to approach and cause a delay before the third quarter began. One half of them were in the first 20 days of September. Almost all were between 1300 and 1900 local time, so the games coincided with peak lightning occurrence time (Fig. 5). Locations were spread across the country from coast to coast and south to north. Results summarized in Table V indicate the same tendency for medium to weak intensity storms to be most commonly causing the halftime delays.

An example of a halftime delay in Fig. 12 shows that negative cloud-to-ground strokes and in-cloud pulses came within 4 km of the stadium and the game was stopped. Lightning persisted within 10 km for 40 minutes, then within 14 km for an hour. When 30 minutes had passed after the last negative cloud-to-ground strokes, the game was resumed and lightning did not return within 17 km. This case appears to have had a well-managed decision process.

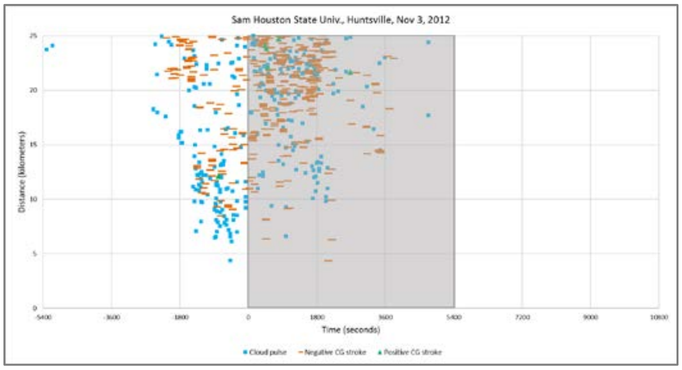

Fig. 12. Same as Fig. 8 for game with a halftime delay at Sam Houston State University in Texas on 03 November 2012.

TABLE V. FIVE TYPES OF LIGHTNING ACTIVITY AFFECTING GAMES WITH HALFTIME DELAYS

Games	Lightning presence for suspended games with halftime delays
1	Classic V shape for steadily moving storm
1	Major storm before, during or after decision time
5	Medium intensity storm with strokes at varying distances
4	Weak intensity storm with small amount of strokes
2	No lightning, or very few strokes

X. 66 EVENTS WITH IN-GAME DELAYS

The largest category was delays within games. While most common in September, they were spread from early August (pre-season NFL games) to one event in mid-December at a Mississippi college where lightning lingers late in the year [Holle et al., 2016]. The time of day was widely distributed from 1400 to 2000 local time. Texas, Florida, Illinois, North Carolina and Ohio all had five or more such in-game delays. Results of analyses in Table VI indicates that 22 of the events had well-defined V-shaped signatures associated with moving storms. However, another 26 cases had weak storms in terms of lightning that was not well defined, and did not move steadily across the stadium locations, yet resulted in delays during the game.

TABLE VI. FIVE TYPES OF LIGHTNING ACTIVITY AFFECTING GAMES WITH IN-GAME DELAYS

Games	Lightning presence for events with in-game delays
22	Classic V shape for steadily moving storm
5	Major storm before, during or after decision time
12	Medium intensity storm with strokes at varying distances
26	Weak intensity storm with small amount of strokes
4	No lightning, or very few strokes

XI. CONCLUSIONS

A total of 136 mostly collegiate football games with lightning delays between 2010 and 2015 were analyzed for the lightning features around the time of the delays. It is likely that many more games were affected by lightning, but were not reported widely to the larger media sites, and therefore not included in this dataset.

It was found that lightning affected games most often in early to mid-September. The time of day was clustered when most games start around mid-afternoon and early evening. States with the most delays were Texas and Florida, although other regions of frequent lightning impacts were in the Midwest and east-central states.

Six games were never started on the scheduled day, 34 started late, and 18 were suspended at some point during the game and never resumed. Another 12 had halftime delays and 66 in-game delays occurred.

Analysis of lightning on a per-game basis showed that only 33 of the 136 games (24%) were affected by thunderstorms that steadily moved across the region of the stadium and could be tracked by linear extrapolation. Instead, the most common types were 46 weak (34%) and 37 medium storms (27%) in terms of lightning occurrence. There were 22 storms (16%) that had a large amount of lightning before, during, or after the decision times that were relatively easy to determine. Another 17 games (12%) had only a small amount of lightning, or none at all within 25 km and 90 minutes. These cases were sometimes accompanied by other factors such as severe weather or other harsh conditions such that lightning may have been used as a justification to stop the games. However, it is very difficult to reconstruct the situation at the stadia after the fact without detailed analyses of other meteorological information. It is recommended that documentation of the decision process be collected and archived so that further insight can be gained into the results of this study.

ACKNOWLEDGMENTS

Researchers at East Carolina University are recognized for their original collection of football game impacts by lightning from 2010 through 2015 that formed the underlying basis for this study. The authors greatly appreciate the significant, timely, and crucial support provided by Mr. William Brooks of Vaisala in Tucson, Arizona in preparing the data and plots for games shown in this study.

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