Diurnal Variations of NLDN-Reported Cloud-to-Ground Lightning in the United States

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ABSTRACT

National maps of cloud-to-ground lightning flash density (in flashes per square kilometer per year) for one or more years have been produced since the National Lightning Detection Network (NLDN) was first deployed across the contiguous United States in 1989. However, no single publication includes maps of cloud-to-ground flash density across the domain and adjacent areas during the entire diurnal cycle. Cloud-to-ground lightning has strong and variable diurnal changes across the United States that should be taken into account for outdoor lightning-vulnerable activities, particularly those involving human safety. For this study, NLDN cloud-to-ground flash data were compiled in 20 km by 20 km grid squares from 2005 to 2012 for the lower 48 states. A unique feature of this study is that maps were prepared to coincide with local time, not time zones. NLDN flashes were assigned to 2-h time periods in 5° longitude bands. Composite maps of the 2-h periods with the most lightning in each grid square were also prepared. The afternoon from 1200 to 1800 local mean time provides two-thirds of the day’s lightning. However, lightning activity starts before noon over western mountains and onshore along the Atlantic and Gulf of Mexico coasts. These areas are where recurring lightning-vulnerable recreation and workplace activities should expect the threat at these times, rather than view them as an anomaly. An additional result of the study is the midday beginning of lightning over the higher terrain of the western states, then the maximum activity moves steadily eastward. These storms pose a threat to late-afternoon and evening recreation. In some Midwest and plains locations, lightning is most frequent after midnight.

1. Introduction

Cloud-to-ground lightning has a major impact on a wide variety of activities and industries. Lightning activity is highly variable on all scales including the diurnal, and this variability should be taken into account for individual safety and for planning outdoor lightning-vulnerable activities. Personal safety situations include recreation, schools, defense, and aviation. The occurrence of lightning also has significant impacts on utility and many other lightning-vulnerable industrial operations. Development of average lightning maps by time of day can help anticipate the typical threat to lightning-vulnerable activities based on averages that are apparent in past climatological data such as will be shown in this paper. In some cases, outdoor activities can be moved to another time of day to accommodate the typical hour-by-hour changes in lightning (Holle et al. 1999). In other cases, planning ahead for lightning-caused interruptions and impacts at fixed assets such as power and manufacturing operations can be done with more certainty with the knowledge of typical lighting patterns through the day. No single day follows the average diurnal pattern, such that real-time lightning and other coincident meteorological data need to be used to modify plans to account for the actual conditions as they develop during the day.

On the national scale, annual maps of cloud-to-ground (CG) lightning have been produced since the National Lightning Detection Network (NLDN) first monitored the contiguous United States in 1989. Such maps for one or more years have been published by Huffines and Orville (1999), Orville (1991, 1994, 2001, 2008), Orville and Huffines (1999), Orville and Silver (1997), Orville et al. (2002, 2011), and Zajac and Rutledge (2001). Villarini and Smith (2013) show NLDN data for the 80 days in a year when lightning is most frequent, which is a subset of all lightning during a year. Lightning

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concentrates along the coasts of large water bodies (Dodge and Burpee 1993) and near large mountains (Reap 1986; Whiteman 2000); is often associated with excessive precipitation (Pessi and Businger 2009), severe (Calhoun et al. 2013), isolated (Holle et al. 1997), and winter storms (Market and Becker 2009); and affects geophysical properties such as NOx production (Nesbitt et al. 2000).

A recent companion study to the present paper showed the monthly distribution of CG flashes over the lower 48 United States (Holle and Cummins 2010; Holle et al. 2011). The results showed a dominance of lightning in June, July, and August. Exceptions were that very few June flashes occurred in the southwest monsoon states of Arizona, Utah, Nevada, western Colorado, and western New Mexico, there was minimum activity in the southern plains states of western Texas, Oklahoma, and Kansas in July, and late summer to autumn maxima occur in some northwestern regions such as Oregon and Idaho. With that background of monthly distributions, the variability within the day will now be examined.

Prior to the existence of lightning networks, maps of thunderstorm hours and days were based on human observers reporting the presence of thunderstorms. Such an observation based mainly on audible thunder is not an especially good indicator of lightning frequency. Easterling and Robinson (1985) used harmonic analyses to map four seasonal patterns of diurnal thunderstorm variations and found that the maximum activity moved eastward in the central United States during evening and nighttime, while summer afternoon heating and coastal sea breezes dominated over Florida and the Gulf Coast.

To date, network-detected lightning data have not been used to compile a full set of national diurnal lightning maps. Previous diurnal lightning results have consisted of time series for a region, occasionally by flow regime, and sometimes a map was shown for one or two time periods. The most complete prior U.S. diurnal lightning study by Zajac and Rutledge (2001) included a normalized amplitude map of summer diurnal lightning distributions across the United States at several cities, a map of the phase of the diurnal cycle of lightning frequency, and a review of previous thunderstorm climatologies prior to the deployment of lightning networks. This summertime diurnal study found lightning over the western and eastern states to be primarily related to solar heating, while the central U.S. pattern was much more complex. A diurnal lightning study by Cecil et al. (2011) indicated a broad evening maximum over the central part of the country with optical transient detector (OTD) satellite data from 1995 to 2000, and lightning imaging sensor (LIS) satellite data from 1998 to 2010.

In the present paper, accurately measured NLDN lightning flashes are utilized to prepare lightning flash density maps at local time. These lightning distributions are related to meteorological factors as they occur during the course of the daily cycle. Particular emphasis is given to the relationship of lightning occurrence through the day to human activities that can be modified (e.g., recreation) or responsive (e.g., utility repairs) to the average daily occurrence of CG lightning. Less-frequent emphasis is given to the significant value of these lightning distributions to vulnerable fixed asset protection, although some operations can be adjusted in advance for the typical time of day of lightning (e.g., handling of volatile material). The goal of the study, then, is to provide a complete easily understood summary of the diurnal variation of cloud-to-ground lightning over the United States.

2. NLDN data and analysis methods

The NLDN detects CG lightning flashes and strokes, as well as a portion of cloud impulses (Cummins et al. 1998; Cummins and Murphy 2009). The present paper deals only with CG flashes, although NLDN stroke data have been available since 1995 (Cummins and Murphy 2009). No polarity separation is made in the present study. There are 3–4 CG strokes per CG flash, and 1.4–1.5 ground strike locations per flash (Cummins and Murphy 2009). NLDN improvements include an upgrade in the early 2000s (Cummins et al. 2006) and another upgrade in 2013. The estimated flash detection efficiency (DE) for the contiguous 48 states is 90%–95% since the previous upgrade (Cummins and Murphy 2009). DE typically decreases to 10% several hundred kilometers from the border of the U.S. land area to the east and west over the oceans and to the south over Mexico. No DE degradation occurs to the north where the NLDN operates seamlessly with the Canadian Lightning Detection Network (CLDN) in Canada. Based on these considerations, the NLDN CG flash dataset used in this study from 2005 to 2012 is during a period when DE over the contiguous U.S. land area uniformly exceeds 90%.

To develop reasonably stable lightning maps, several years of lightning data are needed since convective events tend to be distributed in a nonlinear fashion. Olascoaga (1950) and Riehl (1954) showed that about 50% of rainfall in Argentina occurred on 10% of the days, and 90% of the rainfall fell on 50% of the days. The same relationships apply to smaller areas and shorter time periods of rainfall. Beyond this concentration in rainfall, lightning is concentrated still further. López and Holle (1986), Zajac and Rutledge (2001), and...
Makela et al. (2011) expanded on the concept that flashes are clustered sufficiently in short time and small space intervals that individual storms can dominate a lightning sample that is compiled for one or two years, depending on grid size and flash density. As a result of these considerations, a quality longer-term database is desirable; 2005–12 is used here. During this period, the network had a median location accuracy of better than 500 m over the contiguous U.S. land area. CG flash data are accumulated into 20 km by 20 km grids across the contiguous 48 states and adjacent areas. The choice of an 8-yr, 2-h, 20 km by 20 km grid dataset is based on previous experience with similar national and regional NLDN datasets. These choices result in meaningful general patterns that are not horizontally fragmented. As a result, the diurnal pattern of U.S. lightning can be depicted at a moderate detail that shows the major patterns; local studies continue to be needed to explore detailed features. For the diurnal analyses, flash data are grouped into 2-h time periods by 5° longitude segments. This approach provides results in local mean time (LMT) that identify diurnal changes in lightning patterns without noticeable boundaries between longitude segments. Comparisons at the same local time of day allow the assessment of the relative timing of the cloud-to-ground lightning risk from one place to another across the country. The method differs somewhat from Zajac and Rutledge who used a sliding time scale that changed with time of year and latitude.

The spatial boundaries, apparent on the maps, are as follows:

- **North**—250 km into Canada from the U.S. border.
- **South**—600 km to the south from the U.S. land area into Mexico and the Gulf of Mexico, as far south as 23.2°N.
- **West**—600 km to the west from the U.S. land area into the Pacific, as far west as 125.8°W.
- **East**—600 km to the east from the U.S. land area into the Atlantic, as far east as 65.85°W.

### 3. Annual U.S. flash density

The NLDN flash density map in Fig. 1 has data for all hours and months combined. This map depicts all lightning during the 24-h day at the same horizontal resolution as the 2-h figures to follow, using the same flash data. The range of annual flash density is more than two orders of magnitude, from over 14 flashes km⁻² h⁻¹ yr⁻¹ in three areas of Florida, to less than 0.1 flashes km⁻² h⁻¹ yr⁻¹ along the West Coast and over many ocean areas. Orville et al. (2011) is the latest in a series of national annual flash density maps showing similar features.
Much of the atmospheric moisture over the contiguous United States has its origin in warm oceans adjacent to the south and east of the land area. CG flash densities are highest over Florida (e.g., Lericos et al. 2002) and along the Gulf Coast (Camp et al. 1998; Smith et al. 2005; Steiger et al. 2002) due to the very warm ocean waters that provide deep moisture for strong updrafts to reach altitudes colder than freezing over strongly heated land areas. Lowest flash densities along and near the West Coast in Fig. 1 occur where cold water and large-scale sinking motion inhibit deep convection (Reap 1986).

A general decrease from south to north, and east to west, occurs on a national scale. However, there are important variations over and east of the Rocky Mountains (Cook et al. 1999; Hodanish and Wolyn 2012), and over the interior western states (King and Balling 1994; Watson et al. 1994; Fosdick and Watson 1995). Many of these variations are identifiable in diurnal changes that will be described in the present paper by subdividing the flash dataset in Fig. 1 into 2-h segments.

4. 2-hourly flash density maps

Figure 2 shows the measured 2-hourly average number of flashes per year in LMT over the contiguous United States and adjacent land and ocean areas from the dataset used in this study. CGs plotted in Fig. 2 have a minimum at about 1000 LMT, as in Zajac and Rutledge (2001). The 1600–1800 LMT maximum in Fig. 2 applies to the national dataset; specific locations have more widely varying times than the minimum, as will be described in the present paper.

a. 1000–1200 LMT

The 1000 LMT lightning minimum in Fig. 2 is used as the starting time for the following series of maps. The diurnal cycle of lightning over the United States will be presented by 2-h increments, through the day, then evening, then the nighttime hours until the 1000 LMT minimum is reached again.

The first map from 1000 to 1200 LMT is in Fig. 3a. Notable features are as follows:

- The highest lightning frequency exceeds 0.6 flashes km$^{-2}$ h$^{-1}$ yr$^{-1}$ along the shore of the Gulf Coast and immediately offshore.
- Frequent lightning over 0.4 flashes km$^{-2}$ h$^{-1}$ yr$^{-1}$ occurs in the region from the plains to the Mississippi Valley that are mainly remnants from the previous night’s convection.
- Maxima exceeding 0.2 flashes km$^{-2}$ h$^{-1}$ yr$^{-1}$ coincide with high mountains in the Four Corners states of Arizona, Utah, New Mexico, and Colorado.

Curran et al. (2000) indicated that lightning casualties begin to increase in the late morning toward a much larger afternoon maximum. Late-morning activities such as mountain hikes and beach visits are sometimes vulnerable to lightning in the areas just mentioned. An early flash resulting in a Colorado mountain fatality is described by Hodanish and Zajac (2002). In addition, vulnerable industrial activity could be completed by this
time in these areas when and where lightning occurs before noon; early lightning can be considered to be a normal situation rather than a rare surprise. The Florida peninsula has warm-season flashes in late-morning thunderstorms in Fig. 3a that are also apparent in Lericos et al. (2002), López and Holle (1986), Maier et al. (1984), Reap (1994), and Shafer and Fuelberg (2006, 2008). Most of these past studies subdivided lightning climatologies with respect to flow regimes during the summer. In particular, Lericos et al. (2002) mention that late-morning lightning activity is most prevalent during the southwesterly flow regime. Similarly, Fig. 3a also identifies a late-morning flash concentration due to sea breezes along the Gulf of Mexico and Atlantic coasts (Camp et al. 1998; Smith et al. 2005) and near Houston and southern Louisiana (Steiger et al. 2002).
There is likely some component of the flashes caused by tropical storms and hurricanes as they approach and cross the coast (Demetriades et al. 2010), but the diurnal cycle of heated land dominates the sample over the 8 years.

Colorado has several small high-mountain maxima approaching 0.2 flashes km\(^{-2}\) h\(^{-1}\) yr\(^{-1}\) before noon. The mountainous western half of the state has strong local forcing due to large topographic gradients resulting in well-defined lightning patterns that tend to maximize along the largest slopes being impinged by moisture advection (Cummins 2012; Hodanish and Woly 2012; López and Holle 1986).

Arizona lightning occurs mainly during the summer monsoon months of July and August, and some grid squares during this time period exceed 0.2 flashes km\(^{-2}\) h\(^{-1}\) yr\(^{-1}\) due to major topographic gradients (Fig. 3a). Diurnal Arizona flash variations studied by King and Balling (1994) showed flash activity beginning at the higher terrain and moving toward the lower valleys including metropolitan Phoenix in the evening. Similar timing was shown for the evening Phoenix maximum by Watson et al. (1994) by comparing lightning with precipitation by hour.

New Mexico lightning in the late morning also occurs over higher elevations and slopes and exceeds flash densities of 0.3 flashes km\(^{-2}\) h\(^{-1}\) yr\(^{-1}\) (Fig. 3). Foscoid and Watson (1995) showed hourly New Mexico maps similar to Watson et al. (1994) for Arizona. Over New Mexico and west Texas, regime-flow lightning patterns were compiled by Wagner et al. (2006). Easterly flow in west Texas was the least productive in terms of lightning per day, while westerly flow was least productive in New Mexico. A unique feature of this study indicated the first flashes of the day around this time. Such studies can be valuable when developed for other regions, since they can aid in anticipating the day’s lightning activity for planning outdoor work and recreation.

c. 1400–1600 LMT

Between 1400 and 1600 LMT (Fig. 4a), all areas with lightning exceeding 0.1 flashes km\(^{-2}\) h\(^{-1}\) yr\(^{-1}\) two hours earlier have increased in lightning frequency. There are no new large areas of lightning. Nevertheless there is a considerable amount of lightning at this time when recurring vulnerable outdoor activities should be minimized or contingency plans be taken into account for the possibility of lightning. Activity increases to over 0.7 flashes km\(^{-2}\) h\(^{-1}\) yr\(^{-1}\) across Florida, along and inland from the Gulf of Mexico, in east-central Arizona and Colorado, northwest Mexico, northeast New Mexico, and eastern Oklahoma through Arkansas to southern Illinois, as well as expansion and intensification in other locations in the southeast.

d. 1600–1800 LMT

This 2-h period has the most cloud-to-ground lightning of the diurnal cycle for the contiguous United States as a whole (Fig. 2). Figure 4b shows enhanced frequencies that reach 0.4 flashes km\(^{-2}\) h\(^{-1}\) yr\(^{-1}\) in many regions, especially in the southeastern third of the country compared with two hours earlier in Fig. 4a. This region and period continue to be a time when outdoor activities should be avoided or very carefully monitored because of persistent high lightning frequencies. Most areas to the west of the Continental Divide already begin to show a decrease earlier since these regions are driven primarily by daytime heating that reaches a maximum in midday. This maximum time coincides with an afternoon concentration of much lower annual flash density that nevertheless causes significant impacts at the Nevada test site (Randerson and Saunders 2002).

However, the area to the lee of the Rocky Mountains shows the beginning of a new area of lightning. This swath from south-southwest to north-northeast between west Texas and central Kansas is sometimes the location of the dryline during spring and summer months (Schaefer 1974; Schultz et al. 2007). Clouds form along and east of this low-level convergence boundary and move eastward starting around this time, and sometimes
develop into MCSs, squall lines, or other organized convective systems that continue eastward into the evening and nighttime hours.

One of the notable features during this time period is the late-afternoon to early-evening lightning occurrence in the area of Atlanta, Georgia. The 1996 Atlanta Olympics prompted lightning climatologies to be prepared for the area by Livingston et al. (1996) and Watson and Holle (1996). These studies emphasized the occurrence of lightning later than midafternoon, as evident in Fig. 4. A regional flash climatology for northern Georgia and western North Carolina by Murphy and Konrad (2005) also showed this late-afternoon to evening maximum and attributed it partially to storm size and organization on a regional scale. This evening maximum is somewhat later than in areas to the south and east of Atlanta, and may be underappreciated in planning outdoor events.
e. 1800–2200 LMT

As evening approaches, the spatial pattern of flash density remains unchanged, but the density values gradually decrease, except in the middle of the country (Fig. 5a). This is a time when many outdoor recreational activities such as sports and other events occur, so the later lightning maximum should not be entirely unexpected. Two hours later, from 2000 to 2200 LMT (lower Fig. 5b), there is a strong decline in lightning in most regions near and after sunset in the summer, although a few areas have more lightning detected after sunset (Holle and Cummins 2010; Holle et al. 2011). Lightning from 2000 to 2200 LMT has lower flash densities of less than 0.4 flashes km$^{-2}$ h$^{-1}$ yr$^{-1}$ in most areas, where it is primarily diurnally forced by daytime heating on the southeastern coast and over the western mountains. Note that some evening lightning-vulnerable activities continue into this period such that care needs

FIG. 5. As in Fig. 1, but during (a) 1800–2000 and (b) 2000–2200 LMT.
to continue to be taken to anticipate these continuing storms.

In contrast, the CG flash density in the central states remains the same or is enhanced compared with that shown two hours earlier due to storms propagating generally from west to east. A portion of the evening to nighttime enhancement of the central U.S. lightning is due to mesoscale convective systems (MCS) during spring and summer. These large organized convective systems have been identified in both the tropical and midlatitudes, and tend to occur more often over land areas (e.g., Liang and Fritsch 1997). The largest MCS, the mesoscale convective complex (MCC), was first described by Maddox (1980). MCSs and MCSs are sometimes prolific lightning producers during the night as shown by Holle et al. (1994), Nielsen et al. (1994), and many subsequent studies.

Derechos are also a source of frequent evening and nighttime lightning in the region from the western Great Lakes to Ohio in summer, as well as the southern plains in the cool season (Bentley and Mote 1998; Johns and Hirt 1987). The 29–30 June 2012 derecho that traveled from Chicago to the East Coast had 70 000 cloud-to-ground flashes, which approaches the lightning production of many MCSs. Derechos are frequent in some years and areas, and may contribute significantly to the lightning climatology in certain regions; no study of derecho lightning has been made to date. Derechos tend to originate in late-afternoon to evening and move rapidly from the southwest or west, and provide some contribution to the evening and nighttime lightning frequency in these regions.

f. 2200–0200 LMT

Moving forward in time as the flash density pattern gradual weakens, Fig. 6 shows a pair of 2-h maps around midnight with a large maximum on the plains that is mainly unchanged from earlier time periods. Flash densities in some grid squares exceed 0.7 flashes km$^{-2}$ h$^{-1}$ yr$^{-1}$; these values were observed during the afternoon in Florida and other locations. Lightning density in the area centered on Kansas during these hours is actually larger than during the daylight hours. MCSs and derechos continue on the plains and Midwestern states on some summer nights at this time. During these hours, the exposure of people to CGs is minimal except for homes that catch on fire at night, and camping (Curran et al. 2000). However, the frequent lightning during these nighttime hours is when frequent-lightning-caused power outages and utility repairs can be expected on the plains and Midwest; they are not the exception but the rule according to these flash density maps.

g. 0200–0600 LMT

During the next four hours, Fig. 7 shows that most lightning continues to decrease. However, two areas have significant activity. One is from Oklahoma to Iowa, where flashes continue to move from west to east due to MCSs, derechos, and squall lines that originated over and along the dryline to the lee of the Rocky Mountains. A maximum exceeding 0.5 flashes km$^{-2}$ h$^{-1}$ yr$^{-1}$ is located in a few grid squares over southern Iowa and northwest Missouri. Lightning continue to be a threat at this time for utility outages, house fires, and camping. The other area is an enhancement offshore of the southeast coast over the Gulf Stream that appears to be due to nocturnal land-breeze effects over the warm ocean during the predawn hours.

h. 0600–1000 LMT

As areal coverage and densities approach the minimum in the diurnal lightning cycle after sunrise (Fig. 2), the final pair of 2-h maps is shown in Fig. 8. Flash activity is weaker than in any other 2-h time period. Also, the midcountry maximum has moved eastward until only a few grid squares exceed 0.4 flashes km$^{-2}$ h$^{-1}$ yr$^{-1}$ over Missouri and eastern Oklahoma. The new day’s convection begins with the map from 1000 to 1200 LMT (Fig. 3), when the cycle of thunderstorms develops again along coastlines, over mountains, and in the center of the country as a result of lingering activity from the previous night.

5. Combined diurnal maps

The maps in the preceding 12 two-hour periods show a large number of features that often have gradual trends from one time period to the next. The time of maximum flashes at a location is helpful in understanding the typical diurnal lightning threat, and also can help identify spatial features that represent meteorological factors causing the maxima. Visual inspection of the individual maps with those before and after a time period often does not show the time of maximum lightning. As a result, a pair of maps crossing the time periods was prepared. For ease of understanding, composite maps from noon to midnight LMT are shown, and from midnight to noon in Fig. 9. Figure 9a is for the more active time of day (Fig. 2) for lightning between noon and midnight, and Fig. 9b is for the less active period from midnight to noon.

a. Noon to midnight

Figure 9a shows that most land areas have their peak lightning activity during the 12 h starting at noon. For
example, blue grid squares (see color scale) have lightning most often from 1200 to 1400 LMT. The most common noon-to-midnight time is between 1400 and 1800 LMT when many of the recurring daily outdoor activities engaged by people in work and recreation take place. Florida maxima are all during midafternoon, as well as most southeastern states. Over Arizona, Utah, Colorado, and New Mexico, flashes begin over high terrain in the early afternoon, then progress outward to lower elevations in the evening and nighttime to the east or southwest. The central plains maxima progress at later and later times toward midnight as storms move eastward off the higher terrain to the west.

b. Midnight to noon

Figure 9b plots the grids where lightning has a maximum between midnight and noon. In a number of grid squares of the upper Midwest and northern plains, the
most frequent lightning is after midnight. More than a third of the grid squares in Iowa have peak lightning between 0000 and 0400 LMT, which also coincides with this area’s nighttime maximum of MCSs. For example, an earlier local NLDN flash climatology in the upper Mississippi Valley showed two maxima: a minor one just after noon due to daytime heating, but a much larger one shortly before and after midnight due to MCSs (Cook et al. 1999).

Many of the grid squares in the Atlantic and Pacific Oceans, Gulf of Mexico, and Gulf of California have maxima between midnight and noon. The much lower flash densities over the water result in less organized times of the maxima due to small sample sizes in many grid squares. Near Florida, Georgia, and South Carolina, the ocean immediately offshore had maxima before midnight (Fig. 6a) associated with daytime thunderstorms moving offshore in the evening. Figure 6b shows...
some eastward storm motion after midnight into the adjacent Atlantic. A lightning enhancement over the Gulf Stream relative to land in North Carolina during a winter field program has been identified (Biswas and Hobbs 1990; Dodge and Burpee 1993; Orville 1990). In contrast the monthly NLDN study (Holle and Cummins 2010; Holle et al. 2011) showed the maximum offshore of the southeast states to occur mostly in summer (see Fig. 9b), and the present study shows it to be at night.

6. Conclusions

The first complete survey of CG lightning density over the United States according to local time of day was compiled. CG flashes from Vaisala’s NLDN were combined during 2-h periods into 5° longitude bands that resulted in seamless views of the diurnal variation of lightning at the same local time so that lightning occurrence can be compared. Patterns were related to the primary meteorological
factors that occur over the United States during the course of the diurnal cycle. Such maps are useful for identifying the threat to lightning-vulnerable recurring outdoor activities such as workplaces and recreation.

The minimum time of lightning over the country is between 0800 and 1000 LMT. The first flashes of the daily convective cycle due to solar heating of the land occur between 1000 and 1200 LMT along the Florida and Gulf of Mexico coasts, and over high mountains of the southwestern states. This time period is earlier than is often expected to be a threat for beach and mountain recreation as well as other outdoor activities such as industrial situations. During the following 6 h, lightning increases greatly in frequency in these locations,
as well as spreading to new locations in southeastern states after noon. The most common time of maximum lightning is between 1400 and 1800 LMT, which is the latter part of the work day, as well as the beginning of late-afternoon recreation. A notable maximum in the evening begins on the high plains to the lee of the Rocky Mountains and moves eastward through the night. These storms pose a lightning threat to evening recreation in many areas. The lightning frequencies also show nighttime maxima as late as 0200–0400 LMT in some upper Midwest locations, and coincide with house fires and camping casualties (Curran et al. 2000). Oceanic lightning tends to be during the night and morning hours, although the times of these maxima are variable because of small sample sizes.

The results of the present study agree substantially with Zajac and Rutledge (2001), especially the general phase of the diurnal lightning maximum in their Fig. 10b. The present study includes the full set of maps at individual 2-h time periods at local time, and has more spatial resolution than that prior study. Previous partial diurnal maps and time series referenced in the current study agree with the new maps that provide a more complete context of the diurnal lightning cycle over the United States than has been compiled prior to this time. In addition, the present diurnal study can be combined with a similar monthly lightning frequency summary to help focus on the time of year and time of day of lightning exposure across the contiguous United States.

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