306 MONTHLY DISTRIBUTIONS OF NLDN AND GLD360 CLOUD-TO-GROUND LIGHTNING

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1. INTRODUCTION

National maps of cloud-to-ground lightning flash density (flashes/km^2/year) for the entire year have been produced since the National Lightning Detection Network (NLDN) was first deployed across the contiguous 48 states in 1989. Multi-year national maps since the NLDN was completed have been published by Orville (1991, 2001), Orville and Silver (1997), Huffines and Orville (1999), Orville and Huffines (1999), Zajac and Rutledge (2001), Orville et al. (2002), and Orville (2008).

These publications showed the annual flash distributions from the NLDN, but monthly maps of cloud-to-ground lightning have not been compiled. Zajac and Rutledge (2001) showed summer and cold season maps of lightning distributions, as well as monthly cycles at several cities across the U.S., but did not include monthly maps. Monthly cloud-to-ground time series with one total per month for the entire U.S. were shown by Orville and Silver (1997), Orville and Huffines (1999), and Orville (2001, 2008). Other papers have also graphed annual or seasonal positive flashes, multiplicity, and mean peak current; these topics are not examined in the present paper.

In this paper, we present monthly maps of NLDN-based ground flash density and monthly fraction of totals in the U.S. and surrounding areas. During summer months, NLDN monthly maps of ground flash density are compared with those from the new Vaisala Global Lightning Dataset GLD360. Results show that lightning data over all of Mexico, Central America, and the western Caribbean complement and extend the NLDN coverage in very reasonable patterns. An earlier version of the present paper using the NLDN only is in Holle and Cummins (2010).

2. LIGHTNING DATA

2.1. NLDN data

The National Lightning Detection Network (NLDN) detects cloud-to-ground lightning flashes and strokes, as well as a small percentage of cloud events (Cummins et al. 1998; Orville 2008; Cummins and Murphy 2009). NLDN data shown here are cloud-to-ground flashes only, although cloud data have been available since 2006 (Cummins and Murphy 2009). Improvements to the NLDN network have included upgrades in 1998 (Cummins et al. 1998) and 2003 (Cummins et al. 2006). The estimated NLDN flash detection efficiency for the contiguous 48 states is 90 to 95%. For this study, no separation will be made with regard to polarity.

NLDN data for this paper were accumulated into 20 by 20 km grid squares of cloud-to-ground flash density across the contiguous 48 states and adjacent regions. The time period is from 2004 through 2008, a period that begins after the most recent upgrade to the NLDN.

The spatial boundaries of the NLDN data shown in this study are:

- North - 250 km into Canada.
- South - 600 km to the south into Mexico and the Gulf of Mexico, but no farther south than 23.2° S.
- West - 600 km to the west into the Pacific but no farther west than 125.8° W.
- East - 600 km to the east into the Atlantic but no farther east than 65.85° W.

2.2. GLD360 data

Vaisala's Global Lightning Dataset (GLD360) was launched in September 2009 (Demetriades et al. 2010). GLD360 is the first ground-based lightning detection network capable of providing both worldwide coverage and uniform, high performance without large detection differences between daytime and nighttime conditions. The expected performance of GLD360 is 70% cloud-to-ground flash detection efficiency and 5-10 km median cloud-to-ground stroke location accuracy.

GLD360 cloud-to-ground flash detection efficiency and stroke location accuracy were recently validated over the continental United States using Vaisala's NLDN as ground truth (Demetriades et al. 2010). GLD360 cloud-to-ground flash detection efficiency (relative to the NLDN) ranged from 86% to 92% throughout the 24-hour UTC day, with little day/night variation. GLD360 CG stroke median location accuracy was 10.8 km. More comprehensive validation of detection efficiency is planned to be performed.

GLD360 stroke density data shown in this study are in 20 by 20 km grid squares within geographical boundaries extending beyond the region with NLDN data. For this study, no separation was made with regard to polarity, and a few events may have been cloud pulses rather than cloud-to-ground strokes.

The limits chosen for the monthly comparisons of this paper are:

- Latitude - 6° to 51°N.
- Longitude - 50° to 127°W.

3. ANNUAL FLASH DENSITY DISTRIBUTIONS

Figure 1 shows the most recent map of the annual cloud-to-ground flash density for 11 years from 1997 through 2007 across the contiguous U.S. The range of flash density is very large, from over 14 flashes/km^2/year in three areas of Florida, to less than 0.1 flashes/km^2/year along the west coast. In general, densities are highest in Florida and along the Gulf Coast where adjacent ocean waters are very warm and provide deep moisture for strong coastal updrafts. Low densities along the west coast are located adjacent to cold offshore water that inhibits deep convective updrafts. A general decrease from south to north, as well as east to west, occurs on the national scale. However, there are important variations over and east of the Rocky Mountains, as well as over the interior western states.

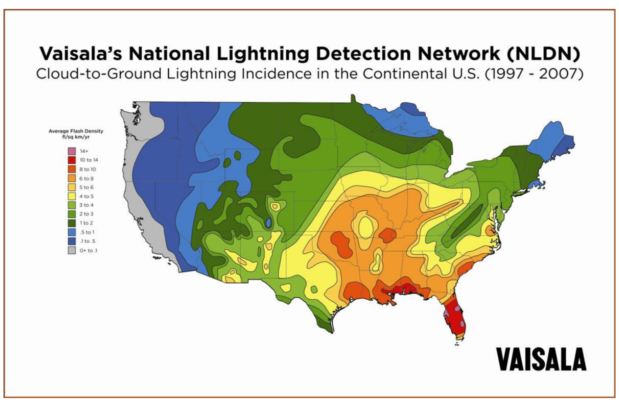

FIGURE 1. Cloud-to-ground lightning flash density per square kilometer per year for the U.S. from 1997 to 2007. Scale is on left side of map.

4. MONTHLY FLASH DENSITY MAPS

Monthly maps of NLDN cloud-to-ground flash density were developed for the U.S. from 2004 through 2008. An average of 27 million cloud-to-ground flashes was detected by the NLDN over the land area of the contiguous U.S during each of these years, when corrected for detection efficiency. Figure 2 shows the measured (not corrected by detection efficiency) monthly distribution of flashes over the contiguous U.S., and adjacent land and ocean areas, as defined in section 2.

Lightning is by far most common during the summer months - two thirds of U.S. cloud-to-ground flashes occur in June, July, and August. The maximum during the warmer months of the year, especially in the southeastern states, is due to daytime heating causing upward vertical motions in the lower and middle levels of the atmosphere. An equally important ingredient is the large amount of moisture in those levels that provides fuel for the daily thunderstorm cycle; much of that atmospheric moisture has its origin in adjacent warm oceans to the south and east.

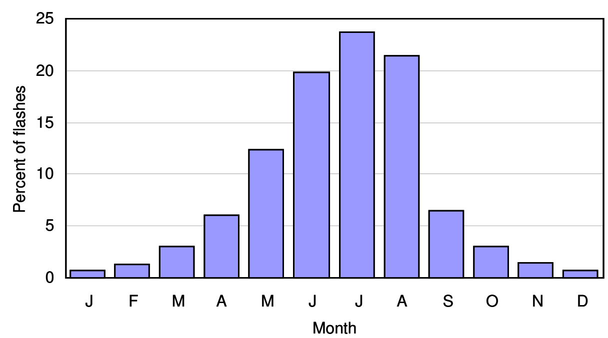

FIGURE 2. Cloud-to-ground flashes per month from 2004 though 2008 for the U.S. and adjacent areas from the National Lightning Detection Network.

4.1. January

For the month of January, Figure 3 shows that most grid squares in the eastern half of the country had some lightning during the month from 2004 through 2008. Several other notable features are:

- Although five years of data are summarized, individual storms can be identified in many regions. Some of these are winter storms with thundersnow (section 6.6).
- Almost no cloud-to-ground flashes were detected in the northern Rocky Mountain and plains states in January in these five years.
- The highest January flash densities exceed 0.5 flashes/km^2/year at the intersection of Oklahoma, Missouri, and Arkansas, and in southern Alabama.
- Some cloud-to-ground flashes are apparent offshore in the Gulf of Mexico and the Atlantic in the domain of the Gulf Stream.
- There is not much lightning over peninsular Florida in January.

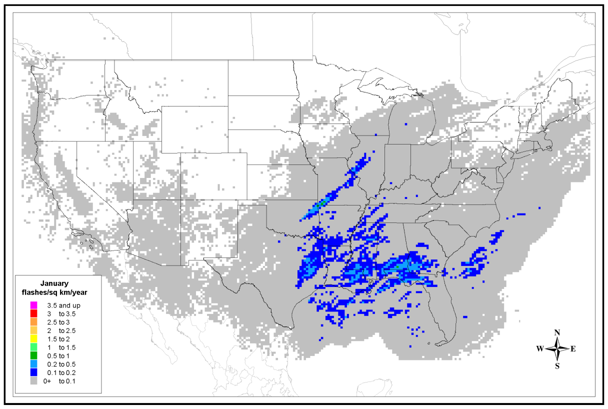

FIGURE 3. Cloud-to-ground lightning flash density per square kilometer in January for the U.S. from 2004 through 2008. Scale is in lower left portion of map.

4.2. February

The February distribution (Figure 4) is substantially similar to January, with two exceptions. The area above 0.1 is about double that of January. In addition, the maxima between 0.5 and 1.0 flashes/km^2/year are now more frequent across Louisiana and adjacent states along the Gulf Coast.

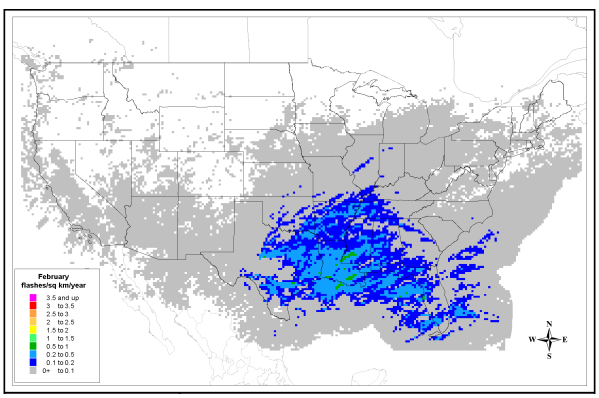

FIGURE 4. Same as Figure 3, except for February.

4.3. March

In March, Figure 5 shows a large northward expansion of higher lightning rates above 0.1, as well as between 0.5 and 1.0. Also, there is somewhat more activity to the northwest and especially the western states.

A few small maxima within lines generally extending from southwest to northeast have grid squares exceeding 1.0 flashes/km^2/year in Texas, Louisiana, Mississippi, Georgia, and adjacent states during March. A small amount of activity persists over the Gulf Stream.

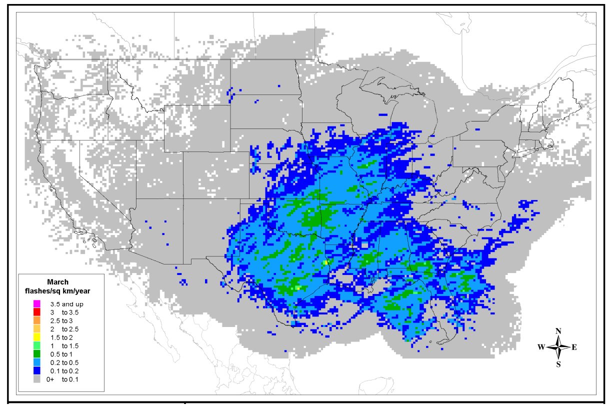

FIGURE 5. Same as Figure 3, except for March.

4.4. April

In April, Figure 6 shows a continuous increase in areal coverage and flash density in most regions since March. The major features are:

- An expansion of the 0.5 to 1.0 lightning densities as far northward as Indiana and Nebraska.
- New areas between 1.0 and 1.5 flashes/km^2/year are most apparent along the Gulf coast and eastern Oklahoma. April maxima in those areas exceed 2.5 in several grid squares.
- From a year-to-date basis, peninsular Florida still does not show any significant maxima.
- There is an increased incidence of lightning off the Carolinas over the Gulf Stream.

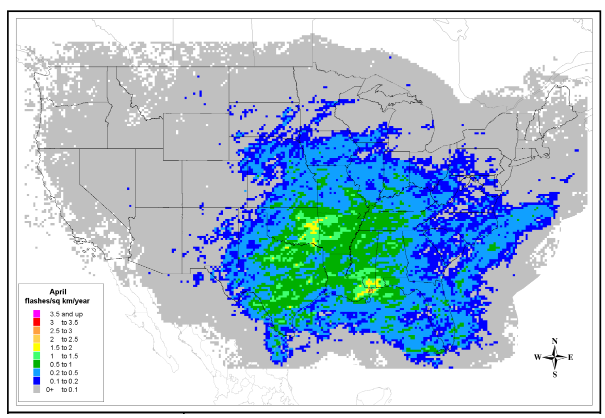

FIGURE 6. Same as Figure 3, except for April.

4.5. May

In May, Figure 7 shows a major expansion in the year-to-date cloud-to-ground lightning activity since April. Flashes were observed within nearly every grid square of the U.S. at some point during this month between 2004 and 2008, and nearly all areas east of the Continental Divide have more than 0.2 flashes/km^2/year. The only exception is that no flashes were detected in some grid squares inland from the west coast, and in southwest Arizona and northern Mexico.

A notable number of flashes occurred beyond the U.S. border into Canada. Highest rates now exceed 2.0 flashes/km^2/year or more from Texas northeast into Kentucky. Note the start of the summer lightning season in south Florida, and the continued and growing maximum over the Gulf Stream.

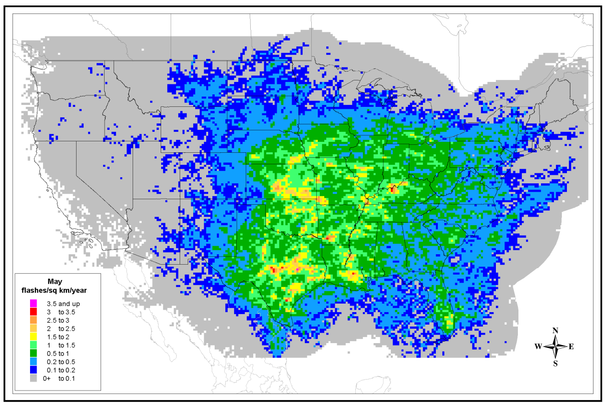

FIGURE 7. Same as Figure 3, except for May.

4.6. June

In June, the NLDN in Figure 8 shows a significant expansion of the area of high lightning frequencies since May. Most notable is the rather sudden development from May to June of the strong lightning maximum over Florida. Maxima exceed 3.0 flashes/km^2/year across much of the peninsula due to the influence of the two coastal sea breezes. An additional sea breeze influence is apparent across the Florida Panhandle to Texas. Lightning resulting from the Atlantic sea breeze extends weakly northward from Florida into South Carolina. High lightning frequencies are also observed by the NLDN from Kansas and Oklahoma eastward to Illinois and other states bordering the Ohio River. A few maxima now appear on the eastern slopes of the Rocky Mountains from Montana to New Mexico. The Gulf Stream maximum has grown in area and sharpened since May.

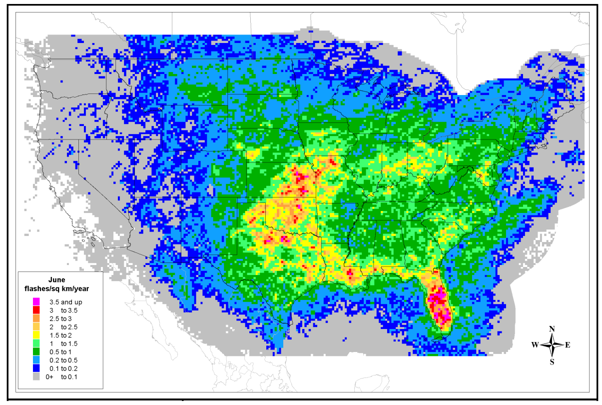

FIGURE 8. Same as Figure 3, except for June.

Also for June, GLD360 in Figure 9 shows substantially the same features over the U.S. as the NLDN in Figure 8. Note that GLD360 data in Figure 9 are for June 2010 only, while Figure 8 from the NLDN is from 2004 to 2008. An additional difference is that since GLD360 data are for strokes, the stroke densities are somewhat higher in many areas than shown by NLDN flash data.

GLD360 maxima are apparent over the central and southern Plains, Florida, and the Gulf Coast although differences are apparent that may be attributed to different periods of observation. Outside of the U.S., however, GLD360 shows the full extent of the coastal maximum all along the Gulf of Mexico around Mexico, maxima over Cuba and Hispaniola, and another center of high lightning frequency in northern South America (Albrecht 2009). The northwest Mexico maximum in a line from northwest to southeast does not reach north to Arizona and New Mexico in June.

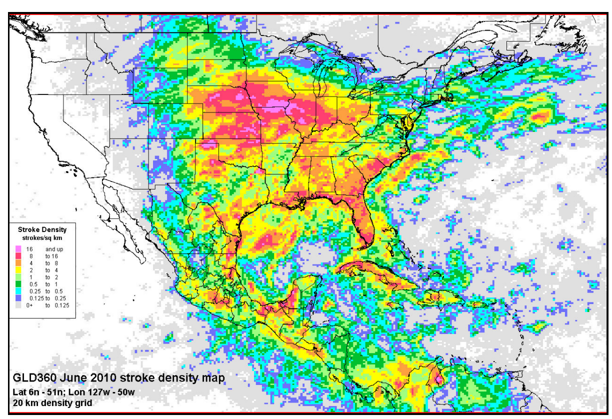

FIGURE 9. Global Lightning Dataset GLD360 cloud-to-ground strokes per square kilometer during June for the U.S., Mexico, Central America, Gulf of Mexico, Caribbean Sea, and northern South America. Scale is in lower left portion of map.

4.7. July

In July, the NLDN in Figure 10 shows the new appearance of two strong lightning maxima over Arizona compared with June as the Southwest Monsoon begins. The east-central Arizona maximum is over the Mogollon Rim while the southern area extends into northwest Mexico. Also resulting from the monsoonal moisture flow is a large increase in lightning in Colorado and New Mexico compared with June. Over Florida, the flash density now exceeds 3.5 flashes/km^2/year over many areas of the peninsula. The Great Plains maximum has shifted eastward to Illinois from its June position, and the southeast U.S. coastal region now has widespread moderate to strong flash activity, as well as offshore over the Gulf Stream.

Also for July, GLD360 in Figure 11 shows generally the same features over the U.S. as the NLDN in Figure 10. The GLD360 maximum in southeast Arizona reaches much farther south into northwest Mexico during July than shown by the NLDN.

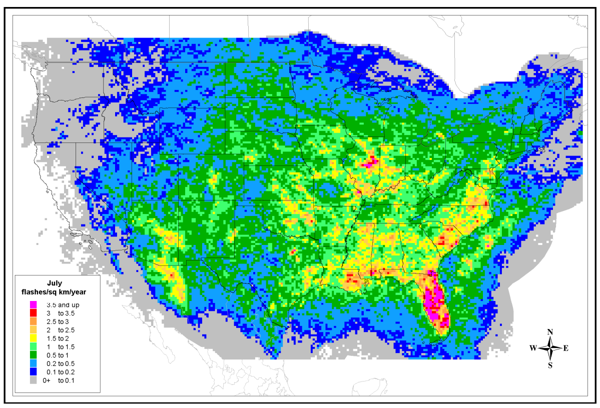

FIGURE 10. Same as Figure 3, except for July.

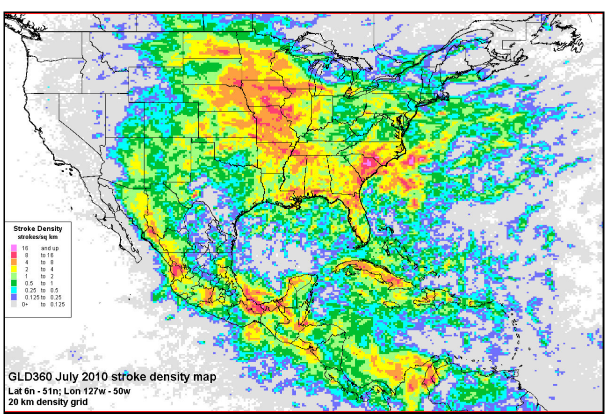

FIGURE 11. Same as Figure 9, except for July.

4.8. August

In August, the NLDN in Figure 12 shows a modest decrease in lightning incidence over Arizona, Florida, the southeast coast, and offshore Gulf Stream regions compared with July, but patterns are mostly the same. The only area with an increase is northern Iowa and surrounding states where mesoscale convective systems are frequent during the month.

The GLD360 map in Figure 13 shows a much more extensive area of high lightning density over northwest Mexico than in July. In fact, it is the largest continuous lightning maximum in North America (Murphy and Holle 2005). The relatively lower lightning density over Florida in the GLD360 map compared with NLDN may represent a period of degraded network performance during part of the month that has not been explored to date.

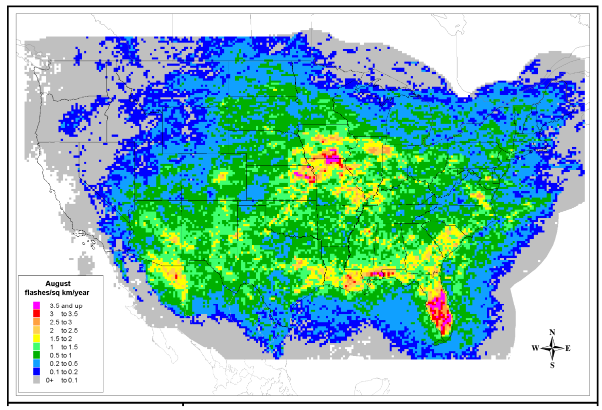

FIGURE 12. Same as Figure 3, except for August.

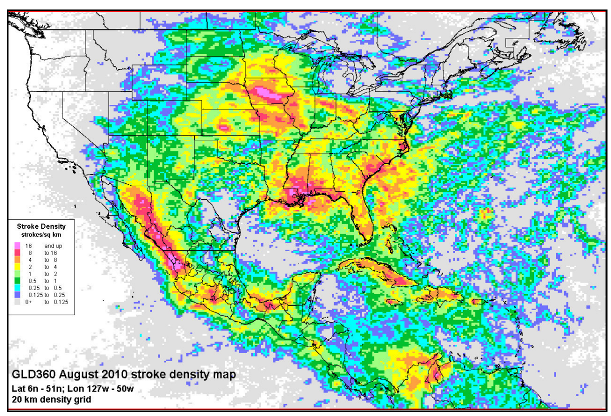

FIGURE 13. Same as Figure 9, except for August.

4.9. September

The September NLDN map (Figure 14) shows a marked decrease in strong flash density values across the entire U.S. Substantial reductions occur in Florida, Arizona, the Plains, and Midwest. The strength of this decrease most likely indicates that the lightning season already began to decrease at some time during late August. Some flashes are seen throughout the country, except in interior Washington and Oregon, and along the California coast.

The GLD360 map in Figure 15 shows that stroke density over northwest Mexico continues to be quite large and has not reduced much since August.

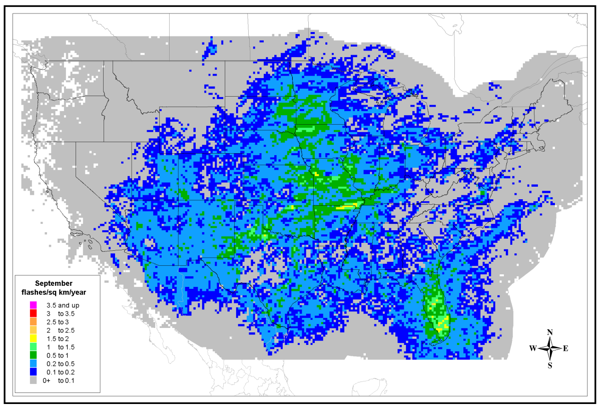

FIGURE 14. *Same as Figure 3, except for September.*

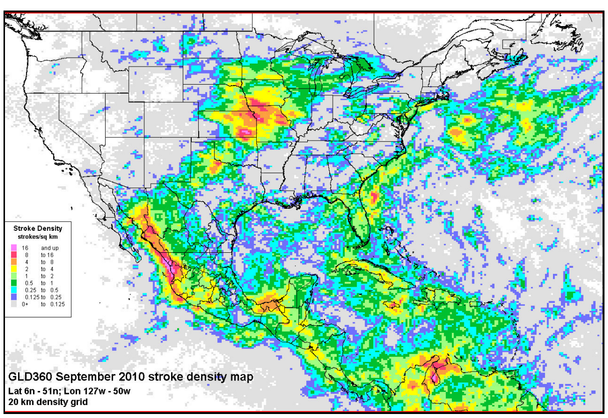

FIGURE 15. *Same as Figure 9, except for September.*

4.10. October

October (Figure 16) shows a continued broad decrease in lightning incidence compared with September. Regions of higher flash densities are scattered across the southern Great Plains and Texas. Almost no lightning is now located in parts of western Washington and Oregon, Montana, coastal northern California, western North Dakota, and northern Maine.

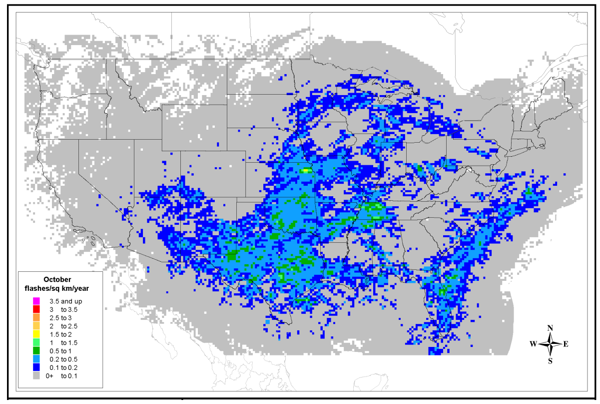

FIGURE 16. *Same as Figure 3, except for October.*

4.11. November

For November, Figure 17 shows that much of the northwest half of the country, and the extreme northeast states rarely had lightning during the 2004-2008 period. The only maxima are in Texas and Louisiana, and nearby regions to their north. Elongated swaths of individual storms, some with snowfall, are beginning to reappear after being absent since February.

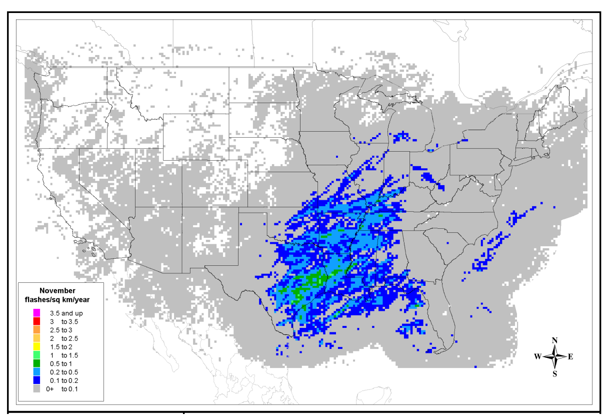

FIGURE 17. *Same as Figure 3, except for November.*

4.12. December

In December, Figure 18 shows a lightning density map that is similar to that of January in Figure 3. Note that a cold season lightning maximum in southeastern Oklahoma was shown by Zajac and Rutledge (2001), which is consistent with the individual monthly maps in the preceding figures.

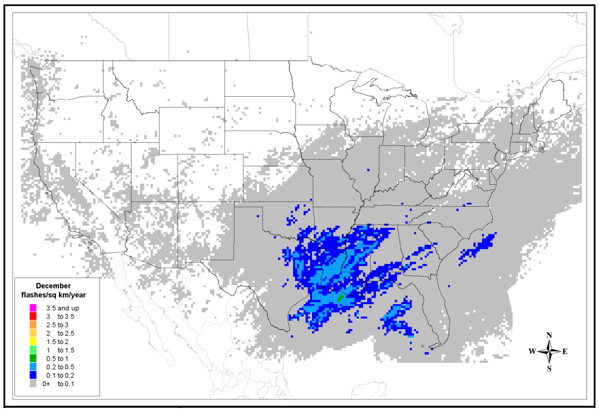

FIGURE 18. Same as Figure 3, except for December.

5. MONTHLY FLASH PERCENTAGE MAPS

Monthly flash density maps in preceding figures showed several regions that had concentrations of flashes in a few specific months. To illustrate these features in a more quantitative manner, monthly maps were developed to show the percentage of flashes compared with the annual totals.

5.1. January

For January, Figure 19 shows that across most of the lower 48 states, January has less than 10% of the annual total of NLDN flashes. However, along the west coast, there are individual 20- by 20-km grid squares where up to 100% of the annual flashes occur in this month. A magenta square indicates that all of the flashes for the year in that grid square in the five-year dataset, probably one, occurred in January. Yellow represents the 50% range, indicating that one of two flashes (or half of the flashes) during the five years in that grid square occurred in January. Also note the concentration of January flashes in the Central Valley of California.

The February and March maps (not shown) are similar to January in Figure 19, except the area covered by a few flashes increases north and west (Figures 4 and 5), and the California Central Valley maximum is strongest in March.

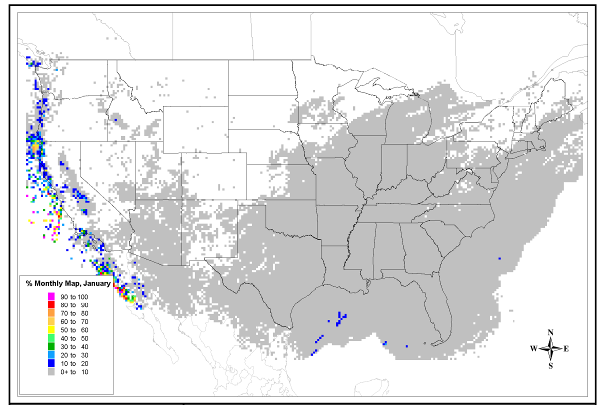

FIGURE 19. Percentage of annual NLDN cloud-to-ground lightning flashes that occur in January for the U.S. from 2004 through 2008. Scale is in lower left portion of map.

5.2. April

For April, Figure 20 shows that some areas of eastern Oklahoma southeastward to the Gulf have up to 20% of their annual lightning; similar values are in southern Texas. The maxima along the west coast have now moved onto the coastal ranges since earlier months. The western slopes of the Sierra Nevada range of California and the Cascades of Oregon and Washington experience much of their annual lightning incidence in April.

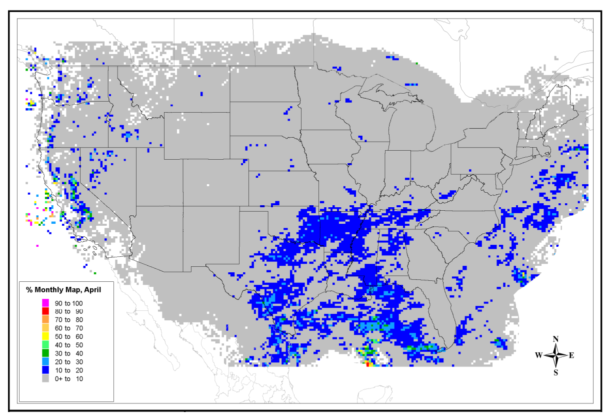

FIGURE 20. Same as Figure 19, except for April.

5.3. May

During May, Figure 21 shows several new areas of high percentages since April. One center appears in west Texas where up to 40% of the year's lightning occurs during May. Further north in Kansas and Nebraska, similar high percentages are found, and scattered areas of 30% are apparent across the Midwest. An area in central Washington exceeds 40 to 50% for May, and some grid squares in Oregon coastal areas are above 80%. Note the very low percentages in Florida. The very high percentages at the edges of coverage, such as far to the east of Georgia, are artifacts of interannual variations in NLDN coverage limits, and are not climatologically relevant.

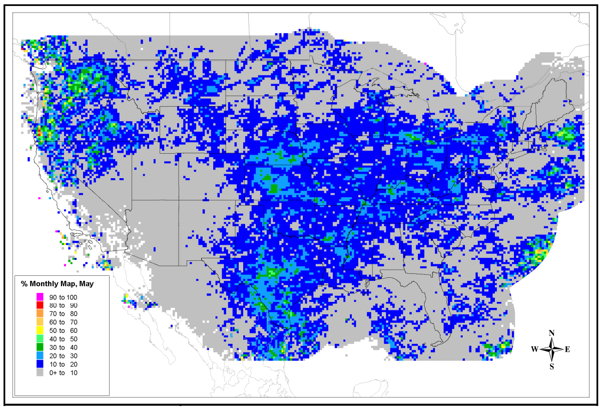

FIGURE 21. Same as Figure 19, except for May.

5.4. June

During June, Figure 22 shows an area exceeding 40% over much of Montana. The high May percentage area in west Texas has moved to the Panhandle, and a small concentration of high values is over northern California. Scattered areas above 40% are apparent across the northeast in June. All of Florida has 20 to 30% of its annual lightning in June. The high-percentage regions southwest of California and in the southern Gulf of Mexico are artifacts of the edge of the network, as noted for May. Several regions are notable for a very low fraction of incidence of June lightning. One region is nearly all of Arizona and surrounding portions of adjacent states, and another is the Central Valley of California.

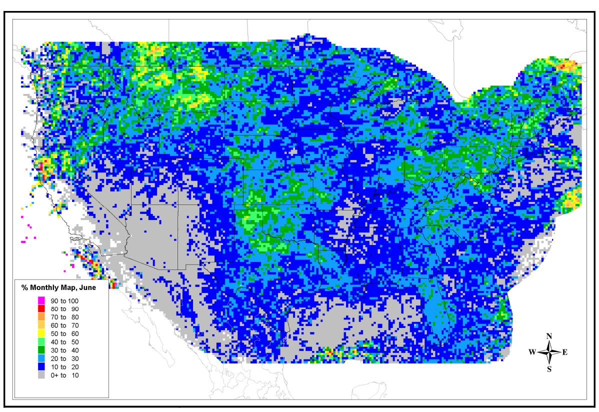

FIGURE 22. Same as Figure 19, except for June.

5.5. July

In July, Figure 23 indicates a sharp increase in the flash percentage in Arizona and nearby states as the Southwest Monsoon begins. In southern Nevada, over half of the year's lightning occurs in July. Also notable are high percentages across New England and the Atlantic coast from Maryland northward, where July is the dominant month for lightning in many larger northeast cities. Much of the northern Florida peninsula has over 30% of its lightning during July. Also notable is a maximum offshore of the Carolinas over the Gulf Stream. An absence of July lightning is apparent in much of Texas and Oklahoma, and to the northeast. In July, these areas are under a persistent high-pressure ridge, when storms pass to the north in the westerly flow regime, and south of the area in subtropical easterly flow.

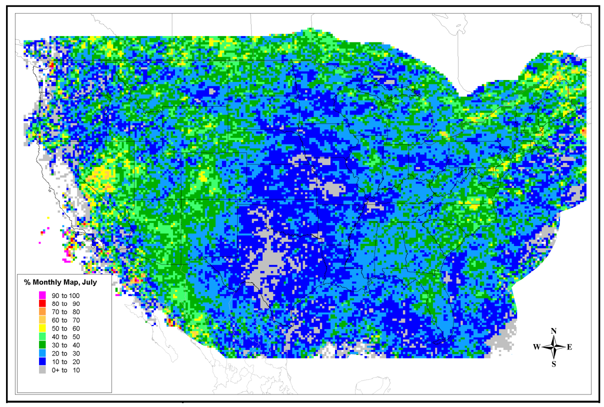

FIGURE 23. Same as Figure 19, except for July.

5.6. August

The August percentage map (Figure 24) shows a continuation of many July features, except the extremes are somewhat subdued. The Texas-Oklahoma minimum continues, and the New England maximum is still dominant. However, the Arizona and associated monsoon maximum regions show up to 50% or more of the year's lightning occurring during August. In fact, the lower deserts of southern California into northern Baja California had most of their year's flashes during this month. One other notable maximum is the central Oregon maximum exceeding 50%. Over most of the Florida peninsula, at least 20% of the year's lightning is during August. The two areas of very high flash percentages off the Mexican coast are artifacts of the edge of the network, as mentioned for May. At this time, we do not have an explanation for the 80 to 90% incidence in the Pacific west of Oregon.

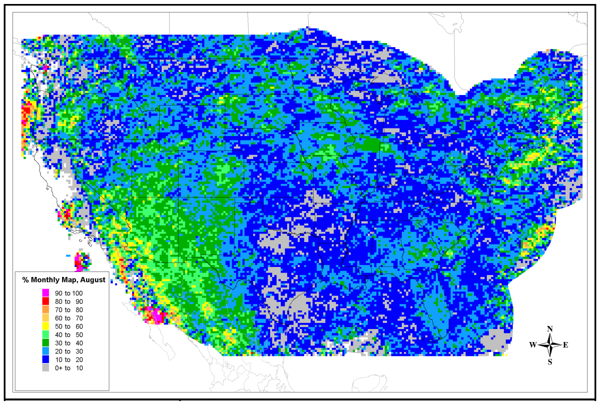

FIGURE 24. Same as Figure 19, except for August.

5.7. September

The September percentage map (Figure 25) indicates a major reduction in the month's percentage of the year's lightning in nearly all areas. Florida has a small monthly contribution in September, as well as low ratios in the Northeast and central U.S. The only sizeable areas with contributions in excess of 20 to 30% are in the upper Mississippi Valley, Utah, and California's Central Valley and southern deserts. The latter maximum may be due to occasional tropical systems during September.

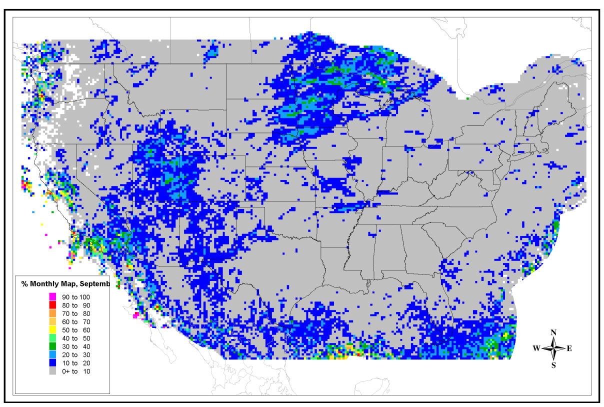

FIGURE 25. Same as Figure 19, except for September.

5.8. October to December

The October percentage map (not shown) is a weaker version of September, except some grid squares around Los Angeles have over 50% of the year's lightning in October. This result may be due to one or two flashes during the five-year period, as for January in Figure 19. November is a very low contributor to lightning across the U.S. In December, the only maximum is in the Central Valley of California, as indicated for January in Figure 19.

6. REGIONAL FEATURES

6.1. Peninsular Florida

The Florida peninsula is frequently considered to be the 'lightning capitol' of North America. However, note that Murphy and Holle (2005) identified an annual flash density maximum in northwest Mexico south of Arizona where the density exceeds the Florida maxima. The present paper shows Florida to have a concentrated season of high flash densities in June, July, and August. There have been many prior studies of this Florida lightning feature; the spatial and diurnal lightning distributions during summer across the peninsula are among the most widely understood lightning features in the world. Monthly peninsular lightning maps have been shown by Hodanish et al. (1997) and in three-month maps by Fieux et al. (2006). Summertime Florida lightning has been studied in terms of location and timing over part of, or all of the peninsula by Maier et al. (1984), López and Holle (1986, 1987), Reap (1994), Lericos et al. (2002), Shafer and Fuelberg (2006, 2008), and Bauman et al. (2008).

Most studies identify low-level flow regimes that control the frequency and location of lightning during the diurnal cycle over the peninsula. Some studies used daily upper-air soundings to forecast the timing and location of lightning. Quite a few studies were initiated in response to requirements for forecasting lightning in the vicinity of the Kennedy Space Center.

6.2. Gulf coast

The present paper identifies a concentration of flashes during June, July and August along the Gulf of Mexico and Atlantic coasts. Previous studies of summertime storms in the northern Gulf coast from the panhandle of Florida to Texas (Camp et al. 1998; Smith et al. 2005) used similar approaches to those described above for Florida. The repeatability of summertime lightning patterns based on low-level flow has led to methods to forecast patterns and timing of lightning across the northern Gulf (Stroupe et al. 2004).

The summertime maxima near Houston and in southern Louisiana have been studied in detail, beginning with McEver and Orville (1995). A later focus has been the relative importance of coastal effects versus anthropogenic impacts by Orville et al. (2001), Steiger et al. (2002, 2003), and Gauthier et al. (2005).

Winter lightning, often in bands, is shown by the monthly maps across the Gulf Coast in the present study. Buechler et al. (1999), Laing et al. (2008), and LaJoie and Laing (2008) related changes from year to year in numbers and patterns of NLDN cloud-to-ground lightning in these regions with the effects of the El Nino-Southern Oscillation.

6.3. Georgia and southeastern states

The 1996 Atlanta Olympics prompted lightning climatologies to be developed for Georgia and surrounding venues by Watson and López (1996) and Livingston et al. (1996). Additional studies have explored the potential for enhancement of urban-induced lightning around Atlanta (Bentley and Stallins 2005; Rose et al. 2008). A climatology of flashes in the higher elevations of northern Georgia and to the northeast was developed by Murphy and Konrad (2005). Our analyses indicate that southern Georgia shares a common intra-annual lightning incidence pattern with the Gulf States, while northern Georgia has a pattern similar to the adjacent southeastern states.

6.4. Colorado

Colorado has strong local forcing due to very large topographic gradients from elevation changes of up to 10,000 feet (3 km) within horizontal distances of 50 km that result in well-defined lightning patterns. The Colorado maps of summer lightning distributions by López and Holle (1986) for the eastern slopes of the Front Range showed maxima on the Palmer Lake Divide that also appear in current summer monthly maps. Hodanish and Wolyn (2004) showed annual maps for the state that indicate similar patterns to those in the preceding monthly figures.

6.5. Arizona, New Mexico, and northwest Mexico

- **Arizona:** The distinct concentration of flashes during July and August in Arizona shown in this study has not been represented elsewhere. However, the lightning density maxima over the Mogollon Rim and southeastern mountains were described in López et al. (1997). Diurnal lightning changes in Arizona were studied by King and Balling (1984), and the timing and meteorological conditions accompanying monsoon lightning over Arizona were studied by Watson et al. (1984a, b).
- **New Mexico:** A lightning climatology was developed for New Mexico by Fosdick and Watson (1995) that extends partly into Arizona. Regime-flow lightning patterns were compiled by Wagner and Fuelberg (2006) for New Mexico extending into west Texas.
- **Northwest Mexico:** The lightning maximum over the Sierra Madre Mountains of northwest Mexico was shown somewhat by NLDN data, and better by the extrapolation of NLDN data into the region by Murphy and Holle (2005). The new GLD360 dataset during summer 2010 shows this region to have a very high lightning frequency that sometimes exceeds that of Florida. More studies will be needed in this area, especially as the maximum moves northward from May to July into the U.S. and has significant impacts during the southwest monsoon in Utah and Colorado.

6.6. Thundersnow

The winter lightning density maps show individual storms with banded structures oriented southwest to northeast. In some cases, these bands are accompanied by snowfall. Such events have been documented most frequently in the central U.S. (Holle and Watson 1996; Market and Cissell 2002; Crowe and Podzimek 2006, Market and Becker 2009; Pettegrew et al. 2009). Additional cases have been shown in southeastern states (Hunter et al. 2001), Oklahoma (Trapp et al. 2001), and far south Texas (Morales 2008; Dolif Neta et al. 2009).

6.7. Other climatologies

Other published cloud-to-ground lightning climatologies using the NLDN include:

- **Central Plains:** The central U.S. from the Texas Panhandle north-northeastward to the Canadian border has anomalously high positive flash percentages, especially related to severe storms (Carey and Rutledge 2003; Carey and Buffalo, 2007). However, the flash densities themselves are not especially unusual on the monthly maps. The 2000 STEPS program was conducted in this region to address these issues (Lang et al. 2004). A climatology of NLDN flashes in the upper Mississippi River Valley (Cook et al. 1999) showed time series of one value per month for the region, as well as the decrease in density from south to north.
- **Derechos:** Monthly maps in July and especially August show a lightning maximum across Illinois and Indiana. In these areas,

there is a warm-season maximum in derechos (large long-lasting systems of straight-line winds) oriented from west-northwest to east-southeast that may contribute to the enhanced flash density in the southern Great Lakes (Johns and Hirt 1987; Bentley and Mote 1998).

- **Lake effects:** Great Lakes lightning maxima have been shown to be oriented along the lakes' long axes (Moore and Orville 1990; Schultz 1999; Steiger et al. 2009). Lightning near the Great Salt Lake was identified in Schultz (1999).
- **Gulf Stream:** Lightning over the Gulf Stream has often been identified as a winter feature due to recurrent convective rainbands forming over the Gulf Stream (Biswas and Hobbs 1990). However, monthly maps in this study show that while there is a relative maximum during some winter months, the highest absolute frequency of cloud-to-ground flashes, and highest percentage monthly contributions, occur in summer. This observation needs elaboration in future studies.
- **Nevada:** A series of lightning studies around the Nevada Test Site showed detailed variations in this lightning-sparse region (Randerson 1999; Randerson and Saunders 2002).
- **Convective SIGMETS:** Convective SIGMETS are issued by NOAA's Aviation Weather Center that define lines and areas of thunderstorms hazardous to aviation (Slemmer and Silberberg 2004). Monthly maps of SIGMETS from March through October show similarities with the lightning maps shown in previous figures. The two areas with the most frequent SIGMETS are the Gulf Coast and Florida during June into September, and over Arizona, New Mexico and Colorado during July and August.

7. LIGHTNING SAFETY ASPECTS

The lightning season is found in this study to be concentrated within a few months in most areas of the country. For example, most Florida lightning is in the three summer months, while Arizona and surrounding states have nearly all of their flashes in July and August. In the Central Valley of California, lightning occurs mainly in the winter months. In New England, Montana, and the Dakotas, lightning rarely happens outside the summer months. With these monthly maps, it is possible to define the season more clearly as to when the lightning threat exists for the public and for specific vulnerable activities such as hiking and boating. Since the lightning threat is usually concentrated in a few months, some of these activities can be pursued outside of those months to avoid lightning.

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