ANNUAL SUMMARY

Lightning Ground Flash Density in the Contiguous United States—1989

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ABSTRACT

The National Lightning Detection Network, composed of 114 wideband magnetic direction finders for locating cloud-to-ground lightning flashes, was operated with full coverage of the contiguous United States for the first time in 1989. More than 13.4 million flashes were recorded during that year. Ground flash density contours were drawn on a grid with 120 horizontal points and 100 vertical points. This produces a flash density resolution of 50 km in the east–west direction and 30 km in the north–south direction. The peak lightning flash density occurred northeast of Tampa, Florida, with yearly values of 10 km\(^{-2}\). An annual flash density of 8 km\(^{-2}\) was recorded over the Gulf Stream off the Carolina Coast. Local flash density maxima were observed in eastern Texas, Kansas, on the Illinois–Indiana border, and inland along the Carolina Coast extending into Virginia.

1. Introduction

Lightning ground flash density, defined as the number of cloud-to-ground flashes per unit time per unit area, is of fundamental importance to the design of lightning protection systems (Uman 1987); yet the flash density is not an easy parameter to measure. However, the development of a large network of wideband magnetic direction finders (Krider et al. 1980; Orville et al. 1983, 1987) for locating lightning ground flashes has provided the first direct measurement of the annual lightning ground flash density for the contiguous United States.

Lightning flash density has been derived previously in two different ways. The first method uses “flash counters” that respond to lightning flashes that produce a time-varying electric field amplitude above some given threshold value. Unfortunately, these counters miss weak flashes at close range and record strong flashes at distant ranges, making it difficult to know the “effective range” of the counter (Prentice 1977). Furthermore, it is frequently unknown if the flash counter is effectively discriminating against intracloud flashes, which must be eliminated if a realistic measurement of ground flashes is to be obtained.

A second method for estimating flash density is to relate it to the thunderday level, i.e., the number of days per year on which thunder is heard. Thunder is recorded routinely at stations by, for example, National Weather Service personnel to produce a record of thunderdays at locations throughout the United States. The results from many stations can then be analyzed to produce a contour map of thunderdays as shown in Fig. 1 (MacGorman et al. 1984). Here the mean annual thunderstorm days are contoured based on reports from over 400 stations, with many having continuous records for 30 years. The flash density, \(N_e\), can then be related to the number of thunderdays, \(T\), by an empirical relation of the form, \(N_e = aT^b\) (Prentice 1977), where the coefficients can be determined for different parts of the country. Unfortunately, there are serious problems with relating the flash density to the thunderday level. MacGorman et al. (1984) summarize these as follows: 1) no account is taken of the duration of lightning activity; 2) the variability of the lightning flash rate is ignored; 3) no discrimination is made between intracloud and cloud-to-ground flashes; and 4) lightning is included from an area that varies from day to day, depending on how far thunder can be heard. Ranges from 1 km to more than 20 km have been reported (MacGorman et al. 1984). To correct the first problem, MacGorman et al. (1984) examined the duration of lightning activity and derived flash density estimates that were a significant improvement over flash densities based on the thunderday. Nevertheless, it appears that the most reliable way to determine the flash density is to calculate it directly from the recent measurements of ground flash locations.

2. Data source

Regional networks to measure the ground flash locations began in the United States in 1976 (Krider et
al. 1980) with the establishment of the western lightning detection network operated by the Bureau of Land Management (BLM). This was followed in 1979 with a research network in Oklahoma operated by the National Severe Storms Laboratory (NSSL) and, in 1982, by a second research network in New York managed by the State University of New York at Albany (SUNYA). All regional networks grew until complete coverage of the contiguous United States was obtained in 1989. Today, the combined three regional networks (SUNYA, BLM, and NSSL) shown in Fig. 2 form the “National Lightning Detection Network,” composed of 114 direction finders and capable of locating cloud-to-ground lightning flashes throughout the contiguous United States. Thus, in 1989 we attained the capability for the first time of making a direct measurement of the annual lightning ground flash density in the United States.

3. Analysis

A total of over 13.4 million ground flashes were recorded in 1989 in the contiguous United States. The distribution of these flashes by month is plotted in Fig. 3, with the highest number in the months of June, July, and August. The peak occurred in July with 3.6 million ground flashes. The relatively slow rise in monthly flash totals from February to June and the relatively fast decrease from August to October has been seen previously and may be a typical characteristic of the varying monthly lightning flash rate in the United States.

The 1989 lightning flash density for the contiguous United States is obtained by plotting the flash location values on a grid with 120 horizontal points and 100 vertical points. These values are then multiplied by 1.4 to correct for an estimated detection efficiency of 70% (Orville et al. 1987) and contoured to produce Fig. 4. On this scale the distance between the vertical grid points is 30 km and between the horizontal grid points 50 km, so flash density variations for distances less than this are not shown. Variations on a smaller scale appear in the data, but are more appropriately left for future papers examining regional flash density differences.

Figure 4 shows several interesting annual flash density variations. The peak of 10 km$^{-2}$ in central Florida is expected and consistent with Fig. 1. The relative annual maximum of 8 km$^{-2}$ over the Gulf Stream is a new finding and a surprise since it is only 20% less than
the peak Florida value. This observation is consistent with the enhanced winter lightning activity over the Gulf Stream reported previously (Orville 1990; Biswas and Hobbs 1990). A broad relative flash density maximum is apparent inland along the Carolina Coast that extends into eastern Virginia. Other maxima occur in eastern Texas, Kansas, and along the Illinois–Indiana border.

Some annual maxima in Fig. 4 can be associated with only a few storms. For example, the peak in the Illinois–Indiana area is associated with thunderstorms in late May and early June. In other cases, only one storm may have a significant effect on the annual flash density. Note the northwest to southeast orientation of the 1–2 flashes km\(^{-2}\) contour region extending from Lake Ontario southeast across New York to Connecticut, where the annual flash density reaches 2–3 flashes km\(^{-2}\). This direction is the path followed by the October 14 storm that produced approximately one-third of the annual flash count for this area.

Variations in the observed flash density values in Fig. 4 are believed to reflect the natural variations in flash density that occurred in 1989. There may, however, be artifacts in the dataset. One example is the relatively lower flash density value of 2–3 flashes km\(^{-2}\) extending into Louisiana that may be real or, in part, the result of not having a direction finder in Louisiana (see Fig. 2). Caution should also be followed in interpreting the flash density in the west using the BLM direction finders. The true flash density may be higher because the BLM flash detection efficiency may be less than the 70% assumed for the NSSL and SUNYA networks. Certainly Fig. 1 suggests that relatively higher flash densities should be expected in northern Arizona.

Another problem exists in the dataset that does not seem to be apparent or important in Figure 4. This problem occurs along the interface of the BLM network with the NSSL and SUNYA networks, or roughly the 104th meridian paralleling the New Mexico–Texas
Fig. 4. Annual lightning flash density contours for 1989 are drawn on a grid of 120 horizontal points and 100 vertical points. This provides for a spatial resolution of 30 km in the vertical and 50 km on the horizontal. The highest lightning flash density is northeast of Tampa, Florida, with secondary maxima occurring over the Gulf Stream in the Atlantic Ocean and in eastern Kansas. The lightning flash density values have been multiplied by a factor of 1.4, derived from assuming a detection efficiency of 70% throughout the network.
border and extending northward. The BLM network uses relative time whereas the NSSL and SUNYA networks use absolute time. The net result of the timing difference is that lightning flashes might be counted twice, producing an “enhanced” ground flash density along the interface. This does not appear to be a problem in Fig. 4 and may be because the double counting would account for only a small percentage of the total number of flashes recorded. One quantitative check on a storm occurring along the network interface in June revealed a 17% double counting rate, which is significant, but does not have any important impact on the ground flash density scale presented in this report.

It should be noted that the flash density values presented ignore a correction for “multiple strike points” proposed by MacGorman et al. (1984). In this work, M. Maier found 1.39 strike points per flash in Florida video recordings reflecting the observation that subsequent strokes in a flash may contact the ground at a different point. Consequently, MacGorman et al. proposed multiplying flash density values by 1.39 to estimate “ground flash strike density.” This potential correction is noted, but is not used in this paper.

4. Conclusion

This paper presents the first annual ground flash density for the contiguous United States. It is important to remember, however, that the ground flash density contours are available for only one year. These may not be representative of the average annual contours as shown by the work of MacGorman et al. (1984) using 30 years of thunderstorm records at Tampa, Florida. They found that in any given year the flash density value could have been anywhere from less than half to twice the 30-yr average. For a period of six years, the flash density value could have been one-half to one and a half times the 30-yr average. Hence, the lightning ground flash density contours in the United States for 1989 presented here fall short of providing values for climatic studies. For this, it will be necessary to operate the National Lightning Detection Network for at least a decade.

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REFERENCES