GLOBAL LIGHTNING ACTIVITY

H. J. Christian

National Space Science and Technology Center
Huntsville, Alabama

ABSTRACT: Our knowledge of the global distribution of lightning has improved dramatically since the 1995 launch of the Optical Transient Detector (OTD), followed in 1997 by the launch of the Lightning Imaging Sensor (LIS). Together, these instruments have generated a continuous seven-year record of global lightning activity. These lightning observations have provided a new global perspective on total lightning activity. For the first time, total lightning activity (CG and IC) has been observed over large regions with high detection efficiencies and accurate geographic location. This has produced new insights into lightning distributions, times of occurrence and variability. It has produced a revised global flash rate estimate (46 flashes per second) and has lead to a new realization of the significance of total lightning activity in severe weather.

Accurate flash rate estimates are now available for large areas of the earth (+/- 72° latitude). Ocean-land contrasts as a function of season are clearly revealed, as are orographic effects and seasonal and interannual variability. The data set indicates that air mass thunderstorms, not large storm systems dominate global activity.

The ability of LIS and OTD to detect total lightning has lead to improved insight into the correlation between lightning and storm development. The relationship between updraft development and lightning activity is now well established and presents an opportunity for providing a new mechanism for remotely monitoring storm development. In this concept, lightning would serve as a surrogate for updraft velocity. It is anticipated that this capability could lead to significantly improved severe weather warning times and reduced false warning rates.

1. INTRODUCTION

LIS and OTD data have been combined to provide a 5-yr OTD average annual and seasonal worldwide distribution of total lightning activity. The global flash rate is further decomposed into its seasonal cycle, and the variation of flash rate is compared between land and ocean, northern and southern hemispheres, tropics and sub-tropics, and the three major continental land masses- Africa/Europe, the Americas, and Asia/Maritime Continent.

The global annual average total (intracloud and cloud-to-ground) flash rate is found to be 46 fl s⁻¹[Christian et al., 2003, revised with LIS data]. The annual global flash rate ranges from a maximum of 55 fl s⁻¹ (in Northern Hemisphere summer) to a minimum of 35 fl s⁻¹ (in Northern Hemisphere winter). These lightning flash rate estimates are less than half the traditional estimate of 100 fl s⁻¹, proposed by Brooks [1925]. Additionally, the OTD/LIS derived global flash rate is significantly less than recently published estimates of the average global flash rate, given that these prior estimates were all greater than 60 fl s⁻¹ [Mackerras et al., 1998; Kotaki and Katoh, 1983; Orville and Spencer, 1979]. Moreover, these prior estimates were reported with a range of uncertainty due to instrument and sampling limitations that approached a factor of two, which is the likely explanation for the discrepancy between the prior estimates and the results obtained from the OTD/LIS data. The range of uncertainty associated with the OTD/LIS derived global flash rate is estimated to be well less than 20%, a value that primarily reflects uncertainty in the flash detection efficiency of the instrument. The observed OTD/LIS flash rate also implies that mean flash dipole moment change is somewhat lower than that used by Heckman et al. (1998).

The annual average global distribution of total lightning flash rate is shown in Fig. 1. Flash rate is contoured in units of fl km⁻² yr⁻¹, based on a 0.5°×0.5° compositing grid smoothed with a 2.5 degree spatial moving average operator. The geographical distribution of flash rate density is in general qualitative agreement with the climatological distribution of thunderstorm days [WMO, 1953], being dominated by the diurnal heating of the major land masses. The peak mean annual planetary flash density exceeds 80 fl km⁻² yr⁻¹ and occurs just west of Kamembe, Rwanda, a place that averages 221 thunderstorm days per year.

Figure 1. The annualized distribution of total lightning activity (in units of fl km⁻² yr⁻¹).
2.1 FLASH RATE EXTREMA

The greatest flash densities occur in coastal areas, mountainous regions, regions frequented by migrating synoptic scale cyclones, and convergence zones such as Inter-Tropical Convergence Zone (ITCZ). Lightning is predominant in the northern Atlantic and Western Pacific Ocean basins year round where instability is produced from cold air passing over warm ocean water. The northern Gulf of Mexico basin and Gulf Stream east of the Carolinas each have a peak flash density in excess of 22 fl km$^{-2}$ yr$^{-1}$, a value equal to the flash density at Wichita, Kansas. Lightning is less frequent (and the atmosphere more stable) in the eastern tropical Pacific and Indian Ocean basins where the overlying air mass is warmer.

The equatorial Congo Basin is the “hot-spot” of the planet. Within the basin, for example, an area of 3 million km$^2$ (roughly four times the area of the state of Texas) exceeds the flash rate density of central Florida (30 fl km$^{-2}$ yr$^{-1}$), the U.S. “hot-spot”. The sharp maximum flash density gradient along the eastern edge of the Congo Basin is defined by the Mitumba mountain range running north-south along the entire length of the basin. The collective boundaries of the east-west mountain ranges that extend from the European Alps to the Himalayas provide additional orographic foci (flow barriers) for the development of thunderstorms, with a local maximum of 33 fl km$^{-2}$ yr$^{-1}$ in northern Pakistan.

Flash density maxima do not necessarily coincide with the absolute thunder day maxima, a different index of lightning activity. Indeed, some of the lower flash density maxima (~20 fl km$^{-2}$ yr$^{-1}$) correspond to locales having the greatest number of thunder days (e.g., Colon, Panama, Carauari, Brazil, Entebbe and Kampala, Uganda). A thunder day will give equal contribution to a day having multiple storms, a very active, long-lived convective complex producing thousands of flashes per hour, a supercell storm, or a small isolated thunderstorm. Thus, the flash density embodies both storm intensity and storm frequency. It is also noteworthy that the period 1995-2000 also includes representative climate variations due to both an El Nino (1997-98) and La Nina (1998-99) event [Goodman et al., 2000].

The annual average distribution is strongly dependent on the seasonal evolution of regional flash rates. Maps of the seasonal distribution and frequency of lightning activity were computed at 2.5° spatial resolution. Flash density is generally greatest in the respective hemisphere spring and summer seasons over land and round in coastal zones.

2.2 THE CONGO AND AMAZON BASINS

Within the equatorial tropics, there is a large contrast in flash density between the Amazon and Congo basins. The Congo basin has high flash densities year-round, yet there is a shift in maximum flash density northward across the equator between December-February and June-August coupled to the general migration of the ITCZ and an associated shift in synoptic scale forcing (wind, pressure, and convergence) and large (>2000 m$^2$ s$^{-2}$) Convective Available Potential Energy (CAPE) over equatorial Africa. From December to February the mean vertical ascent is greatest from 0-20° S, bounded on the north by the ITCZ. During the seasonal period June-August the maximum mean vertical ascent shifts northward across the equator extending from 0-20° N. The high flash density gradient terminates approximately at the ITCZ, which represents the boundary between two primary air masses; the northernmost extent of the moist westerly air originating in the Atlantic and the dry desert air originating in North Africa. The mountains in east central Africa block the low-level moist easterly flow originating in the Indian Ocean.

The Amazon basin has its greatest flash densities during the transitional months of September-November. This is a period when synoptic scale frontal systems make their way northward into the basin and the storms are more strongly forced, leading to deeper storms with stronger vertical velocities and a more developed mixed phase region. It is thought that low level easterly wind flow (and associated frontal intrusion into the Amazon basin) is the most important modulating factor (easterly regimes have the higher flash counts). Recent studies of Amazonian storms and their environment have identified accompanying decreases in cloud condensation nuclei (CCN) concentration and CAPE during the lower flash count westerly regimes. The easterly and westerly regimes and associated vertical structure of storms and related lightning activity are associated with the monsoon/break convective regimes.

2.3 OCEANIC LIGHTNING

From the global and seasonal distributions it is apparent that continentality plays an important role in the distribution of lightning, since a large percentage of the global lightning activity occurs over the land masses. In an effort to quantify this percentage, the globe was divided into separate land and ocean components, and the annual flash rate was re-computed for both the continental regions and the oceanic regions. The ocean domain is defined as all 2.5 degree grid locations with no land cover; the land domain contains all other grid cells (thus the results are additive). The results (Figure 2a) demonstrate that oceanic lightning activity remains fairly constant during the entire 12 month period of observation. The mean annual land to ocean flash ratio is 10:1. The average global annual flash rate for the oceanic regions was found to be 5 fl s$^{-1}$, while continental regions ranged from 31 to 49 fl s$^{-1}$ during the year. Although off-shore regions will contain a mix of maritime and migrating continental storms, varying the land mask to a distance of 500 km produced a negligible change in the global land-ocean flash ratio.

The warm waters of the Gulf Stream provide significant boundary layer heat flux and favorable conditions for convection. Enhanced baroclinity and vertical motion, which in turn will produce more persistent and wide-spread
lightning activity, occurs in association with synoptic scale southwesterly flow ahead of frontal passages and upper troughs. Cyclogenesis and frontal passages are responsible for much of the wintertime thunderstorm activity over the Gulf Stream near the east coast of the United States and in the northern Gulf of Mexico, both being coastal-oceanic regions of high flash density. A similar seasonal variation occurs in the Mediterranean Sea with peak activity in its western and central basin during September-November and in the eastern basin during December-February. The South-Pacific Convergence Zone is a region of enhanced oceanic thunderstorm activity year-round, but the central North Pacific Basin is most active in the period from late Autumn through Winter when eastward propagating frontal systems are more common. In the southern hemisphere the land-sea temperature contrast and semi-permanent high pressure centers in the southern Atlantic and Indian oceans, and Australia are major factors in producing year-round thunderstorm activity extending eastward from the southeast coasts of South America, Africa, and Australia for thousands of kilometers [Barnes and Newton, 1982].

2.4 ZONAL AND MERIDIONAL CONTRIBUTIONS.

By dividing the globe into latitudinal sections, a better understanding of the annual variation in the global flash rate can be obtained. For example, by separately computing the flash rate for the northern and southern hemispheres, it is apparent that the maximum flash rates for each hemisphere occur approximately six months apart and occurs during the corresponding summer season, as shown in Figure 2b. The maximum flash rate for the northern hemisphere, however, is significantly greater than the maximum flash rate for the southern hemisphere. Effectively, lightning activity in North America and northern Asia is responsible for an imbalance in the annual cycle of the global flash rate during the summer months of the northern hemisphere.

By dividing the globe into latitude bands, the contribution of the tropics to the global flash rate becomes apparent. As shown in Fig. 2c, the frequency of lightning activity for the globe was subdivided into zones consisting of 5° S to 5° N latitude, 10° S to 10° N latitude, 20° S to 20° N latitude, and 30° S to 30° N latitude. Some evidence of a semiannual cycle is found, peaking, as expected, near the equinoxes, with the autumnal equinox dominating. Although 78% of global lightning production occurs in the 30S-30N band, the evolution of the global annual cycle is nonetheless dominated by the northern hemisphere extratropical summer.

Figs. 3a and 3b present zonal and meridional totals of annual average flash rate in 2.5-degree bands. From Fig. 3a, it is clear that the tropical bands from roughly 10° S to 10° N contribute nearly twice as much to global lightning production as subtropical bands. While the meridional distribution in Fig. 3b reveals a sharp local peak in Africa, separation into contributions from the Americas (180W-30W), Europe and Africa (30W-65E) and Asia and the Maritime Continent (65E-180E) (Fig. 3c) suggests that the net contributions from the Americas and Europe/Africa are roughly comparable, at least within these meridional bounds. The meridional contribution of the continents to the mean annual flash density, led by Africa and followed by the Americas and Asia, agrees with that of Brooks (1925).

Figs. 3d-3f reveal that the apparent global tropical and subtropical semiannual signal (Fig. 2c) receives unequal contributions from the three primary land zones. South America dominates the autumnal peak, while South and Southeast Asia contribute strongly to the vernal peak. The African semiannual signal is more symmetric. Extratropical North America clearly dominates the global annual cycle. Fig. 9a and 9b further decompose the annual cycle, revealing expected seasonal shifts in the bands of peak lightning production and further illustrating the hemispheric asymmetry. The local minima in Fig. 9b additionally help justify the meridional boundaries selected in Figs. 8c-8f.

3. CONCLUSIONS

Data from the OTD and LIS have been used to determine the average global flash rate, the annual variation of the global flash rate, and the seasonal distribution of lightning. A thorough analysis of the data suggests that the annual average global flash rate, which includes both intracloud and cloud-to-ground lightning, is 46 flashes per second, with an estimated uncertainty that does not exceed ±5 flashes per second. The range of uncertainty for these global totals is primarily attributable to uncertainty (and variability) in the flash detection efficiency of the instrument. For other
applications (e.g., comparisons of spatially local, diurnal or interannual variability), uncertainty due to undersampling may dominate.

It is important to note that significantly higher uncertainty, or lower detection efficiency, than we assume is not supported by aircraft observations, instrument sensitivity modeling, ground validation of the OTD and LIS, and cross-comparison of the OTD and LIS data. Given the uncertainty and implicit biases in prior global flash rate estimates, we conclude that the inferred 46±5 fl s\(^{-1}\) estimate is the most accurate to date.

Approximately 78% of all lightning occurs between 30° S and 30° N latitudes, and while the annual variation of tropical flash rate is fairly small (of order 10%), there appears to be some evidence of a semiannual modulation. The global annual cycle is dominated by land contributions in the northern hemisphere summer, and peaks more than a month after the northern hemisphere summer solstice. Continental, island and coastal regions contribute 88% of the global total production. Evidence of a tropical and subtropical semiannual cycle is also found. South and Southeast Asia and equatorial Africa dominate the vernal maximum, while equatorial-subtropical Africa and South America dominate the autumnal maximum. Africa exhibits less semiannual asymmetry than either South America or Southeast Asia.

![Figure 3. The annual cycle of global flash rate, decomposed zonally and meridionally. (a) Zonal total flash rate in 2.5 deg latitude bands. (b) Meridional total flash rate in 2.5 deg longitude bands. (c) Meridional contributions corresponding roughly to the Americas, Europe and Africa, and Asia and the Maritime Continent. (d), (e), (f) Annual cycles for the three main land regions, decomposed into their tropical and subtropical components.](image)

REFERENCES


WMO (World Meteorological Organization), World distribution of thunderstorm days, WMO Pub. No. 21, TP 6 and supplement, Geneva, Switzerland, 1956.