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ORIGINAL PAPER

# Climatology of lightning flash activities over Sri Lanka

Upul Sonnadara[1] · Wasana Jayawardena[2] · Mahendra Fernando[1]

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## Abstract

Seventeen years of remotely sensed satellite mounted Lightning Imaging Sensor (LIS) data were used to determine the characteristics of lightning activities over Sri Lanka. From 1998 to 2014, there were 12.5 million lightning flashes over the land mass covered by Sri Lanka. There is an increasing trend in the intensity of lightning activities with 22,000 flashes year$^{-1}$. The annual cycle of lightning flashes shows a clear spatial difference of lightning activities during the southwest and northeast monsoon seasons. The highest occurrence of lighting activities is confined to the highly populated western region of the island while the coastal areas in the northern and eastern regions and central hills show relatively low occurrences. The estimated maximum cloud to ground lightning flash density was 53 flashes year$^{-1}$ km$^{-2}$ and the average being 7.7 flashes year$^{-1}$ km$^{-2}$. The density of lightning in the wet zone tends to be twice as much compared to the dry zone. The onset and retreat of lightning seasons are February 25 through May 15 for the warm season which coincides with the first inter-monsoon season and July 31 through November 19 for the cold season which coincides with the latter part of the southwest monsoon season and second inter-monsoon season. Based on thunder day measurements, it is shown that a simple linear relationship can be used to estimate lightning flash densities from thunder days. We have also examined the relationship between lightning flash activities and sea surface temperature over the Arabian Sea and the Bay of Bengal and conclude that sea surface temperature can be used as a proxy to estimate change in lightning activities as sea surface temperatures have strong persistence in the temporal characteristics.

## 1 Introduction

Characteristics of lightning flashes over Sri Lanka have been studied during the last three decades by a number of researchers (Cooray and Lundquist 1985; Cooray and Jayaratne 1994; Gomes et al. 1998; Sharma et al. 2008; Gunasekara et al. 2016). Most of the early studies were carried out remotely by using a flat plate antenna system together with a digital storage oscilloscope to sense and record the electric field generated by lightning strikes. In recent years, the work has been extended by measuring optical and thunder signals generated by lightning (Bodhika et al. 2013). Over the years, these studies have provided valuable insight into the understanding of the physics of the lightning process in Sri Lanka particularly applicable to the tropics.

✉ Upul Sonnadara
upul@phys.cmb.ac.lk

1 Department of Physics, University of Colombo, Colombo 3, Sri Lanka

2 Department of Physics, The Open University of Sri Lanka, Nugegoda, Sri Lanka

Today, lightning detection systems are used in many countries to study long-term characteristics of cloud-to-ground lightning activities. These systems have a typical detection range of 600 km, with many sensors interconnected to form lightning detection networks that span thousands of kilometers covering lightning activities in vast land masses (Diendorfer et al. 1998; Huffines and Orville 1999; Orville and Huffines 2001; Sonnadara et al. 2006). These are more suitable for studies that involve in investigating average lightning parameters and lightning distributions since they are weak in extracting the details of individual lightning parameters but strong in detecting and processing data from many different thunderstorms (Sonnadara et al. 2014).

In late 1990s and early 2000, there have been attempts to study the cloud to ground flash activities of Sri Lankan thunderstorms using the data provided by a lightning locating system (Fernando et al. 1998; Sonnadara et al. 2000; Weerasekera et al. 2001; Liyanage et al. 2002). However, due to number of problems including instrumentation issues, these studies failed to provide an insight into the climatology of lightning characteristics over Sri Lanka. Using thunder day data, for the first time, a recent study reported thunderstorm climatology (Sonnadara 2016) over Sri Lanka.

The present study focuses on the lightning flash characteristics over Sri Lanka using satellite observations. The results are presented for the lightning flash activities in terms of spatial and temporal variations.

## 2 Data and methodology

The National Aeronautics and Space Administration (NASA) records remotely sensed lighting data using satellite-based instruments. They have measured lightning data using Lightning Imaging Sensor (LIS) which was launched on November 28, 1997 aboard the Tropical Rainfall Measuring Mission (TRMM) satellite. The TRMM satellite follows a circular orbit and flies at an altitude of 350 km, with an inclination of 35° to the equator (Boccippio et al. 2000). The data are available for the past 17 years from December 1997 up to April 2015 (http://lightning.nsstc.nasa.gov/). The LIS detects and locates lightning with storm scale resolution of 5–6 km, approximately over 35° S to 35° N. It has the temporal resolution of 2 ms and also estimates the location and measure the radiant energy. LIS has 69–88% flash detection efficiency and detects cloud-to-cloud and cloud-to-ground discharges during day and night conditions. It monitors individual storms and storm systems for the period of 80 s while the storm is in the field of view of the sensor, which is sufficient to measure lightning flash rates in storms. It passes Sri Lanka twice per day which means 160 s day$^{-1}$.

In this work, lightning data from January 1998 to December 2014 period have been extracted from the TRMM web site. The data were used to study temporal and spatial variations of lightning activities over Sri Lanka and the surrounding area in the Indian Ocean. Since a given location is not monitored 24 h a day, only fraction of the lightning activities are captured and, hence, data were scaled to estimate the "true" lightning activities.

The scaled flash count SF was computed by dividing the raw flash count by the detection efficiency which is available for each hour within a 24-h cycle (Cecil et al. 2014).

The number of lightning flashes in a given day was calculated as follows:

$$\text{Flashes per day} = \frac{86,400}{\text{VT}} \times \sum \text{SF}$$

where VT is the view time (in our case 160 s).

The lightning flash density (flashes km$^{-2}$ year$^{-1}$) was calculated as follows:

$$\text{Flash Density}\left(\text{flashes km}^{-2}\ \text{year}^{-1}\right) = \frac{86,400}{\text{VT}} \times \frac{\sum \text{SF}}{A} \times \frac{1}{\text{Years}}$$

where $A$ is the area considered (in our case 5 × 5 km$^{-2}$).

One of the important parameters is the lightning ground flash density. However, LIS data does separate cloud flashes (all flashes that do not terminate at the Earth's surface; intra-cloud, inter-cloud, and cloud-to-air) from ground flashes. The ratio of cloud flashes to ground flashes is not a constant, and it can vary among storms or even when a storm progresses. Moreover, it has a latitude dependence (Mackerras and Darveniza 1994). Further investigating the ratio of cloud flashes to ground flashes, $Z$, over Australia, Kuleshov et al. (2006) concluded that for the range of latitude from 10° S to 40° S the most representative long-term value of $Z$ is about 2 ± 30%, and it is largely independent of latitude. Therefore, the density of ground flashes can be estimated by multiplying the flashes density reported in this paper by a factor of 0.3.

The climate of Sri Lanka is influenced by disturbance within intertropical convergence zone (ITCZ) in addition to southwest and northeast monsoons. Hence, to determine the onset and retreat of lightning seasons, cumulative distributions of lightning activities were used. Since two clear peaks in lightning frequency distributions are noted, year was divided into two seasons: one from January to June and other from July to December. A recent study has estimated the onset (retreat) of rainy season in Sri Lanka for the dry zone by estimating the maximum positive (negative) curvature in the cumulative rainfall distributions (Sonnadara 2015). In this work, we have defined the onset and retreat simply as the 10% and 90% of the cumulative lightning activities that occurs within each season. To reduce statistical fluctuations in daily measurements, the sum of the lightning activities for the first season was computed for 5-day intervals and hence the cumulative percentage of lightning activities was also calculated for 5-day intervals. For the second season, 10-day intervals were used. Then, data from all available years were combined and a 5-point moving average filter was applied to reduce the statistical fluctuations in data which may lead to false onset/retreat dates. A cubic spline interpolation was carried out to interpolate data for daily intervals.

The analysis was further extended by examining the relationship between lightning activities and the sea surface temperature (SST) in the surrounding area of the Indian Ocean (Arabian Sea: 4.5–9.5° N, 78.5–80.5° E and Bay of Bengal: 4.5–9.5° N, 80.5–82.5° E). The SST data was extracted from the Climatic Data Center of the National Oceanic and Atmospheric Administration (NOAA).

## 3 Annual cycle

The annual cycle of the lightning flashes is shown in Fig. 1. A clear bimodal pattern is seen. The maximum lightning activity is observed towards the end of the first inter-monsoon period

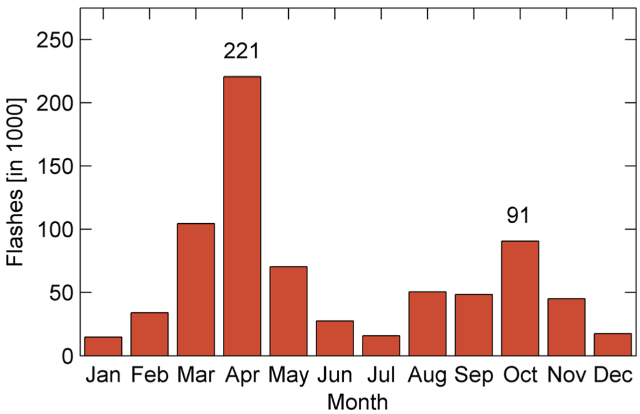



**Fig. 1** Mean number of lightning flashes by month. The observed pattern is consistent with the earlier findings published with the thunder day data (Sonnadara 2016)

(April) with 221,000 flashes. A less pronounced peak occurs towards the start of the second inter-monsoon period (October) with 91,000 flashes. This pattern is consistent with the thunder day observations reported earlier. On average, the maximum number of lightning flashes for a single day is observed towards the middle of April exceeding 18,000 flashes. High lightning activity during the month of April which is the Sinhala/Tamil new year period is quite well known and known as "Bak Maha Akunu." The high percentage of lightning events during inter-monsoons is due to the fact that the ITCZ is positioned over Sri Lanka during these two periods. The ITCZ is a region of light winds near the equator, where winds from the southern hemisphere and northern hemisphere converge and appear as a band of clouds that circle the globe near the equator. Over the Indian Ocean, during the northern hemisphere winter, the ITCZ cloud band is much broader than it is over either the Atlantic or Eastern Pacific ocean. The ITCZ zone induces semi-persistent low-pressure conditions causing heavy rain and lightning throughout the island and at many other places at the same latitude.

In the first inter-monsoon period, the ITCZ moves from south to north over Sri Lanka, with moisture laden air accumulated through the long track over Indian Ocean. Accordingly, the energy released from latent heat can be high, which is favorable for vigorous thunderstorms. Therefore, strong thunderstorm activity with lightning is more frequent during this season compared to the second inter-monsoon period. On the other hand, the rainfall is heavy in October–November period but less pronounced compared to April. This is due to the influence of depressions emerging over the Bay of Bengal, which gives heavy rain apart from local thunderstorms (Suppiah 1989). The percentage of lightning per month is highest (22%) during the first inter-monsoon period and lowest (3%) during the northeast monsoon season. Second highest percentage of lightning per month (9%) can be observed during the second inter-monsoon period followed by the southwest monsoon (6%) period.

## 4 Spatial patterns

### 4.1 Annual pattern

Figure 2 shows the annual pattern of lightning activities over Sri Lanka during the period 1998–2014. The lighting activities are most frequent in the wet zone (southwestern part) of the island. The south western coastal region of the island is known to have high lightning activity exceeding 100 average annual thunder days. The lightning activities are less pronounced in the band between the hill country and the coastal belt in north western, northern, eastern, and south eastern areas which belong to the low land areas in the dry zone. Except for the south western coastal area, comparatively, lower number of lighting activities is observed in the coastal belt and the Jaffna peninsula (which has about 30 thunder days). The maximum lightning activity of 53 flashes km$^{-2}$ year$^{-1}$ is observed at the location 80.30° E, 7.00° N which is above Ratnapura (80.40° E, 6.68° N) and closer to Avissawella (80.18° E, 6.92° N). This area is known to have high lightning activity with average annual thunder days of 150 which is the highest for Sri Lanka. Surprisingly, the high elevation areas in

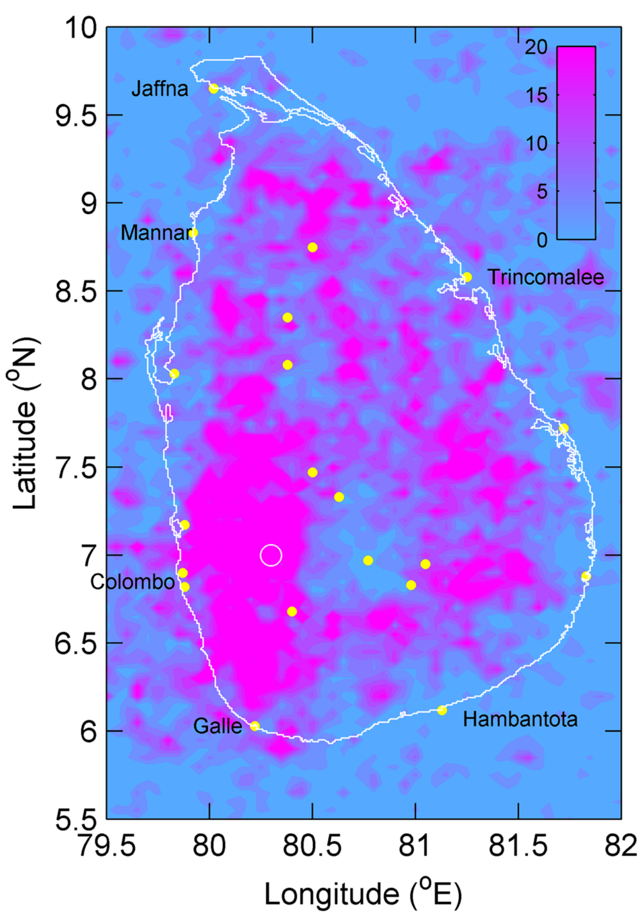



**Fig. 2** Spatial distribution of the lightning flash activities from 1998 to 2014. The circles mark the area where the maximum lightning activity was found

the central hills in the region of Nuwara Eliya (80.77° E, 6.97° N) show less lightning activities compared to its surrounding areas. However, the average annual thunder days reported at Nuwala Eliya is at a moderate value of 65.

The lightning ground flash density is traditionally estimated from thunder days. Thunder day is defined as a 24-h period in which at least one thunderstorm occurred. Long-term thunder day records are available for most stations around the world. Thunder days are recorded as a standard parameter in all metrological stations in Sri Lanka. The relationship between thunder days and ground flash density may depend on the meteorological condition at a given location. The lightning ground flash density *Ng*, can be related to the number of thunder days *T*, by an empirical relation of the form, $N_g = aT^b$ (Prentice 1977) where *a* and *b* are parameters. One of the early derivations of lighting ground flash density from thunder days was carried out by Mackerras (1978) for Australia. He estimated the parameters to be $a = 0.01$ and $b = 1.4$. Based on CIGRE-500 lightning flash counter registrations for 17 selected Australian sites over a period of up to 22 years, Kuleshov and Jayaratne (2004) revised the Mackerras' formula for Australia providing the best estimates of the empirical constants *a* and *b* as be 0.012 and 1.4, respectively. Another study with more observations estimated the parameters to be $a = 0.023$ and $b = 1.3$ (Anderson and Eriksson 1980). The Eriksson's formula gives approximately a factor of 1.5 higher values for flash densities compared to Mackerras formula. A recent study carried out in Sri Lanka using Mackerras formula and Eriksson's formula with thunder day data taken from 20 sites reported an average lightning ground flash density of 4.3 flashes km$^{-2}$ year$^{-1}$ and 6.4 flashes km$^{-2}$ year$^{-1}$ respectively (Sonnadara et al. 2014).

In this work, we have calculated lightning flash density based on LIS data and compared with the average annual thunder days measured at the same 20 sites in Sri Lanka. An area bounded by 0.5° grid with the site at the center was considered when calculating the average flash density values for each selected site. The results of this analysis are given in Table 1. The average flash density for Sri Lanka is 7.7 flashes km$^{-2}$ year$^{-1}$. From the selected locations, estimated flash density at Ratnapura (80.40° E, 6.68° N), where the highest number of thunder days reported, is 17.3 ± 2.5 flashes km$^{-2}$ year$^{-1}$. In the wet zone, flash densities vary from 4.7 to 17.3 flashes km$^{-2}$ year$^{-1}$ while in the dry zone, flash densities vary from 2.8 to 10.4 flashes km$^{-2}$ year$^{-1}$. Overall, the average flash density in the wet zone is twice as much as the average flash density in the dry zone. To estimate the ground flash density from the flash density values, reported values should be multiplied by the ratio between the ground flashes to the total number of flashes over Sri Lanka which is approximately 0.3.

The correlation between the thunder days and lightning flash densities is shown in Fig. 3. When the regression was carried out to find the best fitted values for parameters *a* and *b* for Sri Lanka, it was noted that the exponent *b* is very close to 1, which indicates a linear relationship. Thus, based on the thunder day data *T*, the ground flash density *Ng*, over Sri Lanka can be estimated by using the following simple relationship.

$$Ng = 0.118 \times T \times z$$

where *z* is the ratio of ground flashes to total flashes. One outlier is noted which corresponds to Kurunegala (80.50° E, 7.47° N). This area is closer to the area where high lightning activities are observed. For regions with intense lightning activities, thunder day may not be a good representation of lightning activities.

### 4.2 Seasonal pattern

The seasonal variation of lightning climatology is driven essentially by the two inter-monsoons, first inter-monsoon from March to April and second inter-monsoon from October to November. In between these two seasons, lightning activities are observed throughout the island. However, a clear disparity in lightning activities is seen during two periods with each period being about 4 months long, June to September during the southwest monsoon season and November to February during northeast monsoon season. This behavior is shown in Fig. 4.

During the southwest monsoon season, which is active from May through September, the lightning activities are seen in the northeastern region of Sri Lanka. This means although the wind originates from southwest bringing heavy rains to southwest sector of the island, lightning occurs in the lee ward side of the mountain range in northeast direction. The maximum lightning density is around 9 flashes km$^{-2}$ year$^{-1}$ during the southwest monsoon period. During northeast monsoon season which is active from December through February, the lightning occurs in the lee ward side of the mountain range in southwest sector. The maximum lightning density is around 7 flashes km$^{-2}$ year$^{-1}$ during this season. During the first intermonsoon season (March through April), lightning activities are seen in many parts of the island except the northern, eastern, and southeastern coastal areas. During the second intermonsoon season (October through November), the lightning activities are localized in the periphery of the mountain region.

## 5 Temporal patterns

Figure 5a shows the annual variation of lightning activities over the last 17 years (1998–2014). During this period, there were about 12.5 million lighting flashes over the land area

**Table 1** List of 20 selected locations with meteorological stations, their geographical information, mean annual thunder days, and the mean annual lightning flash densities calculated from LIS data. The errors in flash density values indicate the error in the mean value derived from 17 annual measurements

| No. | Station name | Latitude (°N) | Longitude (°E) | Elevation (m) | Thunder (days) | Density ($km^{-2}$ $year^{-1}$) |
|---|---|---|---|---|---|---|
| 1 | Anuradhapura | 80.38 | 8.35 | 93 | 64.5 | 9.7 ± 1.5 |
| 2 | Badulla | 81.05 | 6.95 | 670 | 87.2 | 10.0 ± 1.5 |
| 3 | Bandarawela | 80.98 | 6.83 | 1248 | 105.9 | 10.0 ± 1.6 |
| 4 | Batticaloa | 81.72 | 7.72 | 8 | 55.6 | 4.3 ± 0.7 |
| 5 | Colombo | 79.87 | 6.90 | 7 | 107.8 | 14.8 ± 1.2 |
| 6 | Galle | 80.22 | 6.03 | 13 | 87.5 | 9.5 ± 1.6 |
| 7 | Hambantota | 81.13 | 6.12 | 16 | 51.1 | 2.1 ± 0.4 |
| 8 | Jaffna | 80.02 | 9.65 | 4 | 30.7 | 2.4 ± 0.5 |
| 9 | Kandy | 80.63 | 7.33 | 417 | 96.8 | 9.5 ± 1.2 |
| 10 | Katunayake | 79.88 | 7.17 | 9 | 96.0 | 16.1 ± 1.7 |
| 11 | Kurunegala | 80.50 | 7.47 | 116 | 75.4 | 18.5 ± 2.5 |
| 12 | Maha Illuppallama | 80.38 | 8.08 | 117 | 73.5 | 9.8 ± 1.5 |
| 13 | Mannar | 79.92 | 8.83 | 4 | 35.8 | 3.9 ± 0.7 |
| 14 | Nuwara Eliya | 80.77 | 6.97 | 1895 | 65.4 | 4.8 ± 1.1 |
| 15 | Pottuvil | 81.83 | 6.88 | 8 | 27.5 | 2.8 ± 0.6 |
| 16 | Puttalam | 79.83 | 8.03 | 2 | 61.7 | 4.8 ± 1.1 |
| 17 | Ratmalana | 79.88 | 6.82 | 5 | 97.0 | 14.9 ± 1.1 |
| 18 | Ratnapura | 80.40 | 6.68 | 34 | 149.5 | 17.3 ± 2.5 |
| 19 | Trincomalee | 81.25 | 8.58 | 24 | 69.8 | 6.9 ± 1.2 |
| 20 | Vavunia | 80.50 | 8.75 | 106 | 51.0 | 10.4 ± 2.1 |

covered by the island. This gives an average of about 750,000 lightning flashes per year which is roughly 1.4 lightning flashes per minute (or a frequency of 42 $s^{-1}$). The highest lightning activity is seen during the year 2011 with 1,153,700 lightning flashes. Although there is a variation of lightning activities between years, the data show a clear increasing trend with 22,000 flashes per year (significant at 0.05 level) which is indicated with the straight line drawn through the data points. Data also indicate that the increase is predominantly due to the summer half of the year or warm season

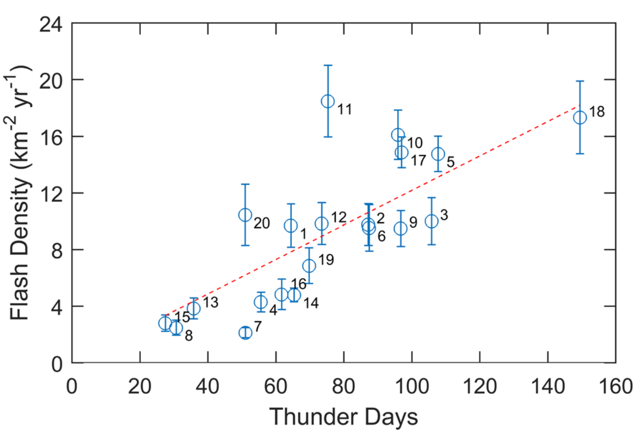



**Fig. 3** Correlation between thunder days recorded in 20 meteorological stations vs. lightning flash density calculated from LIS data. For each site, a grid size of 0.5° was considered when calculating the average ground flash density values. Numbers correspond to the stations given in Table 1

extending from March until September. Spectral analysis indicated that there is a periodic fluctuation in lightning activities occurring in every 4.2 years. However, without having a longer duration of data set, it is difficult to confirm the periodicities in the observed pattern. A recent study carried out with 20 years thunder day data reported that there are no increasing or decreasing thunderstorm days over the island (Sonnadara 2016). Figure 5b shows the thunder days (days with lightning activities) calculated with the LIS data which is consistent with the previously reported observation. Due to short viewing time period, LIS data can miss a thunderstorm and hence the average value of 60 obtained from this work can be considered as a lower value. Data indicate that although the thunder days remains the same, lightning activities are becoming intense over the years. Thus, the measurement of thunder days, which is the only measurement currently carried out by the Department of Meteorology in Sri Lanka related to lightning activity, is inadequate to describe the rapid change in lightning climatology over the island.

## 6 Onset and retreat

The annual cycle of lightning activities indicate that based on lightning frequencies, the year can be divided into two seasons, season one from January to June and season two from July to December. Figure 6a, b shows the cumulative

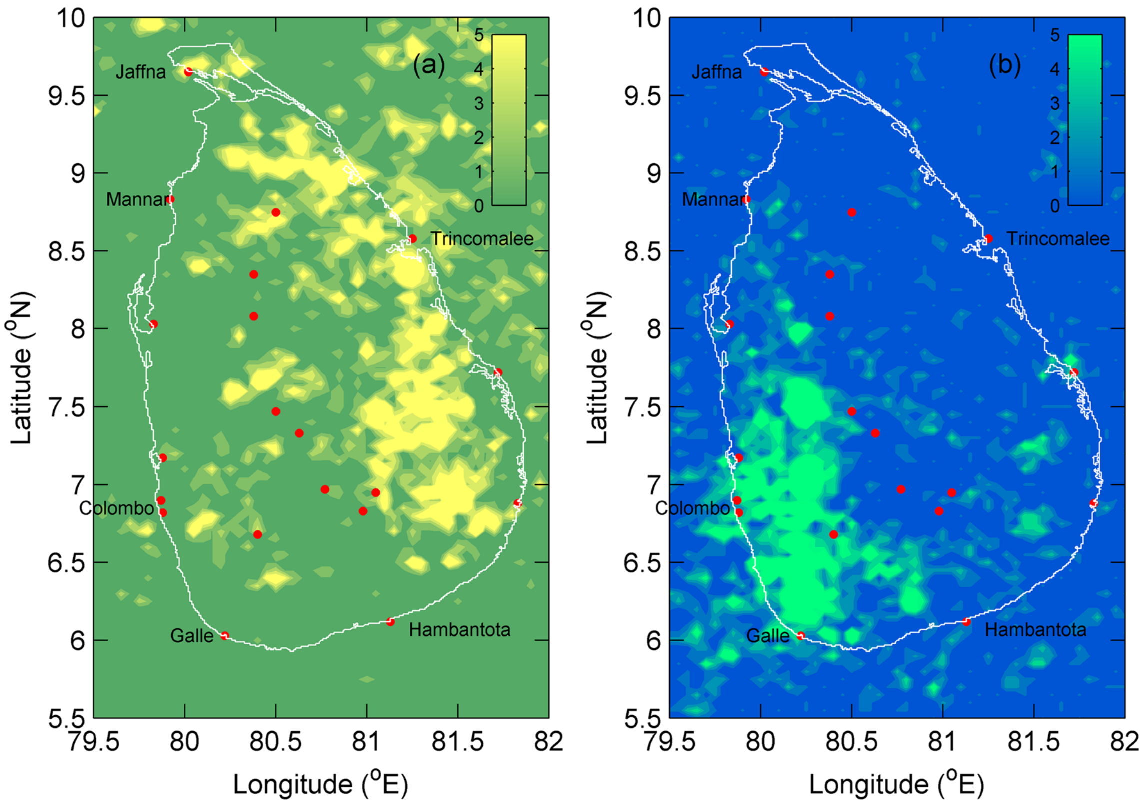



**Fig. 4** Spatial disparity in lightning activities during two monsoon seasons **a** June–September and **b** November–February

distribution of lightning activities over Sri Lanka for the two lightning seasons. On the same graphs, the mean onset date (date at which 10% of the lightning activities received) and retreat date (date at which 90% of the lightning activities received) of the lightning seasons are also indicated. The average onset of lightning season during the first half of the year occurs around the 56 day of the year while the retreat of lightning season occurs around the 136 day of the year. For the second half year, the onset of lighting season occurs around the 213 day of the year while the retreat of lightning season occurs around the 324 day of the year. The average length of the first lightning season is short and limited to about 80 days (a little over 2.5 months) while the length of the second lightning season is long and extends up to 111 days (over 3.5 months). The mean onset and retreat dates extracted from this analysis are shown in Table 2.

Figure 7a, b shows the spatial distribution of the lightning activities during two lightning seasons. The first season, February 25 to May 15, coincides with the first inter-monsoon season. One would expect high lightning activities during this season since ITCZ is present over Sri Lanka. Most parts of Sri Lanka are vulnerable to lightning activities during this season. The second season partly coincides with the latter part of the southwest monsoon season and extends up to the end of second inter-monsoon season. Although the season is long, less lightning activities are observed during this season. Eastern sector of Sri Lanka is vulnerable to lightning during this season.

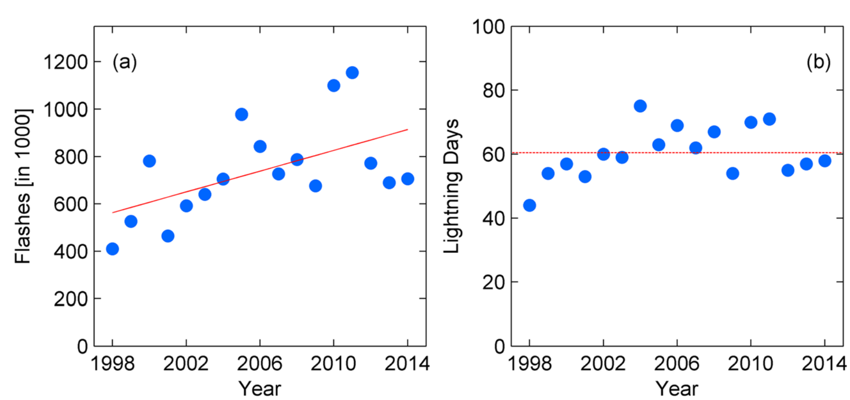



**Fig. 5** **a** Time trend of lightning flashes recorded by LIS during the period 1998–2014. Straight line represents the linear fit to the data. **b** Number of days with lightning activities (thunder days)

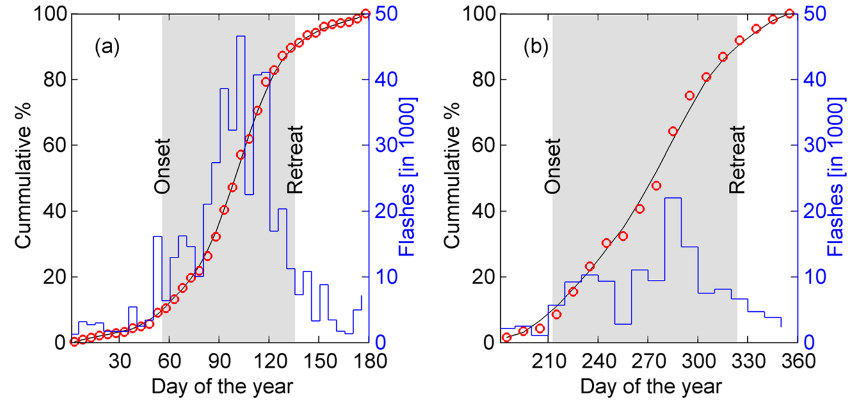



**Fig. 6** Cumulative distribution of lightning flashes. **a** First season: January–June. **b** Second season: July–December. Onset (retreat) is defined as the day at which 10% (90%) of the lightning activities received within the season under consideration. For comparison, annual variation of lightning activities is also shown

## 7 Relationship with SST

Thunderstorms develop when the atmosphere is unstable and where deep intense convective updrafts exist in a moist atmosphere. As an equatorial island, intense heating of the Earth's surface and the warm humid air over surrounding oceans supply enough ingredients for thunderstorm development over Sri Lanka. Sea surface temperature is a decisive parameter of air–sea interactions, and it is strongly related to atmospheric instability. The differences in SSTs over the ocean water lead to differences in air pressure (Lindzen and Nigam 1987). This can cause a pressure difference over the sea surface and wind to flow from a region of high pressure to a region of low pressure. Convergence and convection are expected in the regions of higher SSTs which could lead to the formation of thunder clouds. Since the coastal regions remain warmer compared to the sea surface and lightning activities are affected by moisture content, there is a possibility of lightning over land and SST being linked (Tinmaker et al. 2010, 2014; ).

Figure 8a, b shows the annual cycle of lightning activity over Sri Lanka compared with the monthly mean SST of the Arabian sea and Bay of Bengal for the period from 1998 to 2014. The figures indicate that similar to lightning activity, SSTs also show a bimodal pattern with the maximum occurring in the month of April and the secondary maximum occurring in the month of October/November. Since the onset of the southwest and northeast monsoons occurs in May and December respectively, SST for both the Arabian sea and Bay of Bengal peak roughly 30 days preceding the monsoon onset dates. When the correlation was tested (see Fig. 8c, d), it was found that the SST of the Arabian sea had a higher correlation ($r = 0.81$ significant at 0.01 level) compared to the SST of the Bay of Bengal ($r = 0.77$ significant at 0.01 level). A similar observation was reported for the lightning flash counts over India (Tinmaker et al. 2010).

## 8 Summary and conclusions

In this paper, we have presented, for the first time, characteristics of lightning flash activities over Sri Lanka using 17 years of remotely sensed satellite mounted Lightning Imaging Sensor (LIS) data. The lightning flash activities vary considerably spatially as well as temporarily. The highest was seen with over 1 million flashes. Over the years, an increasing trend in lightning intensity is seen. However, there is no change in thunder days. The annual frequency of lightning activities clearly shows a bimodal distribution with the month of April having the highest occurrence of over 220,000 lightning flashes. The highest lightning flash density of 53 flashes km$^{-2}$ year$^{-1}$ is seen close to the Avissawella an area known to have high thunderstorm activities. Comparatively, hill country shows less lightning activities compared to its periphery which has not been documented before. The average flash density for Sri Lanka was found to be 7.7 flashes km$^{-2}$ year$^{-1}$. In the wet zone, flash densities vary from 4.7 to 17.3 flashes km$^{-2}$ year$^{-1}$, while in the dry zone, flash densities vary from 2.8 to 10.4 flashes km$^{-2}$ year$^{-1}$. Overall, average flash density in the wet zone is twice as much as the average flash density in the dry zone. Based on thunder day measurements, we have derived a simple relationship for estimating the ground flash density. However, further work is necessary in this area to improve the estimate.

There is a clear spatial polarization of lightning activities during the southwest and northeast monsoon seasons. During the southwest monsoon, which is active from May through September bringing heavy rains to the southwest region,

**Table 2** The timing of the lightning season determined from LIS data

| Lightning season | Date of onset | Date of retreat | Length (days) | Lightning activities | As a % of total |
|---|---|---|---|---|---|
| Season 1 | February 25 | May 15 | 80 | 6.49 million | 52 |
| Season 2 | July 31 | November 19 | 111 | 3.76 million | 30 |

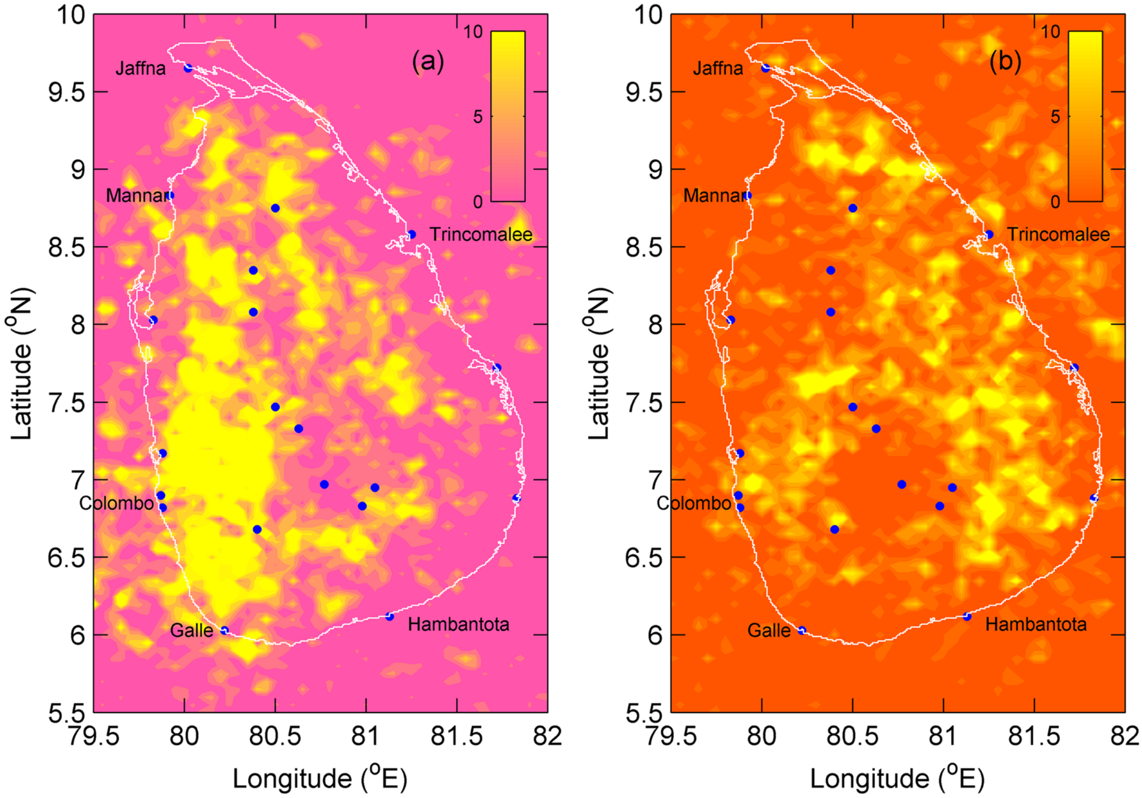
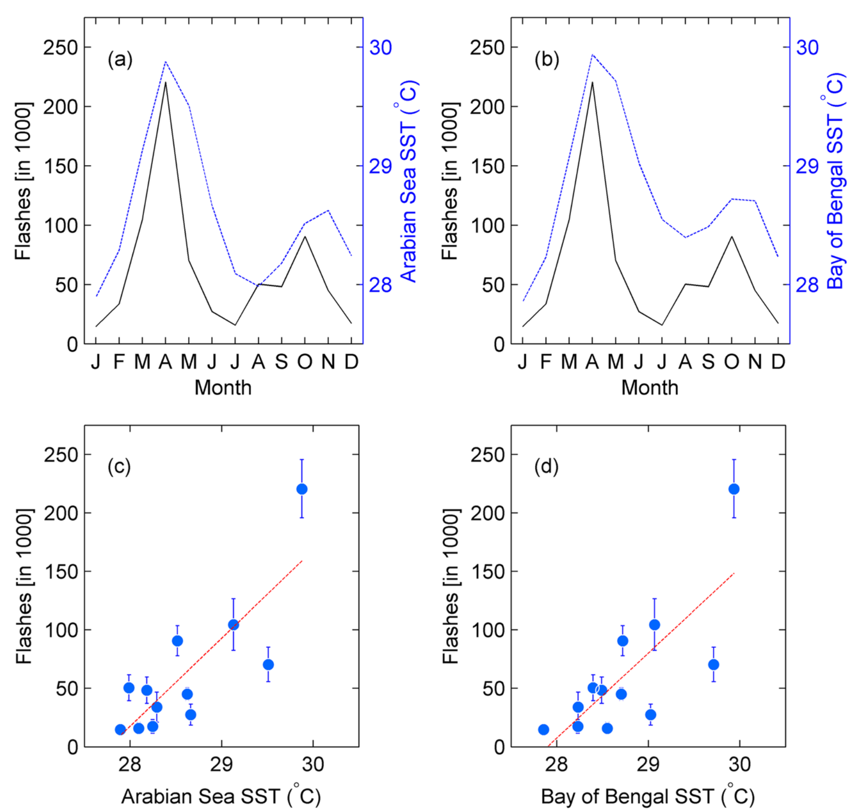



**Fig. 7** Spatial distributions of lightning activities during the two lightning seasons based on annual cycle. **a** Season 1: February 25–May 15. **b** Season 2: July 31–November 19

**Fig. 8** Comparison of monthly lightning activity with monthly mean SST: **a** Arabian Sea and **b** Bay of Bengal; monthly lightning flash count vs SST: **c** Arabian Sea and **d** Bay of Bengal. The error bars indicate the error in the monthly mean value



lightning activities occurs in the north east region. During the northeast monsoon which is active from December through February bringing ample rains to north east region, lightning activities occurs in the southwest region. During both monsoons compared to the direction of the wind, lightning occurs on the leeward side of the mountain region. This is clearly seen during the months from June to September for warm season and November to February for cold season (see Fig. 4). An earlier research work carried out at University of Colombo suggested an explanation for this behavior of lightning distribution (Jayawardena 2012). According to the previous work which was based on the data collected by the Lightning Locating System (LLS) and a numerical weather model MIUU (Meteorological Institute Uppsala University), it showed some evidences of high lightning density over the lee side of central mountain area during the northeast monsoon season. The analysis with the numerical weather model suggested that the enhanced lightning activity is a result of observed convergence at a lee-side wake during that period. Thundercloud formation in the lee-side can be an effect of enhanced vertical motions in this convergence zones. The thermal convection during day time supplies additional ingredients for severe thunderstorm activity.

During the first inter-monsoon season (March through April), lightning activities are seen in most parts of the island except for the coastal areas in the northern and eastern regions. During the second inter-monsoon season (October through November), the lightning activities are localized in the periphery of the mountain region.

Based on the annual cycle of lightning activities, year was divided into two parts of 6 months duration and two lightning seasons are defined. The mean onset/retreat date is defined as the date at which 10/90% of lightning activities are received within each season. For the first half year, the onset of lighting season occurs on February 25 while the retreat of lightning season occurs on May 15. For the second half year, the onset of lighting season occurs on July 31 while the retreat of lightning season occurs on November 19. The average length of the first lightning season is short and limited to about 80 days while the length of the second lightning season is long and extends up to 111 days.

The lightning climatology over Sri Lanka especially temporal variations cannot be described by using thunder days which is the only standard measurement currently carried out by the Department of Meteorology in Sri Lanka related to lightning activities. We have shown that the sea surface temperatures of the Arabian Sea and Bay of Bengal are positively correlated with lightning activities in Sri Lanka.

Considering the damages due to lightning, further work is needed to study the areas prone to high lightning activities.

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