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STUDY OF LIGHTNING ACTIVITY OVER INDIAN SUBCONTINENT

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The seasonal distribution of lightning flash activity over the Indian subcontinent (Equator-35°N and 60°E–100°E) is studied using the quality checked monthly lightning flash data obtained from Lightning Imaging Sensor (LIS) on board the Tropical Rainfall Measuring Mission (TRMM) satellite. This paper presents results of diurnal and seasonal variation of the lightning activity over Indian subcontinent. The diurnal variation of maximum flash rate is observed to peak at 11 UTC and minimum at 04 UTC. Thus it clearly shows that maximum thunderstorms activity occur during late afternoon to evening hours. Seasonal total flash counts during monsoon season are more compared to pre-monsoon season but normalized seasonal total flash counts are observed to be more during pre-monsoon season. Thus thunderstorms during pre-monsoon season are more intense.

1. Introduction

The availability of lightning data and its utilization in the operational weather forecasting has seen phenomenal increase during last 2 decades (Aiya and Sonde, 1963; Toracinta *et al.*, 2002; Khandalgaonkar *et al.*, 2005; Manohar *et al.*, 1999). The recent developments in space technologies enabled detection and spatial location of the lightning from the space using optical sensors. NASA Marshall Space Flight Center in Huntsville, Alabama had developed an optical lightning detection sensor. A prototype (OTD, Optical Transient Detector) was launched in 1995 (Boccippio *et al.*, 2000) and its improved version LIS (Lightning Imaging Sensor) was launched on board the Tropical Rainfall Measuring Mission (TRMM) in 1997 (Christain *et al.*, 1999). The LIS instrument is revolving at an altitude of 350 km with an orbit inclination of 35°. Therefore it has short sampling time and which in turn results in snapshots of few minutes of the lightning activity within a given area of interest. Data obtained from this system is freely available for scientific studies and is useful for lightning analysis especially in the tropics.

Lightning is generally associated with the meso-scale convective systems and it possesses very high temporal and spatial variability. Therefore, it would be appropriate to study such activity with higher spatial resolution. In this study, LIS flash data is utilized for the study of spatial and temporal distribution of lightning activity over the Indian sub continent with the higher spatial grid resolution of $0.2° \times 0.2°$.

2. Data and Methodology

The quality checked monthly LIS data obtained from Marshall Space Flight Centre for the period of 1998–2005 is used in this study. LIS observes lightning activity over the tropical region bounded by 35°N–35°S. This instrument detects total lightning which include cloud-to-ground, intra-cloud and cloud-to-cloud discharges. The LIS is useful for identifying spatial location of lightning, time of lightning events, and radiant energy from lightning activity. Figure 1 shows the extent of the Indian subcontinent selected for this study.

For this study, we have gridded the monthly total lightning flash counts with spatial resolution of $0.2° \times 0.2°$. We used 0.2 degree resolution data to indicate two separate simultaneous events of thunderstorms, which would give accurate representative values of localized lightning flash densities. It is also believed that, there is no need to mask ocean in coastal regions as high grid resolution will lead to much less error in the prepared datasets.

3. Diurnal Variation of Lightning Activity

The diurnal variation of the mean total number of lightning flashes over Indian Subcontinent (0° to 35°N and 60°E–100°E) is presented in Fig. 2. It is seen that maximum lightning flash counts occur at 11 UTC (1630 IST). The maximum flashes occur during late afternoon and evening hours. This result is in agreement with the diurnal variation thunderstorms over Indian

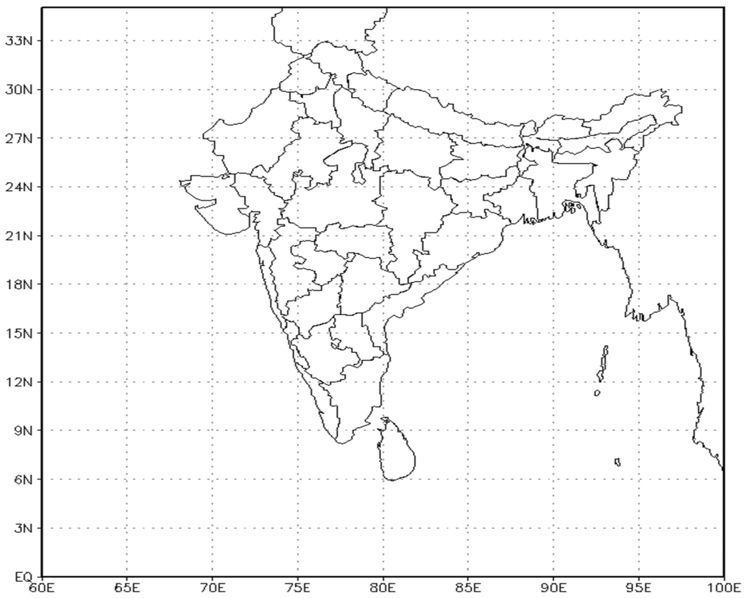

Fig. 1. Map showing region of Indian sub-continent considered in this study.

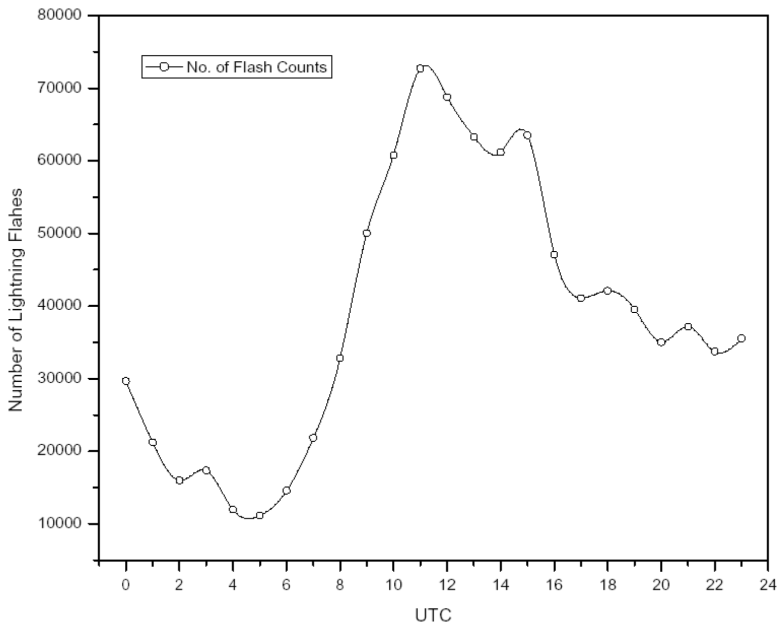

Fig. 2. Diurnal Variation of mean total number of lightning flashes over Indian Subcontinent (0°–35°N and 60°E–100°E) for the period of 1998–2005.

region. The lightning flash counts during morning hours are observed to be low with minima at 04 UTC (1030 IST). The maximum flash counts during late afternoon and evening hours are the result of solar forcing. The Sun heats up the surface during the day. Solar radiations are absorbed within few millimeters of the surface during the day. At night this radiation is easily radiated to space from the land surfaces as they cool. Thus the diurnal temperature range is much more over the land surfaces which affect the diurnal variation of thunderstorms and hence lightning.

4. Latitudinal Variation of Lightning Activity

Indian sub-continent region shows east-west contrast in thunderstorm activity (Mahohar and Kesarkar, 2003). In this viewpoint, we have divided entire Indian subcontinent across the longitude of 80°E. The west region is represented by 60°E–80°E and the east region is represented by 80°E–100°E. Previous studies (Kandalgaonkar *et al.*, 2003, 2005) indicate that latitudinal distribution of thunderstorm activity over the Indian region is different from the rest of the tropics. Therefore it is interesting to study seasonal latitudinal variation of lightning activity. In this context, we have computed the zonal averages for these two regions for different season viz. winter (Jan–Feb), pre-monsoon (Mar–May), Southwest monsoon (Jun–Sep) and post-monsoon (Oct–Dec) (as shown in Figs. 3(a)–3(d), and 4(a)–4(d)).

4.1. *Winter season*

The lightning activity is observed to increase with latitude. Figure 3(a) shows the latitudinal variation of lightning flash density over Indian subcontinent (0° to 35°N and 60°E–80°E) for the period of 1998–2005. It can be seen from Fig. 3(a) that the lightning flash density during winter is more over the northern parts of India with a maximum of $0.85\,\text{km}^{-2}\,\text{month}^{-1}$ over a latitudinal belt 31.8°N–32.0°N. This may be attributed to lower tropospheric low pressure system called western disturbances that pass through the northern latitudes of India during winter. Western disturbance systems acquire fresh moisture supply from Arabian Sea and Bay of Bengal. This convection along with supply of moisture is favourable for the genesis of thunderstorms and may be the reason for increased lightning activity over the northern India.

Figure 4(a) shows that the latitudinal variation of lightning activity over the longitudinal belt 80°E–100°E is high in the equatorial region

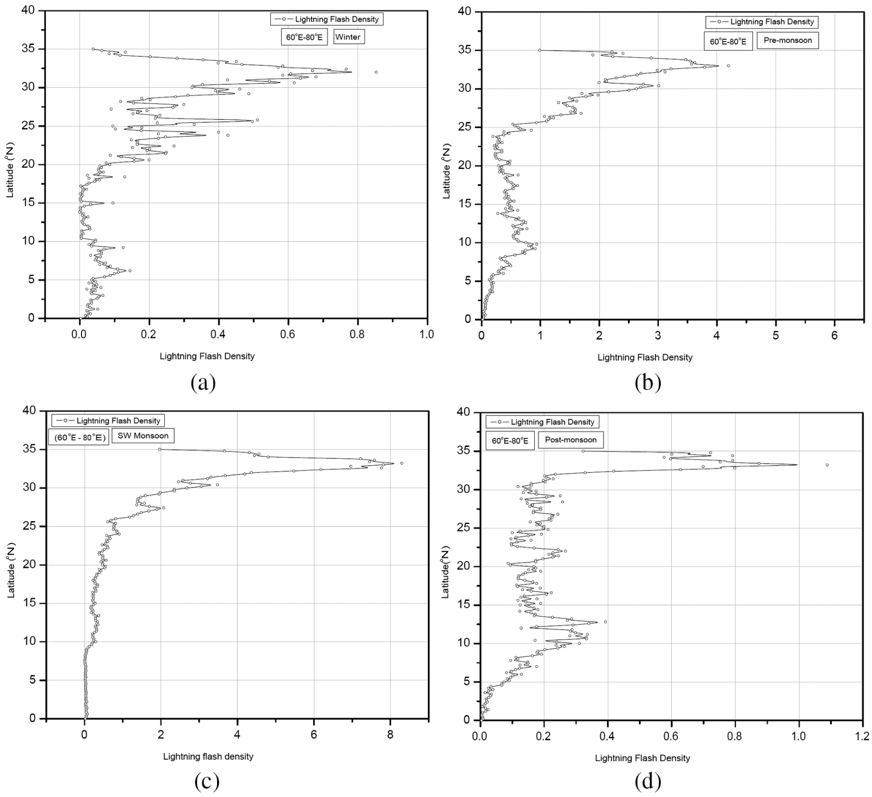

Fig. 3. Latitudinal variation of lightning flash density (Units: km^{-2} month^{-1}) over Indian Subcontinent (0°–35°N and 60°E–80°E) for the period of 1998–2005 during (a) Winter season (Jan–Feb) (b) Pre-monsoon season (Mar–May) (c) Southwest monsoon season (Jun–Sep) and (d) Post-monsoon season (Oct–Dec).

of Equator-5°N with a peak value of 0.58 km^{-2} month^{-1} at 4.0°N–4.2°N. Thereafter, it gradually decreases northward. At north of 20°N, it again increases and attains maxima (at 25°N) of 0.5 km^{-2} month^{-1}.

4.2. *Pre-monsoon season*

The lightning flash density in the region 60°E–80°E depicts secondary maxima of 0.93 km^{-2} month^{-1} at 9.8°N (Fig. 3(b)). The flash density has a decreasing trend up to 24°N, thereafter it increases and principle maxima of 4.2 km^{-2} month^{-1} occurs at 33°N. Figure 4(b) shows the latitudinal variation of lightning flash density over Indian subcontinent (0° to 35°N and 80°E–100°E). It is seen that lightning activity increases steadily at north

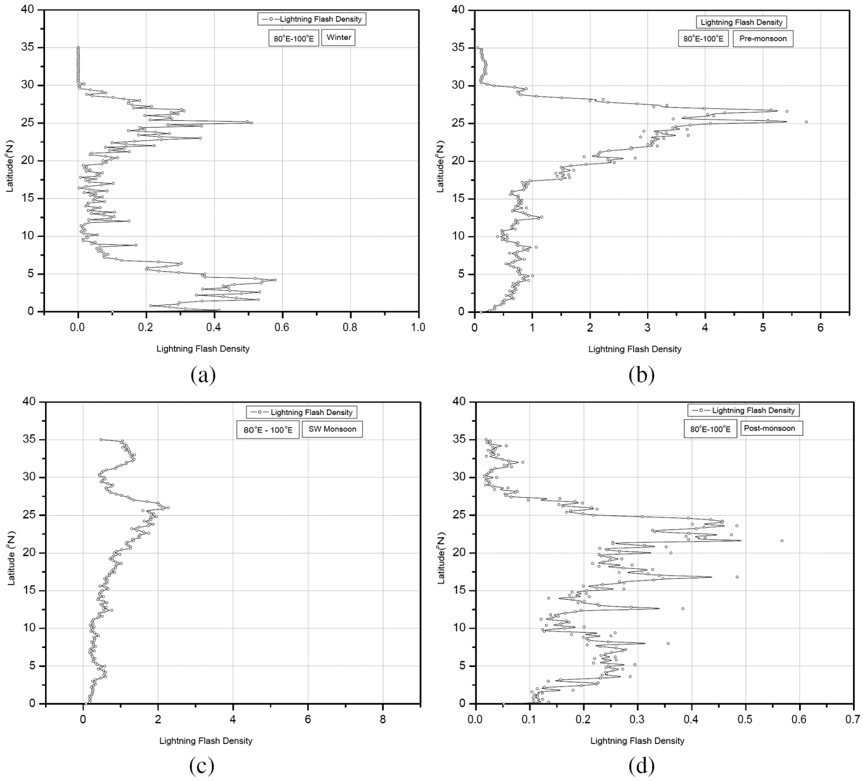

Fig. 4. Latitudinal variation of lightning flash density (Units: km^{-2} month^{-1}) over Indian subcontinent (0°–35°N and 80°E–100°E) for the period of 1998–2005 during (a) Winter season (Jan–Feb) (b) Pre-monsoon season (Mar–May) (c) Southwest monsoon season (Jun–Sep) and (d) Post-monsoon season (Oct–Dec).

of 15°N and peaks in the latitudinal belt of 25.2°N–26.6°N with mean flash density of 4.56 km^{-2} month^{-1}. At north of 28°N, the flash density decreases steeply.

4.3. *Southwest monsoon season*

During the Southwest monsoon season, lightning flash density over the northern latitudinal belts is significant than the peninsular latitudinal belts (Fig. 3(c) and 4(c)). Figure 3(c) shows peak values of 8.3 km^{-2} month^{-1} for the latitudinal belt of 33.0°N–33.2°N (for the region 60°E–80°E). Figure 4(c) denotes peak value of 2.3 km^{-2} month^{-1} for the latitudinal belt of 25.8°N–26.0°N (for the region 80°E–100°E).

In monsoon season, a trough of low pressure at surface runs from head of Bay of Bengal in the east to Ganganagar in the northwest India. This is called the monsoon trough and is a semi-permanent feature of the monsoon circulation. It is the region of convection, which favours the formation of the thunderstorm and lightning in the north.

4.4. *Post-monsoon season*

From Fig. 3(d), it is seen that the lightning flash density is maximum in the northern latitudinal belts with a peak of 1.1 km^{-2} $month^{-1}$ at 33.2°N. It may be attributed to passing western disturbances over the northern India. The flash density then decreases southward and again increases over the latitudinal belt of 20°N–22°N i.e. central parts of India with peak value of 0.3 km^{-2} $month^{-1}$ at about 22°N. Figure 4(d) also shows maximum flash density in this region. Kandalgaonkar *et al.* (2005) attributed this maximum flash density to the retreating of Inter-tropical Conversion Zone (ITCZ) and convection associated with large scale convection.

5. Seasonal Variation of Lightning Flash

The seasonal variation of lightning flash counts is presented in Fig. 5. It is observed that, maxima in the seasonal total lightning flash (STLF) counts occur in the monsoon season (47.2%). This result is in agreement with previous studies made by Manohar and Kesarkar (2005). They studied the climatology of thunderstorm activity over Indian region and observed that the maximum numbers of annual total thunderstorms occur in the monsoon season. Figure 5 also depicts the seasonal total lightning flash counts normalized using number of days of the season. It is seen from this figure that, maxima of normalized seasonal total lightning flash (NSTLF) counts occur in pre-monsoon season with 45.9% of total flashes as compared to 39.3% of total flashes in the monsoon season. It may be inferred that the thunderstorms in pre-monsoon season are more intense than in monsoon season.

6. Annual Variation of Lightning Activity

A spatial plot for annual distribution of lightning density over the Indian sub-continent is shown in Fig. 6. The flash density distribution is in qualitative agreement with the climatology of thunderstorm days.

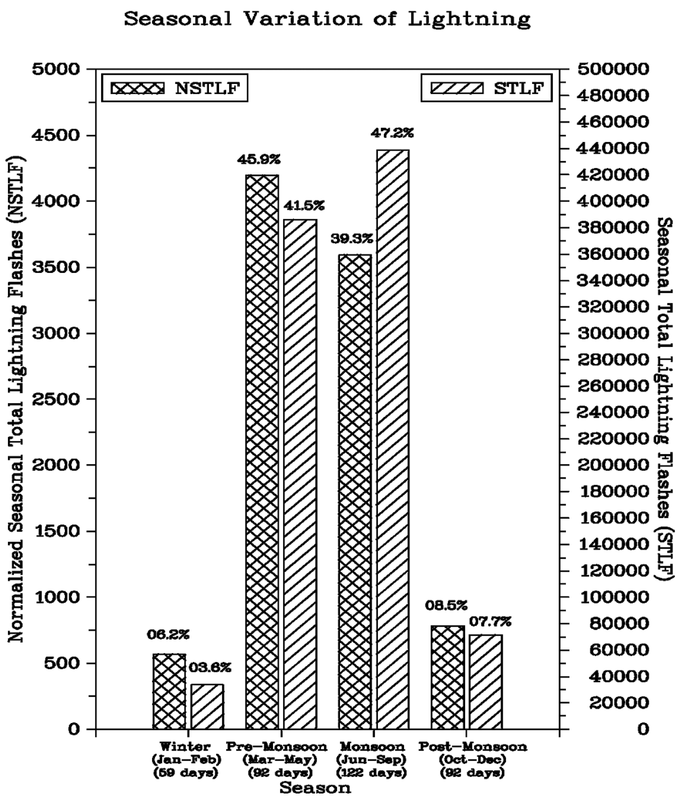

Fig. 5. Seasonal variation of lightning flash counts and normalized lightning flash counts.

The peak lightning flash density of 28.2 $km^{-2} year^{-1}$ is observed at 33.2°N/74.6°E. Previous studies have reported annual flash density maxima of 33.3 $km^{-2} year^{-1}$ at 33.75°N/73.25°E over the Indian sub-continent. The high flash density over northern Pakistan is attributed to the Himalayan orographic barrier. It is clear from Fig. 6 that there is a sharp decrease in the lightning flash density to the north of the Himalayan ranges.

Studies over dynamics of convective systems over ocean are limited. The meteorological features that delineates convective activity over ocean and land are: There are no orographic lifting mechanism over oceanic areas, the Sea Surface temperature (SST) is fairly homogeneous hence pressure gradient is uniform over large oceanic areas in the absence of any synoptic situation, Convective Available Potential Energy (CAPE) over the ocean is relatively weak for severe thunderstorm to occur, convection over ocean

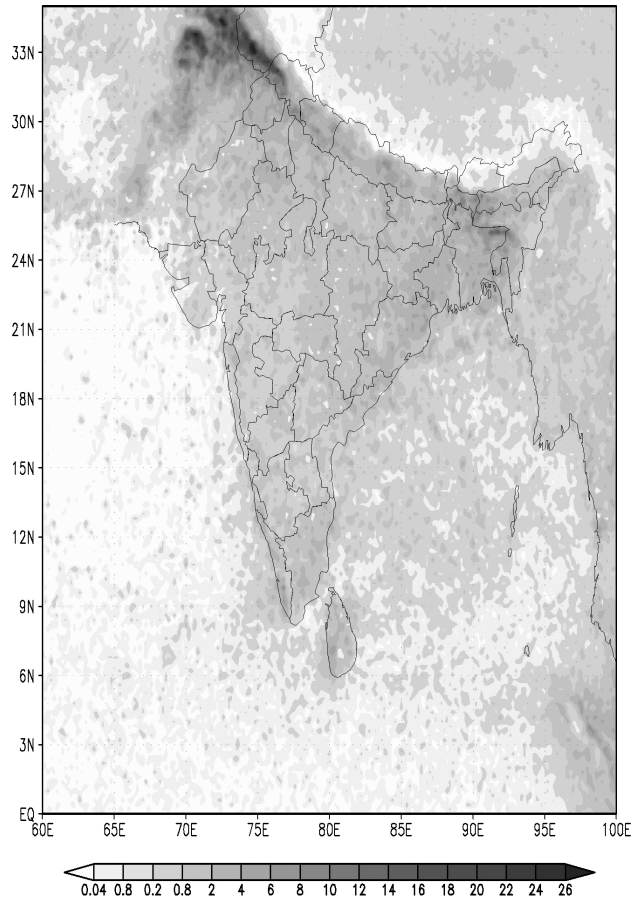

Fig. 6. Annual distribution of lightning activity (Units: km^{-2} year^{-1}) over Indian sub-continent (0°E–35°N and 60°E–100°E) for the period of 1998–2005.

is very weak due to low external trigger energy to overcome Convective Inhibition Energy (CINE), specific heat capacity of the ocean is very high, insolation of short wave energy is mostly reflected back from calm seas, from rough seas the incident energy is reflected at various angles, some of the incoming energy is absorbed up to the mixed layer depth. These features lead to significantly low lightning flash density over Arabian Sea and Bay of Bengal as compared to adjoining land areas (Fig. 6). Most of the lightning activity over the ocean areas is associated with cyclonic circulations.

7. Conclusions

The diurnal variation of maximum flash rate is observed to peak at 11 UTC and minimum at 04 UTC. Thus it clearly shows that maximum thunderstorms activity occur during late afternoon to evening hours. However, it was observed that over the oceanic areas maximum flash rate generally occur during late night and early morning hours.

Seasonal latitudinal variation of lightning flash density during winter season has maxima in the northernmost latitudes of Indian region. During pre-monsoon season the lightning flash density in the region 60°E–80°E increases northward from the equator and peaks up at 9.8°N. It then decreases northward up to 24°N. North of 24°N it increases steeply and peaks at 33°N. In the region 80°E–100°E the flash density peaks in the belt 25.2°N–26.6°N which is the region of intense convective activity over northeast India. In the monsoon season the flash density in the southern parts of India is much low but to the north of 25°N the flash density increases gradually and peaks at 33°N. During monsoon season in the region 80°E–100°E the flash density gradually increase from 20°N to 25°N. Thus along the monsoon trough flash density is more. During the post-monsoon season in the region 60°E–80°E the lightning flash density in the northern latitudes and peaks at 33.2°N. Then it decreases southward. The flash density is more again in the belt 20°N–22°N. The flash density over the peninsular latitudinal belt from 10°N–13°N is also high during post-monsoon season. It has been seen that, the seasonal total flash counts are maximum during the monsoon season and is in agreement with the propagation of Inter-tropical Conversion Zone (ITCZ) over this region.

Seasonal total flash counts during monsoon season are more compared to pre-monsoon season but normalized seasonal total flash counts are observed to be more during pre-monsoon season. Thus thunderstorms during pre-monsoon season are more intense.

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