CHAPTER 5

Response of Average Flash Rate to the Mean Convective Storm Height

5.1 Introduction

Development of precipitation and electrification in a cloud are closely related to the growth of its vertical development (Workman and Reynolds, 1949; Vonnegut, 1963; Krehbiel, 1986; Williams, 2001). For example, recent studies at several places in tropics show that lightning activity in a cloud non-linearly increases with the increase in height of the top of cloud (e.g. Williams, 1991). In order to learn about the processes that cause the initial electrification of cloud, Moore et al., (1960) concluded from their radar observations that the first lightning discharge does not occur unless the cloud has grown to a depth of 3 or 4 km. Further, summarizing the results of his and others observations, Reynolds et al., (1957) and Moore and Vonnegut, (1977) concluded that the presence of precipitation and convective activity are necessary but not sufficient conditions for lightning to occur. Moreover, there are several reports where lightning has been reported to occur in warm clouds i.e. in the clouds whose tops are below freezing level (Foster, 1950; Moore et al., 1960, Pietrowski, 1960).

Currently, in the most accepted mechanism of cloud electrification, the charge separation occurs in the mixed-phase region where the supercooled water droplets and ice particles coexist in the cloud (Reynolds et al., 1957; Takahashi, 1978; Saunders, 1995; Williams, 1989). Presence of both supercooled water droplets and ice particles is essential for this charge generation process to operate. Therefore, the clouds in which only ice phase exists, are expected to be only weakly electrified.

In mid-latitudes, where most of the cloud electrification studies have been made, freezing level is close to the ground and the clouds mostly cross the freezing level before they grow to a depth of 3 km. Therefore, the observations made at these places are not suitable to examine the issues discussed above. On the contrary, the clouds that develop in tropical regions, can grow to heights of significantly > 3 km before their tops
cross the freezing level. The studies made in tropical regions, therefore, can be used to examine some of these issues.

In this chapter, we examine the seasonal variation of the average flash rate with the mean convective storm height mean (MCSHM) of cloud top and study these relationships with respect to the heights of freezing level in different regions. In particular, our objective will be to test the validity of the conclusions, discussed above from surface observations with the data obtained on larger spatial and temporal scales from satellite observations.

5.2 Data-sets

The following data-sets are used in this chapter

(i) LIS/OTD 2.5 Degree Low Resolution Monthly Climatology Time Series (LRMTS)

The product is a 2.5 deg x 2.5 deg gridded composite of Monthly time-series of total (IC+CG) lightning bulk production, expressed as a flash rate density (fl/km²/day). Separate gridded time series from the 5-yr OTD (4/95-3/00) and 8-yr LIS (1/98-12/05) missions are included, as well as a combined OTD+LIS product. Lowpass temporal filtering (110-day for OTD, 98-day for LIS, 110-day for combined) and spatial moving average filtering (7.5 deg) have been applied, as well as best-available detection efficiency corrections and instrument cross-normalizations, as of the product generation date (9/01/06).

(ii) Mean Convective Storm Height Mean

The Mean Convective Storm Height Mean data is derived from the 3A-25 Planetary Grid 2 of TRMM Precipitation Radar data product which has 0.5° grid intervals for the period 1998-2005.

(iii) Freezing Level

Freezing level data which has 2.5 deg grid resolution is downloaded from Climate Forecast System Reanalysis (CFSR) data developed by NOAA’s National Center for Environmental Prediction (NCEP) have been used here.
5.3 Seasonal Variations of the Monthly-averaged Values of Flash Rate, MCSHM and Freezing Level

Figure 5.1 shows the seasonal variations of the monthly-averaged flash rate and MCSHM for different regions. Also shown in Figure 5.2 are the variations of the monthly-averaged values of the freezing level height in different regions. Average height of the freezing level varies over a wide range over the latitudinal range of 8°N to 36°N in South Asia (Pramanik and Koteswaram, 1974). While it remains at a constant height of approximately 5 km for the whole year in peninsular India, its vertical height reduces from 5 km in summer to less than ground level in winter in Tibetan Plateau.
Figure 5.1 (Contd..)
Figure 5.1 Seasonal variations of the monthly-averaged values of average flash rate, mean convective storm height (MCSHM) and mean of freezing level height for each region over the period 1998-2005.

Figure 5.2: Variation of average flash rate with MCSHM in case of clouds in category I (cold clouds) for different regions. Please note a different class of relationship in the TP region.
Trends in seasonal variations of the average flash rate and MCSHM in particular region are broadly similar to each other in some respects. For example, both of them change to single or double periodicity together from region to region. Further, both of them have higher values in summer months and fall to very low values in winter months (Fig 5.1). Mean freezing level is either below or above the MCSHM throughout the year or above/below the MCSHM for part of a year. The data from all regions can be divided in the following two categories:

**Category I:** In this category, the MCSHM is more than the freezing level height, and it is representative of cold clouds with ice phase in them, and

**Category II:** In this category, the MCSHM is less than the freezing level height, and it is representative of warm clouds.

Figure 5.2 shows the variation of the monthly-averaged flash rate with MCSHM for storms in all regions in Category I. Average flash rate is almost zero or has very low values until the MCSHM exceeds 3 km and subsequently increases in all regions, first slowly and then rapidly, as the MCSHM increases. This relationship is significantly different over the TP region which has an average altitude of 4942 m. As a result, clouds do not attain a depth of 3 km until they grow to a MCSHM of ~ 8 km. Therefore, the average flash rate in the storms with a mean convective storm height of < 8 km in this region, is almost nil. Thereafter, the average flash rate slowly increases with the increase in MCSHM. The growth of storms with MCSHM > 10 km is limited because of the presence of the tropopause.

The criteria of the depth of the storm to develop to a minimum height of 3 km before exhibiting the first lightning flash, is also well illustrated in the average flash rate-MCSHM relationship band in Figure 5.2. On the outer limit of this band lie the points corresponding to the NW region and on the inner limit of the band lie the points corresponding to the NE region. The increase in average flash rates at NW (at an average elevation of 2918 m) and NE (at an average elevation of 762 m) do not significantly increase until the MCSHM increases to about 4800 m and 2700 m, respectively. Although values of the average flash rates in all other regions also
increases with the increase in MCSHM, they lie between these two upper and lower limits.

Figure 5.3 shows the variation of the average flash rate with MCSHM for storms of Category II which is representative of warm clouds. The condition of no significant flash rate occurring in clouds until the MCSHM increases to 3 km, is well illustrated in this category also. However, it is important to note that the average flash rate increases with the MCSHM in this category also when the MCSHM is > 3 km.

5.4 Comparison of Average Flash Rates with MCSHM in Storms Occurring Over Oceans, Tibetan Plateau and Land

We have divided the data plotted in Figure 5.2 in three different groups, viz. over oceans, Tibetan Plateau and other land regions. Figure 5.4 illustrates the variations of the average flash rate with the MCSHM in all regions in these three groups. The criteria for the average flash rate to be nil or have very little value until the MCSHM attains a value of 3 km is well illustrated in all the three cases. Over oceans, the average flash rate increases with the increase in the MCSHM but remains < 0.034 fl km$^{-2}$ day$^{-1}$ even when the MCSHM increases to 5 km. The average flash rate in the AS region over Arabian sea is the lowest and in the BB region over the Bay of Bengal is the highest. Over the Tibetan Plateau, the average flash rate increases only when the MCSHM increases more than 8 km but remains < 0.019 fl km$^{-2}$ day$^{-1}$ even when the MCSHM attains a value of 10 km. In all other land regions, the average flash rate increases after the MCSHM exceeds ~ 3 km and attains a comparatively higher value of 0.13 fl km$^{-2}$ day$^{-1}$ when the MCSHM attains a value of 8 km. The highest value of the average flash rate attained at land regions is about an order of magnitude more than over seas or at the Tibetan Plateau.
Figure 5.3 Variation of average flash rate with MCSHM in case of clouds in category II (warm clouds) for different regions.
Figure 5.4 (Contd..)
Figure 5.4 Variation of average flash rate with MCSHM in the regions at (a) Tibetan Plateau, (b) sea, and (c) land.

5.5 Discussion

Our analysis shows that the following results of the past observations, obtained from surface observations, are upheld, on larger spatial and temporal scales, when they are examined from satellite data. The conclusions, drawn from our study, may be valid only on climatic, seasonal or, at the most, monthly time-scales and for large areas. Variability of these results on shorter scales of space and time, may be large. However, it is significant to note that most of the conclusions drawn from our analysis, are in conformity with the conclusions drawn from the surface observations on spatio-temporal scales of a thunderstorm.

(i) Lightning activity does not appear in a cloud until it attains a depth of about 3 km. This condition holds good whether the clouds develop over oceans, Tibetan Plateau or other regions over land.

(ii) The warm clouds with their tops below freezing level, can exhibit lightning activity and the average flash rate, even in such clouds increases with the increase in their depth beyond ~ 3 km.
(iii) The average flash rate over both the oceanic regions and at the Tibetan Plateau is about an order of magnitude less than that over other land regions.

(iv) The low flash rates at the Tibetan Plateau can be associated with two facts. Firstly, the clouds that develop over this region generally consist of ice-phase only. So the mixed-phase region, which is believed to be responsible for the charge generation in clouds, may not exist. Secondly, the height of top of clouds that develop over the Tibetan Plateau, may be limited due to the presence of tropopause.

(v) The Himalayan range has strong effect on the lightning activity. For the same MCSHM, the clouds that develop in the NE may produce 3 to 10 times higher average flash rate as compared to the clouds that develop in NW and HF regions respectively. Moreover, average flash rate in all other regions on land lie between these two extreme limits. So, the two extreme dry and wet environments of the NW and HF regions on the extreme western and eastern ends of the Himalayas, provide conditions for the extreme efficiencies of lightning production.