Mapping the cloud-to-ground lightning occurrence in Fiji

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ABSTRACT

Using the Time Of Group Arrival (TOGA) of sferics two year (Jan2003-Dec2004) annual average of about 3,200 and 1,200 cloud-to-ground (CG) flashes were recorded in the two larger islands, Viti Levu and Vanua Levu, Fiji. A two year average CG flash density showed maxima of 0.80 and 0.35 flashes/km^2 per year in two islands. The diurnal variation showed peak activity between 14:00 hrs- 16:00 hrs LT and the seasonal variation showed enhanced lightning incidences during November-April. Data from Lightning Imaging Sensor (LIS) aboard the NASA Tropical Rainfall Measuring Mission (TRMM) satellite are also presented for the same period at the two locations. Lightning in a 10 km×10 km area was compared with total rain accumulation at a site midway in the area which shows good correlation.

1 INTRODUCTION

Convective events produce very intense rainfall that often leads to river floods and flash floods causing significant damage to property and soil erosion. In most cases, rapidly developing mesoscale convective systems are responsible for the heaviest and most destructive rainfall. Lightning activity and convective precipitation are two related characteristics of thunderstorms, and their relationship can be used as a quantitative indicator of the rainfall regime. The first value of the water volume per flash was proposed by Battan (1965), who found, with little sophisticated observation means, 3×10^4 m^3 per Cloud to Ground (CG) lightning flash. These were based on the study of activities during the summer season. Based on thunderstorm case studies (2 isolated storms) Piepgrass *et al.* (1982) reported a figure of 2×10^4 m^3/CG. Analyzing 9 isolated storms Gungle and Krider (2000) reported that the water volume per flash as 3×10^4 m^3/CG. These figures were based on rain gauge data. Values calculated with Precipitation Radar (PR) measurements were of the same order with reported magnitudes ranging from 4.3×10^4 m^3/CG (Tapia *et al.* 1998) and 7.2×10^4 m^3/CG (Soula and Chauzy 2001).

Results from the new Pacific Lightning Detection Network (PacNet) sensors located in the central Pacific region indicate that the ratio of lightning to rainfall rate remains relatively stable (Cummins and Turner 2004). Using the annual rainfall and lightning incidence collected over periods ranging from 9 to 22 years at 23 stations around the continent of Australia, Jayaratne and Kuleshov (2006) computed the rain yield as 2.64×10^8 kg fl^{-1} in the mid-continental regions and 9.91×10^8 kg fl^{-1} in the near-coastal regions. Rain yield is water mass per flash.

Besides studies related to thunderstorm evolution, the propagation of electromagnetic waves excited by lightning strokes in the Very Low Frequency band (VLF or sferics) stimulated the interest of many researchers. Detection of these VLF signals has lead to the location of the strokes. The relationship between lightning and rainfall suggest that the CG incidence in a location gives a good indication of rainfall in that area, thus a promising application of lightning location is to derive estimates of the rainfall rate from the lightning data (Peterson 1998). In this paper, we summarize the different techniques used for lightning location, and briefly explain the method used in this study. A two year (2003 - 04) data of CG distribution over the two larger islands of Fiji are presented. Rainfall data of one station is compared with CG flashes in a small area encompassing the station.

The spatial distribution analysis can be broadly subdivided into local, regional and global studies depending on the measurement equipment and their resolution. Jayaratne and Ramachandran (1998) have reported the findings of a 5-year study of Intra Cloud (IC) and CG flashes, in Botswana, using a CGR3 counter whose effective area of detection was ~ 600 km^2. The latitudinal variation of IC: CG ratio (Z) was investigated using CGR3 counters and were reported by Mackerras *et al.* (1998). Ground flash densities all over Colombia have been measured using CIGRE and CGR3 counters (Torres 1998). A combination of 4 Lightning Position And Tracking Systems (LPATS) were used in Brazil, covering 420,000 km^2, to analyze CGs (Pinto *et al.* 1999 a, b). The U.S. National Lightning Detection Network (NLDN) uses Improved Performance from Combined Technology (IMPACT) sensors together with LPATS sensors and operates in real time on a continental scale (Cummins *et al.* 1998). The system uses more than 100 sensors located over the continental United States. A 7 station sferic observational network operating on VLF-band has been operated by the UK Met Office (Lee 1986). This measures the Arrival Time Difference (ATD) between sferics received at different stations and used atomic clocks to time stamp the waveform. The detection range is about 8 000 to 10 000 km covering much of Europe. The more recent experimental networks relied on GPS technology (Metoffice 2005).

PacNet lightning detectors have a hybrid design, which includes some of the advantages of accuracy at close range of traditional broad-band detectors and the advantages of long range associated with VLF detectors. The sensors use combined technology which utilizes both time-of-arrival and direction finding methods in the data processing (Cummins and Turner 2004). On the global scale, Optical Transient Detector (OTD) aboard an earth-orbit satellite provided lightning occurrence data (the mission ended in March 2000). At present Lightning Imaging Sensor (LIS) on board the Tropical Rainfall Measuring Mission (TRMM) satellite provides data for studying global lightning patterns (NASA 2003). Ground based VLF lightning location by measurement of TOGA of sferics has been established by the World Wide Lightning Location Network (WWLLN) for global monitoring of lightning (Dowden and Rodger 2001; Dowden *et al.* 2002). This method has been adopted by the authors and preliminary findings of a three month and one year study of lightning location in one of the larger islands in Fiji has been published (Ramachandran *et al.* 2003, 2005).

2 SYSTEM DESCRIPTION

2.1 AN OVERVIEW

Lightning emits a wide spectrum of electromagnetic radiation during its breakdown. In Cloud-to-Ground (CG) lightning stroke, the stepped leader descending from the base of a thundercloud triggers the first return stroke. This stroke is responsible for most of the charge transfer within few tens of microseconds causing a current of tens of kA. The radio impulses emitted by the CG strokes, commonly referred as sferics, have the highest spectral density in the VLF band (3 - 30 kHz) with the peak at ~10 kHz, whereas the Intra Cloud (IC) emissions occur primarily in the VHF band (30 - 300 MHz). At 10 kHz there may be a small, but not well known, fraction of contribution from IC flashes. The sferic radiation propagates with little attenuation in the Earth–Ionosphere waveguide (EIWG) to large distances (Mm) by multiple reflections. University of the South Pacific is one of the 28 Universities/Institutions (Argentina, Ascension Is., Boston, Brisbane, Budapest, Darwin, Dunedin, Durban, Fiji, Finland, Honolulu, India, Lanzhou, Lisbon, Los Alamos, Mexico, Moscow, Osaka, Perth, Peru, Puerto Rico, Rothera, Sao Paulo, Seattle, Sheffield, Singapore, Tahiti, Tel Aviv) which are participating in the global lightning detection programme under the WWLLN. The Time Of Group Arrival (TOGA) at the different sites are recorded with respect to GPS time. Using these times from the different sites, the positions of the strokes are located. Detailed theory of the TOGA principle and description of the measurement method can be found in (Dowden and Rodger 2001; Dowden *et al.* 2002; Ramachandran *et al.* 2003, 2005).

2.2 SITE DESCRIPTION

Fiji islands comprises of many small island groups of which Viti Levu (Lat.: 17.25°S – 18.25°S, Long.: 177.25°E – 178.75°E) and Vanua Levu (Lat.: 16.20°S – 17.00°S, Long.: 178.45°E – 180.05°E), are the two larger islands, occupying landmasses of 10,388 km^2 and 5,536 km^2 respectively, and the other smaller islands occupy 2,406 km^2. Our measurement site for TOGA is the University of the South Pacific (Lat.: 18.14°S, Long.: 178.44°E), in Viti Levu.

3 RESULTS AND DISCUSSION

3.1 WWLLN DATA ANALYSIS

On global scale, the total area of the Fiji islands is very small. Further, since the landmass is small and engulfed in the cool oceanic wind, the formation of convective updraft is inhibited hence the frequency of lightning is reduced. .In this paper we analyze the lightning incidence in the two larger islands. The detection efficiency of the WWLLN is not known for this region. Hence the absolute flash counts may not be accurate, but the trend of spatial and temporal variation will not be affected.

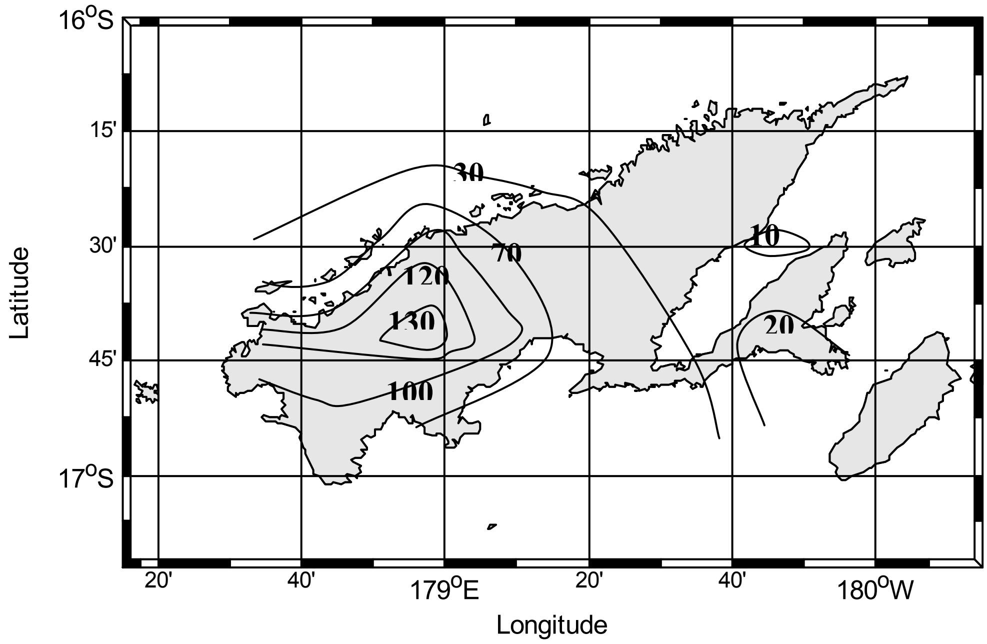

Figure 1a. Spatial distribution of average annual CG flash (Vanua Levu)

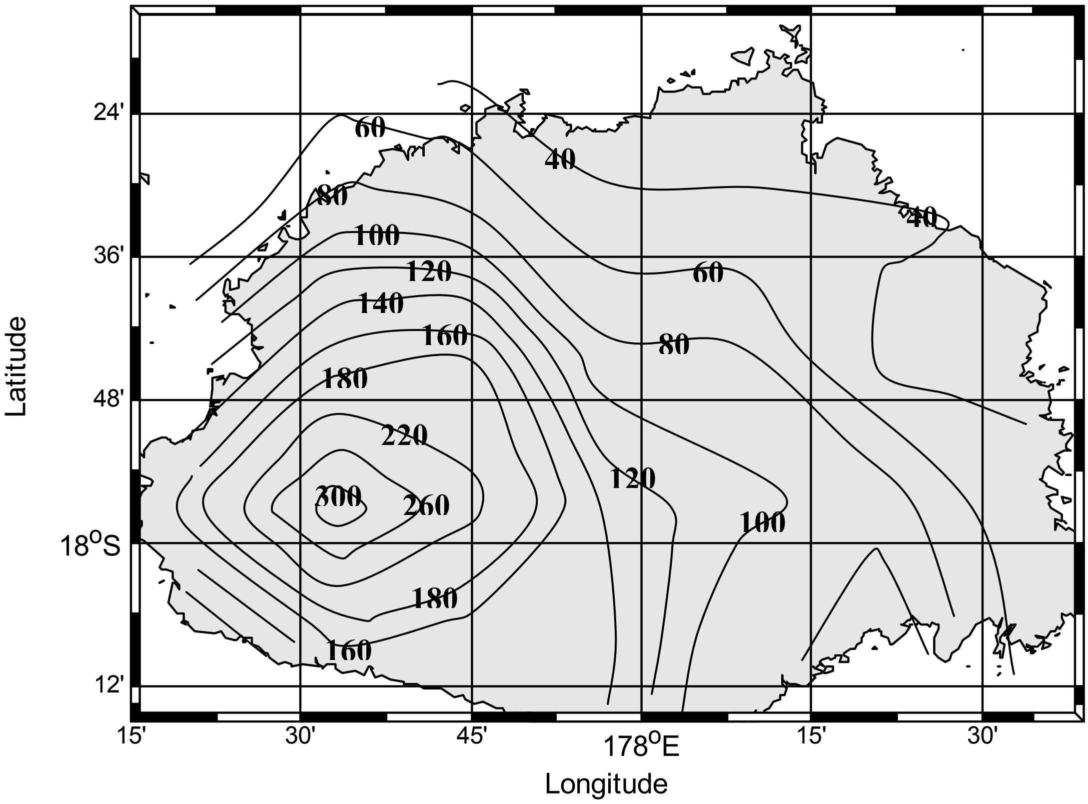

Figure 1b. Spatial distribution of average annual CG flash (Viti Levu)

To find the spatial distribution of lightning in the two islands, increments of 0.2° were considered for both the latitude and longitude. This corresponds to a land area of (~20 km × 20 km). The number of CG strokes in each of these grid areas was grouped. Figures 1a and 1b show the contours of the spatial distribution of the annual CG strokes in Vanua Levu and Viti Levu respectively. The values were averaged for the period Jan 2003 - Dec 2004. In Viti Levu, a pocket of maximum flash is greater than 300 strokes (327). This is equivalent to a flash density of 0.8 flash km^{-2} per year. The maximum flash density in Vanua Levu was 0.35 flash km^{-2} per year. The annual averages of lightning strikes for Viti Levu and Vanua Levu were 3212 and 1212 respectively.

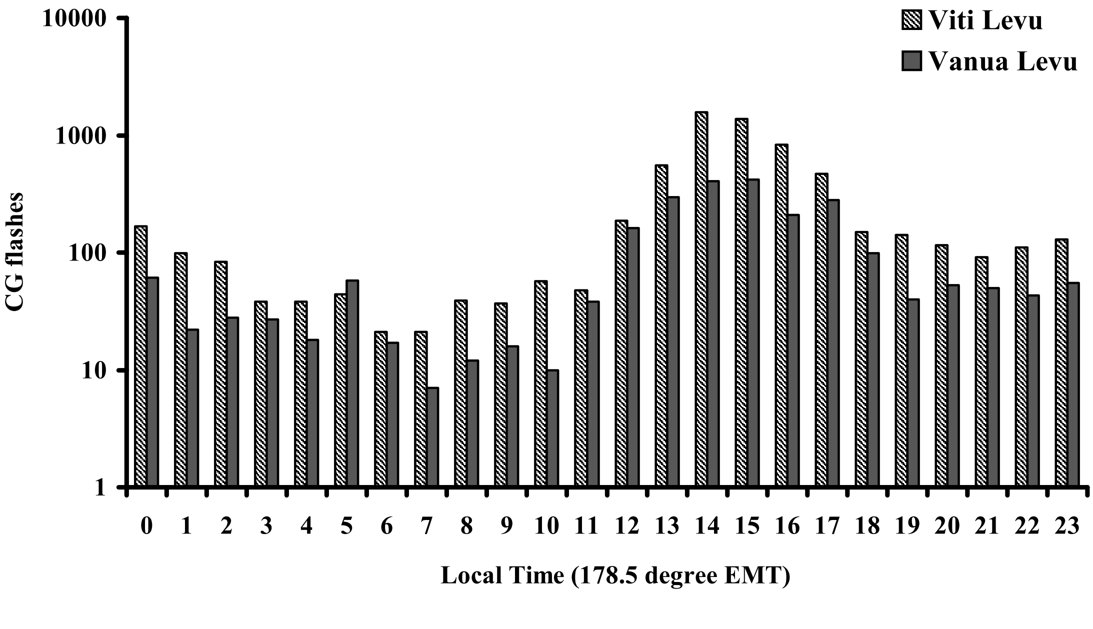

Figure 2. Diurnal variation of CG flashes during 2003-2004

The occurrence pattern shows that lightning activity was more prominent between 13 – 18 hrs LT. There was maximum occurrence between 14 – 16 hrs LT, which may be due to the formation of convective updrafts due to the warming of the Earth's surface by the Sun. Minimum activity was observed between 07 – 08 hrs LT for both islands.

A total of 8849 lightning flashes over Viti Levu and Vanua Levu were registered in the year 2003 and 2004, out of which 2620 were in the year 2003 and 6229 occurred in the year 2004. The lower detection in 2003 could be attributed to the number of detecting stations ~11 stations in March 2003. In the WWLLN system, a lightning is confirmed if a minimum of four stations record the sferics. With the increase in the number of stations (~24 active stations) the detection efficiency increased and more flashes were detected in 2004. The diurnal variation of CG flashes in the two islands for the year 2003 and 2004 is shown in figure 2.

Fiji is a tropical island nation in the South Pacific region. The seasons in a year are broadly classified as summer and winter. May to October and November to April are classified as winter and summer months respectively. Figure 3 shows seasonal variation of lightning occurrence over Viti Levu and Vanua Levu during the year 2003 and 2004. The flash counts are an average for the two years. Lightning activity is more pronounced during summer and less during the winter months for both the islands.

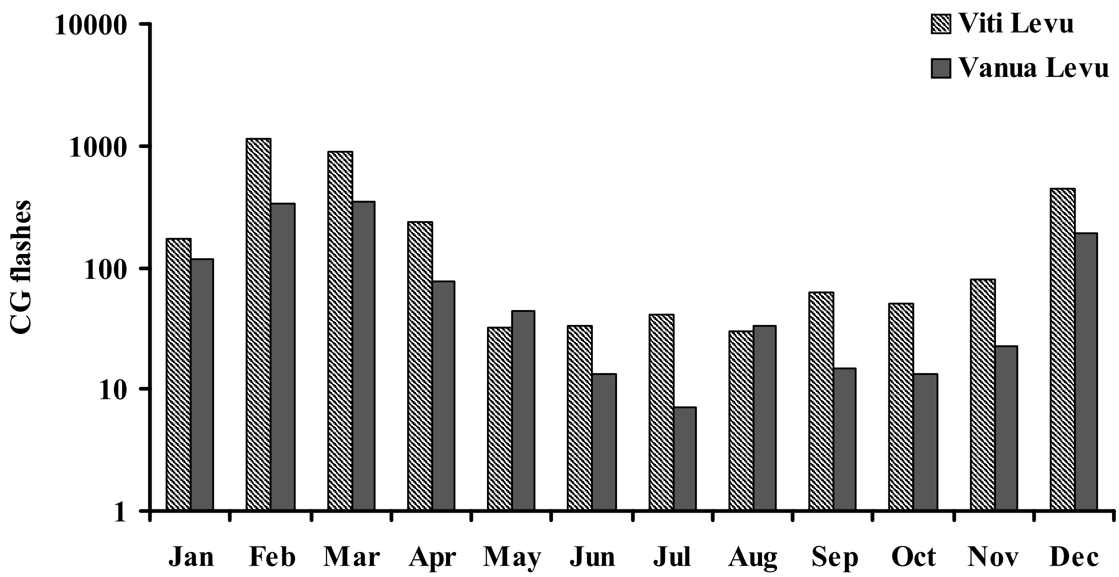

Figure 3. Seasonal variation of CG flashes during 2003 – 2004

3.2 LIS DATA ANALYSIS

For a comparative study, LIS data from TRMM satellite available online (http://thunder.msfc.nasa.gov /data/lisbrowse.html) were analyzed. The LIS never observes a given location for more than a few minutes each day as the satellite passes over and the data may be unsuitable for studying localized weather. Further, LIS data does not differentiate between IC and CG flashes. Generally, when the CG strokes are high, it is expected that the total lightning activity, *i.e.* CG + IC, also to be high (Jayaratne and Ramachandran 1998; Mackerras *et al.* 1998). Knowing Z at a geographical location, the approximate numbers for IC and CG can be estimated. Pinto and Pinto (2003) reported common features in the ground-based observations and three-year LIS data. Mushtak *et al.* (2003) have analyzed the LIS data for 11 months to study the latitudinal variation of the number of total flashes (IC + CG) and the flash rate. The data obtained by LIS for the two years are presented in this analysis. Figure 4. shows the seasonal variation of the total flashes in the two islands. The figure reveals enhanced lightning activity during the summer months, similar to that observed from the TOGA records. The diurnal variation was also studied using the LIS data which showed increased activity in both islands between 12 – 17 hrs (LT). During the winter months, Vanua levu did not record any activity and Viti levu recorded some activity in August. This may be due to the fact that winter storms are few and the LIS may have missed detection during its pass over the islands.

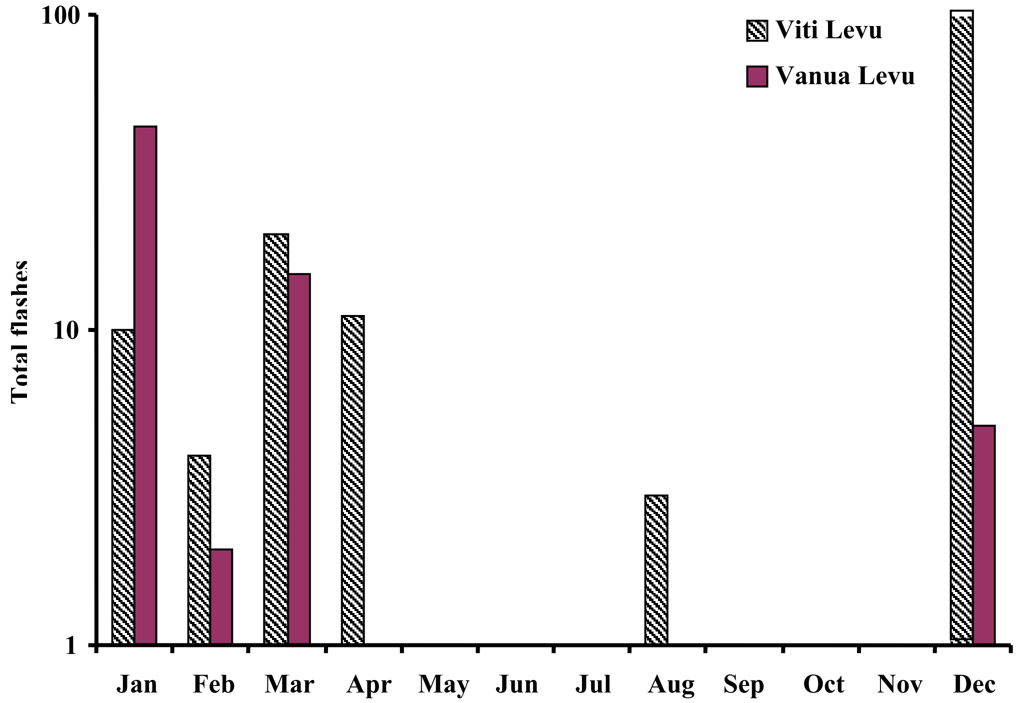

Figure 4. Monthly variation of LIS lightning flashes during 2003 – 2004.

3.3 CORRELATION BETWEEN LIGHTNING AND RAINFALL

To find the correlation between lightning and rainfall the site Suva was considered. The grid for the spatial distribution for lightning was refined to (Lat.: 18.1°S – 18.2°S, Long.: 178.4°E – 178.5°E) to give a surface area ~ 10 km×10 km. The monthly variation of total rainfall over Suva during 2003 and 2004 and the lightning occurrence over Viti Levu are shown in Figure 5. The rainfall records in Suva show a seasonal pattern with reduced levels during the winter months except for the month of August, which has a significantly high record.

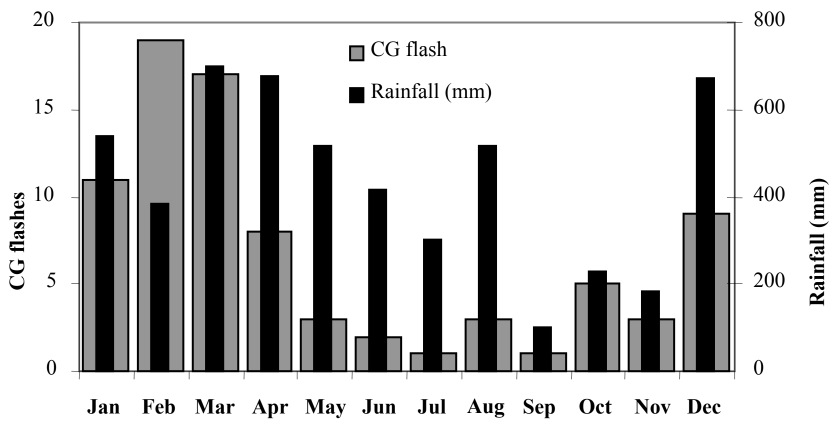

Figure 5. Lightning and rainfall at Suva

Figure 5 shows a good correlation for both lightning activity and rainfall for the two years. The total rain accumulation was 5237 mm for the two years. Assuming this as the average accumulation for the 10 km × 10 km area the water volume per flash is ~6×10^6 m^3 in this oceanic region. This figure is 2 orders of magnitude higher than those predicted earlier, which were mainly for continental regions. However our results are similar to those reported from studies in Australia (Jayaratne and Kuleshov 2006) especially the near-coastal regions (9.91×18^8 kg fl^{-1}). A better way to estimate the ratio would have been to consider the rainfall only on the days lightning activity was observed. Also the detection efficiency of the WWLLN for this region must be established.

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