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Cloud-to-ground lightning in southeastern Brazil in 1993

2. Time variations and flash characteristics

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Abstract. About 1.1 million cloud-to-ground lightning flashes were recorded by a lightning positioning and tracking system in southeastern Brazil in 1993. The data have been analyzed in terms of their monthly, seasonal (summer/winter), and diurnal (local time) variations. The monthly variation shows a double peak characteristic of tropical lightning activity. The seasonal variation indicates that most flashes occur in the spring and summer seasons, with less than 25% occurring in the autumn and winter. The lightning flash polarity and multiplicity were found to be very similar in the summer and winter seasons. Radiation field and direct current lightning data were obtained in towers located in the same region of the network to verify the multiplicity data obtained by the network. The results indicate that the multiplicity obtained by the system is much lower than that obtained by radiation field measurements of close lightning in the same region of Brazil. The lightning flash peak current were found to be larger in the summer than in the winter, in contrast with results obtained in other parts of the world. The diurnal variation of the negative flashes shows in the summer and winter seasons the same behavior, with a peak around 1500-1800 LT, associated with the maximum convective activity in the afternoon. The diurnal variation of positive flashes, in turn, shows this behavior only in the winter. In the summer, it shows a maximum around 1400-1500 LT, with a secondary peak at 1900 LT. However, considering only positive flashes with peak currents higher than 15 kA, the diurnal distribution in the summer is similar to that for negative flashes. This fact indicates that the positive flashes with a peak current less than 15 kA are probably intracloud flashes erroneously identified by the network. The results are discussed in association with the findings presented in paper 1 [*Pinto et al.*, this issue] and compared with results obtained in other parts of the world.

1. Introduction

Time variations of lightning activity through the days, months, and years have been studied by several authors [*Lopez and Holle*, 1986; *Orville*, 1994; *Reap*, 1994; *Watson et al.*, 1994; *Pinto et al.*, 1996; *Orville et al.*, 1997; *Hodanish et al.*, 1997; *Orville and Silver*, 1997; *Rocha et al.*, 1997; *Pinto et al.*, 1997; *Orville et al.*, 1997]. The hourly variability of the cloud-to-ground lightning activity over land is well known to have a large peak associated with the maximum convective activity in the afternoon. Variations can also exist associated with local meteorological and orographic aspects. The monthly variability, in particular from summer to winter season, is also well documented. Lightning activity over land has a maximum in the summer season and a minimum in the winter season. Also, there is evidence indicating that not only the number of flashes but also the flash characteristics change from one season to the other, mainly the flash polarity [e.g., *Orville et al.*, 1987, 1997]. In contrast with the others the annual variability is not well known. At present, the only data set available to investigate such variability is restricted to the contiguous United States for a 6-year period [*Orville*, 1994; *Orville and Silver*, 1997]. No clear tendency in these data was resolved yet. The time variation of the lightning activity is very important as a tool to understand well the behavior of thunderstorm mesoscale systems, as well as can be used to predict variations in the global atmospheric electric circuit [*Williams*, 1994] and in the global temperature [*Price and Rind*, 1994].

In this paper, we present for the first time the variation of the lightning activity in Brazil throughout a whole year [1993]. This study is the second 1-year continuous study of lightning time variations and flash characteristics in the tropics. The data were obtained in southeastern Brazil in the region of geographic coordinates 14°-23°S and 39°-52°W, and their geographical distribution is presented in paper 1 [*Pinto et al.*, this issue]. Even though the results presented in this paper are not necessarily representative of the whole country (and probably, they do not), they should be considered the best available information. Considering that Brazil is one of the principal regions of the world in terms of lightning activity [*Pinto*, 1997; *Goodman and Christian*, 1993], the time variations presented here may be used to help to understand the global circuit variability.

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2. Lightning Data

The lightning data used in this paper were obtained by a lightning positioning and tracking system (LPATS), version III, located in the state of Minas Gerais, southeastern Brazil, during the year of 1993. A map indicating the location of the LPATS sensors as well as more detailed information about the system are presented in paper 1 and references therein. It was also used lightning radiation field data obtained from a tower (called the CTA tower) located in São Jose dos Campos (approximate geographic coordinates 23°S and 46°W). The CTA tower data were used to check the multiplicity obtained by the system.

3. Results and Discussion

Figure 1 shows the monthly variation of lightning flashes during the year 1993. The variation shows a double peak in the months of March and November. Different from the distribution found in middle latitudes [*Hodanish et al.*, 1997; *Orville and Silver*, 1997], where only one peak exists, the monthly variation in southeastern Brazil, a tropical region, is characterized by a double-peak distribution related to the monthly variation in the surface air temperature in the tropics [*Williams*, 1994]. The same double-peak distribution was found by *Orville et al.* [1997], studying cloud-to-ground lightning data collected in Papua New Guinea in 1993, in the tropics. In that case, however, the peaks occurred in February and November.

Figure 2 shows the seasonal distribution of cloud-to-ground lightning flashes in southeastern Brazil. As expected, most flashes occur in the spring and summer seasons, with less than 25% occurring in the autumn and winter seasons. To identify different characteristics of the flashes at different seasons, we have compared the polarity, multiplicity, and peak current of negative and positive cloud-to-ground flashes in the summer with those in the winter.

Figure 3 shows the percentage of negative, positive, and bipolar flashes for summer, winter, and the complete year of 1993. The existence of bipolar flashes, i.e., flashes with negative and positive strokes in them, may be a result of the criteria adopted for the time and distance between successive strokes to combine them into flashes [*Pinto et al.*, 1996]. However, it is also possible that they are (at least, partially) real flashes. Goto and *Narita* [1995] have published current oscillograms of bipolar flashes. It is worth noting that in the past [*Berger*, 1972; *Narita et al.*, 1989] the term bipolar flashes was used to describe flashes containing a stroke with both polarities, i.e., a stroke whose the current waveform changes its polarity along the time. At present, the stroke-processing algorithm of the National Lightning Detection Network (NLDN) in the United States combines strokes with opposite polarity, but the reported polarity of the flash is considered that of the first stroke [*Cummins et al.*, 1998]. It can be seen in Figure 3 that the polarity of flashes remains almost the same in both seasons. The percentage of positive flashes in both seasons is around 35%. If we neglect the positive flashes below 15 kA, assuming that they are contaminated by intracloud flashes, the percentage above drops to about 20% (in both seasons). This last result is still very different to that found by *Orville et al.* [1997] in the United States, where the percentage of positive flashes varies from about 5% in the summer to about 20% in the winter. *Orville et al.* [1987] have found even larger differences from summer to winter in the east coast of the United States. Percentages of positive flashes higher in the winter than in the summer have also been observed in Japan [*Takeuti et al.*, 1978; *Brook et al.*, 1982]. *Orville et al.* [1997] found percentages around 3-4% in both summer and winter in Papua New Guinea. It is worth noting that in both studies in the tropics the percentage of positive flashes remained the same along the year, in spite of the different values, whereas in the other studies outside the tropics the percentage of positive flashes was larger in the winter than in the summer. Another important point related to the constant percentage of positive flashes in both seasons in Figure 3 is that this result seems to indicate that these flashes are probably not influenced by smoke fire effects. Recently, results [*Lyons et al.* 1998] seem to indicate that such fires tend to cause an increase in the number of positive flashes. However, in Brazil such fires usually show a clearly seasonal variation with a maximum from May to November. So, such an effect should cause in an enhancement of positive flashes only in the winter data in Figure 3, what was not observed.

Figure 4 shows the multiplicity for negative and positive cloud-to-ground flashes in southeastern Brazil in 1993. As expected, the negative flashes show a larger multiplicity than the positive flashes. The values for summer and winter, however, are very similar. With respect to the percentage of single-stroke flashes, it was found that it has a slight tendency to increase in the winter, mainly for negative flashes. The same result was obtained by *Orville et al.* [1987]. With respect to multiple-stroke flashes, the average number of strokes per flash was found to be 2.9 for negative flashes and 2.2 for positive flashes. These values remain the same in both seasons and are very similar to the annual values found by other authors using the same technique [*Cook and Casper*, 1992; *Montandon et al.*, 1992]. However, they are lower than the values reported by other authors who used other techniques [*Schonland*, 1956; *Berger*, 1967]. Neglecting the

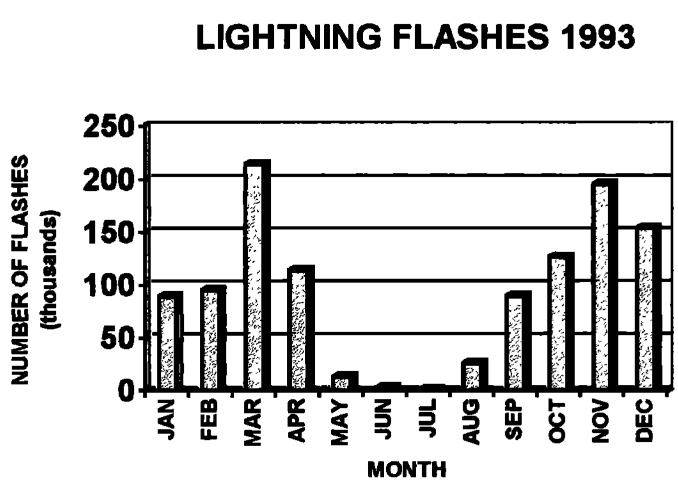

Figure 1. Monthly variation of the number of cloud-to-ground lightning flashes in southeastern Brazil in 1993.

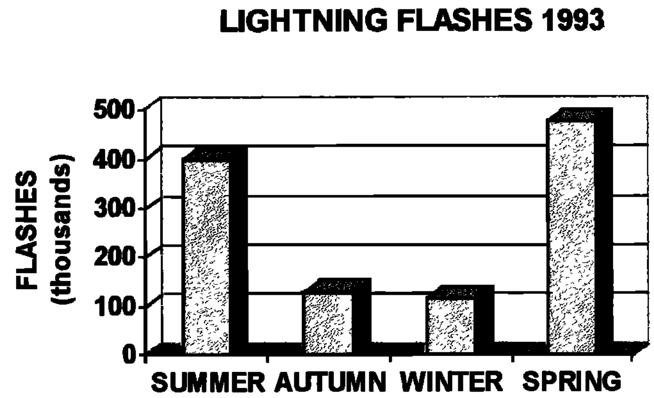

Figure 2. Seasonal variation of cloud-to-ground lightning flashes in southeastern Brazil in 1993.

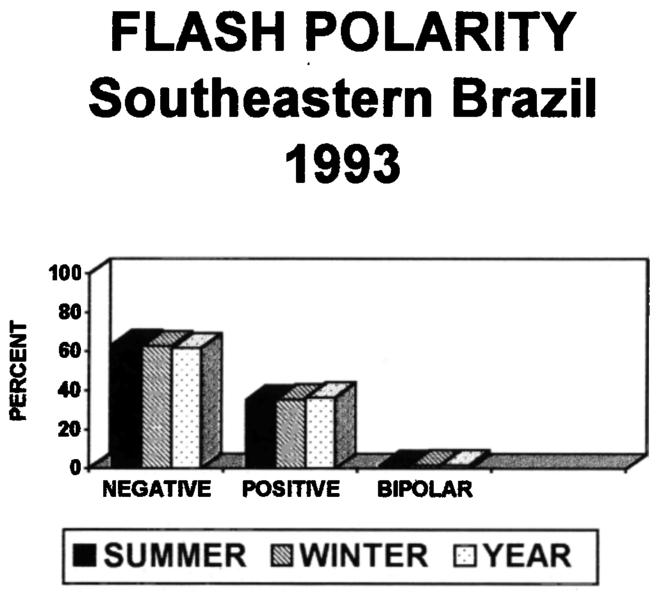

Figure 3. Percentage of negative, positive, and bipolar flashes in the summer, winter, and the whole year of 1993.

positive flashes below 15 kA, the results above remain almost the same. The multiplicity of multiple positive flashes has a small decrease from 2.2 to 2.1. Figure 5 shows the multiplicity of 24 negative cloud-to-ground flashes recorded in São José dos Campos, Sao Paulo, southeastern Brazil (approximate geographic coordinates 23°S and 46°W), on March 7, 1997. The data were obtained by an electric field antenna and collected from the top of a 24-m-high tower (called the CTA tower). The average multiplicity of multiple-stroke flashes was 5.1, and the percentage of single stroke flashes was 21%. The average multiplicity of multiple stroke flashes is very close to the value obtained in southeastern Brazil from 1985 to 1994 by direct current measurements of negative cloud-to-ground flashes [*Diniz et al.*, 1996]. *Diniz et al.* [1996] have reported from an analysis of 26 negative cloud-to-ground flashes an average multiplicity of multiple-stroke flashes of 6.1 and a percentage of single-stroke flashes of 63%. With respect to the average multiplicity of negative multiple-stroke flashes, both results above are in better agreement with the data obtained by *Schonland* [1956] and *Berger* [1967] than with the data in Figure 4. This fact seems to indicate a possible influence of the technique of LPATS on the multiplicity results and could be explained by assuming that the system has a lower efficiency than other techniques to detect low-intensity subsequent strokes and/or that the system does not discriminate strokes that occur very close in time (the manufacturer claimed that the system recognizes strokes separated by at least 7 ms), mainly at times of high activity. Evidence suggesting that the multiplicity measured with lightning direction finders tends to be lower than individual measurements have been reported [*Reap and MacGorman*, 1989; *Samsury and Orville*, 1994]. The percentage of single-stroke flashes, by turn, has been shown in the literature to be quite variable, probably indicating different space charge distributions inside the thunderstorms, even though the influence of the different techniques used cannot be ruled out. However, it is worth mentioning that direct current measurements tend to overestimate the actual number of single- stroke flashes due to the existence of multiple-ground termination flashes. This fact, together with an apparent low efficiency of the LPATS technique to record low-intensity subsequent strokes, may explain the high percentage of single-stroke flashes reported by *Diniz et al.* [1996] and observed in the LPATS study as compared with the results obtained in the CTA tower. Clearly, a more complete analysis of the multiplicity obtained from lightning network data is necessary [*Cummins et al.*, 1998].

Figure 6 shows the distribution of first-stroke peak current for negative and positive cloud-to-ground flashes in southeastern

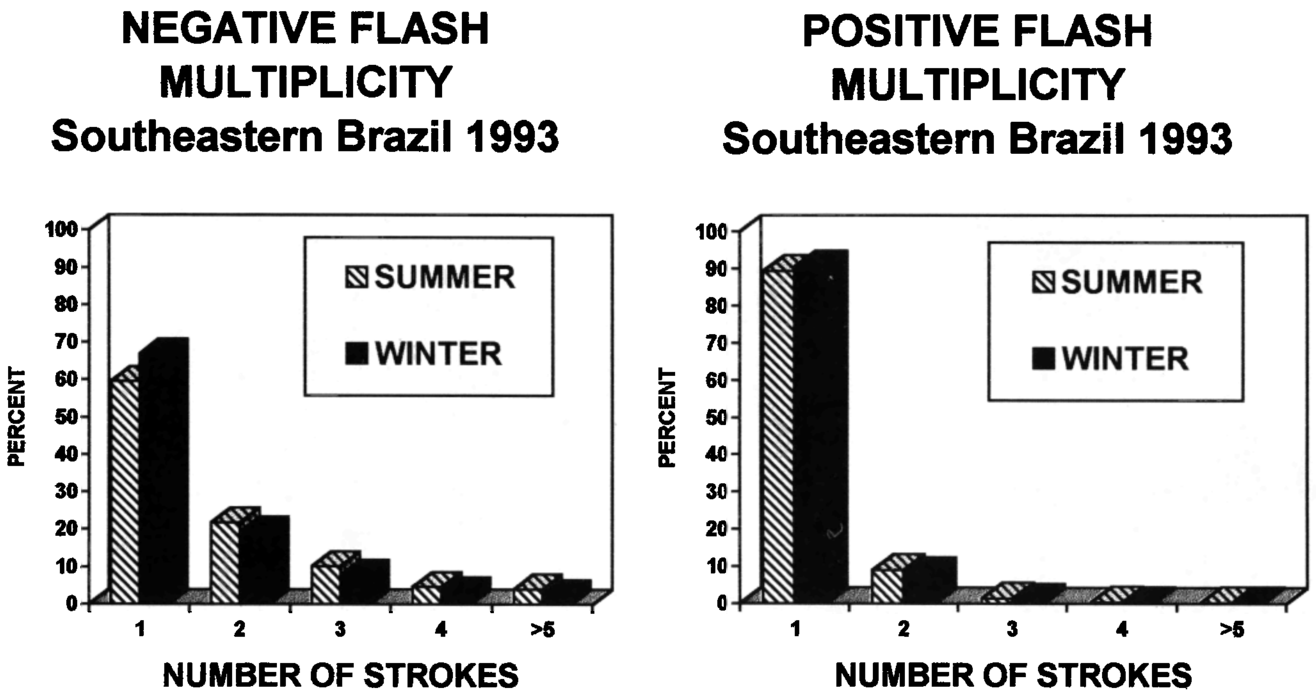

Figure 4. Distribution of the number of strokes per flash for (a) negative and (b) positive flashes in the summer and winter seasons.

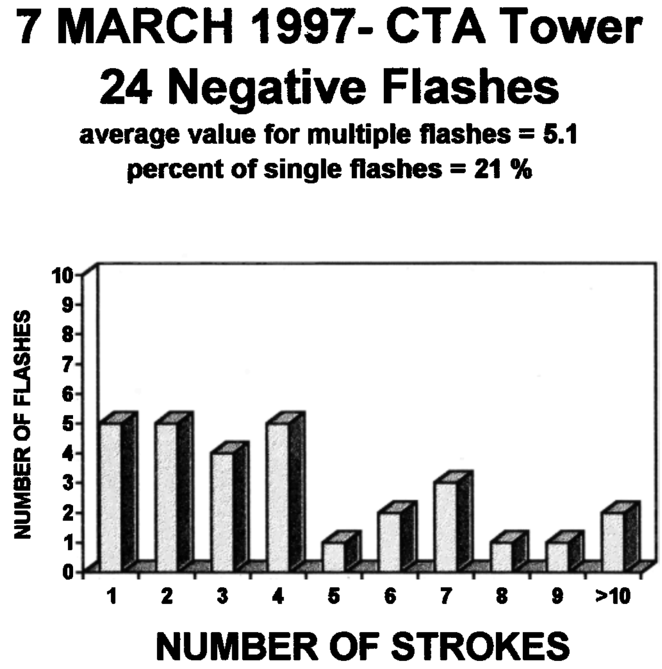

Figure 5. Distribution of the number of strokes per flash for 26 negative cloud-to-ground flashes recorded on March 7, 1997, in the CTA tower. The average multiplicity for multiple-stroke flashes and the percentage of single-stroke flashes are indicated.

Brazil in 1993. For both polarities the values in the summer tend to be higher than those in the winter. The average peak currents in the summer are 42 kA for negative flashes and 22 kA for positive flashes, whereas in the winter they are 29 kA and 19 kA, respectively [*Rocha et al.*, 1997]. Such behavior is in contrast with the results obtained from median peak current radiation field data reported by *Orville et al.* [1987], which indicate a peak current in the winter higher than in the summer. On the other hand, the low-average peak current for positive flashes in this study may be a result of the possible contamination of these flashes by intracloud flashes, as discussed in paper 1. Neglecting the positive flashes below 15 kA, the average peak current of positive flashes would be 41 kA in the summer and 31 kA in the winter. These peak-current values are very close to negative values, in contrast with the results obtained by *Orville et al.* [1997] in Papua New Guinea, which indicate that the positive flashes have a larger peak current than negative flashes. Even after neglecting the positive flashes below 15 kA, the average positive peak current in the summer remained larger than that in the winter, again in contrast with the results of *Orville et al.* [1997] in Papua New Guinea.

Figure 7 shows the diurnal variation of the number of negative and positive cloud-to-ground flashes in southeastern Brazil in 1993. The negative flashes (Figure 7a) have a typical diurnal distribution with a large peak in the afternoon (1500-1800 LT) with a half width of about 6 hours in both seasons (summer and winter). This peak is probably associated with the maximum convective activity in this period in response to the diurnal cycle of insolation. The summer curve has a minimum around 0800-1100 LT and the winter curve a broad minimum from about 0100 to 1100 LT. The small peak at 0600 LT in the summer curve is probably not significant, being a result of the small sample of data in this period. The positive flashes (Figure 7b) have a distribution similar to the negative flashes, only in the winter. In the summer the variation is more complex, with a main peak around 1400-1500 LT and a secondary peak at 1900 LT.

A more detailed analysis of the curves presented in Figure 7a indicates that the ratio between the maximum and the minimum value of the hourly negative flash rate is about 40 in the summer and 15 in the winter. For positive flashes in the winter (Figure 7b), this ratio is 25. These values are of the same order of those reported by other authors for cloud-to-ground flashes [e.g., *Reap*, 1986; *Lopez and Holle*, 1986; *Williams and Heckman*, 1993; *Watson et al.*, 1994]. On the other hand, curves similar to that for positive flashes in the summer season (Figure 7b) have also been reported by other authors [*Maier et al.*, 1984; *Lopez and Holle*,

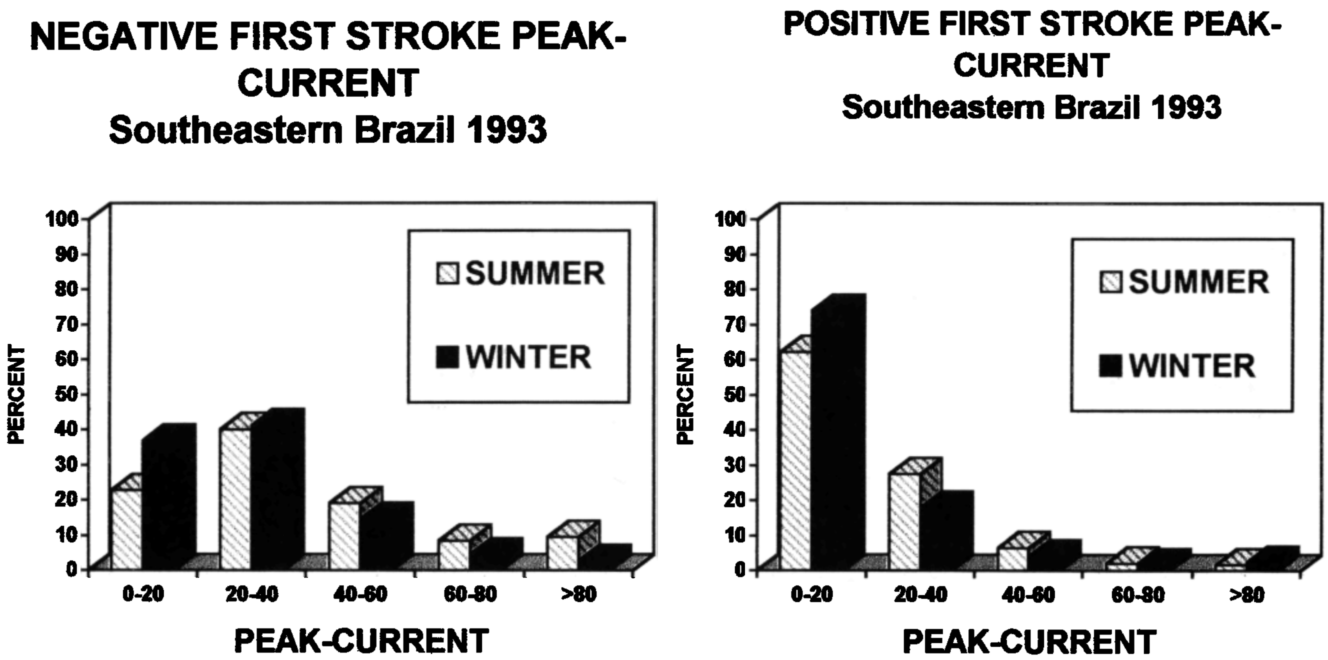

Figure 6. Distribution of first-stroke peak current for (a) negative and (b) positive cloud-to-ground flashes in the summer and winter seasons.

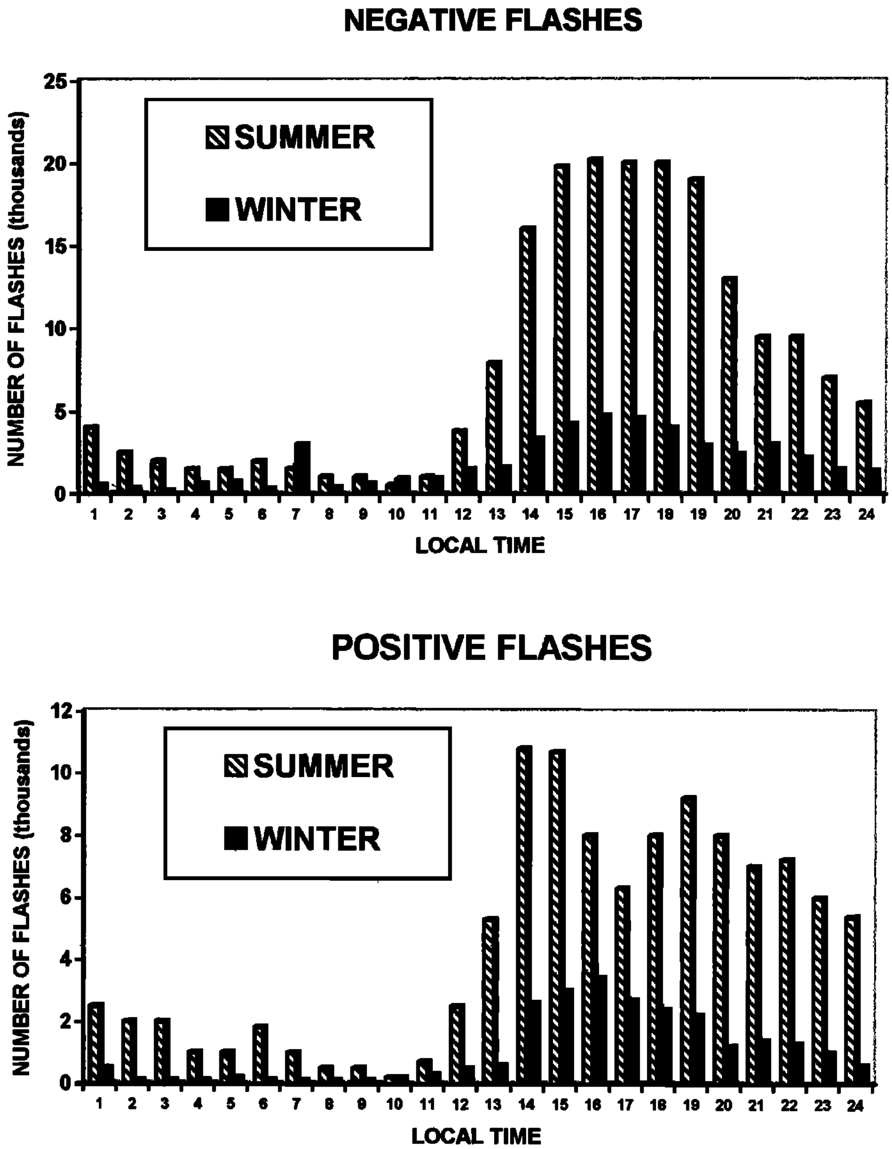

Figure 7. Diurnal variation of (a) negative and (b) positive cloud-to-ground flashes in the summer and winter seasons.

1986]. *Maier et al.* [1984] analyzed 27,358 flashes (both cloud-to-ground and intracloud flashes) recorded by a field-mill network in Florida during the summers of 1976, 1977, 1978, and 1980. They found three peaks in the diurnal variation. However, they considered only the peak around 1500 LT as significant, attributing the others to the relatively small data sample. *Lopez and Holle* [1986], in turn, analyzed 50,664 negative cloud-to-ground flashes recorded in Florida in the summer of 1983, using a lightning location system consisting of three direction finders. They found a diurnal variation with a main peak around 1400-1500 LT, a secondary peak around 2000-2100 LT, and a minimum around 0900-1000 LT. *Lopez and Holle* [1986] suggested that this variation may be associated with local mesoscale circulation, which are set up in response to the interplay of large-scale circulation impacting on the diurnal cycle of insolation and the underlying topographic features of the region. This assumption is supported by the results obtained by *Orville et al.* [1997] in Papua New Guinea where the diurnal distribution shows two peaks around 1500 LT and 0200 LT.

Although the assumption that other physical aspects, besides the diurnal cycle of insolation, could explain the diurnal distribution of positive flashes (Figure 7b), we have investigated a possible influence of the contamination of low-peak-current positive flashes by intracloud flashes on the diurnal distribution of positive flashes. Figure 8 shows that for positive flashes above 15 kA the diurnal distribution is close to that for negative flashes, while below 15 kA, it has two peaks. Figure 8 seems to indicate that the diurnal distribution of positive flashes in the summer is a result of the contamination of positive flashes below 15 kA by intracloud flashes. This different behavior was found to be more evident when the positive flashes are separated in two groups: below 15 kA and above 15 kA. Surprisingly, this value is the same as that found by *Zaima et al.* [1997] because the limit in which the contamination of positive flashes by intracloud flashes occurred in LPATS measurements in Japan. The reason for which intracloud flashes produce two peaks in the diurnal distribution remains to be investigated. In this context the lack of two peaks in the diurnal distribution of positive flashes in the winter could

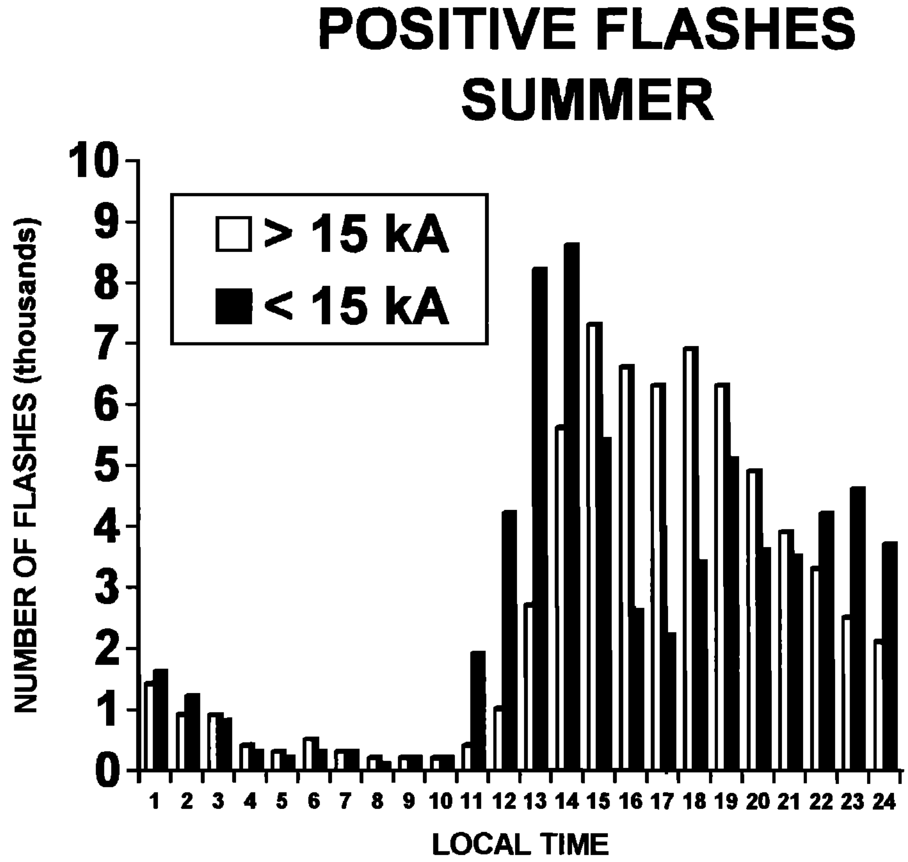

Figure 8. Diurnal variation of positive cloud-to-ground flashes in the summer season for peak currents >15 kA and <15 kA.

be explained by assuming that at winter the contamination is less pronounced. Evidence supporting this fact is given by *Zaima et al.* [1997].

4. Conclusions

This paper presents results of 1-year of cloud-to-ground data obtained in southeastern Brazil in 1993. It should be considered as the second 1-year continuous lightning data analysis in the tropics. From the analysis of the monthly, seasonal, and diurnal variations of about 1.1 million cloud-to-ground lightning flashes, we have concluded that

(1) the monthly variation of the cloud-to-ground lightning activity shows a double peak in the months of March and November characteristic of the tropical region. This result confirms the previous result obtained by *Orville et al.* [1997], studying cloud-to-ground lightning data obtained in Papua New Guinea in the same year;

(2) the seasonal variation shows that most cloud-to-ground flashes occur in the spring and summer seasons, with less than 25% occurring in the autumn and winter. The lightning polarity and multiplicity were found to be very similar in the summer and winter seasons, even though the multiplicity data obtained by the LPATS system were found to be much lower than the value measured in the same region of Brazil by radiation field measurements of close lightning. The peak current was found to be larger in the summer than in the winter for both seasons. Such a result is in contrast with the results obtained by *Orville et al.* [1997] in Papua New Guinea. Neglecting the influence of positive flashes below 15 kA, the average peak current values for negative and positive flashes were found to be very similar, again in contrast with the results obtained by *Orville et al.* [1997], but in agreement with the results obtained by *Petersen and Rutledge* [1992] in the northern part of Australia;

(3) the diurnal variation of the negative cloud-to-ground flashes show a typical behavior found in most parts of the world, i.e., a peak around 1500-1800 LT with a half width of about 6 hours associated with the maximum convective activity in this period, and a minimum in the morning hours. The ratio between the maximum and the minimum hourly negative flash rate was higher in the summer (40) than in the winter (15). The diurnal variation of positive flashes follows this behavior only in the winter, whereas in the summer it shows a different behavior, with a main peak around 1400-1500 LT and a secondary peak at 1900 LT. Such a behavior seems to be related to the contamination of positive flashes by intracloud flashes. The minimum, however, still occurs in the morning hours.

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