Monthly distribution of cloud-to-ground lightning flashes as observed by lightning location systems

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[1] This paper presents a comparison among the mean monthly distributions of the number of cloud-to-ground (CG) flashes, the percentage of positive CG flashes and the peak current of negative and positive CG flashes obtained in Brazil for the period from 1999 to 2004, with the same distributions observed by similar networks for long time periods in other countries. From a correlation analysis, it was found that the mean monthly distributions of the number of CG flashes are very similar, even though the period of larger lightning activity along the year in Brazil, a tropical country, is longer than in the other temperate countries. The mean monthly distributions of the percentage and the peak current of positive CG flashes are also very similar, while the mean monthly distribution of the peak current of negative CG flashes in Brazil differs from the other countries. This difference is related to a significant decrease in the mean negative peak current in Brazil in the months of August and September. Apparently, the decrease is related to the injection in the atmosphere of large amounts of smoke from fires in these months, since the results also show a significant correlation between the monthly distribution of the number of fires and the negative peak current. **Citation:** Pinto, O., Jr., K. P. Naccarato, I. R. C. A. Pinto, W. A. Fernandes, and O. P. Neto (2006), Monthly distribution of cloud-to-ground lightning flashes as observed by lightning location systems, *Geophys. Res. Lett.*, *33*, L09811, doi:10.1029/2006GL026081.

1. Introduction

[2] Lightning location systems (LLS) using electromagnetic radio-frequency locating techniques at different frequency ranges from VLF to VHF [*Rakov and Uman*, 2003] have been in operation over many decades to detect and locate all types of flashes. In particular, in the last decade, LLS at VLF/LF range designed to detect mainly cloud-to-ground (CG) flashes are in operation in many countries, including United States [*Cummins et al.*, 1998a, 1998b; *Zajac and Rutledge*, 2001; *Orville and Huffines*, 2001; *Orville et al.*, 2002], Austria [*Diendorfer et al.*, 1998; *Schulz et al.*, 2005], China [*Chen et al.*, 2002, 2004], Spain [*Soriano et al.*, 2001, 2006], Canada [*Burrows et al.*, 2002], Italy [*Bernardi et al.*, 2002], Japan [*Shindo and Yokoyama*, 1998; *Suda et al.*, 2002], Brazil [*Pinto*, 2003, 2005] and many others. These LLS consist basically of several sensors, which determine the angle to the lightning stroke at the sensor location and/or the time of the lightning event, and a processing unit, which calculates stroke characteristics like the strike point location and time, peak current, and others. For a comprehensive description of lightning locating techniques, see for example, *Cummins et al.* [1998a, 1998b] and *Rakov and Uman* [2003]. The VLF/LF LLS have collected a large number of data, which have been used in many applications by power utilities, weather services, aviation, geophysical research, and others. This paper presents a comparison among the mean monthly distributions of the number of CG flashes, the percentage of positive CG flashes and the peak current of negative and positive CG flashes obtained in Brazil for the period from 1999 to 2004 (six years) with the same distributions observed by similar networks for long time periods (seven to ten years) in other countries (United States, Austria, Italy and Spain).

2. Data Analysis

[3] Data from the Brazilian Integrated Lightning Detection Network (RINDAT) from 1999 to 2004 (six years) were used in this analysis. During this period the network was composed initially by 20 sensors and at the end by 24 sensors (8 Impact and 16 LPATS sensors), as indicated in Figure 1. The region considered in the analysis is indicated in the figure. Data from the sensors were sent to a LP2000 central processor where they were stored and, later, reprocessed to recover data losses due to delays in the communication links. More details about RINDAT are given by *Pinto* [2003, 2005], *Pinto and Pinto* [2003], *Pinto et al.* [1999a, 1999b, 2003, 2006], and *Naccarato* [2005].

[4] Mean monthly distributions of the number of CG flashes, percentage of positive CG flashes and peak current of negative and positive CG flashes in Brazil, for the period from 1999 to 2004, were computed and compared to distributions obtained by similar networks for long time periods in other countries: United States (ten years [*Orville and Huffines*, 2001]), Austria (ten years (W. Schulz, private communication, 2005)), Italy (seven years [*Bernardi et al.*, 2002]) and Spain (ten years [*Soriano et al.*, 2006]). In order to compare them, all distributions were first shifted in time to make the months with largest lightning activity (January for Brazil, July for United States and Austria, and August for Italy and Spain) coincident. This month is referenced as month 7 in all figures throughout this paper. Then, the distributions were normalized at this month. Differently than the distribution of the number of CG flashes, in which the normalization was merely an artifact of data analysis, since the mean values represent the different lightning activities, the normalization for the other distributions was adopted considering that, at the month with largest lightning

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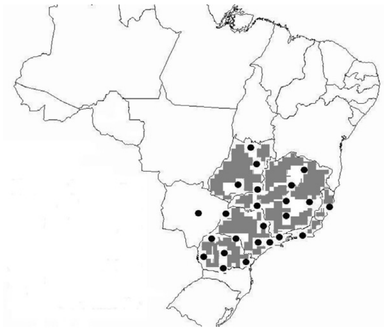

Figure 1. RINDAT sensor configuration at the end of 2004. Also indicated is the region considered in this analysis.

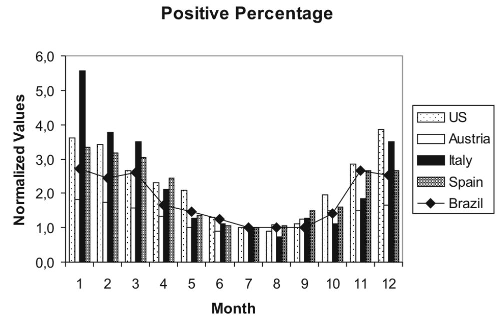

Figure 3. Normalized mean monthly distribution of the percentage of positive CG flashes observed at different countries for long time periods.

activity, the mean values tend to be the same. This assumption is based on the fact that the large number of storms, sampled at this month, minimizes possible variations in these mean values, related to different meteorological conditions. Also, this assumption consider that the differences in the mean values of peak current and percentage of positive flashes obtained by different networks reported in the literature are partially due to differences in the flash detection efficiency and CG to intracloud discrimination of the networks, which are strongly dependent on the configuration (base lines, type of sensors, field-to-current conversion equation, propagation model, stroke grouping algorithm, etc) of the network. However, it is worth mentioning that these configuration differences are the same throughout the year for each network, so that their impact on the monthly distribution should be the same along the year.

[5] After the normalization, the mean monthly distributions for all countries were correlated to one another. The correlation analysis was done using parametric statistics, once twelve data points for each groups was a sample large enough to verify the Gaussian distribution assumption of the data. The correlation between variables was determined by Pearson's correlation (R), and p-values (p_p) less than 0.01 are considered significant. The correlation analysis was also applied to correlate the mean monthly distribution of the negative peak current in Brazil with the mean monthly distribution of the number of fires observed by the satellite NOAA 12 during the period from 1999 to 2004 in the same region where CG flashes were considered.

[6] The comparison among mean monthly values for Brazil and the each other country was made using a non-parametric statistical analysis considering the small sample sizes (number of years). Therefore, the comparison between the groups was done using the Mann Whitney test. P-values (p_n) less than 0.01 are again considered significant [*Hoel*, 1984].

3. Results

[7] Figures 2–5 show the normalized mean monthly distributions of the number of cloud-to-ground (CG) flashes, the percentage of positive CG flashes and the peak current of positive and negative CG flashes, following the methodology described previously. Except for the number of CG flashes, which is dependent on the area covered by the network, the absolute values to which the other parameters were normalized are given in Table 1. The differences in the values in Table 1 were assumed to be a consequence of the differences in the networks. The large difference of the values for Austria with respect to the other countries can be explained by the very short base line of the network in this country compared to the others. Figure 2 also shows that the period of larger lightning activity along the year in Brazil, defined arbitrarily as the number of months in which the lightning activity is larger than 50% of the peak activity, is longer (six months) than in the other countries (three months in United States and Austria, four months in Italy and five months in Spain). The correlation analyses among

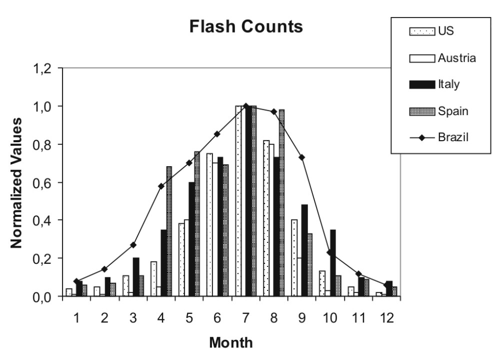

Figure 2. Normalized mean monthly distribution of the number of CG flashes observed at different countries for long time periods.

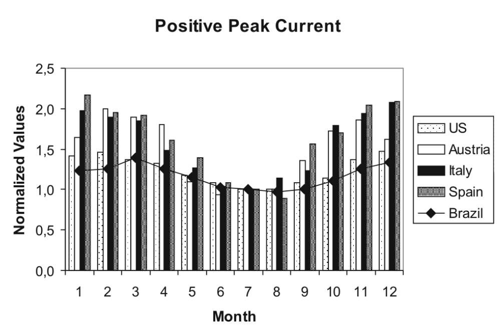

Figure 4. Normalized mean monthly distribution of the positive peak current of CG flashes observed at different countries for long time periods.

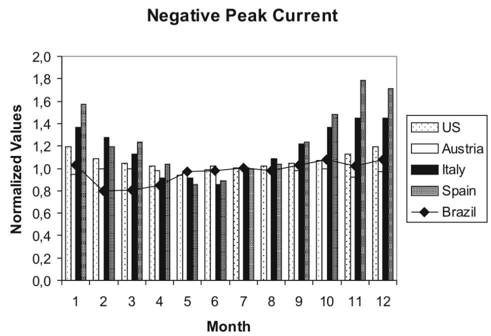

Figure 5. Normalized mean monthly distribution of the negative peak current of CG flashes observed at different countries for long time periods.

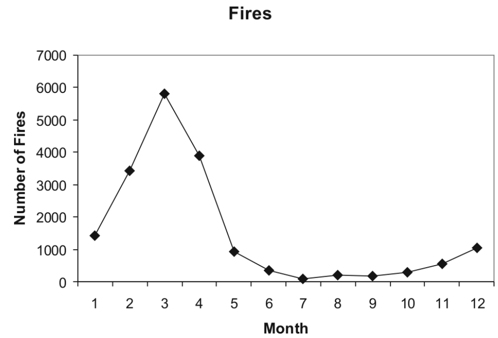

Figure 6. Mean monthly distribution of the number of fires in the same period and region where CG flashes were considered.

these distributions showed that all countries presented very similar distributions of the number of CG flashes, the percentage of positive CG flashes and the peak current of positive CG flashes ($R > 0,7851$ and $p_p < 0.002$ for all correlations).

[8] On the other hand, the mean monthly distribution of the peak current of negative CG flashes in Brazil is different that in the other countries ($R < 0,4290$ and $p_p > 0,164$ for all correlations). The difference is mainly related to a significant decrease in the mean negative peak current in Brazil in the August/September months in comparison with the other countries ($p_n = 0,0095$ for both months). Figure 6 shows the mean monthly distribution of the number of fires as observed by the satellite NOAA 12 during the period from 1999 to 2004 observed in the same region where CG flashes were considered. Apparently, the decrease in negative peak current is related to the injection in the atmosphere of large amounts of smoke from fires in these months, since a significant correlation between the monthly distribution of number fire spots and the negative peak current ($R = -0.8533$, $p_p = 0.0004$) was found. This result is consistent with the observations of *Fernandes* [2005], who found a decrease in mean monthly peak current of negative flashes from August to December in the North region of Brazil for two years of data, and with the results from *Murray et al.* [2000], who found a small decrease in the negative peak current of CG flashes in a thunderstorm event, both apparently related to the smoke from fires. It is worthy noting that *Lyons et al.* [1998] found, for the same event of *Murray et al.* [2000], a large effect on the percentage and peak current of positive flashes. This effect was not found in this paper. At present it is not clear how the injection of smoke from fires over a large area of Brazil may cause a decrease in mean negative peak current in the months of August and September. Assuming that the explanation is not related to any kind of changes in the microphysics electrification processes in association with the injection of the smoke inside the storm, one can speculate that the decrease may be related to an increase in the mean negative charge center altitude inside the storms injected by smoke from fires. Evidences supporting this speculation have been provided by *Williams et al.* [2002], who found that the storm dynamics can be affected by smokes from fires, and by *Fernandes* [2005], who found that the percentage of intracloud flashes tends to increase in this type of storms. At higher altitude, the breakdown field would be lower and, in consequence, the peak current would also be lower. It is interesting that this speculation is consistent with the seasonal variation of the negative peak current, which shows larger values in the winter (when the negative charge center altitude tends to be lower) for all countries in the analysis, except for Brazil.

Table 1. Absolute Values of Peak Current and Percentage of Positive Flashes at the Month of Largest Lightning Activity for the Different Networks

Country	Peak Current of Positive Flashes, kA	Peak Current of Negative Flashes, kA	Percentage of Positive Flashes, %
Brazil	29.5	26.5	8.5
United States	23.5	24.5	4.5
Austria	10.7	10.7	12.0
Italy	27.0	22.0	5.0
Spain	36.0	27.0	7.0

4. Conclusions

[9] This paper presents a comparative analysis of the mean monthly distributions of the number of CG flashes, the percentage of positive CG flashes and the peak current of negative and positive CG flashes observed in Brazil for the period from 1999 to 2004 (six year), with the same distributions observed by similar networks in other countries (United States, Austria, Italy and Spain) for long time periods (seven to ten years). It was found that the period of large lightning activity along the year in Brazil, the only tropical country in the analysis, is longer than in the other countries; all countries presented very similar distributions of the number of CG flashes, the percentage of positive CG flashes and the peak current of positive CG flashes; the mean monthly distribution of the peak current of negative CG flashes in Brazil is different from those in the other countries. The difference is due to a significant decrease in the mean negative peak current in Brazil in the months of August and September, apparently related to an increase in the number of fires in these months. A significant correlation between the monthly distribution of number of fire and the negative peak current was found, suggesting that the decrease is caused by smoke from fires;

however, more studies should be done in order to confirm this suggestion.

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