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AN OVERVIEW OF CLOUD-TO-GROUND LIGHTNING RESEARCH IN BRAZIL IN THE LAST TWO DECADES

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1. BRIEF HISTORY

The first systematic observations of cloud to ground (CG) lightning in Brazil began in the decade of 1960 by recording the number of thunderstorm days (thunderdays) at different sites. The observations were done up to 1980, when the first map of the CG activity in the country was obtained. However, due to the limited number of observation sites, only a very approximate map of the lightning activity was obtained (Figure 1). Based on it, it was estimated an average flash density of 7 flashes.km-2.year-1, indicating a larger lightning activity compared to most of the countries in the temperate region.

The thunderday observations were followed by observations carried out by a network of flash counters in part of the Southeast region of the country (Figure 2). A 43-flash counter network operated from 1985 to 1995, recording pulses by a trigger circuit with a band pass filter centered at 10 kHz. (Pinto et al., 2003a).

In 1985, an instrumented tower to record CG flashes was installed in the Morro do Cachimbo Station (MCS), in the Southeast region of the country. The station was built by the local power company, the Companhia Energética of Minas Gerais (CEMIG) under the orientation of Dr. A. J. Eriksson (Eriksson, 1979), with the goal to determine the electric parameters of direct discharges in towers. The station records the nearby CG lightning activity, the atmospheric electric field, and the direct current measurements. In addition, it provides photograph records and video images of the flashes striking the 60-m metallic tower. The tower is located on the top of a mountain about 1430 m above the sea level and 200 m above any other mountain in the region. The current is measured by two current transducers, with a bandwidth of DC to 1 MHz. The accuracy of the current and sampling time of the data were initially limited to 760 A – 1 ms and 116 A – 0.2 ms for the main and the parallel transducer, respectively. The MCS uses a fiber optic link installed into an open duct with a copper plate ground system to transmit the information from the sensor to equipment room (Pinto et al., 2005). Figures 3 and 4 show the details of the base of the tower and of the current sensors, respectively. The first results obtained at MCS were published by Trignelli et al. (1995). Later, Pinto et al. (1997) presented a comparative analysis of mean peak current at MCS with similar observations in San Salvatore, Switzerland, Italy, and South Africa, and Pinto et al. (2003b) and Visacro et al. (2004) extended the comparison to other waveform parameters.

In 1988 the first lightning location system was installed in Brazil, also in the Southeast region (Pinto et al., 1996). The regional network was a small 4-sensor LPATS (Lightning Position and Tracking System) network. In the following years, the network expanded to cover all Southeast region and, later, other regions of the country, becoming a national network named Brazilian Lightning Detection Network (BrasilDat). Other type of sensor was added to the network, the IMPACT sensor, improving the data reliability. Also, because the network does not cover the entire country, a detailed detection efficiency model was developed to improve the data reliability mainly in the borders of the network (Naccarato et al., 2006). At the present time BrasilDat is composed by 46 sensors, covering the South, Southeast and part of the Center and North regions of the country (Figure 5), and it is the third largest network in the world and the largest in the tropics (Pinto et al., 2006a,b; 2007). The network is still growing and it is expected to cover the whole country in 2010.

Lightning observations with high-speed cameras began in Brazil in 2001. The first observations were made in Southeast region by a high-speed digital video camera model Red Lake Motion Scope 8000S (Figure 6) with a resolution and exposure time of 1 ms. All high-speed video recordings had a 1 s pre-trigger time and a total recording time of two seconds (2,000 frames). The pre-trigger time of 1 s proved to be long enough to prevent the missing of first strokes. Also, the total recording time of 2 s was long enough to capture the whole flash. All images were GPS synchronized, time stamped and without any image persistence (Saba et al., 2006). The main goal of these observations was to validate the BrasilDat data. Later, the observations were extended to the South region of the country and to investigate other lightning characteristics, in particular the flash multiplicity.

2. LIGHTNING CHARACTERISTICS

Lightning characteristics are an important input for understanding the lightning physics, the conception of power delivery systems and to prevent lightning damages. In this section we summarize the knowledge about them obtained from observations in Brazil.

2.1 Density

The first values of flash density in Brazil were estimated from thunderstorm days. Based on these data, it was estimated an average value for the whole country of 7 flashes.km-2.year-1. More recently a annual average flash density map was published (Pinto et al., 2007) for the Southeast region of the country based on the BrasilDat network (Figure 7).

In this region of the country maximum flash densities are obtained over the city of São Paulo, suggesting an urban effect on lightning activity. For the spatial resolution of 1 km x 1 km, the maximum value in this region corresponds to 17 flashes km-2 year-1, with is similar to the maximum values observed for this resolution in Europe (Schulz et al., 2005) and North America (Orville et al., 2002).

For the other regions of the country the data available from BrasilDat are still insufficient to get a statistical significant map of the lightning activity (about two years or less). At the present time, the best approach to get a map of the lightning activity for these regions is to compare the CG data obtained by BrasilDat with that the Lightning Imaging Sensor (Christian et al., 1989) in the Southeast and extrapolate the result of this comparison assuming a constant CG to intracloud flash ratio (Figure 8). Although this extrapolation may be not correct, mainly in the South region of the country, where large mesoscale convective systems are common and, in consequence, a large ratio should be expected, it can give more reliable information about the flash density for the whole country than that obtained from the old thunderstorm day map (Figure 1).

2.2 Polarity

The lightning polarity of CG flashes is usually expressed by the percentage of positive CG flashes. Only two sources of data are available: the MCS and BrasilDat, since the high-speed camera not allow to obtain the polarity of the flash.

The percentage of positive CG flashes at MCS is approximately 2 % (Pinto et al., 2003b), which is much lower than those observed in San Salvatore Station (SSS) in Switzerland by two similar towers, 10% and 9 % (Berger, 1967; Berger et al., 1975). Two hypotheses might be invoked to explain this difference: different latitudes or different predominant meteorological systems. Recent results obtained in the United States by Orville and Huffines (2001) have indicated that the percentage of positive flashes depends more on the differences in the thunderstorm morphology and evolution than on the latitude. In consequence, the observed difference in the percentage of positive flashes probably reflects a difference in the predominant thunderstorm characteristics in the tower locations.

Average distribution of the percentage of positive CG flashes obtained by BrasilDat is shown in Figure 9. In the region of the MCS the percentage obtained from BrasilDat (3-5 %) is in good agreement with that obtained from the observations in MCS. From Figure 9 it can also be observed, similar to the observations by the NLDN in the United States (Orville and Huffines, 2001), the percentage of positive flashes has large variations from a few percents to almost 30%. The largest values are associated with the common occurrence of large mesoscale convective systems in the South region.

2.3 Peak Current

Peak current of CG flashes has been measured in the MCS. The average peak current of negative CG flashes observed in the MCS is 41 kA, in contrast with the 30 kA observed in the SSS (Pinto et al., 1997). For positive CG flashes, the average peak current is not statistically significant, due to the low number of events. Peak current observations by instrumented towers like MCS are subjected to contaminations by tower reflections and biased toward higher values due to the tower ability to attract flashes increases for flashes with larger peak currents. While the influence of tower reflections on the peak current observations for towers with heights of the order of the MCS (60 m) can be ignored in a first approximation (Rakov, 2002; Guedes et al., 2003), the influence of the height of the peak current can be significant (Borghetti and Nucci, 2004). Such influence can also be enhanced if the tower is located on the top of a mountain (Rizk, 1994), as is the case in MCS that is located on the top of a 1430 m hill above sea level. As a direct consequence, the effective height of the tower is around 210 m (Erikson, 1979), what may cause a significant increase on the average peak current.

Peak currents have also been estimated from the BrasilDat network. The average values observed for negative and positive flashes are 23 kA and 28 kA, respectively (Naccarato, 2005). These values are larger than the values obtained by the North America Lightning Detection Network (NALDN), a similar network, of 17 kA and 20 kA, respectively (Orville et al., 2002). In both networks, however, large regional differences are observed. Lightning peak currents estimated by lightning location networks involve many approximations (Cummins et al., 1998). Peak current estimates from the measurements of lightning electromagnetic fields are obtained by empirical (e.g., Rakov et al., 1992; Willett et al., 1989) or theoretical (e.g., Rachidi and Thottappillil, 1993) equations relating the electromagnetic field and the lightning current. The equations, in turn, have an inherent difficulty in extracting reliable values, since they are dependent on unknown parameters such as the return stroke velocity. Although these approximations cause a significant error in the estimation of the peak current of individual flashes, for a large number of flashes the error in the average peak current is significantly reduced (Rachidi et al., 2004). In addition, the average peak current obtained by lightning location networks is very sensitive to the detection efficiency of the network. The lower is the detection efficiency, the larger is the average peak current. For instance, for the Austrian Lightning Detection and Information System, believed to have a larger detection efficiency compared to BrasilDat and NALDN, the average peak current of negative and positive CG flashes for the period from 1999 to 2001 is 13 kA and 19 kA, respectively (Schulz et al., 2005). Naccarato (2005) have developed a peak current dependent detection efficiency model, so that the average peak current can be corrected by this effect.

Considering the intrinsic limitations of the techniques discussed above, the results suggest that the average peak current of CG flashes in Brazil is not much different that observed in other countries (for a review, see Rakov and Uman, 2003). This suggestion is in general agreement with the comparison of recent observations made by a same technique in Europe and Brazil by Huntrieser et al. (2007).

2.3 Multiplicity

Positive flashes are basically single stroke flashes. For this reason, the discussion is concentrated only in negative CG flashes. The percentage of multiple negative CG flashes at MCS (52 %) is higher than those at SSS for the two towers, 31 % and 35 % (Berger, 1967; Berger et al., 1975). Two hypotheses may be invoked to explain this difference: different latitudes or different predominant meteorological systems. Recent results obtained in the United States by Orville and Huffines (2001) have indicated that the multiplicity of negative flashes has regional variations. The authors speculate that these variations may be related to variations in the horizontal dimensions of the thunderstorms at different locations. Such a hypothesis, if proved, could explain the observed difference found in this work.

The multiplicity of negative CG flashes has also been reported by BrasilDat (Naccarato, 2005). However, due to the low stroke detection efficiency of the network (about 55 %), the average value (1.9) is underestimated considerably. The same is observed by other networks.

The most accurate-stroke-count technique to study lightning multiplicity is the high-speed cameras. This technique enables the identification of each stroke and its termination to ground. Figure 10 shows an example of a return stroke with its preceding stepped-leader recorded in a sequence of frames of the high-speed camera. The multiplicity obtained in the Southeast region of Brazil for negative CG flashes is 3.8. This value is similar to those obtained by accurate-stroke-count techniques in other regions (Saba et al., 2006).

3. CONCLUSIONS

The CG lightning data obtained in Brazil in the last two decades allow quantifying for the first time the lightning characteristics in the country. Considering that the dataset is the largest ever obtained in the tropics they also can be considered as representative of the tropical region of the world. The results suggested that, except for the higher flash density, the other characteristics are similar to those obtained in the temperate region.

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Figure 1. Map isoceraunic of Brazil obtained by thunderday observations from 1960 to 1980.

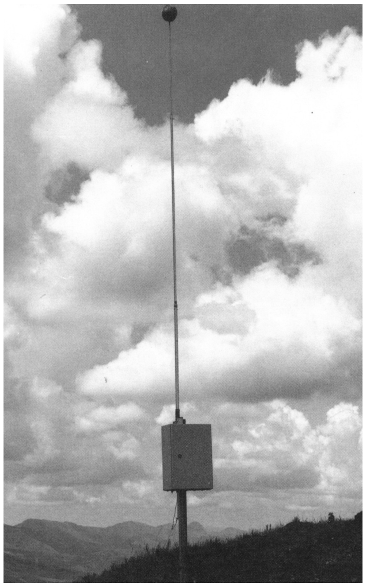

Figure 2. A CIGRE 10 kHz flash counter installed in the Southeast Brazil in 1985.

Figure 3. The photo shows the detail of the base of the tower in the Morro do Cachimbo Station.

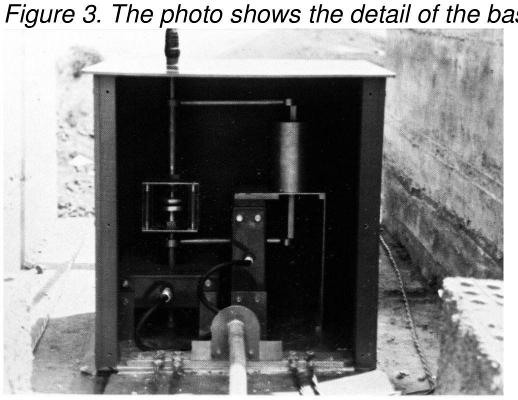

Figure 4. The photo shows the detail of the current sensors in the Morro do Cachimbo Station.

Figure 5. Map of the location of the lightning sensors of the BrasilDat at the time of this publication.

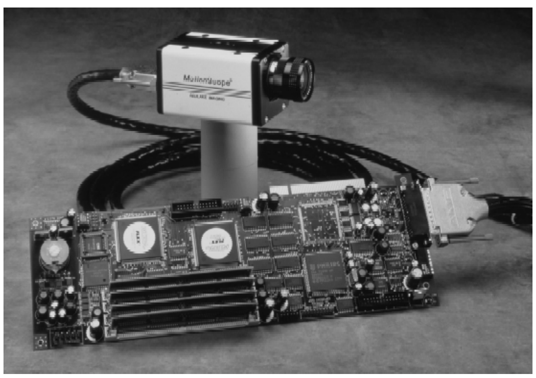

Figure 6. The photo shows the Red Lake Motion Scope 8000S high-speed camera and its PC hardware.

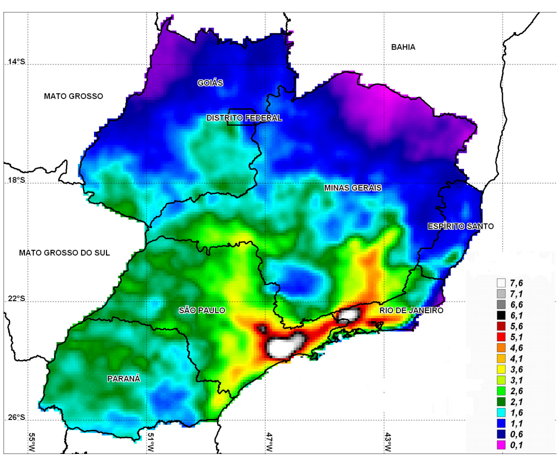

Figure 7. Annual average CG lightning flash density (in flashes.km-2.year-1) in the Southeastern Brazil from 1999 to 2004 for a spatial resolution of 10 km x 10 km obtained by the BrasilDat network. Regions in white correspond to densities larger than 7.5 flashes km-2 year-1.

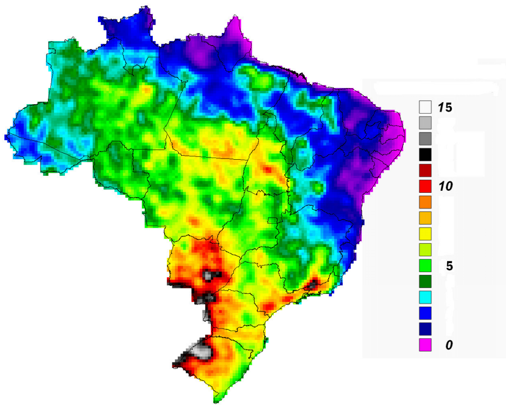

Figure 8. Map of the annual average CG lightning density (in flashes.km-2.year-1) in Brazil obtained from a comparison between CG lightning data from BrasilDat and the Lightning Imaging Sensor (LIS) in the Southeast of Brazil from the period 19998-2006 for a spatial resolution of 30 km x 30 km.

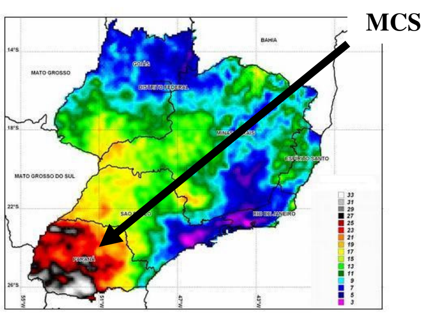

Figure 9. Average distribution of the percentage of positive CG flashes from 1999 to 2004 for a spatial resolution of 10 km x 10 km obtained in the Southeast of Brazil by BrasilDat. The location of MCS is indicated in the figure.

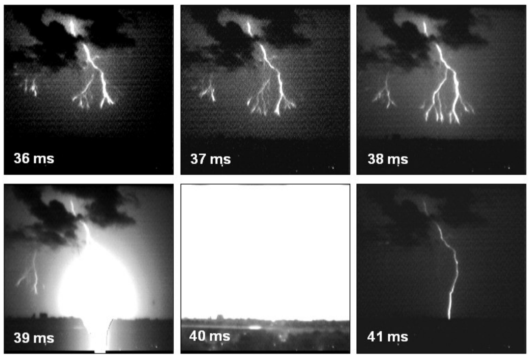

Figure 10. Example of a return stroke with its preceding stepped-leader recorded in a sequence of frames of the high-speed camera.