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Climatology of large peak current cloud-to-ground lightning flashes in southeastern Brazil

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[1] The goal of this article is to present the first climatology of large peak current cloud-to-ground (LPCCG) flashes in southeastern Brazil, in terms of flash density, percentage of positive LPCCG flashes, peak current, and diurnal distributions. The results are based on data provided by the Brazilian Lightning Detection Network (BrasilDat) from 1999 to 2006, and only flashes with peak currents >75 kA recorded during the months of December, January, February, and March (the approximate summer season in the Southern Hemisphere) were considered in order to compare with similar data obtained by Lyons et al. (1998) in the contiguous United States. The LPCCG data set, consisting of approximately 122,000 flashes, is currently the largest data set available for the tropical region. The LPCCG flashes represent about 3% of all flashes recorded during this period. All LPCCG distributions were obtained for both negative and positive flashes. The flash density distributions for negative and positive LPCCG flashes are different and furthermore differ from the flash density distributions for all negative and positive cloud-to-ground (CG) flashes. This suggests that the flash density distribution of CG flashes is peak current dependent. While the negative LPCCG flash density distribution has no significant dependence on any specific geographical or meteorological feature, the positive LPCCG flash density distribution and the distribution of the percentage of positive LPCCG flashes are closely related to the occurrence of mesoscale convective systems. The peak current and diurnal distributions of LPCCG flashes were found to be similar to those obtained in the contiguous United States.

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1. Introduction

[2] Cloud-to-ground (CG) lightning flashes with large peak current (LPCCG) have significant effects on different areas. Many studies have shown a clear association between LPCCG flashes of positive polarity and sprites and elves in the stratosphere and mesosphere, even though these phenomena not necessarily need to be originated by LPCCG flashes. For instance, *Lyons et al.* [1998] reported on the first climatology of LPCCG lightning flashes, compiled from the U.S. National Lightning Detection Network (NLDN), arbitrarily defined as those with peak currents >75 kA. Analysis of 1.46 million LPCCG flashes from 14 summer months (June, July, August, and September) from 1991 to 1995, corresponding to 2.4% of all flashes recorded, reveals distinct geographic differences in the distribution of positive and negative polarity flashes. Positive LPCCG flashes were concentrated in the high plains and upper midwest, the region in which a large majority of optical sprite and elves observations have been obtained. By contrast, negative LPCCG flashes preferentially occurred over the coastal waters of the Gulf of Mexico and the southeastern United States. From the total set of LPCCG flashes, only 13.7% were positive. Almost 70% of the positive LPCCG flashes, however, occurred in the central United States (geographic coordinates 30°N–50°N, 88°W–110°W). The percentage of all LPCCG flashes that were positive approached 30% in the central United States compared to 4.5% for the remainder of the country. In terms of the peak current distribution, for all ranges of peak current above 75 kA, negative LPCCG flashes were clearly dominant. For peak currents >75 kA and >200 kA, negative LPCCG flashes outnumbered positive LPCCG by ratios of 6.4 and 4.1, respectively. In terms of diurnal distribution, the negative LPCCG flash distribution was found to peak in the afternoon, while the positive LPCCG flash distribution peaks a few hours later (four hours in the central U.S.). The negative LPCCG flash distribution also has a secondary peak in the morning hours, absent in the positive LPCCG flash distribution. Lyons et al. suggest that these results contribute to a better understanding of the climatology of LPCCG flashes, which will greatly assist in the design of global radio frequency remote sensing systems to study these phenomena. Recently, other climatology studies of LPCCG have been reported in the literature [*Diendorfer and Schulz*, 2008; *Kochtubajda et al.*, 2008].

[3] The study of LPCCG flashes is also important for lightning protection. Guidelines for lightning protection generally assume median peak current values, differentiating between median values of positive and negative flashes. However, if LPCCG have marked differences in their con-

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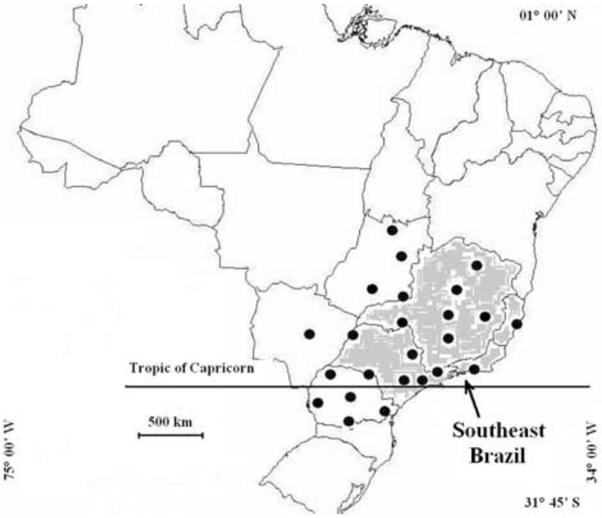

Figure 1. Map of Brazil indicating the configuration of the BrasilDat network at the period of this analysis and the southeast region (shaded area).

centration in different regions, there probably is a need to take these findings under consideration for engineering applications for utilities and other lightning sensitive installations. In addition, since NO_x production by lightning is supposed to be related to peak current [*Schumann and Huntrieser*, 2007], the regional differences in LPCCG flash densities may prove important. Recent evidences, however, suggests that NO_x production may be better correlated with continuing current than with peak current [*Rahman et al.*, 2007].

[4] Another motivation to study the climatology of LPCCG flashes is related to the fact that this population of flashes is less sensitive to changes in the detection efficiency of the lightning location networks than the climatology of all CG flashes inside or close to the perimeter of the network and this fact may help to understand the effects of the DE on the climatology of all CG flashes. Despite the importance of knowing the climatology of LPCCG, most studies have focused on the climatology of all CG flashes [*Diendorfer et al.*, 1998; *Orville and Huffines*, 2001; *Orville et al.*, 2002; *Pinto et al.*, 2003; *Schulz et al.*, 2005; *Soriano et al.*, 2006; *Zajac and Rutledge*, 2001].

[5] The goal of this article is to present for the first time the climatology of the LPCCG flashes in southeastern Brazil (geographic coordinates 14°S–26°S, 40°W–53°W) during the summer season in terms of the flash density, percentage of positive LPCCG flashes, peak current, and diurnal distributions, on the basis of data provided by the Brazilian Lightning Detection Network (recently renamed to BrasilDat) from 1999 to 2006. The results are compared to the geographical distributions for all CG flashes in the same region and discussed in comparison with similar observations made by *Lyons et al.* [1998] in the contiguous United States (hereinafter referred to as U.S.).

2. Brazilian Lightning Detection Network

[6] Data from the Brazilian Lightning Detection Network (BrasilDat) from 1999 to 2006 for peak currents >75 kA were used in this analysis. A spatial resolution of 10 km × 10 km was adopted.

[7] Consistent with the approach by *Lyons et al.* [1998], data were not corrected by a detection efficiency (DE) model. Considering the BrasilDat network configuration, such approach should not have a significant effect on the results since the DE is expected to be almost uniform in the region of study for the peak current flashes considered [*Naccarato et al.*, 2006]. From the period of study (1999 to 2006) the network consisted of 24 sensors (8 IMPACT and 16 LPATS), which determine the azimuth 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, among others. For a comprehensive description of lightning locating techniques, see, for example, *Cummins et al.* [1998a, 1998b] and *Rakov and Uman* [2003, p. 555]. Figure 1 shows the configuration of BrasilDat for the period of this analysis and the southeast region (the shaded area), which includes the states of Minas Gerais, São Paulo, Espirito Santo and Rio de Janeiro. The region of study includes the southeast region and a 100 km band region extending over the ocean along the coast, in order to investigate a possible effect associated with the land-ocean boundary on the flash density. More details about BrasilDat are given by *Pinto* [2003], *Pinto and Pinto* [2003], and *Pinto et al.* [1999a, 1999b, 2003, 2006a, 2006b, 2007].

[8] In order to compare the results of this study with those obtained by *Lyons et al.* [1998] in section 3, it is important to address the differences between BrasilDat and NLDN at the time of the observations by Lyons et al. (1991 to 1995). Although both networks are hybrid network containing LPATs and IMPACT sensors, they changed during the periods considered in this comparison. While the number of BrasilDat sensors in southeastern Brazil increased with the addition of three new IMPACT sensors, the configuration of NLDN changed in many ways, including the number, gain and trigger threshold of sensors [*Cummins et al.*, 1998a, 1998b]. In spite of the many differences between both networks, the mean overall (both in space and time and for all flashes) DE of both networks is almost the same, varying from less than 70% in the beginning of the periods to 80–90% at the end [*Pinto et al.*, 2006a, *Naccarato et al.*, 2006; *Lyons et al.*, 1998]. It is also worth mentioning that for both networks the current estimation algorithm it is not calibrated for first strokes. About the propagation models used in estimating peak currents and the conversion factor from measured peak field to inferred peak current, it was used the default parameters provided by the central processors in each case. In case of the conversion from peak fields to current values, different regression lines were used in NLDN at the time of Lyons et al. data (1991–1995) and BrasilDat data. The differences resulting from this fact, however, are not significant for this analysis [*Cummins et al.*, 2006].

3. Results and Discussion

[9] A data set consisting of approximately 122,000 flashes was analyzed. It represents about 3% of all CG flashes recorded during the period. This percentage is very close to the 2.4% reported by *Lyons et al.* [1998].

[10] Figures 2 and 3show the geographical distributions of negative flash density for LPCCG flashes and for all CG flashes in southeastern Brazil. In order to use a same color

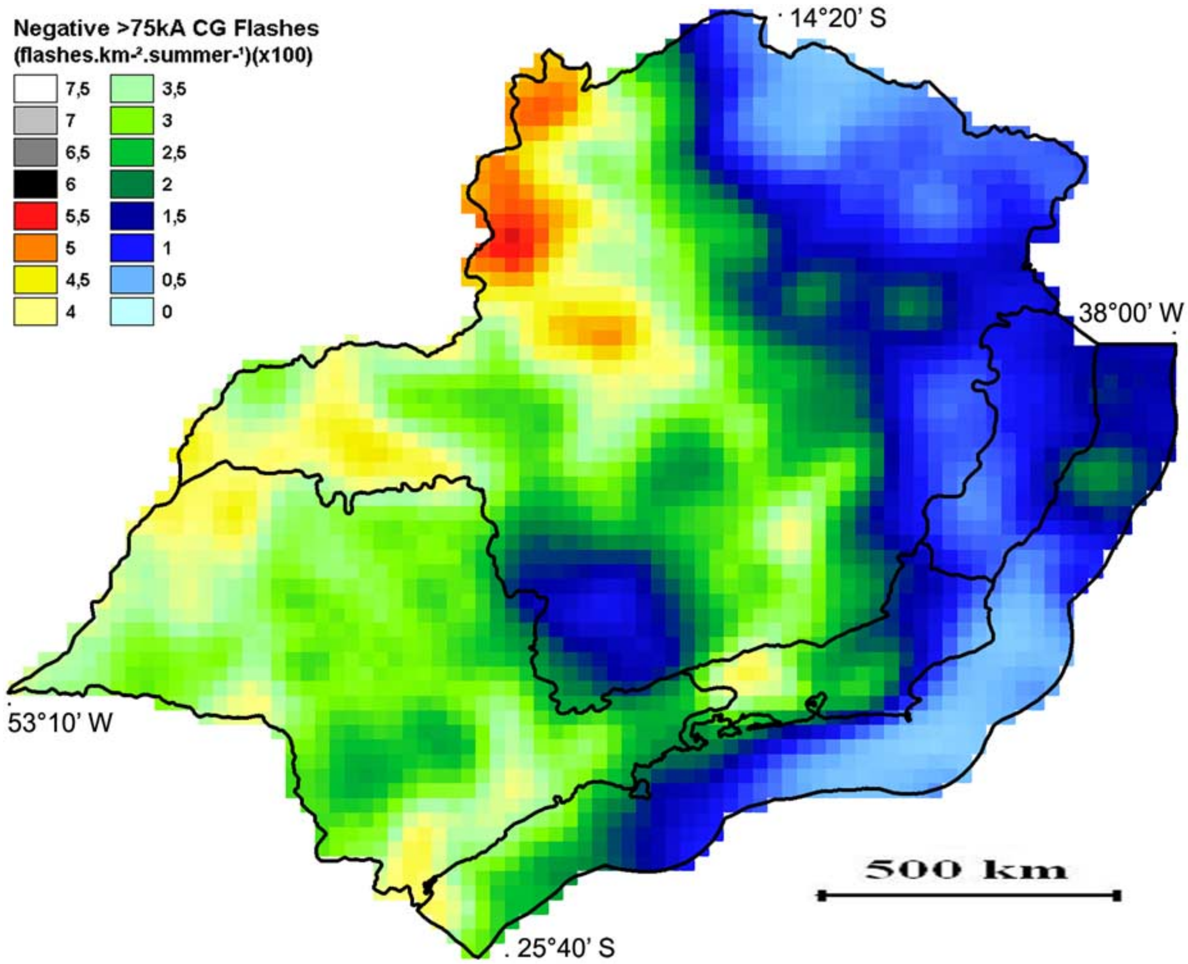

Figure 2. Map of the negative LPCCG flash density in southeastern Brazil for the period of the study and for the spatial resolution of 10 km × 10 km.

scale in both Figures 2 and 3 to facilitate the comparison, the negative LPCCG values in Figure 2 were multiplied by 100. A comparison between Figures 2 and 3 reveals that the spatial distributions although have some similarities (the main is the increasing flash density toward the southwest), are quite different, suggesting that the flash density distribution of CG flashes is peak current dependent. A similar result has been published recently by *Diendorfer and Schulz* [2008]. The negative CG flash density distribution is strongly influenced by the terrain height (that is, the altitude above the sea level), as it can be seen from a detailed comparison of Figure 3 with the map of terrain height in Figure 4. The comparison shows that the maximum values occur just in the southern border of the mountains with a blue minimum in the center region of the mountains (see *de Souza et al.* [2009] for more details). On the other hand, the negative LPCCG flash density distribution is less influenced by the altitude, showing a maximum in the northwest region. This fact suggests that the percentage of negative LPCCG flashes with respect to the total number of negative CG flashes is lower at high altitudes in southeastern Brazil. This result is general agreement with the observations by *Schulz and Diendorfer* [1999] that the mean peak current of negative flashes tends to decrease at high altitudes. *Lyons et al.* [1998] also did not find any evidence that the negative LPCCG flash density is related to altitude.

[11] The CG flash density in Figure 3 also shows a significant peak over the city of São Paulo (the green spot in the lower part of Figure 3), as already reported by *Naccarato et al.* [2003], not so evident on Figure 2 what seems to suggest that the urban effect on lightning is more apparent for low peak current flashes. In addition, a clear decrease in the flash density over the ocean is observed in both Figures 2 and 3, in agreement with satellite observations in this region. Figures 2 and 3 seem also to suggest a gradient parallel to the coast in the lightning activity. The gradient would be a response of the gradient parallel to the coast of the sea surface temperature (SST) usually observed in the ocean in this region [*Levitus*, 1982].

[12] Figures 5 and 6show the geographical distributions of positive flash density for LPCCG flashes and for all CG flashes, in the same format and also same scale of Figures 2 and 3. Differently of all negative CG flashes, for all positive flashes only flashes with peak currents above 15 kA were considered to avoid intracloud contamination. The positive LPCCG flash density values in Figure 5 were multiplied by 5 and the positive CG flash density values in Figure 6 were multiplied by 500. A comparison between Figures 5 and 6

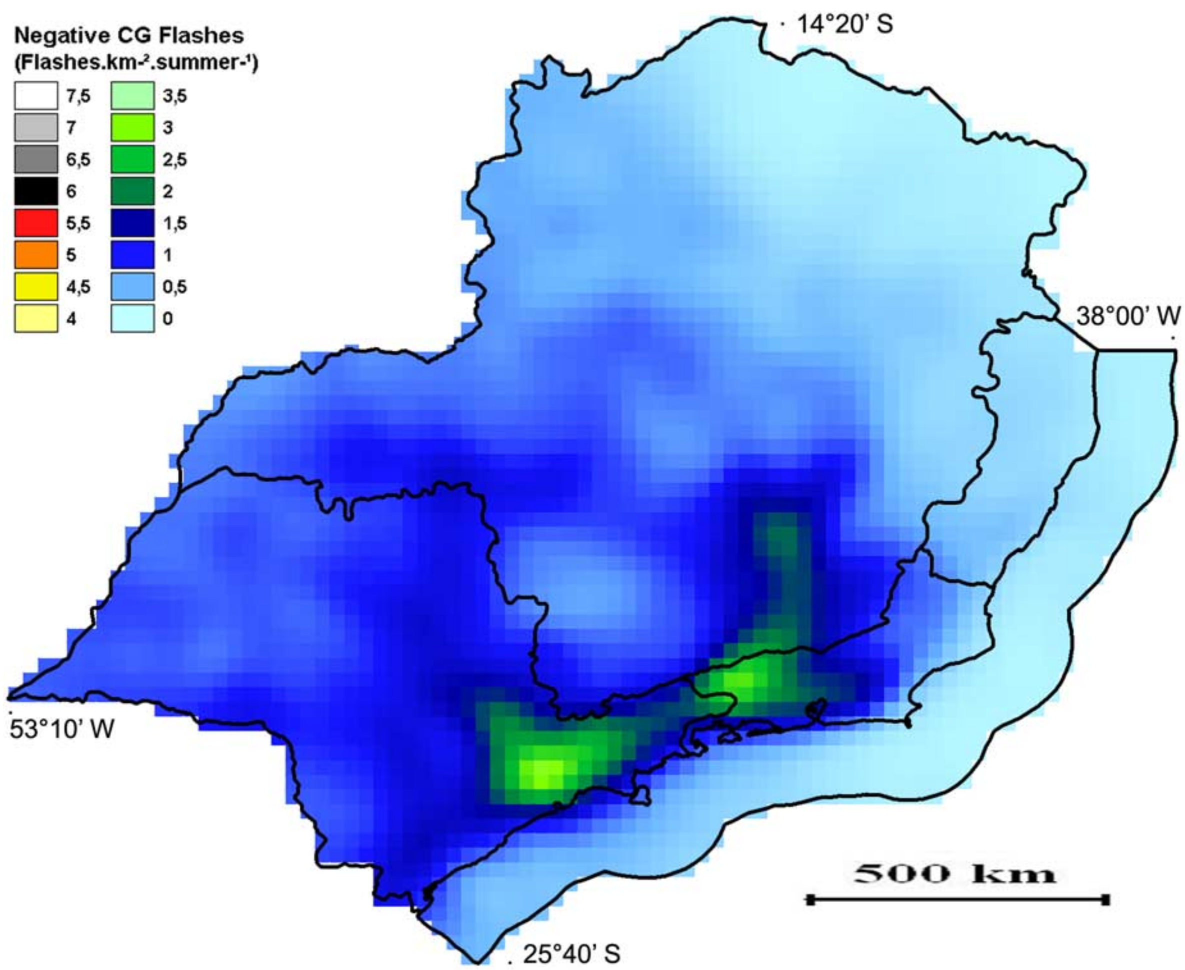

Figure 3. Map of the all negative CG flash density in southeastern Brazil for the period of the study and for the spatial resolution of 10 km × 10 km. The city of São Paulo is coincident with the green spot in the lower part of the figure.

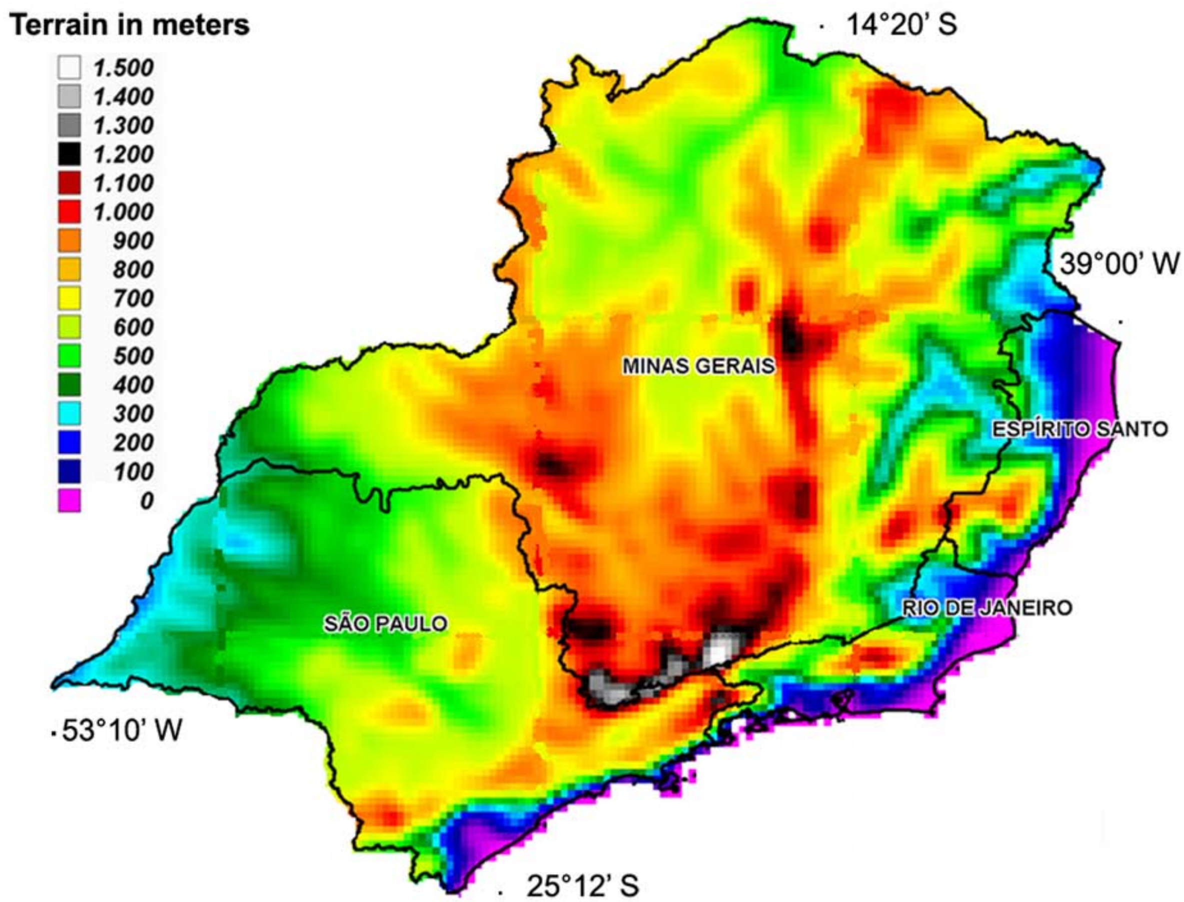

Figure 4. Map of the terrain height for southeastern Brazil in meters.

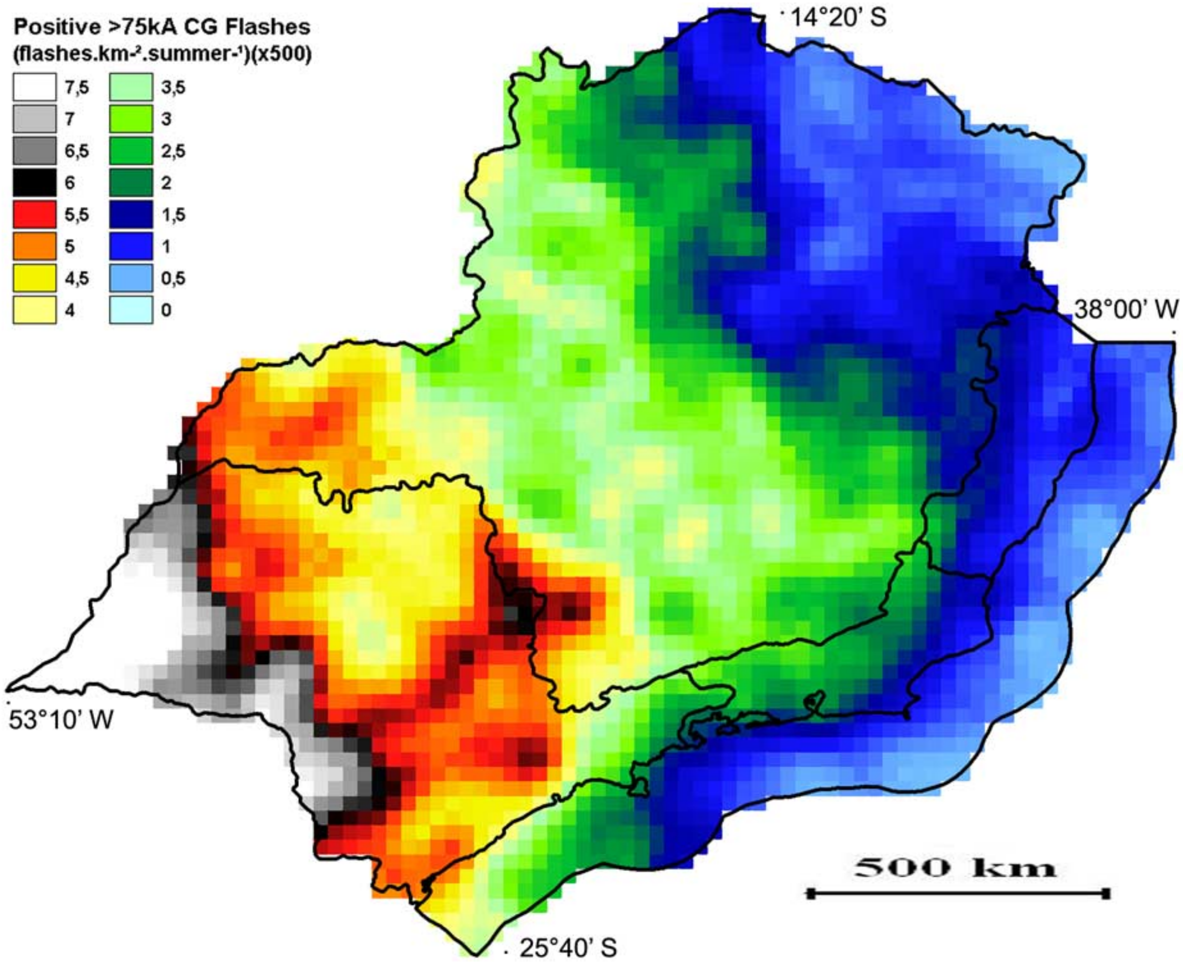

Figure 5. Map of the positive LPCCG flash density in southeastern Brazil for the period of the study and for the spatial resolution of 10 km × 10 km.

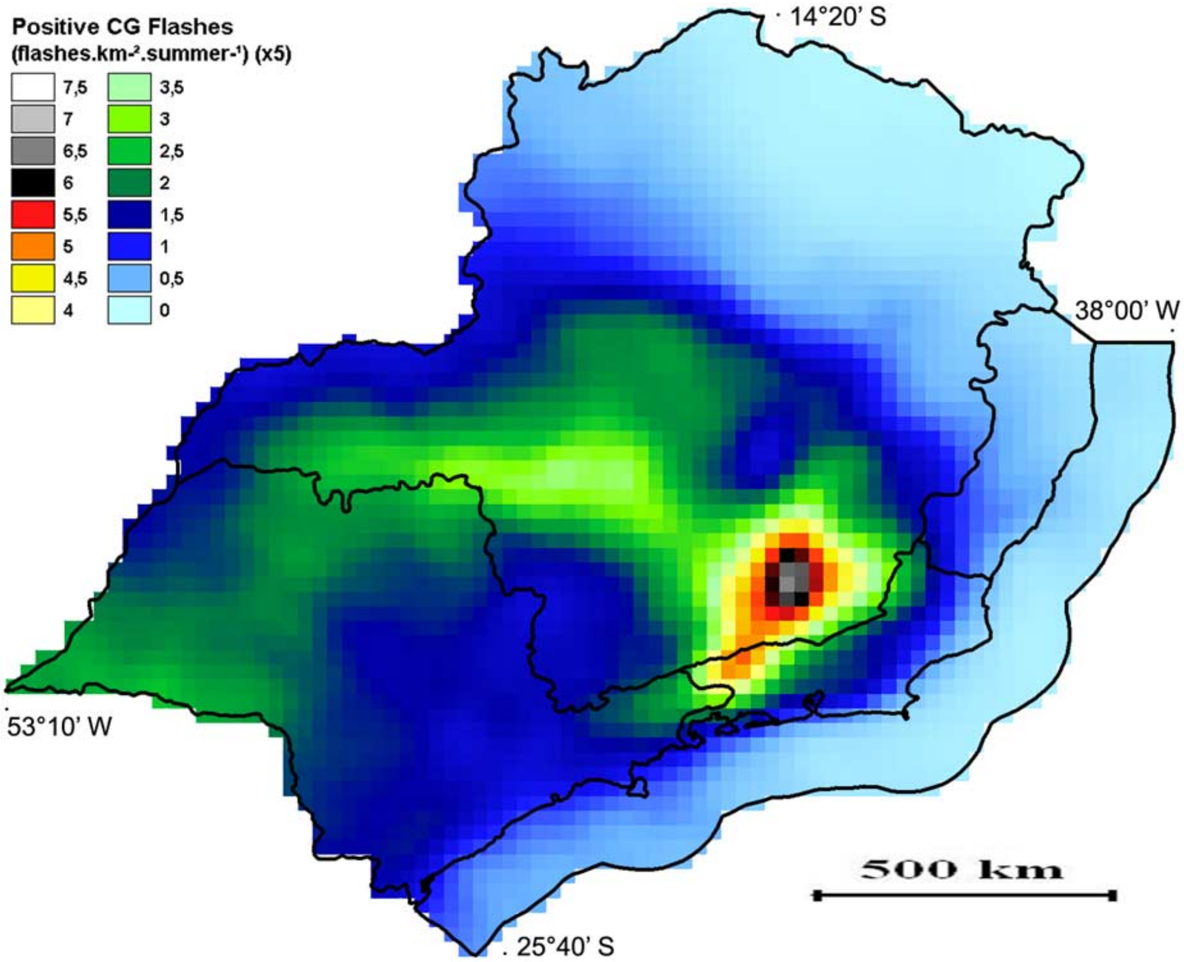

Figure 6. Map of the all positive CG flash density in southeastern Brazil for the period of the study and for the spatial resolution of 10 km × 10 km.

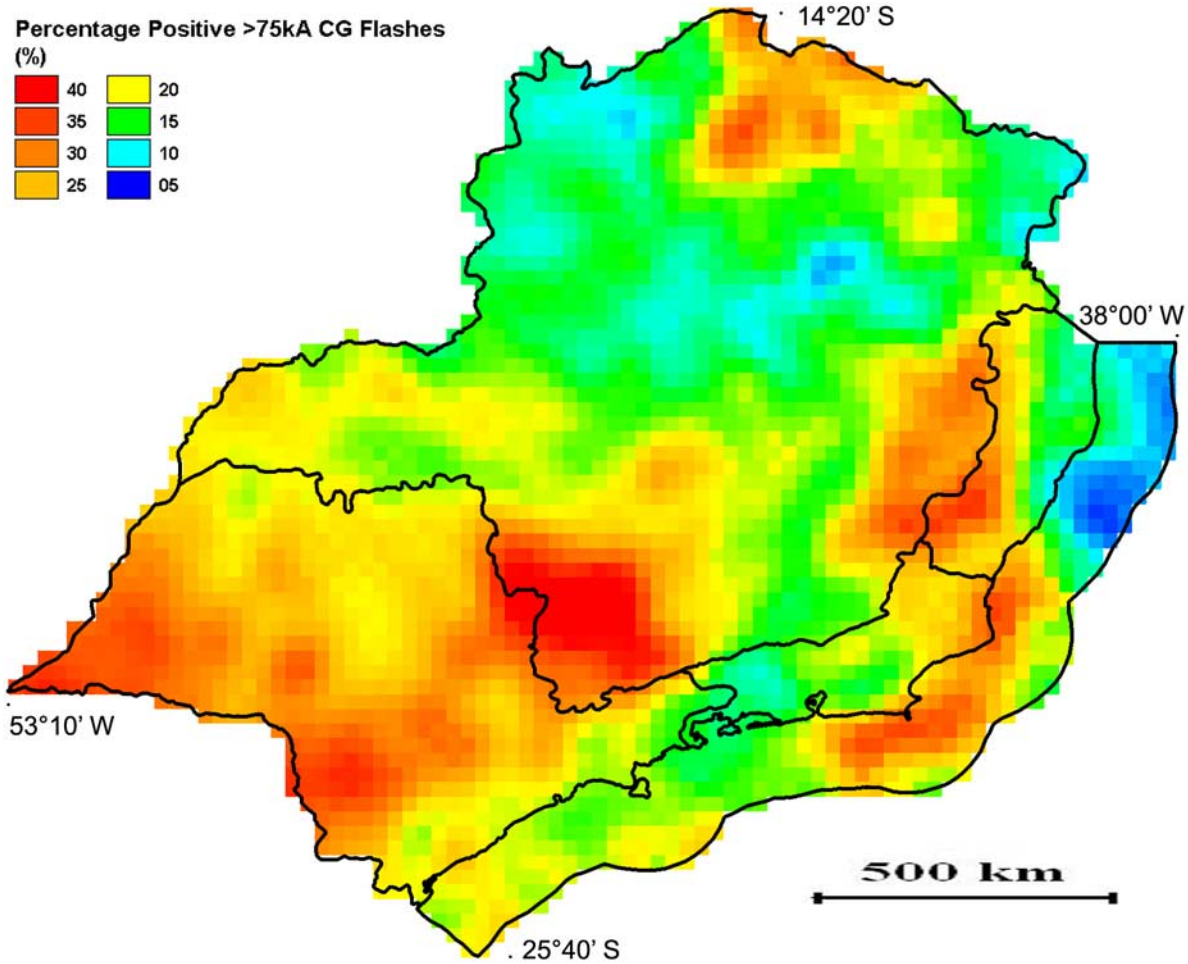

Figure 7. Map of the percentage of positive LPCCG flashes with respect to all LPCCG flashes in southeastern Brazil.

reveals again that the spatial distributions are quite different. The spatial distribution for all positive CG flashes is also apparently influenced by altitude, as it can be seen comparing Figure 6 with the map of terrain height in Figure 4. For instance, the maximum in Figure 6 occur in the north border of the higher mountains (see *de Souza et al.* [2009] for more details). On the other hand, the spatial distribution for positive LPCCG flashes is not. Considering that the distribution of mesoscale convective systems (MCS) in the tropical South America decreases with decreasing latitude, with a sharp drop in the south part of the southeastern region [*Velasco and Fritsch*, 1987; *Fritsch and Forbes*, 2001; *Durkee and Mote*, 2009], it seems that the spatial distribution for positive LPCCG flashes is related to the occurrence of this kind of storms. A close relation between positive CG flash activity and MCS has been reported by many authors (see, for a review, *Rakov and Uman* [2003]). In most cases, the majority of the positive CG flashes emanates from the trailing stratiform region of the MCS, although in some cases a substantial fraction, even a majority, originate in the convective region. The fact that the distribution of positive LPCCG flashes is more influenced by the occurrence of MCS than the distribution of all positive flashes suggests that the percentage of positive LPCCG flashes with respect to the total number of positive CG flashes is higher in regions with high occurrence of MCS, in agreement with the observations of *Lyons et al.* [1998] that the positive LPCCG flash density is closely related to the occurrence of MCS.

[13] The positive LPCCG flash density distribution is also quite different from the negative LPCCG flash density distribution, as it can be seen comparing Figures 2 and 5. The same was observed by *Lyons et al.* [1998]. In Figure 5, a northeast–southwest increase, typically of the relative frequency of occurrence of MCS is evident, while it is not evident on the negative LPCCG flash density distribution in Figure 2. Such a decrease reinforces the idea that positive LPCCG flashes are more frequent in thunderstorm associated with MCS than in isolated thunderstorms.

[14] Figure 7 shows the geographical distribution of the percentage of positive LPCCG flashes with respect to the total number of LPCCG flashes. The percentage of positive LPCCG flashes varies from approximately 5% to 40%, with a mean value of 21%. This value is slightly higher than the value obtained by *Lyons et al.* [1998] for U.S. (13.7%). The geographical distribution of the percentage of positive LPCCG flashes shows a trend to decrease from southwest to northeast, in agreement with the discussion related to Figure 5.

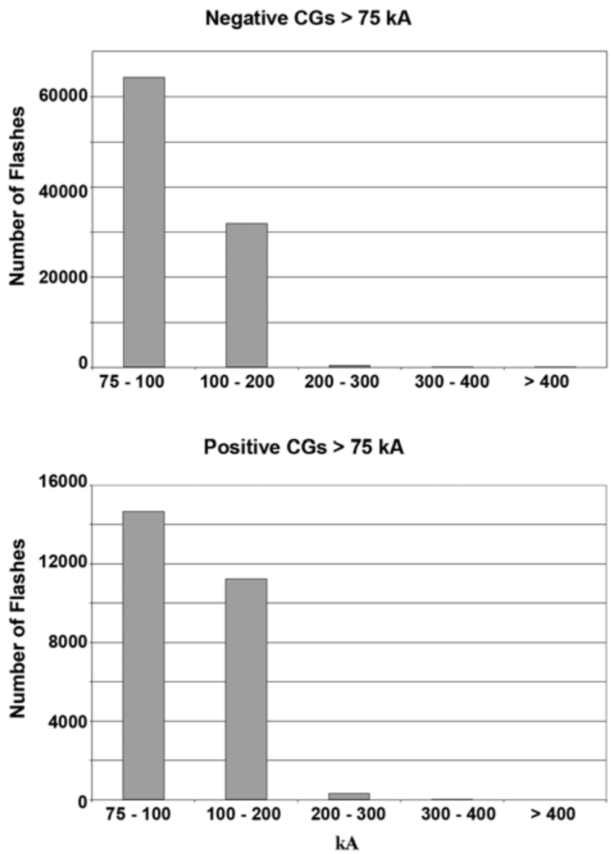

Figure 8. Peak current distribution of negative and positive LPCCG flashes.

[15] Figure 8 shows the peak current distributions of negative and positive LPCCG flashes in southeastern Brazil (not including the ocean region). The distributions are similar to those obtained by *Lyons et al.* [1998] for U.S.. For peak currents >75 kA and >200 kA, negative LPCCG flashes outnumbered positive LPCCG by ratios of 4.4 and 1.1, respectively. These values are lower than the values reported by Lyons et al., 6.4 and 4.1, respectively.

[16] Figure 9 shows the diurnal UT distribution of negative and positive LPCCG flashes in the southeast region (not including the ocean). The negative LPCCG flash distribution was found to peak at 20:00 UT (17:00 LT), while the positive LPCCG flash distribution peaks three hours later (23:00 UT). About the same time lag (3–4 h) was found by *Lyons et al.* [1998] for U.S. in the morning hours. Although Lyons et al. did not mention any explanation about this UT phase shift, it may be explained as part of the time evolution of the lightning activity of most storms (including MCS) that tend to present positive CG flashes at later times. The negative LPCCG flash distribution has no secondary peak in the morning hours, differently of what was observed by Lyons et al. for U.S. The positive LPCCG flash distribution also has no peak in the morning hours, in agreement with the observations in U.S.. However, the near parity of the two polarities observed in the central U.S. between 08:00 UT and 10:00 UT (corresponding to 20:00 and 22:00 LT) and attributed by Lyons et al. to the existence of large MCS in this region was not observed for any hour in southeastern Brazil. This fact may be explained by the lower occurrence of MCS in this region of Brazil than in the central U.S. [*Velasco and Fritsch*, 1987].

4. Conclusions

[17] This paper presents the results of the first climatological study of LPCCG flashes in southeastern Brazil. The study is also the first to be carried out in the tropics. The results were compared with those obtained in the United States by *Lyons et al.* [1998] in a similar study. The negative and positive LPCCG flash density distributions are quite different from each other, in agreement with observations in United States, and from the respective distributions for all flashes, suggesting that the flash density distribution of CG flashes is peak current dependent. While the negative CG flash density distribution is influenced by terrain height, the negative LPCCG flash density distribution is not related to terrain height. This fact suggests that the percentage of negative LPCCG flashes with respect to the total number of negative CG flashes is lower at high elevations in southeastern Brazil. Also, the CG flash density distribution shows a peak in the region of the city São Paulo, not so evident on the LPCCG flash density distribution, suggesting that the urban effect on lightning is more evident for low peak current flashes. In turn, while the spatial distribution for all positive CG flashes is also apparently influenced by the terrain height, the spatial distribution for positive LPCCG flashes is appar-

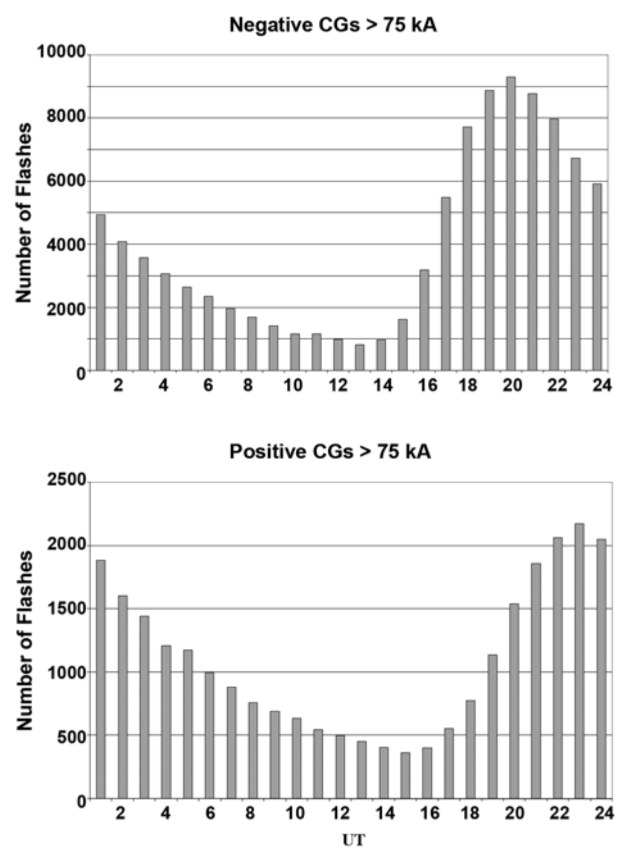

Figure 9. Diurnal UT distribution of negative and positive LPCCG flashes.

ently related to the occurrence of MCS. This fact suggests that the percentage of positive LPCCG flashes with respect to the total number of positive CG flashes is higher in regions with high occurrence of MCS and severe storms, in agreement with the observations in the United States. Peak current and diurnal distributions of LPCCG flashes were found to be similar to those reported for United States, although some differences were evident. While the negative LPCCG flashes outnumbered positive LPCCG in both regions, the behavior is lesser pronounced in the southeastern region of Brazil than in the United States. Finally, the positive LPCCG flash diurnal distribution peaks about three hours later than the negative one in both regions, although at different local times.

[18] **Acknowledgments.** The authors would like to thank FAPESP (grant 03/08655–4) and CNPq for supporting this research.

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