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Cloud-to-ground lightning in southeastern Brazil in 1993

1. Geographical distribution

O. Pinto Jr., I.R.C.A. Pinto, M.A.S.S. Gomes, I. Vitorello, and A.L. Padilha
Instituto Nacional de Pesquisas Espaciais (INPE), São José dos Campos, Brazil

J.H. Diniz, A.M. Carvalho, and A. Cazetta Filho
Companhia Energética de Minas Gerais (CEMIG), Belo Horizonte, Brazil

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 1-year continuous lightning data set is the first obtained in Brazil. It has been analyzed for geographical distribution of total flash density, percentage of positive flashes, negative and positive flash densities, and negative and positive flash peak currents. The dependence of the flash density and peak current on latitude, altitude, and soil resistivity was investigated. Negative flash peak current was found to be inversely correlated with latitude, but no other significant correlation was found for flash density and peak current with these parameters. Positive flashes were found to be contaminated by intracloud flashes. The maximum total, negative, and positive flash densities were 15.5, 9.1, and 7.7 flashes/km^2 per year, respectively. The average percentage of positive flashes was 36.5%. The geometric means of negative and positive peak current were 30.9 kA and 17.8 kA. The high density, high percentage and low average peak current of positive flashes found in this study are probably a result of such a contamination. Neglecting positive flashes below 15 kA, assuming that they correspond to intracloud flashes erroneously identified by the system, the maximum positive and total flash densities would be 3.9 flashes/km^2 per year and 11.7 flashes/km^2 per year. The percentage and geometric mean peak current of positive flash would be 23% and 38.7 kA, respectively. The results are discussed in the context of other similar measurements made at different parts of the world.

1. Introduction

The geographical distribution of cloud-to-ground lightning flashes has been studied by several authors. *Orville* [1991,1994] and *Orville and Silver* [1997] have published results for the contiguous United States from 1989 to 1995, using a network of over 100 wideband magnetic direction finders augmented by time-of-arrival sensors beginning in 1994. *Hodanish et al.* [1997] have published results for the state of Florida from 1986 to 1995. On the basis of a grid of 3000 points, covering the contiguous United States, with a spatial resolution of 90 km in the east-west direction and to 65 in the north-south direction, *Orville and Silver* [1997] reported that the annual highest flash densities have been found to vary between 9 and 13 flashes/km^2 per year, sometimes occurring in Florida, sometimes in other states. The annual percentage of positive flashes was always below 10%. The annual highest flash densities for negative and positive flashes were found to vary between 9 and 13 flashes/km^2 per year and between 0 and 1.8 flashes/km^2 per year, respectively. No data about flash peak current were available in these studies.

Similar results for other parts of the world, in particular in the tropical areas, are very scarce. *Orville et al.* [1997] have recently published results obtained for about 1 year in the tropical area of Papua New Guinea. They found a highest flash density of 2.0 flashes/km^2 per year, an annual percentage of positive flashes of 5.6%, and annual average peak currents of 25 kA for negative flashes and 33 kA for positive flashes.

The dependence of the cloud-to-ground flash density and peak current on several parameters such as latitude, altitude, and soil resistivity has been investigated by several authors. Whereas the mean number of strokes per flash and the intervals between strokes do not show any systematic latitude dependence [*Thomson*, 1980], the stroke peak current seems to depend on latitude [*Orville*, 1990; *Pinto et al.*, 1997]. *Orville* [1990], using data of a network of magnetic direction finders covering the eastern United States; and *Pinto et al.* [1997], using data of direct peak current measurements obtained from several instrumented towers at different latitudes, have found that the flash peak current (first stroke) tends to increase from medium (around 45°) to low (around 20°) latitudes. The dependence of cloud-to-ground lightning parameters on altitude has been studied by *Robertson et al.* [1941] and *Reap* [1986]. *Robertson et al.* [1941] reported results obtained in 1937-1941 in the Rocky Mountains of Colorado showing that the peak current of flashes striking power lines tends to be lower for the higher altitude regions. From an analysis of over 2 million negative flashes for the 1983-1984 summer season in the western United States, *Reap* [1986] found that the higher the altitude the larger the flash density and earlier the peak in the daily flash distribution. The first result, however, is in apparent controversy with the recent results published by *Orville and Huffines* [1999] from a 10-year study. The dependence of cloud-to-ground lightning parameters on soil resistivity is a matter of controversy. Although it has been

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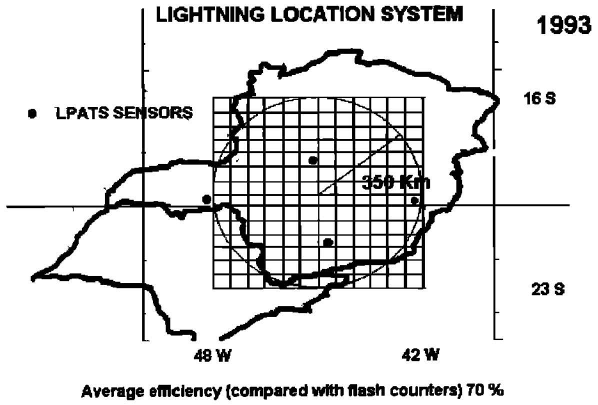


Figure 1. Region considered in this study and the locations of the LPATS sensors in 1993 (indicated by circles). These locations are indicated in Plates 1-4. The average efficiency of the system in this region was estimated from a comparison with results of flash counters and assumed to be 70%.

speculated that the soil resistivity (or conductivity) may influence the characteristics of cloud-to-ground lightning flashes, information about such a relationship is not available in the literature. *Kamra and Ravichandran* [1993] pointed out the influence of the soil resistivity on the atmospheric electric field produced by a thunderstorm. However, at the present time, no conclusive results have been published indicating a dependence of the flash density or peak current on soil resistivity.

In this paper the results of the analysis of about 1.1 million cloud-to-ground lightning flashes, recorded in southeastern Brazil for the whole year of 1993, are presented in terms of their geographical distribution and their possible dependence on latitude, altitude and soil resistivity. In a companion paper [*Pinto et al.*, this issue], the same lightning data are discussed in terms of their temporal variations and flash characteristics. This study is the first lightning study to consider a continuous 1-year data set in Brazil.

2. Lightning and Correlated Data

The 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 1993. At that time, the system was composed of four sensors, as illustrated in Figure 1 (for more details, see *Pinto et al.* [1996]. Figure 1 shows the location of the sensors and the region considered in this study. Although the system was originally designed to cover a total area of 1,400,000 km^2, we have considered in this study only the region located between 16° and 23°S and 42° and 48°W (about 420,000 km^2). This region corresponds approximately to the region for which the distance of any point to the geometric center of the sensors is below or equal to 350 km. The reason for this limitation was to guarantee high detection efficiency and high location accuracy. For the comparison of LPATS results with balloon electric-field data [*Pinto et al.*, 1992 a, b] and CIGRÉ 10 kHz lightning flash counter data [*Diniz et al.*, 1996] it was estimated that in this region the average detection efficiency is around 70% and the location accuracy is better than 10 km. All flash density values in this paper are the result of multiplying the measurements by an arbitrary factor of 1.4 to correct for the 70% efficiency. In fact, the assumption of uniform flash detection efficiency may not be real. It is possible that it may be lower than 70 % near the edges of the region considered. However, in the lack of exact information on the detection efficiency it seems to be reasonable.

The lightning data were referenced to grid blocks that are approximately 55 x 55 km. This size was adopted so that the error in the flash location would not affect significantly the results; that is, misplacement of flashes by one grid block when the flash location is close to the grid block borders would not affect significantly the results. A similar procedure was adopted by *Reap* [1986]. Here is worth mentioning that possible variations in the lightning parameters for distances less than 50 km would not be observed in this analysis. For each grid block, an average terrain elevation and soil resistivity were estimated. The altitude was taken from the ETOPO5 (Earth topographic 5 min model) grid elevation model provided by the National Geographical Data Center of the National Oceanic and Atmospheric Administration (NOAA) and was found to vary from 300 m to about 1200 m. The soil resistivity was inferred from a geological map, at the scale 1:2,500,000, considering that it is correlated with age and lithology. This assumption can be considered as true at the scale of the grid blocks adopted here [*Parkhomenko*, 1967]. The resistivity values were arbitrarily grouped in five categories according to their relative resistivity (very low, low, moderate, high, and very high).

3. Results

The results of the analysis of 1,118,000 flashes recorded in southeastern Brazil in 1993 are summarized in Plates 1 - 4. Plate 1 shows the total cloud-to-ground flash density for the year 1993. Total flash density refers to the combined number of negative and positive flashes. The maximum flash density is 15.5 flashes/km^2 per year, with a secondary maximum of 12-14 flashes/km^2 per year. Both are located in high-elevation regions with average altitudes above 900 m. These values are slightly higher than the maximum total flash density reported by *Orville and Silver* [1997] (11-13 flashes/km^2 per year) in the contiguous United States for the period 1992-1995 with a spatial resolution of 90 x 65 km.

Plate 2 shows the percentage of positive flashes for the year 1993. The percentage in each grid block varies from 9% to 72%, with an average value of 36.5%. This value is much higher than the correspondent values in the contiguous United States, which are always below 10% for the period of 1992-1995 [*Orville and Silver*, 1997]. As it will be discussed in section 4, we believe that this value is probably a result of the contamination of positive flashes by intracloud flashes.

Plate 3 shows the flash density for negative and positive flashes. Maximum flash densities were found to be 9.1 flashes/km^2 per year, for negative flashes, and 7.7 flashes/km^2 per year, for positive flashes. Whereas the negative flash density in Plate 3a shows a geographic distribution very similar to that of total flash density and in general agreement with the lightning distribution obtained by flash counters [*Diniz et al.*, 1996], the positive flash density in Plate 3b shows a clear relationship with the location of the lightning sensors shown in Figure 1. This point will be discussed in more details in section 4.

Plate 4a shows the geometric mean peak current for negative flashes. The global average value is 30.9 kA, with individual grid block values varying from 21.8 kA to 60.3 kA. In turn, Plate 4b shows the correspondent values for positive flashes. The global average value for this case (17.8 kA, with variations from 10 kA to 38.9 kA) is lower than that for negative flashes. This result is in contrast with most other studies, which indicate that the average peak current of positive flashes is normally higher than that for negative flashes. Such difference can be explained assuming that the low-peak current positive flashes are

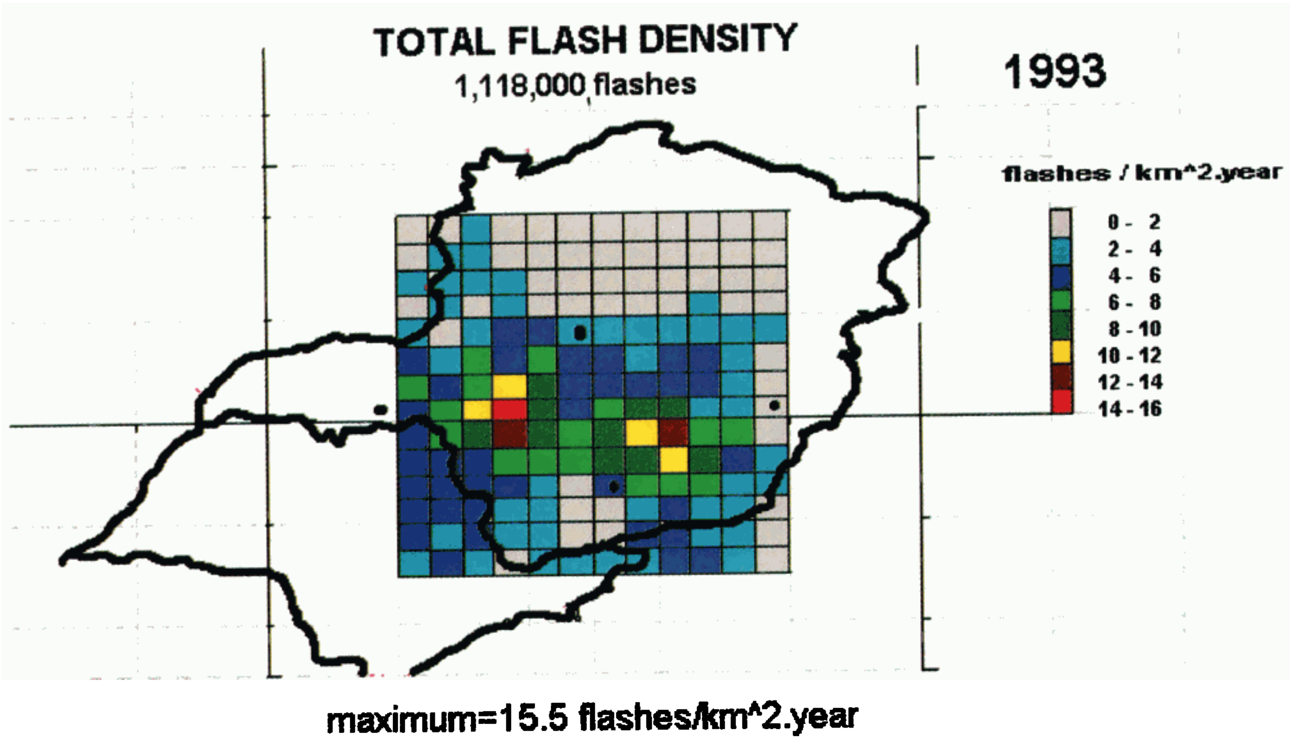


Plate 1. Total flash density measured in southeastern Brazil in 1993.

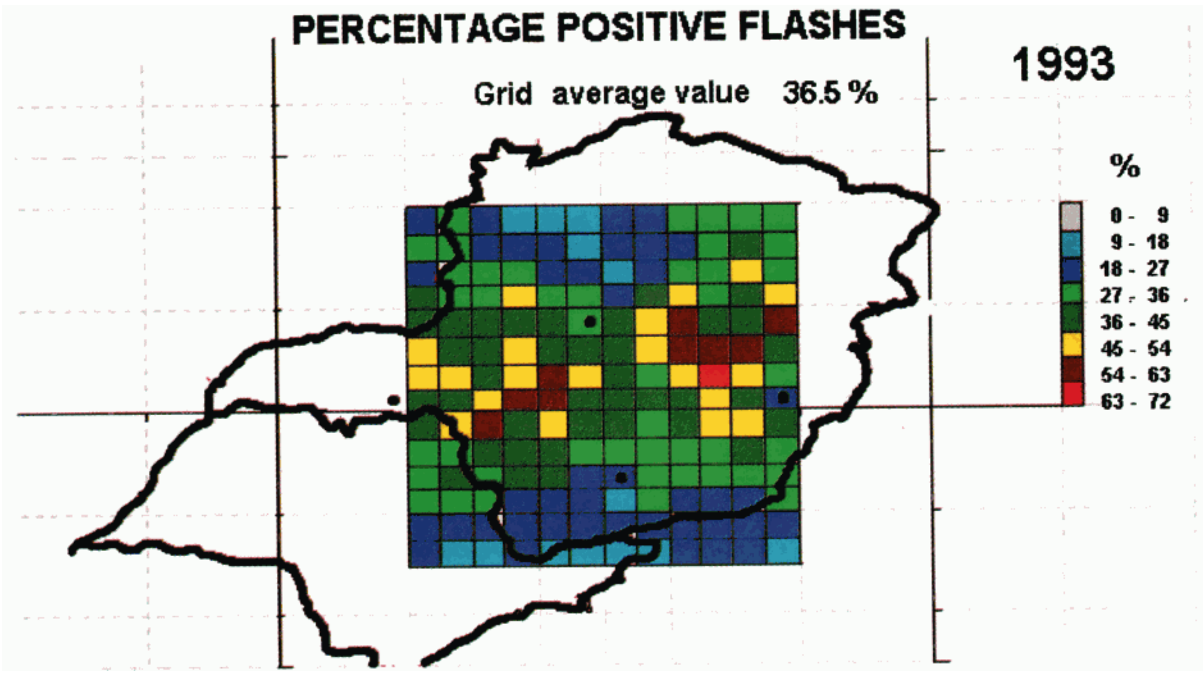
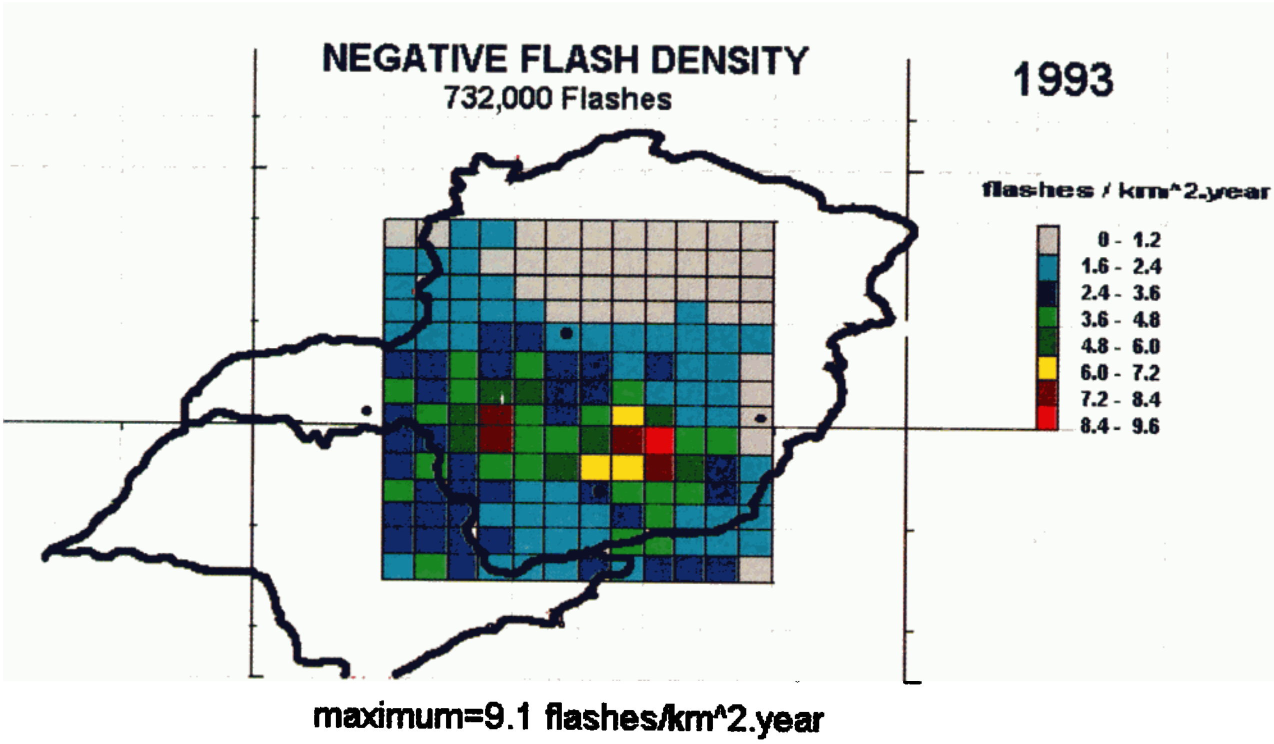


Plate 2. Percentage of positive flashes in southeastern Brazil in 1993.

a



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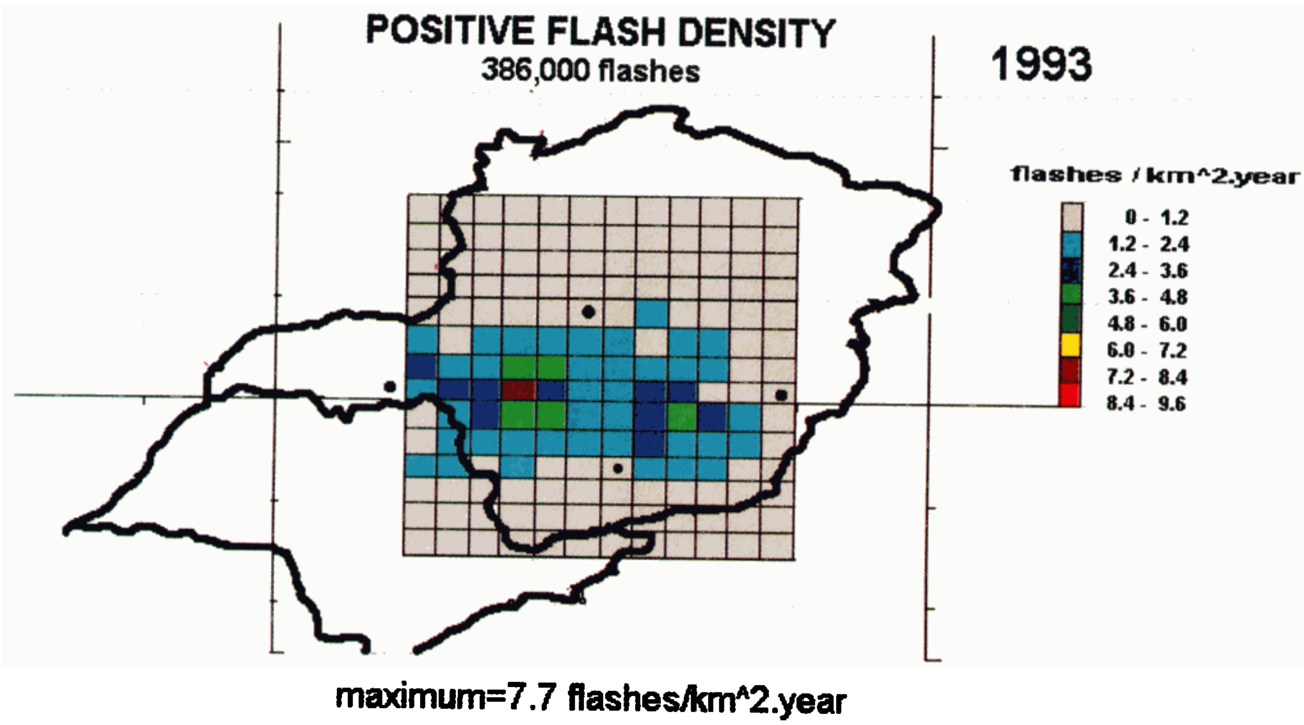
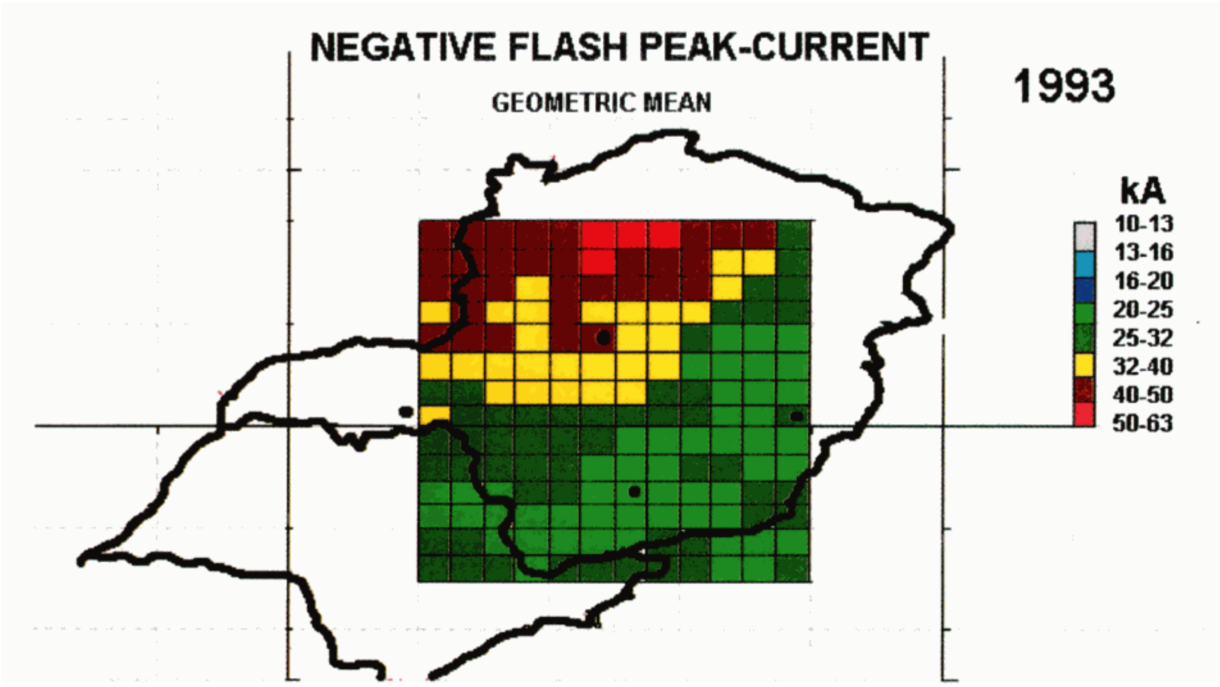


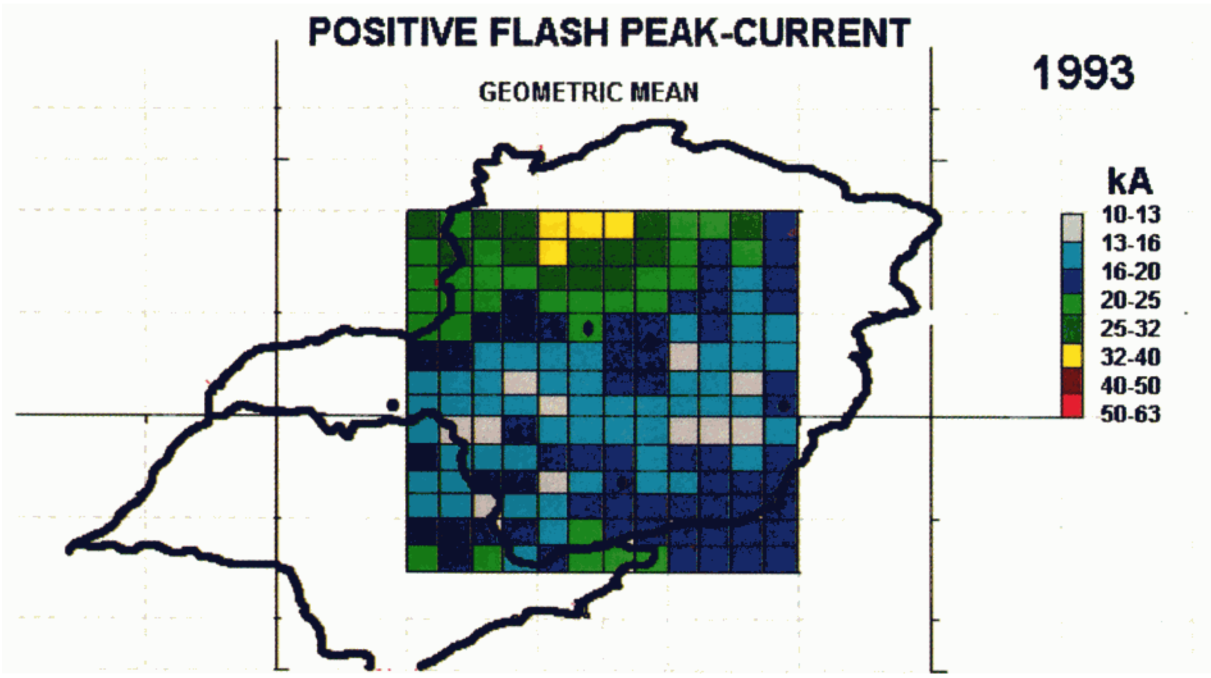
Plate 3. (a) Negative and (b) positive flash density in southeastern Brazil in 1993.

a



Average=30.9 kA, minimum=21.8, maximum=60.3 kA

b



average=17.8, minimum=10.0 kA, maximum=38.9 kA

Plate 4. (a) Negative and (b) positive flash peak current in southeastern Brazil in 1993.

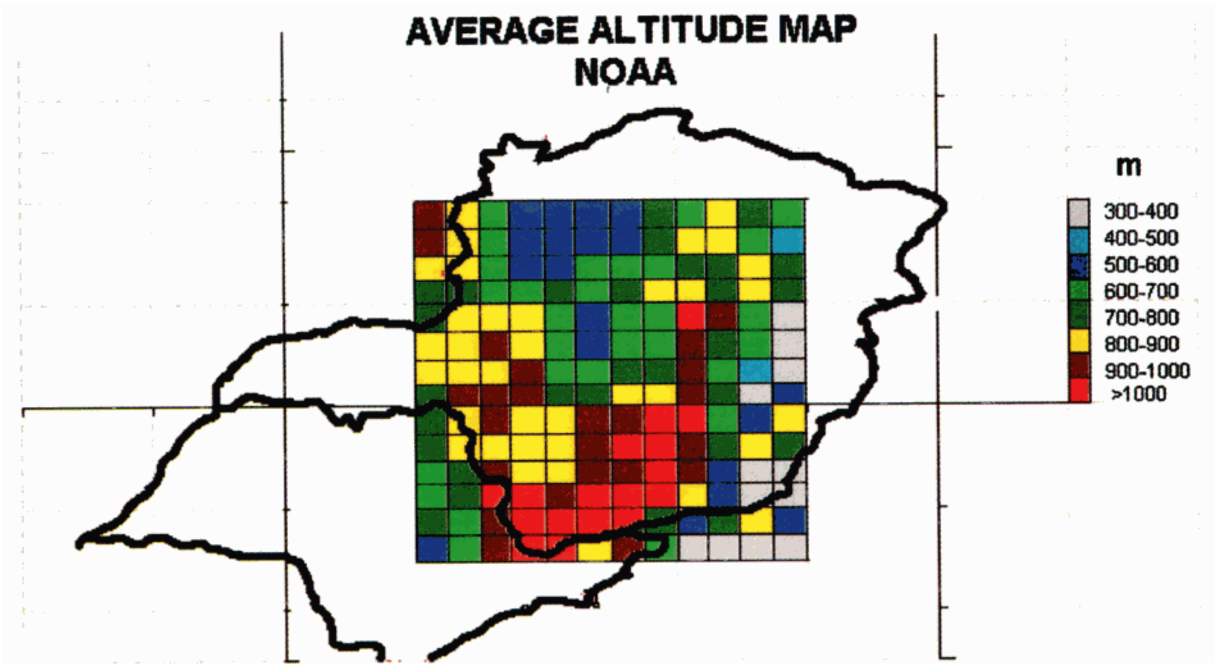


Plate 5. Average altitude map for the region considered in this study obtained from the ETOPO elevation model provided by NOAA.

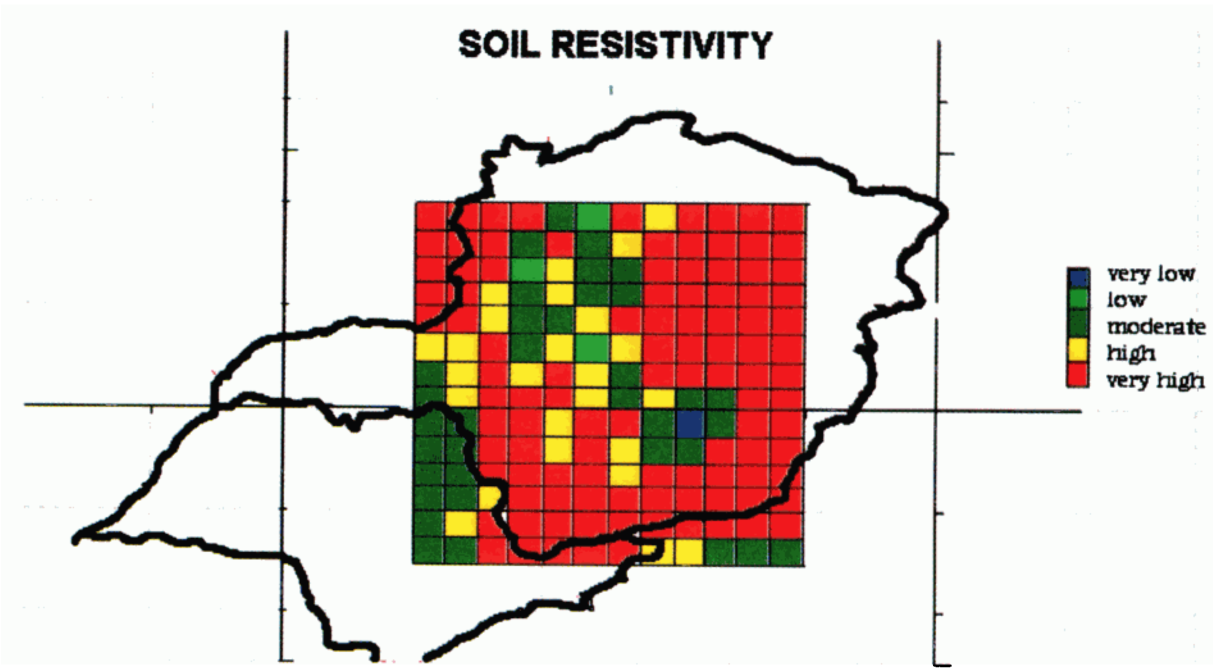


Plate 6. Soil resistivity map for the region considered in this study.

contaminated by intracloud flashes, as it will be discussed in section 4.

4. Discussion

The discussion that follows is divided into five topics: percentage of positive flashes, peak current of positive flashes, maximum cloud-to-ground flash densities, dependence of lightning parameters on latitude, and dependence of lightning parameters on altitude and soil resistivity. As mentioned before, possible variations of lightning parameters for distances less than 50 km would not be observed in this analysis.

4.1. Percentage of Positive Flashes

As it was seen in Plate 2, the percentage of positive flashes is much higher than the results reported by *Orville and Silver* [1997] in the contiguous United States. A comparison of Plate 2 with Figure 1 shows that the higher values are concentrated in the region inside the baselines connecting the sensors. It is also in this region that the higher positive flash densities (Plate 3b) and lower-peak current (Plate 4b) do occur. Such geographic distributions, not observed for high peak current positive flashes and negative flashes, indicate that the location of the LPATS sensors probably has an influence on the results for positive flashes. This assumption is reinforced by the results shown in Figures 2 and 3. Figures 2 and 3 show that the positive flash density tends to decrease with the increase of the distance from the grid block to the geometric center of the sensors, and the logarithm of the peak current tends to increase with this distance. Similar trends were not observed for negative flashes. The above dependence of the positive flash density and peak current should be expected to occur if the location of the sensors is playing a role in the positive flash measurements. To understand this influence, we have investigated the possibility that part of the positive flashes may actually be intracloud flashes. If intracloud flashes are being erroneously identified as positive cloud-to-ground flashes, we should expect an increase in the positive flash density and a decrease in the average positive peak current with respect to the actual values, in agreement with the results obtained. For a LPATS version III system, such as the one used in this study, the discrimination between intracloud flashes and positive flashes was based on the assumption that when three or more sensors, placed 200 km or more apart, simultaneously detect intense electromagnetic pulses, the source is thought to be a return stroke due to a cloud-to-ground flash. The results presented here seem to indicate that such a criterion for discrimination may not be valid. Recent results reported by *Zaima et al.* [1997] have arrived at the same conclusion. They also suggest that the contamination of the positive flashes by intracloud flashes is mainly concentrated in the measurements below 15 kA (additional evidence supporting this value is discussed by *Pinto et al.* [this issue]). In summary, the measurements of positive flashes in this study are probably contaminated by intracloud flashes. Considering that about 50% of the positive flashes have peak currents below 15 kA [*Pinto et al.*, this issue], the magnitude of the contamination may be quite significant. Neglecting positive flashes below 15 kA, assuming that they correspond to intracloud flashes erroneously identified by the system, the percentage of positive flashes would be 23%. This value is still large compared to those obtained by *Orville et al.* [1997] for Papua New Guinea and by *Orville and Silver* [1997] for the contiguous United States. In this sense, it is worth discussing other plausible explanations for the large number of positive flashes above 15 kA. A large population of low peak current positive flashes has been detected in the United States recently [*Cummins et al.*, 1998]. The origin of these flashes is not known at this time. It is possible that the large number of positive flashes above 15 kA has the same origin of these flashes, although no evidence supporting this view exists. A large number of positive flashes has also been observed in association with the trailing stratiform region of mesoscale convective systems [e.g., *Rutledge and MacGorman*, 1988; *Rutledge et al.*, 1990; *Engholm et al.*, 1990; *Stolzenburg*, 1990] and with the anvil and convective regions of some severe storms [*Rust et al.*, 1981a, b; *MacGorman and Burgess*, 1994; *Stolzenburg*, 1994]. However, the average positive peak current in these studies is normally very high (above 50 kA). Although a complete meteorological analysis of thunderstorm occurrence and development in the region of this study does not exist, the available satellite information indicates

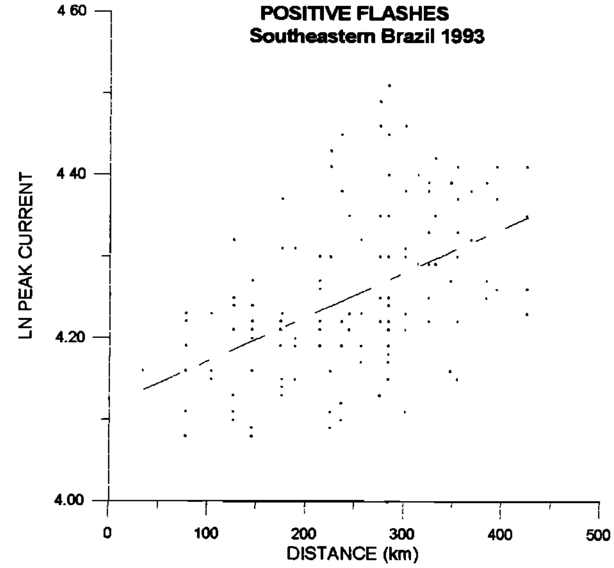


Figure 3. Logarithm natural of the positive flash peak current (in kiloamperes) versus distance (in kilometers) from the geometric center of the system. The best fit line (ln peak current = 0.0005 distance + 4.1174) is also indicated. The correlation coefficient is 0.46. The average standard deviation of the logarithms of the peak current is 0.15.

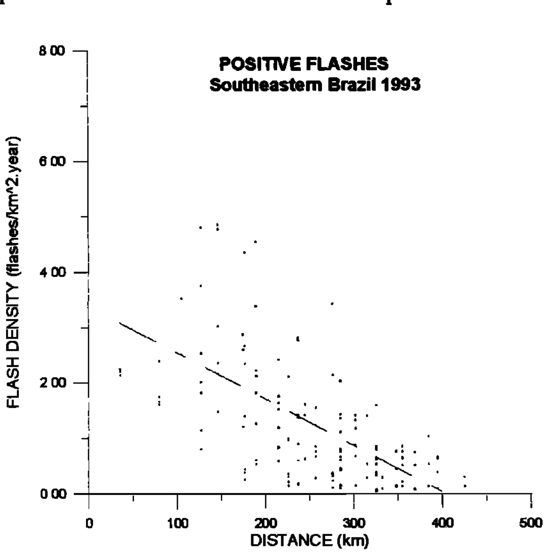


Figure 2. Positive flash density (in flashes/km^2 per year) versus distance (in kilometers) from the geometric center of the system. The best fit line (density = 0.008 distance + 3.378) is also indicated. The correlation coefficient is 0.63.

that most flashes recorded in 1993 were associated with isolated thunderstorms. In addition, there are no surface indications that such storms are severe. Analysis of the relative location of positive and negative flashes for several cases throughout the year did not find any evidence of bipolar patterns typical of mesoscale convective systems with stratiform regions. The diurnal distribution of positive flashes [see *Pinto et al.*, this issue] is also characteristic of isolated thunderstorms. Consequently, there is no evidence supporting the view that the number of low-peak current flashes reported in this study is associated with severe storms. In summary, at present the origin of the high number of positive flashes above 15 kA is not known.

4.2. Peak Current of Positive Flashes

The global geometric mean value of the peak current for positive flashes was found to be 17.8 kA, with individual grid block values varying from 10 kA to 38.9 kA. Neglecting the positive flashes below 15 kA, the global value would be 38.7 kA. In this case, the value is larger than that for negative flashes, a result in agreement with it is expected from the present knowledge about positive flashes.

4.3. Maximum Flash Densities

Considering the discussion above, we are led to conclude that the maximum positive flash density (7.7 flashes/km^2 per year) as well as the maximum total flash density (15.5 flashes/km^2 per year) obtained in this study, should be considered as upper limits to the actual values. Neglecting the positive flashes below 15 kA, these values decrease to 3.9 flashes/km^2 per year and 11.9 flashes/km^2 per year, respectively. The maximum total flash density in this case is approximately the same as the maximum values reported by *Orville and Silver* [1997] in the United States. The maximum flash density, however, remains much larger than the values obtained by *Orville and Silver* [1997]. On the other hand, the maximum negative flash density (9.1 flashes/km^2 per year) should be considered as very close to the real value. This assumption is based on several points. First, most negative flashes have peak current intensities larger than 15 kA. Second, the negative flash density and logarithm of the peak current have no clear dependence on the distance from the grid block to the geometric center of the sensors. Also, this assumption is supported by simple theoretical grounds, in which the normal thunderstorm dipole model causes all intracloud flashes to have

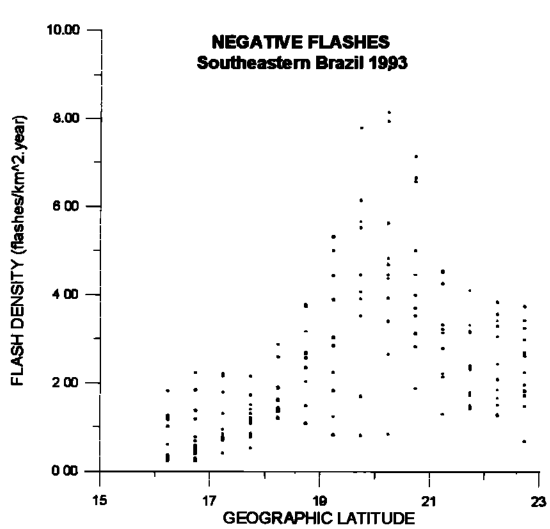


Figure 4. Negative flash density (in flashes/km^2 per year) versus geographic latitude.

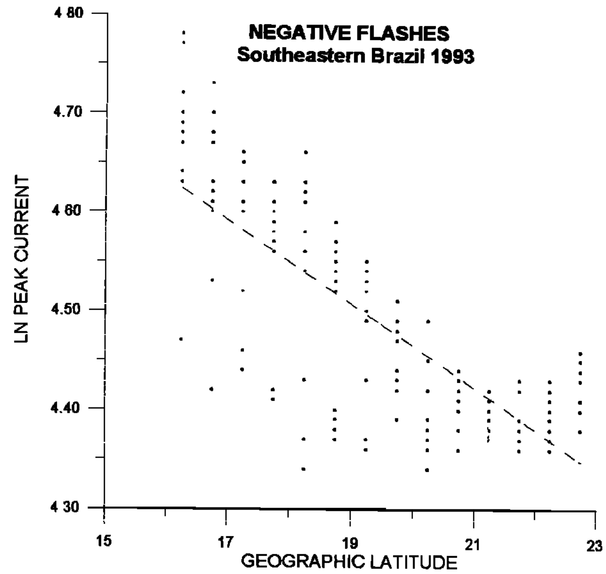


Figure 5. Logarithm natural of the negative flash peak current (in kiloamperes) versus geographic latitude. The best fit line (ln peak current = -0.04 latitude + 5.31) is also indicated. The correlation coefficient is 0.77. The average standard deviation of the logarithms of the peak current is 0.15.

waveforms similar to positive flashes, as well as independent results obtained by similar networks [*Zaima et al.*, 1997]. The maximum negative flash density obtained in this study is very close to the maximum values obtained by *Orville* [1994] and *Orville and Silver* [1997] in the contiguous United States from 1990 to 1995, with a spatial resolution of the same order as the one used in this study. During this period the maximum annual negative flash densities in the United States remained between 11 and 13 flashes/km^2 per year, sometimes occurring in Florida, sometimes in the Midwest [*Orville and Silver*, 1997]. On other hand, the maximum negative flash densities (positive and negative) obtained in this study are larger than the correspondent values obtained by *Orville et al.* [1997] in Papua New Guinea. It is possible that larger flash densities exist in small regions of southeastern Brazil and United States, which cannot be resolved in both studies. On the basis of the thunder day level, it is also probable that larger flash densities exist in other regions of Brazil, where no lightning systems exist.

4.4. Dependence of Density and Peak Current of Negative Flashes on Latitude

Considering that positive flashes are probably contaminated by intracloud flashes, from hereinafter, only negative flashes will be considered. Figure 4 shows the negative flash density as a function of latitude. There seems to be no dependence on this parameter. The results indicate a maximum around 20°S, coincident with the results obtained by flash counters [*Diniz et al.*, 1996]. Also, they indicate that the region southward of the maximum (21°-23°S) has slightly larger flash densities than the region northward of the maximum (16°-18°S). Such a difference is well known from several other observations in the past (flash counters, balloon electric-field data, thunderstorm days) and has been attributed to large-scale meteorological aspects and the local topography [see *Pinto* [1997] and references therein).

Figure 5 shows the logarithm of the peak current as a function of latitude for negative flashes. In this figure (see also Plate 4a) we can see, indicated by a linear fit (correlation coefficient of 0.77), that the lower the latitude the higher the peak current. Such variation is in apparent agreement with the results obtained by *Orville* [1990] in the eastern United States, who found that the peak current of negative flashes increased by almost a factor of 2 from 45°N to 25°N. *Orville* [1990] suggested that the peak current may vary as a function of latitude because of the increasing volume of cumulonimbus clouds and the longer lightning channels at lower latitudes. The increasing volume and longer lightning channels would be the result of higher cloud top and -10° isotherm altitudes at lower latitudes, respectively. In our case, however, we found an increase by about the same factor for just 7° of latitude change (from 23°S to 16°S), instead of 20° change in the case of the data reported by *Orville* [1990]. This fact may indicate that the peak current of negative flashes in different regions tends to increase with latitude at different rates. However, it may also indicate that other aspects are contributing to such a peak current variation. One aspect is related to the regional meteorology. Information provided by the government of the state of Minas Gerais indicates that the north part of the region considered in this study is a semiarid region, with average annul total precipitation around 1000 mm, while in the south, this value is around 1400-1500 mm. Also, the average temperature in the north is 3-4° Celsius higher than that in the south. If these differences are related in some way to the peak current variation, here reported, is not known. A second aspect is related to the altitude. Our analysis, however, did not find such a relationship (see afterward). Another aspect is related to possible reduced network efficiency in the north part of the region studied. An analysis of Plate 4a, however, seems to indicate that it is not the case, at least in terms of the distance with respect to the geometric center of the sensors. In summary, the peak current dependence on latitude for negative flashes supports the existence of small-scale large peak current variations. The reasons for such variations, however, are not clearly identified yet.

4.5. Dependence of Density and Peak Current of Negative Flashes on Altitude and Soil Resistivity

Plate 5 shows an altitude map for the region considered in this study. The map was obtained from the ETOPO5 grid elevation model provided by the National Geophysical Data Center from the National Oceanic and Atmospheric Administration (NOAA). Average altitude values for each grid block vary from 300 m to >1000 m, with a peak value of about 1250 m. This figure indicates that most high-elevation terrains are located below 20°S.

Figure 6 shows the negative flash density versus altitude. There is a slight tendency for the flash density to increase with altitude, in agreement with the results obtained for negative flashes by *Reap* [1986] for the western United States. For the same altitude interval considered in this work, *Reap* [1986] found an increase by about a factor of 2, which is in agreement with the increase found in this work. Such a tendency could be explained by assuming that the thunderstorm frequency increases with altitude. Figure 7 shows the logarithm of the peak current versus altitude for negative flashes. It can be seen that there is no relationship between both. *Robertson et al.* [1941] reported that lightning

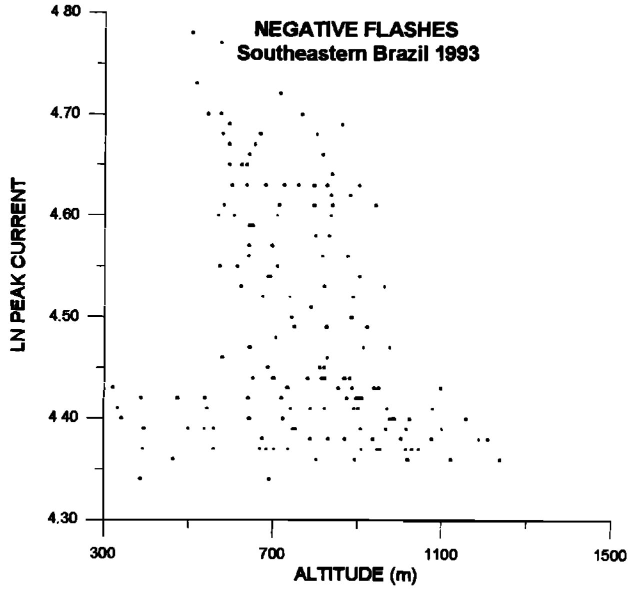


Figure 7. Logarithm natural of negative flash peak current (in kiloamperes) versus altitude (in meters).

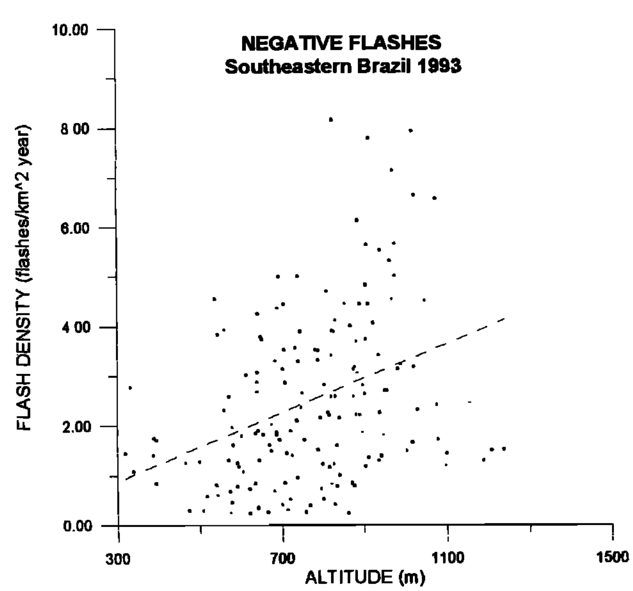


Figure 6. Negative flash density (in flashes/km^2 per year) versus altitude (in meters). The best fit line (density = 0.003 altitude – 0.160) is also indicated. The correlation coefficient is 0.36.

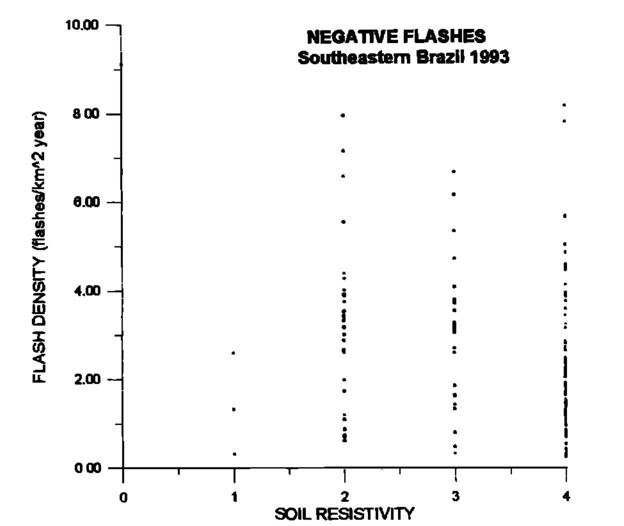


Figure 8. Negative flash density (in flashes/km^2 per year) versus soil resistivity. The values in the horizontal axis indicate the following: 0, very low; 1, low; 2, moderate; 3, high; and 4, very high resistivity.

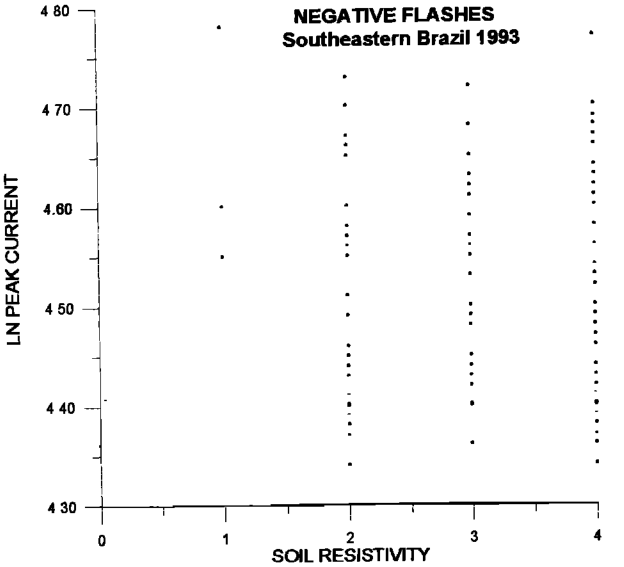


Figure 9. Logarithm natural of negative flash peak current (in kiloamperes) versus soil resistivity. The values in the horizontal axis indicate the following: 0, very low; 1-low; 2, moderate; 3, high; and 4, very high resistivity.

measurements in the Rocky Mountains for altitudes between approximately 2000 m and 4500 m indicated that lightning peak current decreases with altitude. Even though the altitudes associated with these measurements are different from those related to our measurements, it is worth noting that all measurements in Figure 7 above 1000 m show a very low peak current. The decrease of the peak current with altitude could be explained by considering that large altitudes would act to reduce the distance between the negative charge center in the cloud and the ground and, in consequence, to increase the electric field between both. Such a larger field could facilitate the beginning of the flash at small charge centers, producing lower peak-current flashes. Although reasonable, the mechanism above cannot be confirmed by the data in Figure 7. In fact, lower-peak-current values can also be seen below 500 m.

Besides altitude, another aspect that deserves investigation is the soil resistivity variation. In regional studies, faced with the impossibility of adequately making in situ measurements over large regions, resistivities can be inferred from correlated data, such as soil ages and types, lithological formations, landforms, and seasonal climatic variations. Strategically located sites of local resistivity measurements can be used to constrain the regional resistivity map constructed from such data. Thus to define the resistivity in the study area, we have estimated, from a geological map, a resistivity for each block on the basis of the superficial lithology. The few available in situ resistivity measurements in the same area are in agreement with the estimated values, even though they are biased toward high resistivity sites located in crystalline terrains [*Araujo et al.*, 1979]. As a result, Plate 6 shows a map of the approximate soil resistivity sorted in five arbitrary categories going from very low to very high values.

Figures 8 and 9 show the flash density and the logarithm of the peak current of negative flashes versus the soil resistivity. The resistivity is shown in terms of five different groups indicated in Plate 6, here represented by numbers 0 to 4. Again, no relationship is evident, although the grid block associated with the lowest resistivity is coincident with the maximum of the negative flash density. A more detailed analysis, however, should be done, preferentially using smaller grid blocks, to try to verify if the soil resistivity may affect the flash characteristics.

5. Conclusions

About 1.1 million cloud-to-ground lightning flashes were analyzed in southeastern Brazil in 1993 in terms of their geographical distribution. This is the second 1-year continuous study of lightning in the tropics. The main conclusions are as follows:

1. The geographical distribution of negative cloud-to-ground flashes was not correlated with latitude, being apparently dominated by large-scale meteorological aspects and, in minor scale, by the topography, even though no significant relationship with altitude was found. The maximum flash density was 9.1 flashes.km^2 per year and occurs in the same region where the soil resistivity is lowest. This coincidence, however, may be fortuitous, since no significant relationship between lightning parameters and soil resistivity was found. The global mean geometric peak current of negative flashes was 30.9 kA, with variations of a factor of 2 apparently related to the latitude. The peak current shows a slight tendency to decrease at altitudes higher than 1000 m and below 500 m. The lack of a significant relationship between lightning parameters and the Earth's surface-related aspects, such as altitude and soil resistivity, as suggested by the results of this study, however, could be explained by the large uncertainty in quantifying these parameters in association with the large size of the adopted grid blocks. It is possible that assuming smaller grid blocks, with sizes around 10 x 10 km or less, such relationships become apparent. In such cases, however, a data set larger than that considered in this study will be necessary to obtain statistical confident results.

2. The geographical distribution of positive cloud-to-ground flashes seems to be influenced by the location of lightning sensors. The influence can be explained by assuming that the positive flashes are contaminated by intracloud flashes. The values of maximum positive flash density (7.7 flashes/km^2 per year), percentage (36.5%), and geometric mean peak current (17.8 kA) are influenced by such a contamination, not representing the real values in this region of the world. Neglecting positive flashes below 15 kA, assuming that they correspond to intracloud flashes erroneously identified by the system, the correspondent values would be 3.9 flashes/km^2 per year, 23% and 38.7 kA. With the assumption above, the maximum total flash density found in this study would be 11.7 flashes/km^2 per year. At this time, these values are the best estimate of these quantities in southeastern region of Brazil.

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M. A. S. S. Gomes, A. L. Padilha, I. R. C. A. Pinto, O. Pinto Jr., and I. Vitorello, Instituto Nacional de Pesquisas Espaciais - INPE, Av. Astronautas 1758, São José dos Campos, SP,12227-010, Brazil. (osmar@dge.inpe.br.)

A. M. Carvalho, A. Cazetta Filho, J. H. Diniz, Companhia Energética de Minas Gerais – CEMIG, Av. Barbacena 1200, Belo horizonte, MG, 30123-970

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