Thunderstorm incidence in Southeastern Brazil estimated from different data sources

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Abstract

This paper describes a comparative analysis of the thunderstorm incidence in Southeastern Brazil obtained from thunderstorm days observed at two different epochs (from 1910 to 1951 and from 1971 to 1984) and from lightning data provided by the Brazilian lightning location system RINDAT (from 1999 to 2006) and the Lightning Imaging Sensor (LIS) on board the TRMM satellite (from 1998 to 2010). The results are interpreted in terms of the main synoptic patterns associated with thunderstorm activity in this region, indicating that the prevailing synoptic pattern associated with thunderstorm activity is the occurrence of frontal systems and their modulation by the South Atlantic Convergence Zone (SACZ) and topography. Evidence of urban effects is also found. The results are also discussed in the context of practical applications involving their use in the Brazilian lightning protection standards, suggesting that the present version of the Brazilian standards should be revised incorporating RINDAT and LIS data. Finally, the results are important to improve our knowledge about the limitations of the different techniques used to record the thunderstorm activity and support future climatic studies.

1 Introduction

The thunderstorm incidence in a given place can be recorded by different techniques. The first technique used to record thunderstorm activity was to record the number of days per year in which an observer heard at any time of the day, thunder. This technique was called thunderstorm days - TD (WMO, 1953; Rakov and Uman, 2003). This technique has been used since the end of the nineteenth century for different applications (e.g. Changnon and Hsu, 1984; Pinto, 2009; Bielec-Bakowska and Lapikasza, 2009; Wei et al., 2011). One of the main applications of TD is provide information to lightning protection standards through the so-called isoceraunic maps (Rakov and Uman, 2003). Such maps have been extensively used in many national lightning protection standards. More recently, these maps have been replaced by lightning density maps obtained by lightning location systems (LLS) or optical satellite instruments (Diendorfer et al., 2009). Another important application of TD data is study climatic changes in the thunderstorm activity (Pinto and Pinto, 2008).

In the second half of the twenty century other technique to monitor the thunderstorm activity became available, the lightning location systems (LLS). More recently optical lightning sensitive sensors on board satellites have been used to monitor thunderstorm activity on large scale. However, all techniques have limitations. For instance, TD values are subject to limitations related to changes in the operational man-made procedure adopted to make the observations. Also changes in the environment or the local orography around the observational site may influence the maximum distance from the site that thunder is heard. More details about the other limitations are described elsewhere (Changnon and Hsu, 1984). In turn, observations by LLS and optical sensors are subject to changes in the sensor detection efficiency due to variations in ground conductivity, satellite orbit, among others.

This paper describes a comparative analysis of the lightning incidence in Southeastern Brazil obtained from thunderstorm days observed at two different epochs (from 1910 to 1951 and from 1971 to 1984) and from lightning data provided by the Brazilian lightning location system - RINDAT (from 1999 to 2006) and by the Lightning Imaging Sensor (LIS) on board the TRMM satellite (from 1998 to 2010). Previous comparative analyses in Brazil (Pinto and Pinto, 2003) were limited to a smaller number of data sources and data sample. The analysis here is restricted to this region of Brazil due to fact that it is the unique region of the country where thunderstorm day data for two different epochs and RINDAT data are available.

In the Southeastern region of Brazil, the main synoptic patterns associated with thunderstorm activity are believed to be the occurrence of frontal systems (Cavalcanti and Kousky, 2003) and local convection related to topography (Campos et al., 2011), although no detailed study exists. Frontal systems are frequent throughout the whole year, come from Argentina and sometimes are preceded by deep convection, called pre-frontal (Andrade, 2007). Their frequency of occurrence is modulated by many mechanisms, among them the so-called South Atlantic Convergence Zone (SACZ), a prominent band of cloudiness extending from the Amazon region to the subtropical Atlantic Ocean, passing over the Southeastern region (Carvalho et al., 2002), and by blocking anticyclones (Wiedenmann et al., 2002), which in turn are influenced by large scale phenomena such as Southern Oscillation – ENSO (Barros et al., 2002; Wiedenmann et al., 2002). The SACZ is developed when the convection from a cold front is coupled with the Amazonian convection, forming a zone of heavy precipitation oriented northwest-southeast all along Brazil that lasts for several days to weeks.

2 Data sets and Methodology

Three different data sources related to the thunderstorm activity were used in this study. The first set of data comes from man-made TD observations in two different epochs. One corresponds to observations made in the first half of the twentieth century between 1910 and 1951 from a small (53) number of observation sites and the period of observations at different sites varies from 5 to 42 years. These observations were part of a global effort of the World Meteorological Organization (WMO, 1953) to obtain a global map of the thunderstorm activity. In Brazil they were done in all regions of the country. Figure 1 shows the location of the sites for this period in Southeastern region. The other corresponds to observations made between 1971 and 1984, considering a larger number (500) of observation sites. Again, the period covered by the observations changes considerably in different states, varying from 5 to 14 years. Figure 2 shows the location of the sites for this period in the Southeastern region. Most of the observational sites mentioned above are not operational anymore. Only airports still keep recording thunderstorm days at the present time.

The two other datasets used in this study are thunderstorm-related lightning data recorded by two different techniques. One set comes from cloud-to-ground lightning data obtained by the RINDAT network, a LF network that partly covers the Brazilian territory, from 1999 to 2006 (Pinto et al., 2007). This information is believed to be the most accurate available information to describe the thunderstorm activity in a given region and in this study is considered as a ground true. Figure 3 shows the location of the lightning sensors in the Southeastern region. The sensors are LPATS and IMPACT sensors and the baseline is typically 350 km. The performance of RINDAT network was evaluated extensively in the past (for a review see Pinto, 2009). For the Southeastern Brazil, the average RINDAT flash detection efficiency is thought to be approximately 85%.

The third dataset is total lightning data observed by the Lightning Imaging Sensor (LIS), an optical sensor on board the Tropical Rainfall Measuring Mission (TRMM) satellite, obtained from 1998 to 2010 (Christian et al., 1999). Due to the orbital characteristics of the TRMM satellite, LIS data needs a long period of integration to provide a reliable pattern. In this study, 13 years of data were used, although a definitive pattern was obtained after 10 years of data. LIS data are corrected by local time detection efficiency and view time dependence on latitude (Naccarato et al., 2008) and converted to cloud-to-ground data assuming an intracloud to cloud-to-ground ratio of 4, which is obtained by comparing RINDAT and LIS flash data (Pinto et al., 2003). This value, however, can change at different places due to the predominance of different types of thunderstorms at different locations; in consequence, the assumption of a constant ratio should be seen as a first approximation. In particular, in the Southern region of Brazil where a larger number of mesoscale convective systems occurs compared to the other regions makes, this ratio is probably higher.

3 Results and Discussion

Figures 4 and 5 show maps of the average annual number of thunderstorm days for a resolution of approximately 50 km (0.5° x 0.5º grid cell). Here, we have used a 0.5° x 0.5º grid cell for plot thunder records, to avoid a high interpolation error due to the limited number of stations. Figure 4 corresponds to the observations made between 1910 and 1951 and Figure 5 to observations made between 1971 and 1984. We assume here that the interannual variability is negligible, because for some cells the relative differences in Figures 4 and 5 are higher than 100%. Those differences are too high to be associated only to interannual variations.

Figure 6 shows data obtained from RINDAT from 1999 to 2006 presented in two different ways. Figure 6a shows cloud-to-ground lightning flash density in flashes/km^2.year for a 10 km resolution, the best resolution that can be obtained considering the time period. Data are not corrected for the detection efficiency of the system. Figure 6b shows RINDAT data converted to thunderstorm days in the same resolution of Figures 4 and 5 (50 km), assuming that if lightning is recorded in a circle of radius of 15 km (the typically range of thunder audibility - Rakov and Uman, 2003) centered in a given cell in a given day, this day is classified as a thunderstorm day in that cell**.** Figure 6c shows a comparison of thunderstorm days computed by thunder observations and estimated from RINDAT data for three different ranges: 5, 10 and 15 km in the Guarulhos International Airport in São Paulo, supporting that 15 km range of thunder audibility as a reasonable value. The same analysis was done for the other 8 airports in the Southeast Brazil where thunderstorm observations are still done routinely obtaining values between 10 and 15 km.

Finally, Figure 7 shows the cloud-to-ground flash density obtained from LIS data in the Southeastern Brazil for a resolution of approximately 50 km (0.5° x 0.5º grid cell), after correcting the data for detection efficiency and view time and converting total to cloud-to-ground flash as explained previously. The resolution of LIS data is limited by the view time of the satellite and the time period of the data.

From the analysis of Figures 4 to 7 several aspects related to physical processes responsible for the thunderstorm activity are evident. First, all figures show a systematic decrease from the lower left corner to the upper right corner. This variation is consistent with the location of the SACZ, which develops oriented northwest-southeast along the Southeastern region and lasts for several days in the summer causing deep convection. Second, from the high resolution data in Figures 6a it can be seen that the thunderstorm activity is also modulated by the orography, which is shown in Figure 8. The influence of orography has been discussed also by Bourscheidt et al. (2008). Third, also from Figure 6a it can be seen a large spot (the region in white in the state of São Paulo) of high flash density coincident with the location of the city of São Paulo, the largest city of the country with population larger than 10 million people, suggesting that the urban activity is affecting the thunderstorm activity (Naccarato et al., 2003; Pinto et al., 2004; Farias et al.; 2008; Bourscheidt et al., 2012). The effect of orography and urban area are not evident in the low resolution data in Figures 4, 5, 6b and 7. In general, these results suggest that the prevailing synoptic pattern associated with thunderstorm activity in the Southeastern Brazil is the occurrence of frontal systems and their modulation by the SACZ and the orography, and in the particular case of the city of São Paulo by the urban activity.

From the analysis of Figures 4 to 7 also a practical relevant result is evident. At present time, the observations of thunderstorm days shown in Figures 4 and 5 are used to produce the isoceraunic maps presented in the Brazilian Standard for protection of structures against lightning (ABNT NBR-5419). The isoceraunic values in the maps are converted to flash density and used in the standards to define the level of protection. In order to test if these maps represent accurately the thunderstorm spatial distribution in this region, a linear correlation analysis between these maps and RINDAT and LIS data was performed. Figure 9 shows the correlation of the RINDAT data converted as described above with the data Figures 4, 5 and 7. The highest correlation is found between thunderstorm days computed from

RINDAT and LIS flash counts. This result suggests that LIS data can replace thunderstorm days in the Brazilian standards.

4 Conclusions

The results of this study of the thunderstorm activity in the Southeastern Brazil indicate that:

- the prevailing synoptic pattern associated with thunderstorm activity in the Southeastern Brazil is the occurrence of frontal systems and their modulation by the SACZ and the orography, and in the particular case of the city of São Paulo by the urban activity;
- the thunderstorm day values obtained from 1971 to 1984 with a large number of observational sites represent quite well the thunderstorm spatial distribution in the Southeastern Brazil as observed by lightning data obtained by the Brazilian lightning location system - RINDAT from 1999 to 2006. In contrast, the thunderstorm day values obtained from 1910 to 1951 with a lower number of observational sites fail to represent this spatial distribution. This result suggests that the Brazilian Standard for protection of structures against lightning (ABNT NBR-5419) should be revised;
- the better correlation of RINDAT data with LIS data than with thunderstorm day data suggest that LIS data could be used to replace the past thunderstorm days in the Brazilian standards for lightning protection.

Finally, the results are important to improve our knowledge about the limitations of the different techniques used to record the thunderstorm activity and support future climatological studies.

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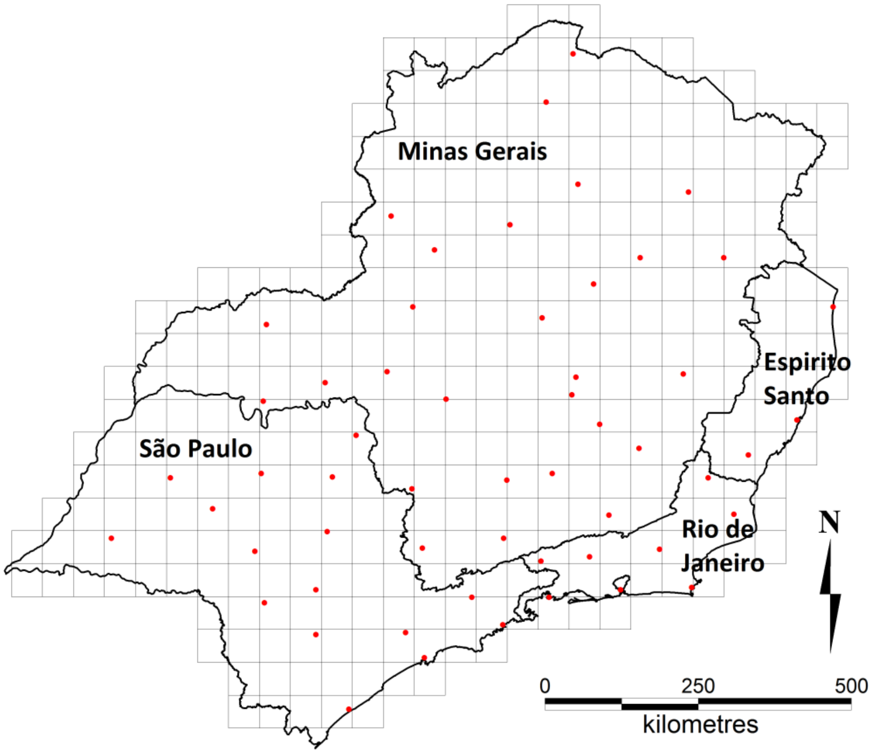


Figure 1. Location of the 53 observation sites in the Southeastern Brazil used to record thunderstorm days from 1910 to 1951. The names of the states are also indicated.

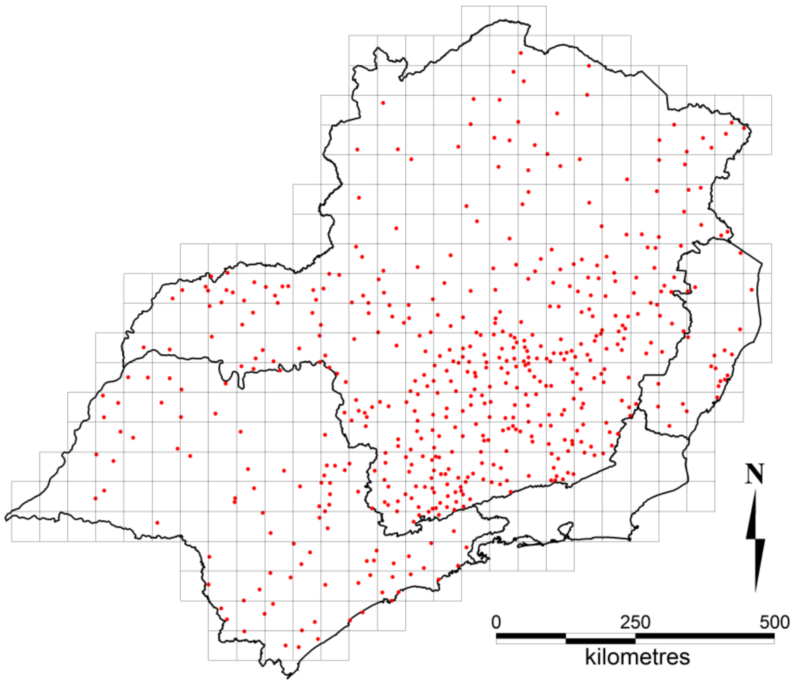


Figure 2. Location of the 500 observation sites in the Southeastern Brazil used to record thunderstorm days from 1971 to 1984.

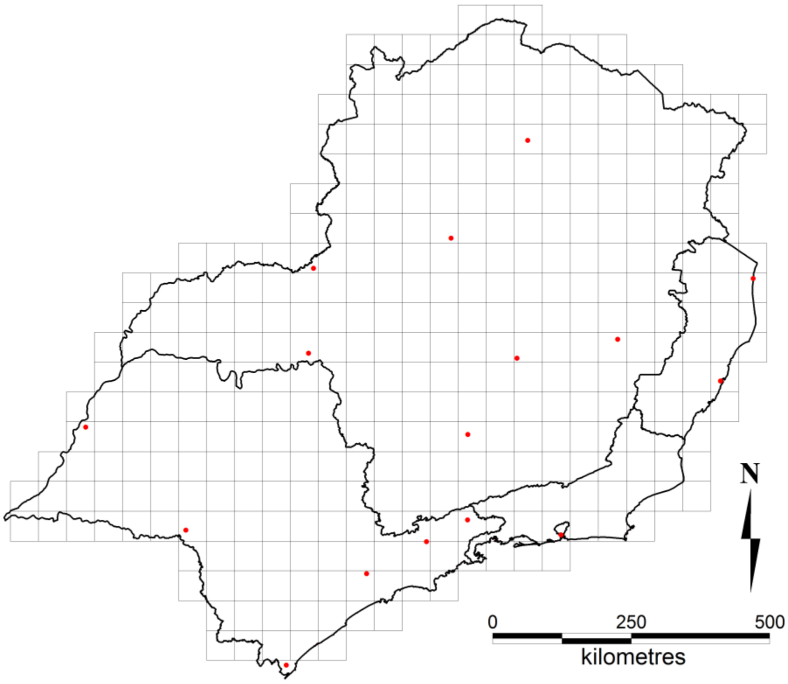


Figure 3. Location of the lightning sensors of RINDAT for the period of study in the Southeastern Brazil.

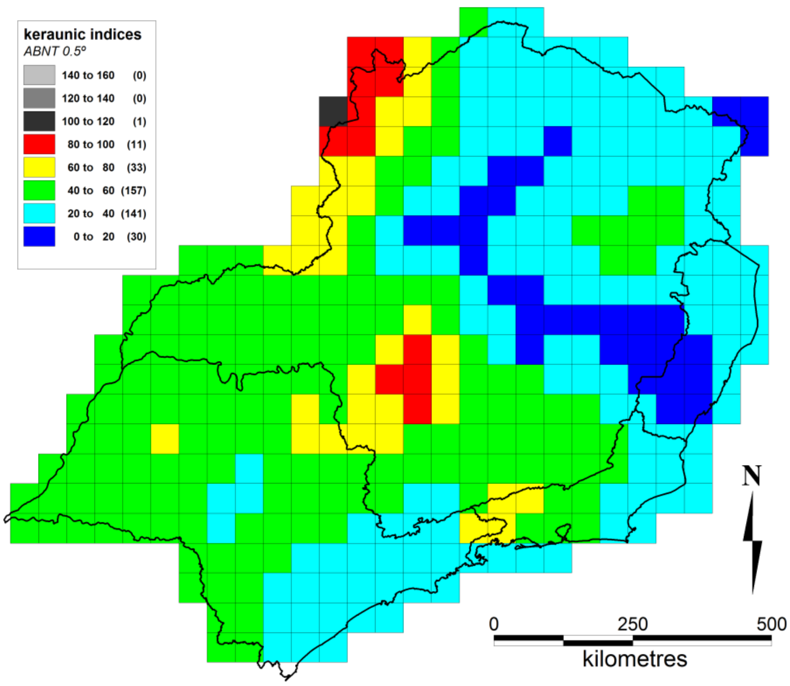


Figure 4. Map of the average annual number of thunderstorm days in the Southeast region of Brazil

based on observations between 1910 and 1951.

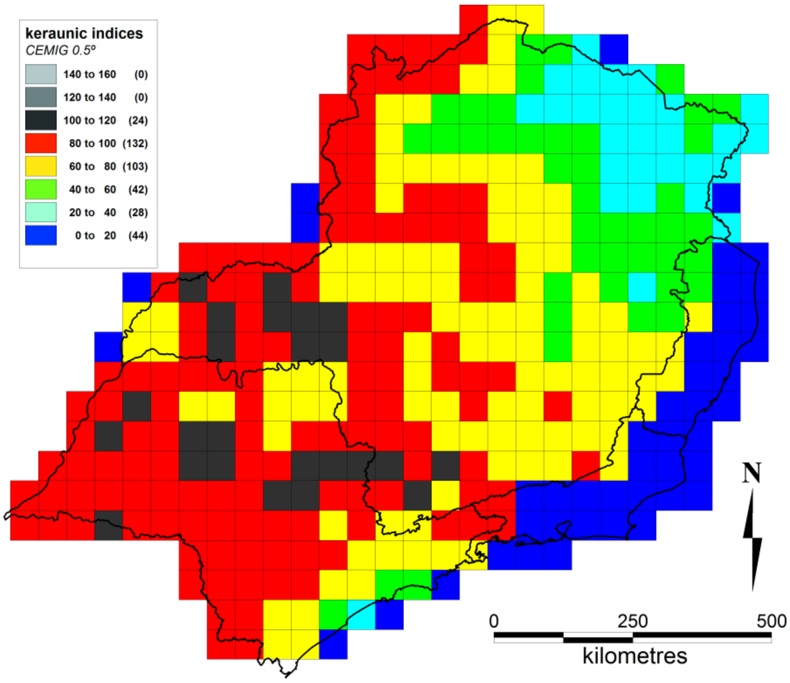
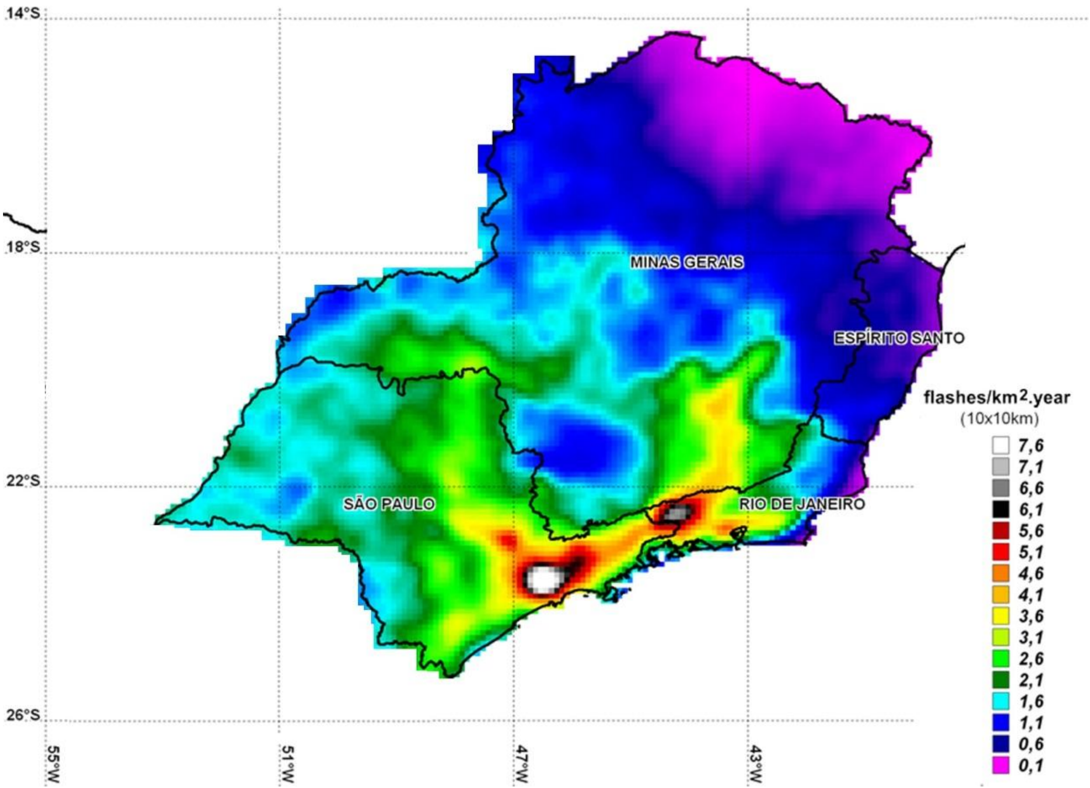
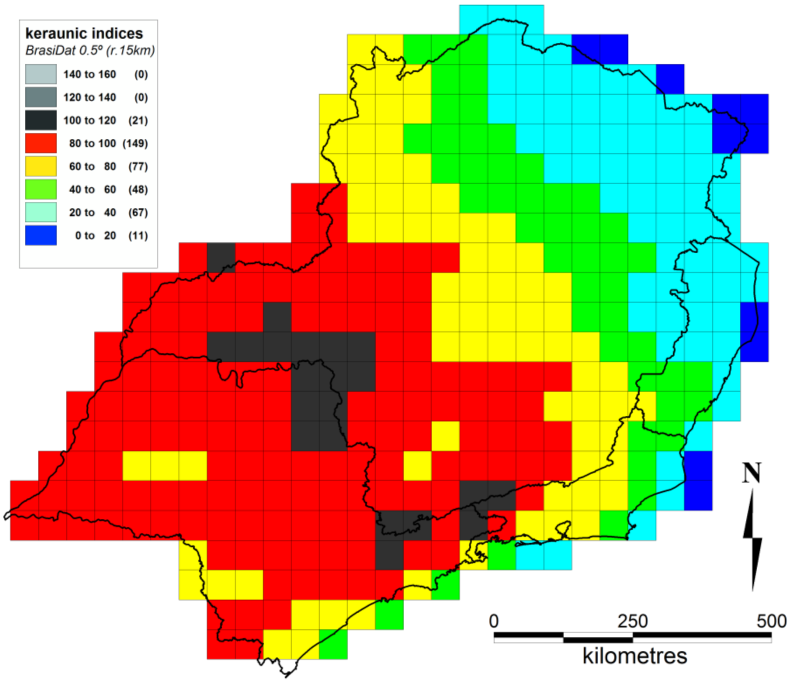


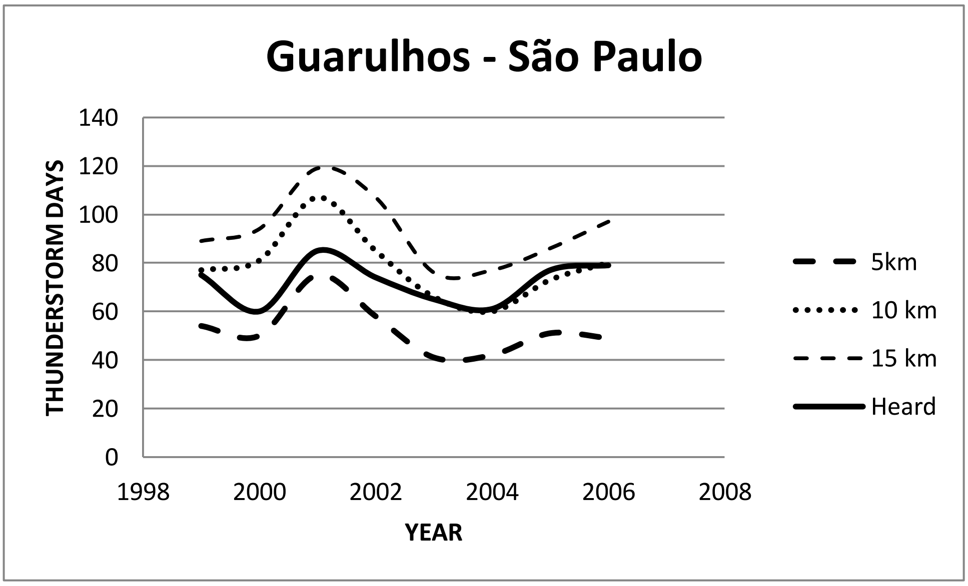
Figure 5. Map of the average annual number of thunderstorm days in the Southeast region of Brazil based on observations between 1971 and 1984.



(a)



(b)



(c)

Figure 6. Map of the (a) average annual flash density in flashes/km^2.year and (b) average annual number of thunderstorm days in the Southeast region of Brazil based on RINDAT lightning data obtained from 1999 to 2006; (c) Thunderstorm days in the Guarulhos International Airport in São Paulo based on man-made observations (heard) and estimated from RINDAT for three different ranges: 5, 10 and 15 km.

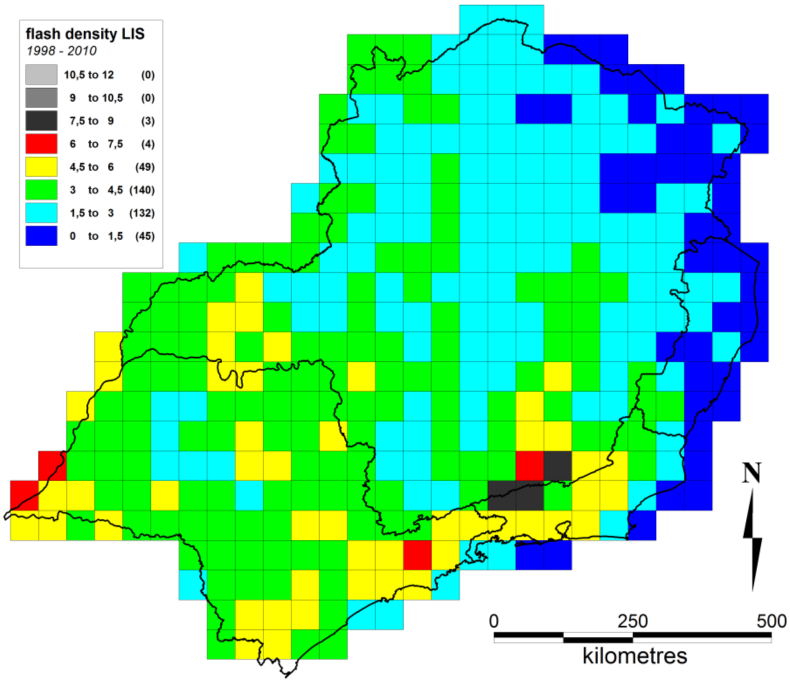


Figure 7. Map of the cloud-to-ground flash density in the Southeast region of Brazil based on lightning LIS data obtained from 1998 to 2010.

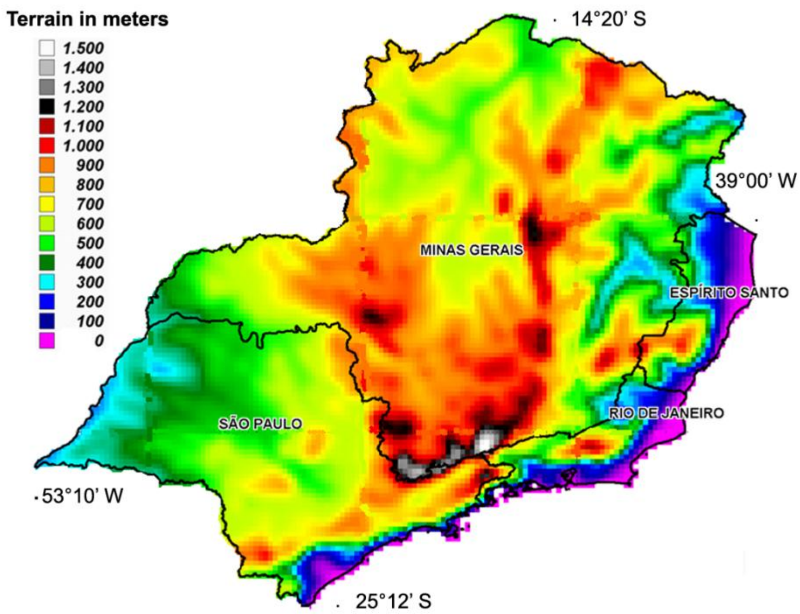
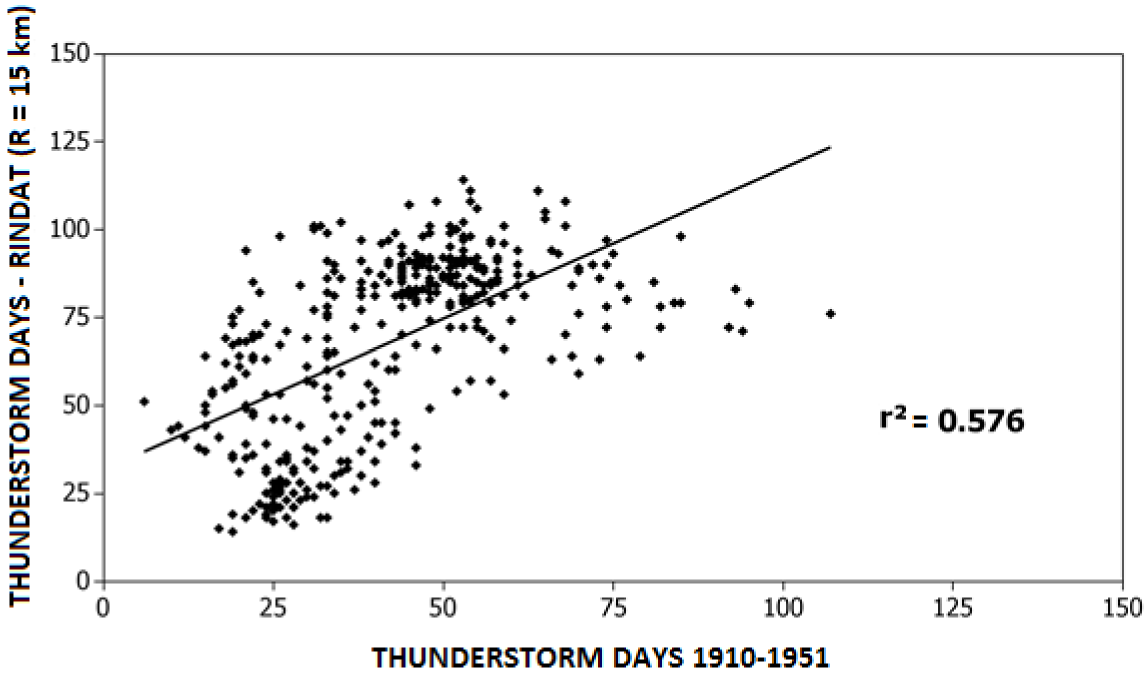
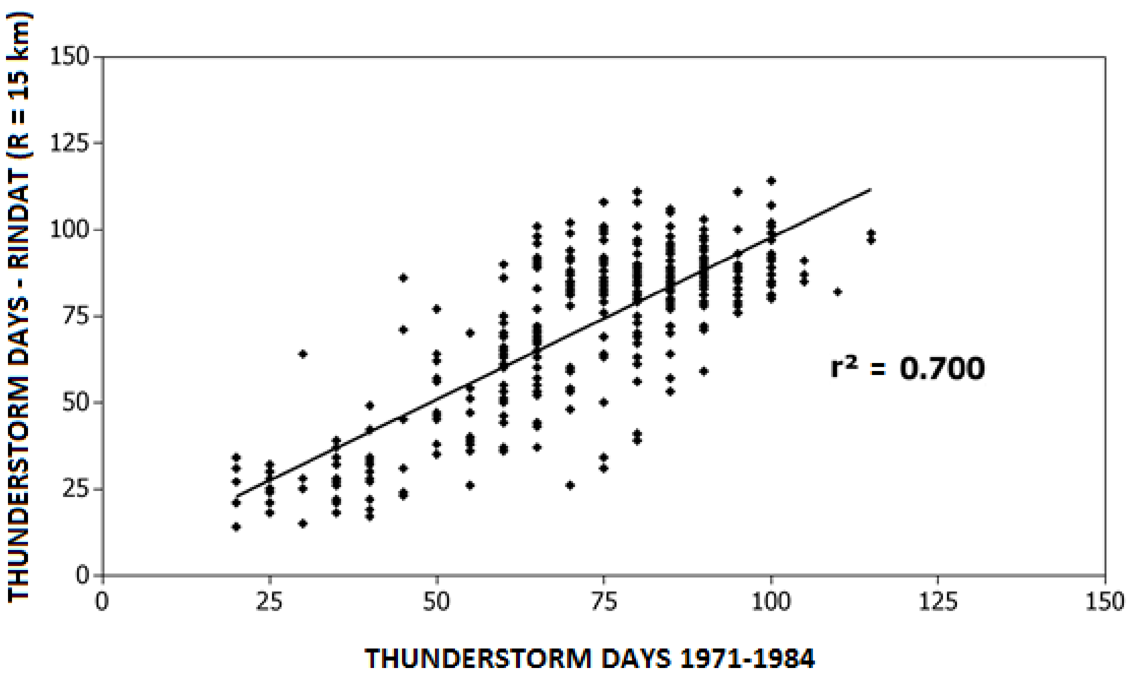


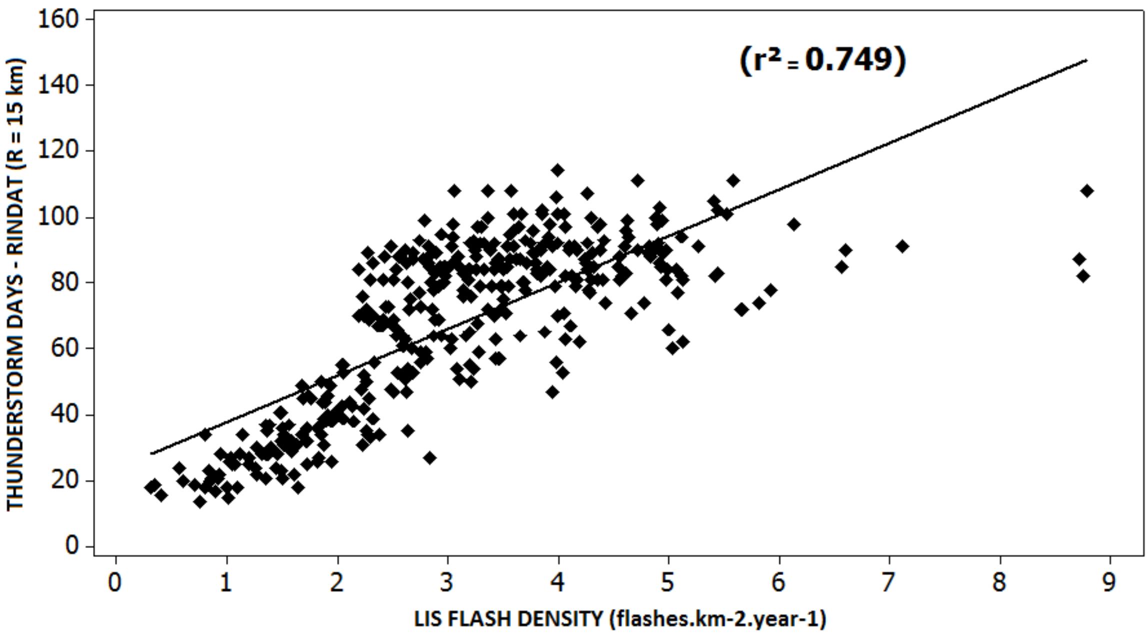
Figure 8. Map of altitude for the Southeastern Brazil.


THUNDERSTORM DAYS - RINDAT (R = 15 km)
150
125
100
75
50
25
0
0
25
50
75
100
125
150
THUNDERSTORM DAYS 1910-1951
r^2 = 0.576

(a)


THUNDERSTORM DAYS - RINDAT (R = 15 km)
150
125
100
75
50
25
0
0
25
50
75
100
125
150
THUNDERSTORM DAYS 1971-1984
r^2 = 0.700

(b)



(c)

Figure 9. Scatter plot of the correlation between RINDAT data converted to thunderstorm days with: (a) thunderstorm days from 1910 to 1951 (Figure 4); (b) thunderstorm days from 1971 to 1984 (Figure 5); (c) flash density from LIS (Figure 7). In all plots the value of the correlation coefficient (r) is indicated. All data have a resolution of approximately 50 km (0.5° x 0.5º grid cell).