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ABOUT SENSITIVITY OF CLOUD-TO-GROUND LIGHTNING ACTIVITY TO SURFACE AIR TEMPERATURE CHANGES AT DIFFERENT TIME SCALES IN THE CITY OF SAO PAULO, BRAZIL

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1. INTRODUCTION

Even though the lightning activity is a result of microphysical and termodynamics nonlinear processes acting through the entire troposphere, being influenced by many meteorological variables, it is well established that it is very sensitive to variations in the surface air temperature at many temporal scales (Williams, 1992, 1994, 1999, 2005).

In terms of temporal scales, lightning is generally more prevalent on average in the afternoon than at night and in the summer than in the winter, in direct response to variation in the solar insolation. It is also generally expected that global lightning activity tends to increase at climate scale in response to global warming (Williams, 1992). However, at present time there do not appear to be any long term trends in the lightning activity (Price and Asfur, 2006b; Markson, 2007), although many recent studies indicate a high positive correlation between surface air temperature and lightning activity (Williams et al., 2005; Price and Asfur, 2006a; Sekiguchi et al., 2006). The lack of a long term trend in the lightning activity may in part explain why there is no specific reference to future changes in lightning activity in the last IPCC report (IPCC, 2007). In part, this fact is a result of the lightning spatial distribution, which indicates that lightning is on average considerably more frequent over warmer land areas than over the sea and in the tropics than in the temperate and polar regions, while the global warming is more pronounced at high latitudes (IPCC, 2007). If on the one hand no trends are observed in experimental data, on the other hand most climate models predict an increase in the lightning activity (for a review, see Schumann and Huntrieser, 2007).

In a global perspective, the lightning sensitivity to global surface air temperature changes has been estimated from the analysis of lightning data obtained by satellites (Reeve and Toumi, 1999; Ming et al., 2005), lightning-related thunderstorm day records (e.g. Changnon, 1988, 2001), lightning-related upper-tropospheric water vapor (Price and Asfur, 2006), lightning-related global atmospheric circuit ionospheric potential (Markson, 2007, Williams, 2007) and lightning-related Schumann resonance intensity changes (Williams, 1992; Sekiguchi et al., 2006. However, the observational analyses are limited to the still short duration period of data (satellite lightning data and Schumann resonance data), the low accuracy of data over an extended period (thunderstorm days and upper-tropospheric water vapor data) or to the low sensitivity of the data to lightning changes (ionospheric potential data). The lightning sensitivity to global surface air temperature changes can also be estimated from global general circulation models of the atmosphere (e.g. Price and Rind, 1994), assuming an empirical relationship between lightning activity and a model parameter. However, the models still have many limitations. For instance, the models should be capable to consider high spatial resolution to resolve convective activity and to include atmosphere-ocean and photochemical-related processes. In addition, they also need to include detailed surface emissions and heigh-dependent meteorological fields. At the present time, however, many of these aspects are not well established. For instance, there is a lack of more complete information about the NOx production by different sources and tropospheric meteorological data, mainly in the tropical region (IPCC, 2007). Such limitations cause a considerable variation in the predictions of such models, so that no definitive conclusions concerning the future impact of the global temperature changes on the lightning activity can be reached. Finally, the lightning sensitivity to global surface air temperature changes can also be estimated based on physical arguments (Williams, 2004). They suggest that a weaker sensitivity of global lightning at longer time scales in response to a convective adjustment.

In a local perspective, in turn, the temporal variations of the lightning activity are actually more complex, since local aspects may be as important as global aspects. Many local aspects could be important, among then changes in the local circulation of air masses in response to teleconnections, such as El Niño-related processes, and changes related to urban effects, such as the heat island. These aspects may affect differently the lightning activity at different time scales, so that the lightning sensitivity to local surface air temperature changes may be different from that at global scale.

In this paper cloud-to-ground (CG) lightning data collected by the Brazilian Lightning Detection Network (BrasilDat) from 1999 to 2006 were analyzed to investigate the lightning sensitivity to surface air temperatures in the city of São Paulo, Brazil. This region was chosen by two reasons: first, the very high lightning activity (peak of 17 flashes.km-2.year-1); and second, the observed and documented increase in the surface air temperature in the last decades (Cabral and Funari, 1997). Both aspects are apparently related to the existence and growing of large urban area of São Paulo in the last decades and the heat island effect associated with it (Naccarato, 2003). Similar aspects have been observed in Hong Kong (Kai-hing, 2003).

2. LIGHTNING AND TEMPERATURE DATA

Data from the Brazilian Lightning Detection Network (BrasilDat) from 1999 to 2006 in the city of São Paulo were used in this analysis to investigate the temporal sensitivity of lightning activity to surface air temperature changes. The data were corrected by a detection efficiency model to consider changes in the network configuration during the period of analysis, even though for the region of the city of São Paulo the changes in the network configuration produce very small changes in the detection efficiency. Yearly, monthly and daily time scales were considered. The network consists basically of several sensors, which determine the angle to the lightning stroke at the sensor location and/or the time of the lightning event, and a processing unit, which calculates stroke characteristics like the strike point location and time, peak current, and others. For a comprehensive description of lightning locating techniques, see for example, Cummins et al. (1998a, b) and Rakov and Uman (2003). Figure 1 shows the configuration of the BrasilDat network at the period of this analysis and a map of flash density in the region of the city of São Paulo, where the present analyses were performed. More details about BrasilDat can be found in Pinto (2003, 2005), Pinto and Pinto (2003) and Pinto et al. (1999a, b; 2003; 2006a,b, 2007). Figure 2 shows a map of the flash density in the city of São Paulo for a spatial resolution of 1 km x 1 km in the period of the study. The regions in white in the figure represent values of flash density larger than 11 flashes.km-2.year-1.

The temperature data correspondent to daily means were obtained from three different surface meteorological stations in the city of São Paulo located at Água Funda and Mirante de Santana (Cabral and Funari, 1997) and at the University of São Paulo (private communication). The data were also validated comparing them with data from other stations (CETESB, 2005).

3. RESULTS AND DISCUSSION

2.1 Yearly variation of the lightning activity

Although thunderstorm day data (TD) are available for the city of São Paulo for a long time period (Nogueira Filho et al., 2002), the usual low accuracy of this type of data (Changnon, 2001) avoid that any statistical significant result can be obtained. For this reason, the yearly variation of the lightning activity was investigated based only on the numbers of flashes detected by BrasilDat.

Figure 3 shows the yearly numbers of flashes observed by BrasilDat (divided by 1000) and surface air temperatures from 1999 to 2006 in the city of São Paulo. It can be observed a reasonable agreement between the yearly number of flashes and the temperature values.

Figure 4 shows the relationship between the yearly number of flashes (divided by 1000) detected by BrasilDat and the surface air temperature in the city of São Paulo from 1999 to 2006. A linear fit and its correlation coefficient are indicated, as well as the standard deviations. In this figure, it was assumed that the standard deviations of the all values can be represented by the standard deviation of the TD values from 1980 to 2006 (13% of the average), considering that the yearly values of the number of flashes have no individual standard deviation associated with them. The standard deviations in the temperature data were calculated based on the data for the three stations and found to be very low, since the data are very well correlated. From the linear fit, it was obtained an average increase in the number of flashes by 39% for one degree of temperature.

2.2 *Monthly variation of lightning activity*

Figure 5 shows the average monthly numbers of flashes observed by BrasilDat divided by 1000 and surface air temperatures from 1999 to 2006 in the city of São Paulo. The data were obtained averaging the monthly number of flashes for each year. Both show the typical seasonal variation with higher values during the summer and lower values during the winter, with intermediate values at the other seasons.

Figure 6 shows the relationship between the average monthly number of flashes (divided by 1000) detected by BrasilDat and the surface air temperature in the city of São Paulo from 1999 to 2006. Only data from October to March are considered in Figure 6 because during the winter there is almost no lightning in the city of São Paulo. A linear fit and its correlation coefficient are indicated in the figure, as well as the standard deviations of the average monthly number of flashes. From the linear fit, it is obtained an average increase in the number of flashes by 41% for one degree of temperature.

2.3 *Daily variation of lightning activity*

Figure 7 shows the average hourly numbers of flashes observed by BrasilDat and surface air temperatures from 1999 to 2006 in the city of São Paulo. The data were obtained averaging the hourly number of flashes for each year. Both show the typical daily variation with higher values during afternoon and lower values during the morning.

Figure 8 shows the relationship between the average hourly number of flashes detected by BrasilDat and the surface air temperature in the city of São Paulo from 1999 to 2006. Only data from 12:00 LT to 24:00 LT are considered in Figure 8 because during the morning hours there is almost no lightning in the city of São Paulo. A linear fit and its correlation coefficient are indicated in the figure, as well as the standard deviations of the average hourly number of flashes. From the linear fit, it is obtained an average increase in the number of flashes by 29% for one degree of temperature.

4. DISCUSSION AND CONCLUSIONS

Recently, Williams (1994) has made a very comprehensive review about the sensitivity of global lightning activity to variations in the global surface air temperature at many temporal scales. After revised the scarce information available on this topic he suggested that the lightning sensitivity to temperature appears to diminish at the longer time scales. The suggestion was based mainly on lightning-related information and not on quantitative lightning data, mainly for longer time scales. Williams (1994) claimed that this behavior might be explained by convective adjustment. However, it was not investigated if this adjustment should also be expected at local basis.

The study presented above is the first to investigate in details the sensitivity of the CG lightning activity on surface air temperature changes at different time scales in a local perspective and in a large urban area (the city of São Paulo). The results shown in Figures 4, 6 and 8 suggest the lightning activity increases with the increase in the temperature, with a sensitivity of 39 %, 41 % and 29 % per degree centigrade for yearly, monthly and daily time scales, respectively. Considering the statistical limitations of the data (expressed by the standard deviations in these figures), these values seem to indicate that the lightning sensitivity to temperature changes in an urban area is almost constant for different time scales, in contrast with it is expected globally (Williams, 2004). If the same happens at other large cities remains to be investigated.

Clearly, more research should be done in order to better understand the relationship between lightning and surface air temperatures at different time scales, contributing also to the effort to understand the impact of the global warming on the local and global lightning activity. The paper should end with a section of no more than 300 words summarizing the results of the presentation.

ACKNOWLEDGEMENTS

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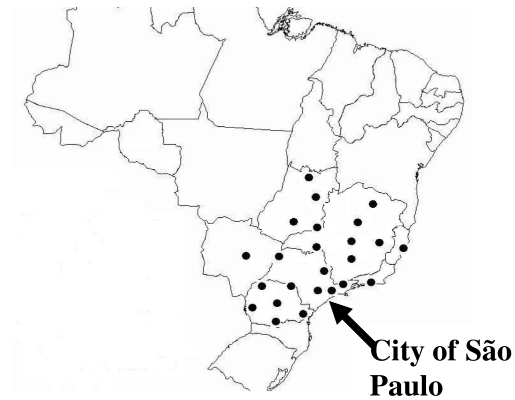


Figure 1. Map of Brazil indicating the configuration of the BrasilDat network at the period of this analysis and a map of flash density in the region of the city of São Paulo (in the inset), where the present analyses were performed.

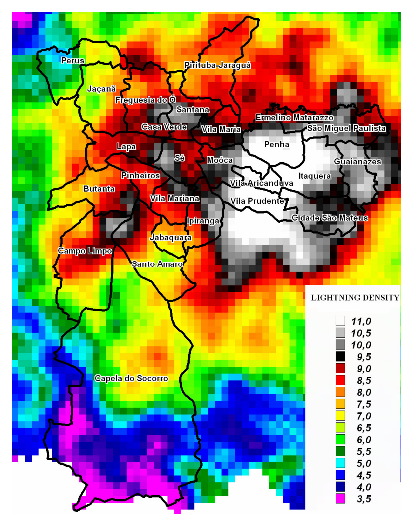


Figure 2. Map of flash density (in flashes.km-2.year-1) in the city of São Paulo for a spatial resolution of 1 km x 1 km in the period of the study. The regions in white represent values of flash density larger than 11 flashes.km-2.year-1.

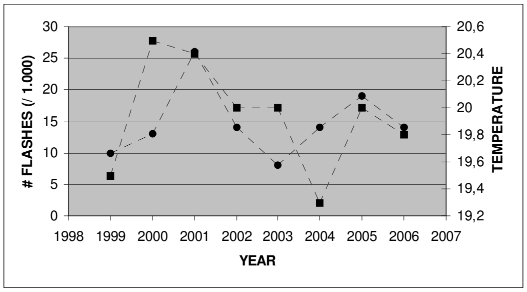


Figure 3. Yearly numbers of flashes observed by BrasilDat divided by 1000 (circles) and surface air temperatures (triangles) from 1999 to 2006 in the city of São Paulo.

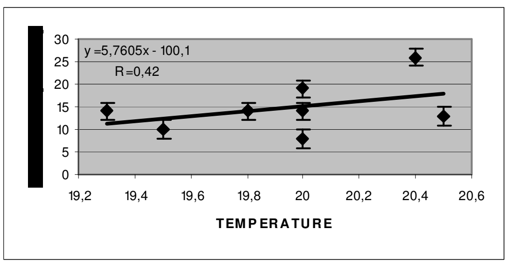


Figure 4. Relationship between number of flashes (divided by 1000) and surface air temperature from 1999 to 2006 in the city of São Paulo. A linear fit and its correlation coefficient are indicated, as well as the standard deviations calculated based on the TD values.

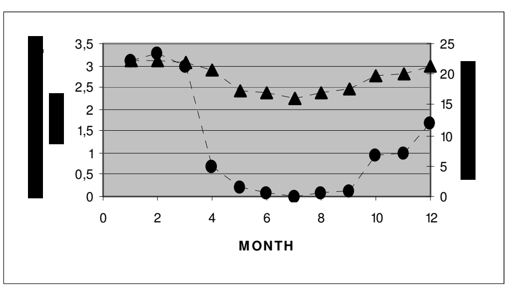
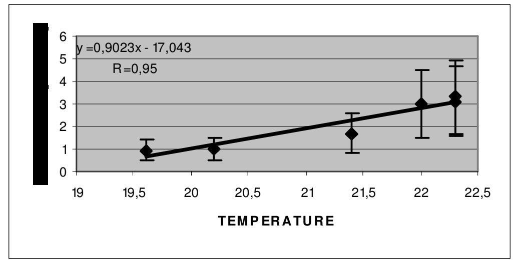


Figure 5. Average monthly numbers of flashes observed by BrasilDat divided by 1000 (circles) and surface air temperatures (triangles) from 1999 to 2006 in the city of São Paulo.



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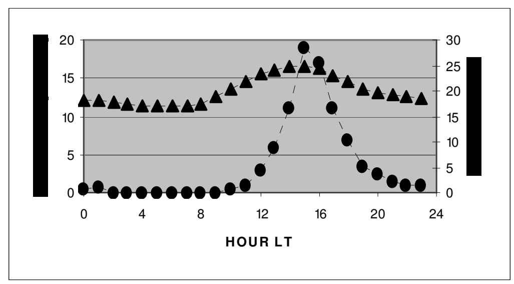

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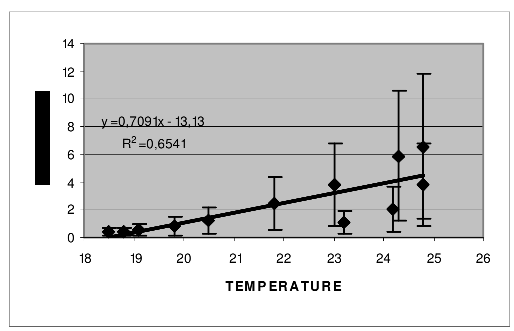

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