The Spatial-Temporal Relationship between Cloud-to-Ground Lightning and Precipitation Distributions in the State of São Paulo

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ABSTRACT: This work analyzes and compares the cloud-to-ground (CG) lightning and precipitation distribution characteristics over the state of São Paulo, Brazil. For this, we used CG lightning data provided by the Brazilian Lightning Detection Network (BrasilDat) and precipitation estimates from the 3B42_V6 TRMM rainfall product, both for a 6-year period (2004–2009), with a 25 km spatial resolution and daily temporal resolution. In summary, the results show that the annual and seasonal behaviors are similar, with the maximum lightning occurrence and precipitation located in eastern São Paulo state and the principal contribution from the summer season. The principal CG lightning density is more strongly associated with those with negative polarity (around 13 per year) than positive polarity one (around 2.4 per year) in this region. This superiority is also noticed over the course of the seasons, especially during the summer. On average, over the metropolitan area of São Paulo (SP_Grid, with 1° x 1° resolution), the annual cycle of precipitation and CG lightning density has similar features, however, the opposite happens with the CG lightning current peak, with its maximum occurring during the winter. On SP_Grid, during the summer, there is more rain and lightning occurrence, but less intense, CG lightning (smaller CG lightning current peak). On the other hand, in winter there is less rain and fewer, but more intense, CG lightning.

1. INTRODUCTION

The state of São Paulo, located in southeastern Brazil, is characterized by having a low and middle latitude climate (NIMER, 1989), and it is the home of the largest urban center in Brazil, the São Paulo Metropolitan Region (SPMR). Moreover, local factors such as the sea breeze and topography (such as the Sea and the Mantiqueira Mountains) in the eastern part of the state, are important local factors capable of intensifying severe weather in this region. In this way, the precipitation over the State of São Paulo is associated with several factors, ranging from the local to global scale. The major atmospheric systems associated with rainfall over the state are: the South Atlantic Convergence Zone (SACZ), frontal systems, sea breezes and local convection, responsible for localized rainfall as a result of surface heating and orographic sources (Reboita et al., 2010).

The processes of cloud electrification and lightning production depend on a complex interaction between cloud microphysics and dynamics, characteristics strongly associated with the type and location of storms and large-scale weather conditions (Gungle and Krider, 2006; Mattos and Machado, 2011). Precipitation plays a important role in the formation and maintenance of cloud electrification, from small to large spatial scales (Macgorman and Rust, 1998). Several issues are raised, for example, how are lightning related to rainfall at

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various spatial and temporal scales? This study aim to analyze the relationship between the precipitation space-time characteristics and CG lightning properties in the state of São Paulo and the SPMR. With this, we seek to understand the possible prognostic role of CG lightning in rainfall occurrence over large urban centers.

2. DATA AND METHODOLOGY

This work used CG lightning data provided by the Brazilian Lightning Detection Network (BrasilDat) and precipitation estimates from the 3B42_V6 Tropical Rainfall Measuring Mission (TRMM) rainfall product, both with a 25 km spatial resolution and daily temporal resolution and for a 6-year period (2004-2009), and topography from the Shuttle Radar Topography Mission (SRTM) with a spatial resolution of 90 meters (not shown).

Initially, this study focused on the entire state of São Paulo (southeastern Brazil), and both spatial and temporal characteristics of CG lightning and precipitation were analyzed. The second part of the study focused on an area (1° x 1°) in the SPMR (SP_Grid), where the maximum density values of CG lightning are located.

3. RESULTS

3.1 Spatial-temporal mean distributions

Figure 1 shows the distribution of annual average (2004-2009) precipitation and CG lightning (number and current peak) in the entire state of Sao Paulo at a resolution of 25 km. In general, the precipitation (Figure 1a) was fairly uniform over the state, with average annual totals between 1400 and 2000 mm and the maximum located in the southeast and northeast sectors, mainly in higher elevation regions of the state. Seasonally, despite showing similar spatial patterns, the large part of these annual values came mainly from the summer season. The winter period contributed the least to the annual accumulated precipitation (figures not shown).

It can be noted clearly that the highest annual average of CG lightning density (18-20/km^2*year), across the state concentrated around the SPMR (Fig. 1b). On the other hand, the most intense current peak (Fig. 1c) values were found in the western part of the state, reaching an average of 30 kA/year, while the precipitation was 1400 mm year^{-1} (Fig. 1a). The urban effect (aerosol plus heat island) over the SPMR combined with topography and mesoscale circulations could be important factors contributing to these characteristics. Rodriguez et al. (2010) found stronger air convergence from the northwest and southeast on thunderstorm days over the SPMR and Naccarato et al. (2003) and Farias et al. (2009) have shown that the urban pollution and thermodynamic aerosol effect is important in intensifying thunderstorms, of which the second seems be the major component. It is important to discuss that the density of -CG lightning (reaching 13 years^{-1}) was larger than that of +CG lightning (up to 2.4 year^{-1}) in this region.

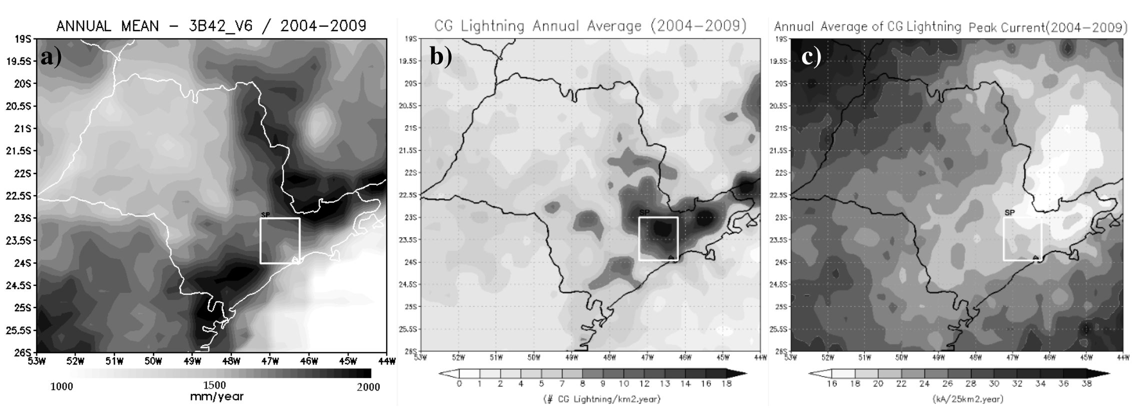

Figure 1. Annual mean of (a) precipitation (in mm/year), (b) CG lightning density (CG lightning/25 km²*year) and (c) CG lighting current peak (kA/25km²*year) over the state of São Paulo-Brazil, during 2004 to 2009.

3.2 Temporal characteristics of São Paulo Grid

Figure 2 shows the average annual cycle from 2004 to 2009 of precipitation and CG lightning occurrence (number and CG lightning current peak) on SP_Grid. Note that the precipitation and lightning had a seasonal pattern in phase with their highest values between December and March, mainly associated with SACZ episodes. June to August was considered the driest period, with a minimum (maximum) in June (July) for both rainfall and number of CG lightning. On the other hand, the current peak variable is lagged with the other variables, with the maximum value in July and August. This unusual peak in winter can be a severe contamination of positive CG lightning occurrences (as they are more intense than negative CG lightning) during this period of the year. Thus, the occurrence of frequent cold fronts in winter may contribute to formation of more stratiform systems, which have positively charged tops and are more exposed to the soil, producing a high possibility of positive CG lightning occurrence and, consequently, a higher current peak. This confirms the known influence of the solar annual cycle in changing the physical and electrical structure of clouds.

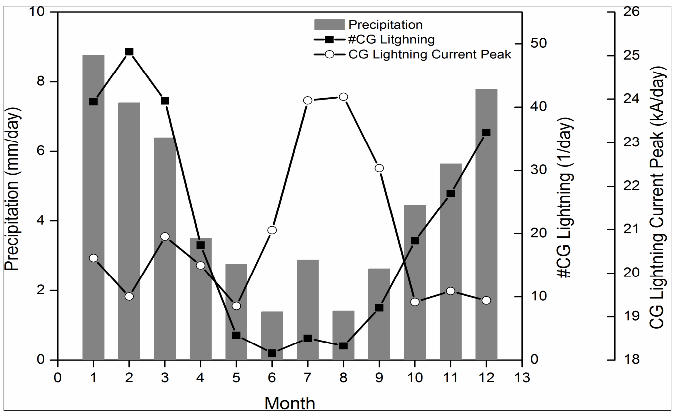

Figure 2. Mean annual cycle of precipitation (mm/day), CG lightning number (#CG lightning/day) and CG lightning current peak (kA/day), over the SP_Grid, during 2004 to 2009.

Figure 3a shows that the precipitation, lightning and current peak distributions are similar and in phase, indicating that 80% of cases have values of less than 12 mm, 55 occurrences, and 24 kA, respectively. On the other hand, there seems to be a slight positive correlation between the occurrence of lightning and precipitation (Fig. 3b), depending on the lightning current peak. However, the increase in standard deviation for the highest rainfall (> 25 mm/day) associated with a few events in this region makes it impossible to infer any significant relationship between rainfall and lightning physical features. Moreover, these results show that precipitation has a lag time in relation to lightning.

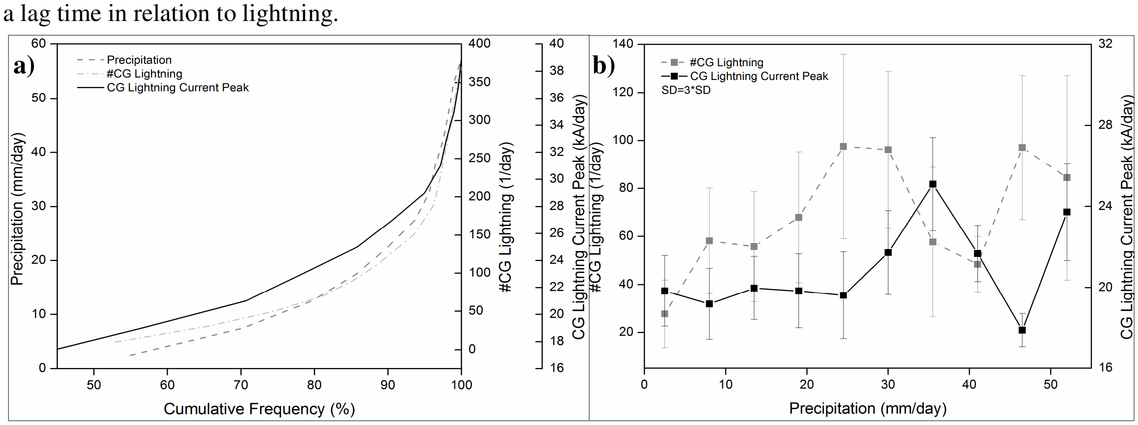

Figure 3. (a) Cumulative frequencies of the precipitation, CG lightning occurrence and CG lightning current peak and (b) dispersion relation between CG lightning and current peak as function of the precipitation for the SP_Grid, during 2004 to 2009.

4. CONCLUSIONS

This study analyzed the spatial-temporal characteristics of precipitation and CG lightning properties over the state and metropolitan region of São Paulo for six years (2004-2009). The precipitation showed a strong positive spatial correlation with lightning occurrence and a negative correlation with peak current, consistent with many studies in the literature (Grunger and Krider, 2006). These results show the important influence of the simultaneous combination of urban, orographic, sea and large-scale factors on intensification of storms in large metropolitan areas. The temporal distribution showed that in summer there is the highest occurrence of lightning and heavy rainfall, however, the lightning is less intense. In contrast, in the winter there is less rain and lightning, but these are more intense. This fact strengthens the hypothesis that the annual solar cycle may influence the physical and electrical structure of clouds, which in turn affect the characteristics of precipitation and lightning. Finally, the low direct correlation between precipitation and lightning may be associated with a temporal lag between these variables.

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