GROUND'2014
&
6th LPE

International Conference on Grounding and Earthing
&
6th International Conference on Lightning Physics and Effects
Manaus, Brazil May, 2014

EFFECTS OF BRAZILIAN LARGE URBAN AREAS OVER LIGHTNING – A REVIEW

Victor Hugo P. de Meireles[1], Kleber P. Naccarato[2]
[1] Lightning Nowcasting Center (FUNCATE), Sao Jose dos Campos, Brazil
[2] Atmospheric Electricity Group – ELAT, CCST / INPE, Sao Jose dos Campos, Brazil

ABSTRACT - The urban effect over the lightning activity is a recent subject. The first works start at the end of the 20th century. After this study, many others studies were made to cities in Europe, USA and Brazil. Apparently the urban effect on lightning activity is a combination of thermodynamic effect (Urban Heat Island) due to differential heating of the surface over the cities (thermal hypothesis) and the increasing pollute concentrations in the local atmosphere (aerosol hypothesis), caused mainly by human activity. Thus, this paper aims to carry out a review of four important studies about the influence of urban effect on lightning activity to important areas of Brazil. These studies are: Naccarato et al. (2003), Pinto et al. (2004) and Farias et al. (2008, 2012). The first two studies concluded that there is an increase in lightning activity and a decrease in the percentage of positive CG flashes. The others two papers showed the presence of a weekly cycle in lightning activity over Sao Paulo city.

1 - INTRODUCTION

The first works on the urban effect over the lightning activity start at the end of the 20th century [17]. After this study, many others studies were made to cities in Europe, USA and Brazil [3, 4, 5, 6, 8, 10, 11, 16]. Apparently the urban effect on lightning activity is a combination of thermodynamic effect (Urban Heat Island) due to differential heating of the surface over the cities (thermal hypothesis) and the increase of pollute concentrations in the local atmosphere (aerosol hypothesis), caused mainly by human activity [8]. However, the physical mechanisms responsible for these effects are still not well established due to the their complex correlations.

This paper reviews four important studies on the urban effect over lightning activity to important areas in Brazil. These studies are: Naccarato et al. [8], Pinto et al. [11] and Farias et al. [3, 4].

2 – THE METROPOLITAN REGION OF SÃO PAULO

Naccarato et al. [8] published one of first studies to correlate the urban effect and positive cloud-to-ground (+CG) flashes in Brazil. They studied the +CG lightning incidence in three major metropolitan areas: São Paulo (RMSP), Campinas (RMC) and São José dos Campos (RMSJC), all these areas located in São Paulo state (Southeastern Brazil).
In this paper, the authors used CG lightning data obtained by 14-sensor hybrid network composed by both LPATS series III and IV, and IMPACT sensors. This data set comprises the summer seasons of 1999 to 2002, which correspond to the months of December, January and February. The estimated network detection efficiency to the study area is 90% and the location accuracy is less than 1 km. The CG flash data were reprocessed using a configuration that requires at least 4 time measurements and does not allow any LPATS series III data which were identified as intracloud discharges (IC) to be used.

A medium urban area (Sorocaba, also located in the state of Sao Paulo) was also included in the analysis, since PM_{10} measurements are available there for comparison to the three main urban areas. These measurements were provided by automatic station of the CETESB (the governmental agency for natural environment protection of state of Sao Paulo), which continuously measure the concentration of PM_{10} (in $\mu g/m^3$) and compute an average value every full hour. Since the SO_2 concentrations were not available for all the considered urban areas the authors not included in work. Further, they selected seven circular areas with 10 km radius over RMSP, RMC, RMSJC and city of Sorocaba, where the PM_{10} concentrations and the CG flash data were compared only for thunderstorms days. The authors were aimed identify a possible correlation between the urban aerosol and lightning activity over these metropolitan areas.

In their results, they observed a clear enhancement of the CG flash density over the three metropolitan areas (Figure 1a). The increase of the CG lightning activity for the RMC and RMSJC related to their surroundings was about 50 – 60% and in the RMSP, a higher variation, of 150 – 200% (this lightning activity in São Paulo is larger than a factor of two with respect to the surroundings). These results are in agreement with [17].

Also observed a decrease the percentage +CG flashes over the urban areas (Figure 1b) where the flash density reaches its higher values. Over the RMC and RMSJC areas, the decreasing related to their surroundings was about 5 – 7%. The lowest percentages were found over the RMSP, where a reduction of about 10 – 12% was observed.

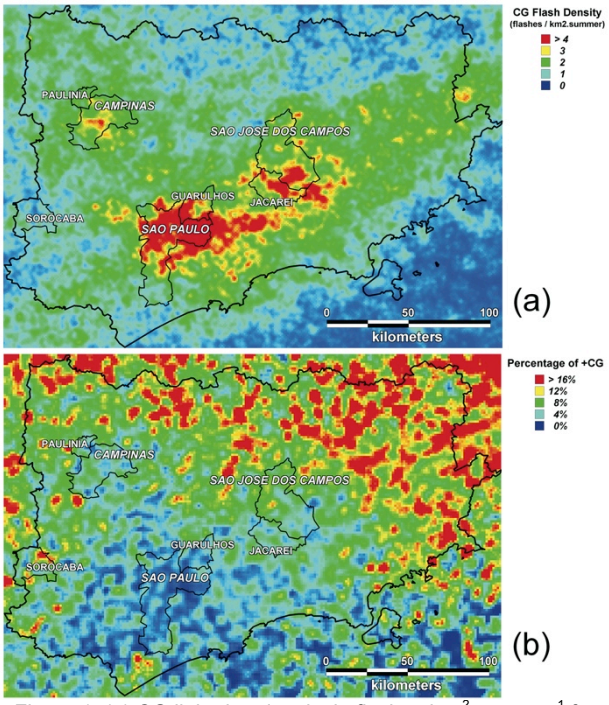

Figure 1. (a) CG lightning density in flashes.km^{-2}.summer^{-1} for with 1 km resolution. (b) Percentage of +CG flashes with 2 km resolution. The outlined area in both figures is located between latitude 22.19°S and 24.25°S, and longitude 44.62°W and 47.62°W. In the legend, intermediate values are represented by the variation of the primary colors.

Furthermore, the authors observed no effects in the average peak current and multiplicity of the CG flashes over the three metropolitan areas. These results, according to the authors, are in agreement with [16], but in contrast to [7] for the 1998 smoke event in the central USA. The authors speculate that this could be evidence that the smoke aerosol affecting the CG lightning activity in a different way related to the urban aerosol.

The authors examined two hypotheses:

(1) thermal hypothesis (due the effect of Urban Heat Island which increases the convergence of the urban area and contributing to the increase in storms);

(2) aerosol hypothesis (anthropogenic particulate emissions that affects the electrification process of the thunderstorms, which contributes to the increased of lightning activity).

Another result observed by the authors was that the spatial distribution of CG flashes had great spatial correlation with the configuration of the Urban Heat Island of RMSP (obtained from the thermal band of LandSat – 7) and the most urbanized area, in other words, the highest CG lightning density area is similar to the area of higher estimated surface temperature and the more urbanized in the RMSP (Figure 2). The authors speculate that this gives supports to thermal hypothesis.

However, a positive correlation between the number of CG flashes and average concentration of PM_{10} indicates that the aerosol hypothesis also support the increasing number of lightning (Figure 3). In this way, the authors concluded that both hypotheses contribute to the increased activity of CG lightning and probably the two hypotheses have interactions with each other. Moreover, the authors observed a negative correlation between the percentage of positive CG flashes and the average concentrations of PM_{10}, which cannot be completely explained by thermal hypothesis, providing additional evidence that the aerosol also plays an important role on the lightning polarity over urban areas.

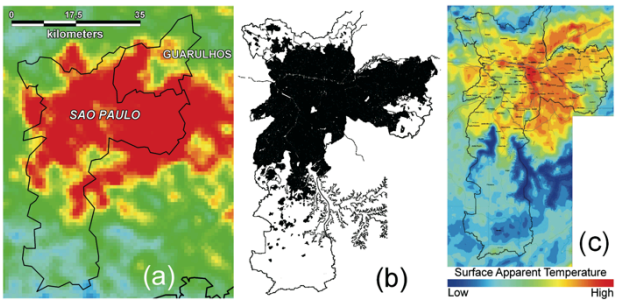

Figure 2. Spatial comparison of the CG lightning density with the RMSP urban heat island and the geographic position of the São Paulo city. (a) Same as Figure 2a, but showing only the RMSP. (b) Location of the Sa˜o Paulo city (the black areas indicates where the urbanization occurs within the geopolitical contour of the city). (c) Apparent surface temperature of RMSP computed using the LandSat- 7 thermal data.

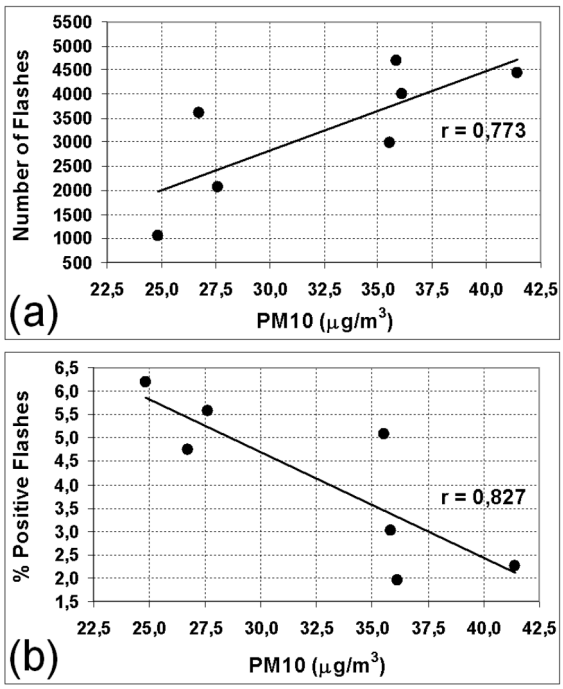

Figure 3. (a) Positive linear correlation (r = 0.773) between the number of CG flashes and PM10 concentrations in the seven circular areas with 10 km radius. (b) Negative linear correlation (r = –0.827) between the PM10 concentrations and the percentage of +CG flashes for the same circular areas.

3 – THE METROPOLITAN REGION OF BELO HORIZONTE

Another important paper in Brazil about the urban effect and characteristics of CG lightning was conducted by [11] for the city of Belo Horizonte and surroundings areas. The study used lightning data of 8 years (1989 – 1996) were obtained from the LPATS sensors network, with only CG lightning with peak current larger than 15 kA

were considered. The data were organized into blocks of, approximately, 0.08º longitude and 0.08º latitude, corresponding to an approximate resolution of 9 km.
The results of this study showed a large enhancement of 100% in the negative flash density and 50% in the positive flash density over and downwind of Belo Horizonte city, compared to the nearby surroundings areas (Figure 4). A decrease of 25% in the percentage of positive CG flash was also observed in this same area (Figure 5). The authors concluded that this result is in agreement with those obtained previously by [16].

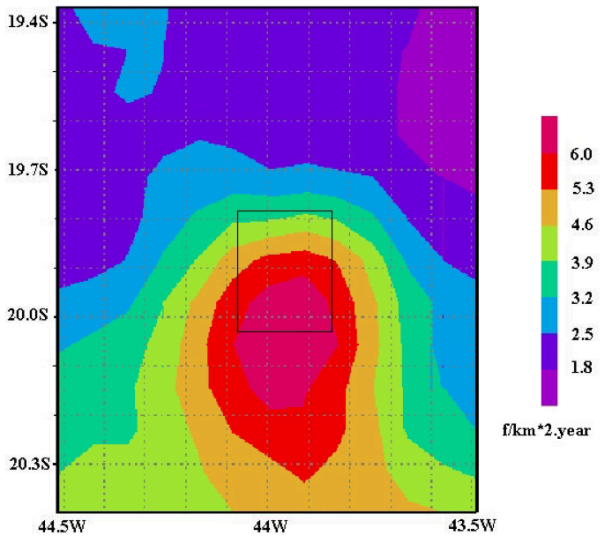

Figure 4. Eight-year (1989–1996) mean annual negative flash density in flashes.km^{-2}.yr^{-1} centered on Belo Horizonte (indicated by a black rectangle), at a spatial resolution of 9 km.

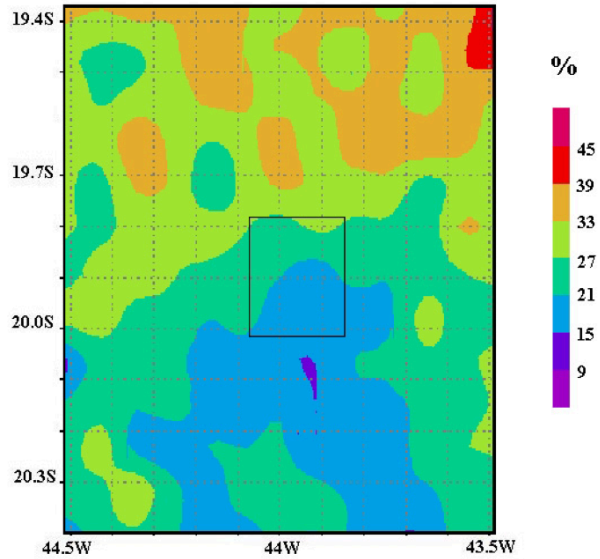

Figure 5. Eight-year (1989–1996) percent positive lightning centered on Belo Horizonte (indicated by a black rectangle), at a spatial resolution of 9 km.

Related to the total number of lightning, the authors were observed an enhancement of approximately 85%. This value is much higher than what was found by [16] Houston (45%), and is similar to that found by [17] for 16 US cities. The authors concluded that the strength of the urban effect in Belo Horizonte is much higher in Houston and has ratified the results found by [8].

Concerning the peak current (positive and negative flashes) the urban effect was not observed which is in agreement with Steiger et al. [16]. Though a decrease in peak current in both polarities was evident in the southeast of Belo Horizonte, mainly in the negative CG lightning (Figure 6). The authors speculate that this reduction in peak current can be related to high altitudes, as noted by [15] and [9].

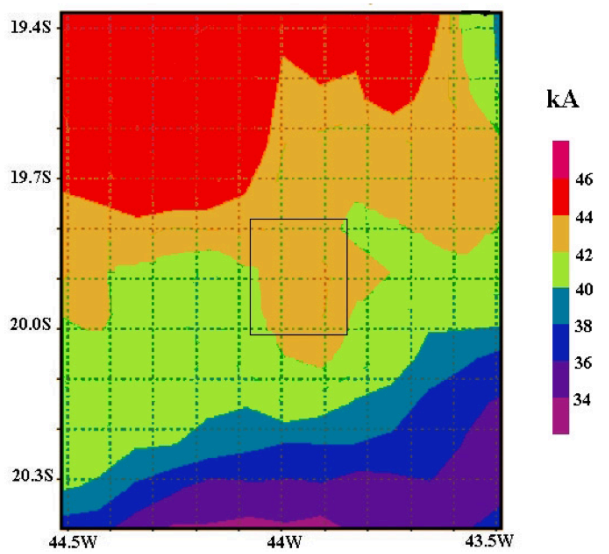

Figure 6. Eight-year (1989–1996) mean negative peak current in kA centered on Belo Horizonte (indicated by a black rectangle), at a spatial resolution of 9 km.

4 – THE WEEKLY CYCLE IN THE METROPOLITAN REGION OF SÃO PAULO

In the paper by Farias et al. [3], the CG lightning data used were provided by RINDAT network [12, 13, 14] over a 50 km diameter area that includes the main urban area of Sao Paulo city for a 6-year period (1999 – 2004). In this period, only days with CG flashes during the spring and summer seasons (from october to march) were considered and, for these days, only lightning data from 14 h to 20 h LT, which corresponds to the time of the day with maximum lightning activity. The region was considered representative of the Urban Heat Island and presented the highest concentration of pollutants (PM_{10}).

The first approaches tested in paper were:

(1) the number of CG flashes per individual storm was calculated and compared to the average PM_{10} concentration related to that particular storm;

(2) the average number of CG flashes per individual storms in the 6 year period for the 30 more polluted days and the 30 less polluted days.

In the first approach, an increase in the number of flashes per individual storm with the PM_{10} concentrations was observed. However, the high variability in the data prevented any statistically significant result. In the second approach, the mean values were quite different, but the

difference was not significant due to the high standard deviation values. The large variability of the CG lightning activity based on individual thunderstorms, which presents variations of several orders of magnitude depending on different meteorological conditions.

In order to overcome this limitation, the authors considered two new approaches:

(1) the CG lightning data were converted to the number of days with lightning (NDL). The mean NDL and its standard deviation were calculated for each weekday considering each year separately. Then, the values were compared to the average concentration of particulate matter (PM_{10}) for each weekday calculated for each year separately. The comparison was extended also to the weekly variation of cloud base height (CBH), relative humidity (RH), air temperature (AT), wet bulb potential temperature (WBPT), dew point temperature (DPT), equivalent potential temperature (EPT) and the SO_2 concentrations;

(2) the thunderstorms were classified according to different levels of pollution (from 0 to 90 μg/m^3 with bins of 10 μg/m^3) and the number of CG flashes and the maximum storm flash rates (in flashes per minute) were calculated for each storm, then averaged for three different ranges (0-30, 30-60 and 60-90 μg/m^3).

Both approaches rely on average values in order to reduce the large variability in the number of CG lightning counts. The data was collected by automatic stations CETESB existing in the area.

The authors explain that the inclusion of SO_2 in the analysis was due to the results of some studies, which suggest that increase in cloud condensation nuclei (CCN) activity can be related to the oxidation of SO_2 into surface inside the cloud droplets.

The authors concluded that there was a decrease in the number of days with lightning (NDL) in the weekend over the Sao Paulo metropolitan area (Figure 7), apparently associated with a decrease in the PM_{10} and SO_2 concentrations (NDL decreased 17%, PM_{10} 19% and SO_2 11%). The correlation between NDL X PM_{10} and NDL X SO_2 is high, 0,89. The authors conclude that this fact is supported by the almost constant behavior of the thermodynamic variables through the week. It was verified that the NDL with a large number of CG flashes (>100) did not decrease during the weekend, in agreement with the results of [16] over Houston. The authors speculate that the effect on the CG flashes activity tend to be more evident on days with less than 100 flashes.

The authors also observed that the average values of the number of CG flashes for three different ranges of PM_{10} concentrations (0-30, 30-60 and 60-90 μg/m^3) increase from the first to the second range (considering more than 2500 thunderstorms) and, then, remained practically constant (Figure 8). Conversely, the average maximum storm flash rate did not present the same behavior for the same PM_{10} ranges. According the authors, these results suggest the PM_{10} concentration (pollution), tends to increase the lifetime of the storms in RMSP and, in consequence, the number of flashes per storm, and not the flash rate.

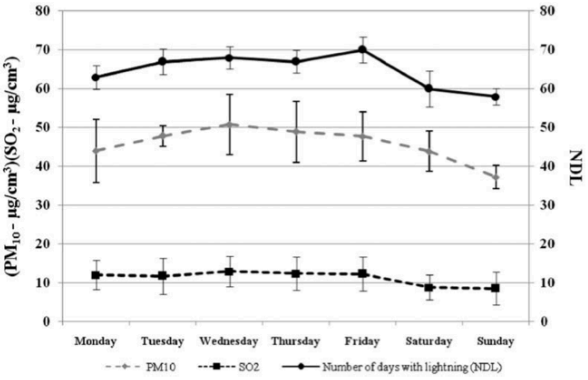

Figure 7. Weekly distribution of NDL, PM_{10} and SO_2.

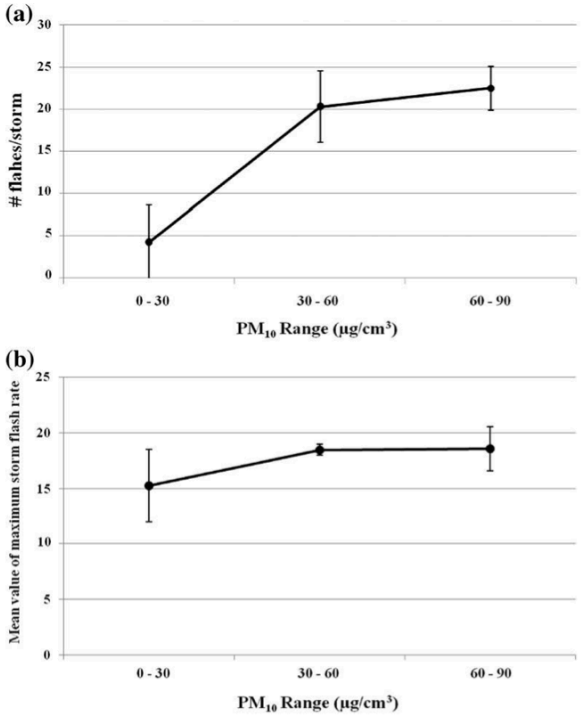

Figure 8. Average values for three different levels of PM_{10} concentration of (a) the number of flashes per storm and (b) the maximum storm flash rate.

Whereas the enhancement in the CG lightning activity in Sao Paulo is larger than a factor of two with respect to the surroundings [8], the authors suggest that the role of the PM_{10} concentration in the enhancement in the overall CG lightning activity in Sao Paulo is less relevant than the Urban Heat Island effect.

In another paper, Farias et al. [4] used the same methodology of the previous work for the urban area (RMSP). PM_{10} and SO_2 concentrations data, air temperature data (same data sources, automatic stations of CETESB) and CG lightning data from their previous paper [3] was used, but with changes in the time interval (now between 14 h to 21h LT) and an extended data period (1999 – 2008).

The authors used a method based on estimation of the sampling error in a sinusoidal fit to the weekly cycle specified, as was shown at [2], with the time series is broken into 7-day chunks. As a complementary analysis, the authors calculated the storm flash rate and average air temperature in different particulate matter (PM_{10}) concentration levels: low (0 – 30 $\mu g/m^3$), medium (30 – 60 $\mu g/m^3$) and high (over 60 $\mu g/m^3$). In order to verify the potential influence of aerosol on lightning activity some days to build the lightning dispersion as function of PM_{10} concentration were chosen. For this reason the days were selected based on two criteria: (1) number of lightning over 300; (2) according to three ranges of PM_{10} (described above).

The authors found that the cloud-to-ground lightning, sulfur dioxide and particulate matter were statistically significant to the level of the p=0,05 and p=0,01 (Figures 9 and 10). On the other hand, air temperature does not present statistical significance. The authors suggest that air temperature does not have statistical significance. The authors evaluated the influence of the average air temperature to the same particulate matter (PM_{10}) concentration levels and, as expected by the authors, the values for air temperature do not show variation on the different PM_{10} concentration levels.

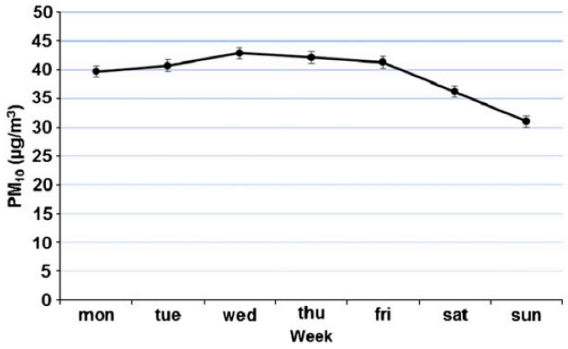

Figure 9. Weekly distribution of PM10 to MRSP, Campinas and São Jose dos Campos.

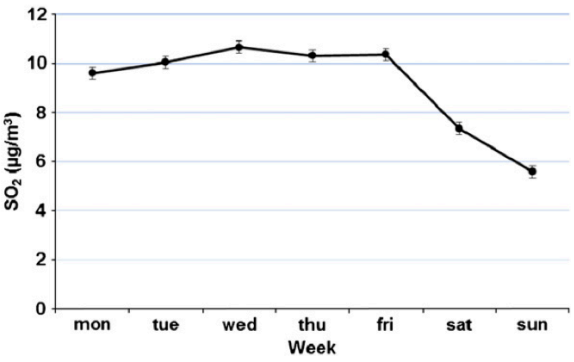

Figure 10. Weekly distribution of SO2 to MRSP, Campinas and São Jose dos Campos.

The authors also observed that the storm flash rate and the PM_{10} concentration levels were similar behavior to results found in the previous work [3]. This same behavior was observed for the comparison between of the number of lightning for the selected days. The authors concluded that until saturation level of PM_{10} concentration occurs lightning activity intensification over RMSP and, after reaching this level, the storm flash rate and the number of lightning of the selected days decreases for bigger PM_{10} concentrations (Figure 11). According to the authors, this behavior was also observed by Altarazt et al. [1].

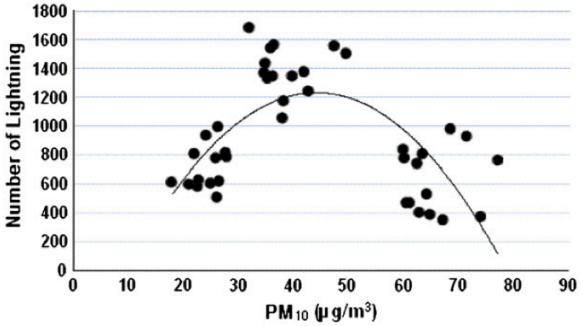

Figure 11. Lightning dispersion as function of different PM10 concentration levels.

5 - CONCLUSIONS

In this paper a review of four important studies about the influence the urban effect on the lightning activity to important areas of Brazil. The papers are: Naccarato et al. [8], Pinto et al. [11], Farias et al. [3, 4].

Naccarato et al. [8] was one the first studies in Brazil about the influence the urban effect on the lightning activity and has been the basis for the other Brazilian articles about this topic. The authors have made an important discussion of the two hypotheses (thermal and aerosol) and concluded that not one or another hypothesis alone can be explaining the enhancement in lightning activity and decreases of positive CG percentage. Furthermore, the authors found a negative correlation between positive CG flashes percentage and the PM_{10} average concentrations, which cannot be fully supported by the thermal hypothesis, provides additional evidence that the aerosol also plays an important role on the lightning polarity over urban areas.

Pinto et al. [11] concluded that the strength of the urban effect in Belo Horizonte city is much higher than in Houston [16] and similar to that found by Westcott [17]. They also concluded that the decrease in peak current observed may be related to high altitudes as note by Reap [15] and Orville & Huffines [9].

Farias et al. [3, 4] concluded that there is evidence of a weekly cycle of lightning and PM_{10} and SO_2 concentrations with reduced values during the weekend in the Sao Paulo metropolitan area (RMSP). They also found that the storm flash rate associated with three different PM_{10} concentrations (0 – 30, 30 – 60 and above 60 $\mu g/m^3$) has a large enhancement the lightning activity between the first to the second level of PM_{10} concentrations and then remained almost constant. The authors speculate that there is a saturation level of PM_{10} concentration at lightning activity intensification on over the metropolitan region of Sao Paulo.

The great contribution of these papers was to show that the urban effect caused by the metropolitan areas

Brazilian influence the intensification of lightning activity. The results obtained by Farias et al [3], Naccarato et al. [8], Pinto et al. [11] showed an enhancement in lightning activity and a decrease in the positive CG flashes percentage. Moreover, no apparent urban effect was found in relation to the peak current and multiplicity, which agrees with the results found by Steiger et al. [16] for Houston.

Another contribution of Farias et al. [4] was evidence of a weekly cycle in lightning activity and PM_{10} and SO_2 concentrations with decrease their values during the weekend in metropolitan area Sao Paulo. The authors also speculate that there is a saturation level of PM_{10} concentration at lightning activity intensification over the metropolitan region of Sao Paulo.

6 - REFERENCES

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Main author
Name: Victor Hugo Pezzini de Meireles
Address: Av. Dr. João Guilhermino, 429, Office 153, Sao Jose dos Campos, SP, Brazil.
Tel: + 55 12 3019 4621
E-mail: victor@tempestades.org.br