Atmospheric Research 135–136 (2014) 370–373

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

The influence of urban effect on lightning activity: Evidence of weekly cycle

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ARTICLE INFO

Article history:
Received 15 March 2012
Received in revised form 10 September 2012
Accepted 25 September 2012

Keywords:
Lightning activity
Urban areas
Weekly cycle
Aerosol
Statistical significance

ABSTRACT

A cloud-to-ground (CG) lightning data provided by the Brazilian lightning detection network (BrasilDAT) for a ten year period (1999–2008), and particulate matter (PM_{10}), sulfur dioxide (SO_2) and air temperature data from the environmental agency of São Paulo State (CETESB) for the same period, were examined in order to look for the influence of urban effect and weekly cycles in lightning activity over metropolitan region of São Paulo (MRSP). The results show that there is a significant weekly cycle in PM_{10} over the MRSP and lightning activity (CG lightning) on the area involving the MRSP, Campinas and São Jose dos Campos regions, both with reduction on the weekend. The average number of flash per storm and air temperature in three different ranges of PM_{10} concentrations was also examined. For the first one, there is an increase of the average number of flash per storm from low to intermediate range and a trend to decrease from intermediate to high range. However, the air temperature tends to stay the same in all ranges. These results suggest that pollution tends to saturate the intensification of storms and lightning activity in a specific level. After that, the increase of aerosols provided by pollution tends to decrease the lightning activity.

1. Introduction

The influence of urban effect on the lightning activity is a recent subject, the first records start at the end of the 20th century (Westcott, 1995). Many other studies were done after it, for example, Orville et al. (2001), Steiger et al. (2002), Naccarato et al. (2003), Pinto et al. (2004), Kar et al. (2007, 2009), and Farias et al. (2009). Apparently the urban effect on lightning activity is a combination of thermodynamic effect due to differential heating of the surface over the cities (heat islands) and to increasing pollutant concentrations in the local atmosphere, caused mainly by human activity (Naccarato et al., 2003). Even though until now the physical mechanisms responsible for these effects are not well known due to the complex relationships among the involved variables, strong evidence of the contribution of this effect on lightning is documented in the scientific literature on the increasing number of lightning cloud-to-ground (CG) and reducing percentage of positive flashes over urban centers such as the metropolitan regions of São Paulo, Belo Horizonte, and Seoul (Naccarato et al., 2003; Pinto et al., 2004; Kar et al., 2007, 2009). Recent results presented by Bell et al. (2009) and Farias et al. (2009) using cloud-to-ground lightning strike data on summers showed that the concentration of particulate matter can influence the lightning activity through weekly variations. Analyzing the behavior of lightning activity over metropolitan cities of India, Lal and Pawar (2011) found that, over an inland city, where the increase of aerosol concentration is negligible, the enhancement in convective activity and lightning is controlled by thermodynamic effect, and on the other hand, on cities where aerosol concentrations tend to increase, aerosols play major role in enhancing lightning activity. Several studies have showed the influence of aerosol on cloud microphysical process, precipitation and also on cloud electrification. The radiative effects of aerosols on clouds mostly act to suppress precipitation, due to the decrease of the amount of solar radiation that reaches the land surface, causing less heat to be available for evaporating

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http://dx.doi.org/10.1016/j.atmosres.2012.09.007

water and energizing convective rain clouds (Ramanathan et al., 2001). On the radiative aerosol effect, the absorption of solar radiation by aerosol can change the atmospheric stability profile by heating the aerosol layer and cooling the layers below (Koren et al., 2008). Consequently, this may reduce the relative humidity, stabilize the temperature profile and reduce the surface moisture fluxes, inhibiting deep convective clouds and reducing the electrical activity potential (Altarazt et al., 2010). On the other hand, the microphysical effect adds CCN (Cloud Condensation Nuclei) slowing the conversion of cloud drops by nucleating larger number of concentrations of smaller drops. Consequently, this fact tends to increase the amount of water inside the clouds, changing the drop distribution, ice microphysical process and also the cloud electrifications (Kaufman and Fraser, 1997; Rosenfeld and Lensky, 1998; Khain et al., 1999; Rosenfeld, 2000; Sherwood, 2002; Bréon et al., 2002).

2. Methodology

In this work, we used two main sources of dataset, the cloud-to-ground lightning data provided by the Brazilian lightning detection network (BrasilDAT) (Pinto et al., 2006a, 2006b, 2007) over the metropolitan region of São Paulo and an extended area composed by the metropolitan regions of São Paulo, Campinas and São Jose dos Campos for a period of 10 years (1999–2008). 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 21 h LT, which corresponds to the time of the day with maximum lightning activity. The dataset of pollution was provided by the environmental agency of São Paulo State (CETESB) through automatic stations distributed on MRSP, up-country and coast areas of São Paulo State. This network is connected to a central computer by telemetry system and records continuously the concentration of pollutants in the atmosphere and some meteorological parameters. These data are processed based on averages and legal standards established by the weather forecasts. The data are available on hourly frequency and for the particular case of this work, particulate matter (PM_{10}), sulfur dioxide (SO_2) and air temperature data among 14 h and 21 h LT, in accordance with the period of maximum lightning activity, were used.

All regions were considered representative of the urban heat island and presented the highest concentration of pollutants (PM_{10}).

The probability to detect a weekly cycle in a climatic data is very low. However, such cycles exist within urban centers and surrounding areas, attributed to anthropogenic causes (Gordon, 1994). Some studies such as Bell et al. (2008, 2009) show that in those specific areas with big urban density, these weekly cycles are not a coincidence, but a consequence of chances in the microclimate caused by human activities. The method used is based on estimation of the sampling error in a sinusoidal fit to the weekly cycle specified in Eqs. (1a) or (1b) (Bell et al., 2008).

$$r(t) = r_0 + r_7 \cos[\omega_7(t-\phi_7)] \tag{1a}$$

$$r(t) = r_0 + r_7 \cos(\omega_7 t) + s_7 \sin(\omega_7 t) \tag{1b}$$

The time series is broken into 7-day chunks, each of which is fit to the linear version of Eq. (1b) with 3 unknown amplitudes, with

$$r_7^2 = c_7^2 + s_7^2 . \omega_7 = {}^{2\pi}\!/_7 \text{ and } \phi_7 = \left({}^7\!/_{2\pi}\right) \operatorname{arctg}\left({}^{s_7}\!/_{c_7}\right).$$

If $\boldsymbol{n}$ weeks of data are available and provide $\boldsymbol{n}$ estimates of the coefficients c_7 and s_7, then the error variance in c_7 and s_7 is estimated as the variance of the $\boldsymbol{n}$ estimates divided by $\boldsymbol{n}$, assuming that the amplitudes are not very correlated from week to week. Under the null hypothesis $r_7 = 0$, r_7^2 is distributed for large $\boldsymbol{n}$ as a chi-square variable with 2 degrees of freedom, and the probability that r_7 exceeds R by accident is given by:

$$\mathrm{Prob}(r_7 > R) = \exp\left({}^{-R^2}\!/_{\sigma_7^2}\right) \tag{2}$$

with $\sigma_7^2 = [\mathrm{var}(c_7) + \mathrm{var}(s_7)]/n$. On the other hand, if $\boldsymbol{n}$ is not large, it is more appropriate to use the Fisher F probability distribution, because in this case s_7^2 is estimated from a finite number of samples. Thus, Eq. (2) to become in: where $n' = n - 1$:

$$\mathrm{Prob}(r_7 > R) = \left[1 + \left(R^2/\sigma_7^2\right)/n'\right]^{-n'}.$$

As a complementary analysis, we calculated the storm flash rate and average air temperature in different particulate matter (PM_{10}) concentration levels (described below). 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, number of lightning over 300 and according to the three ranges of particulate matter (PM_{10}) concentration, low (0 μg/m^3–30 μg/m^3); medium (30 μg/m^3–60 μg/m^3) and high (over 60 μg/m^3).

3. Results and discussion

The results show the weekly behavior for the variables tested on statistical significance analysis. The methodology described above was applied to cloud-to-ground lightning, average air temperature, sulfur dioxide (SO_2) and particulate matter (PM_{10}), for the metropolitan region of São Paulo and for the extended area involving the metropolitan regions of São Paulo, Campinas and São Jose dos Campos. Fig. 1 shows the lightning density on the extended area which is possible to see that the major lightning density over the urban centers. Figs. 2 and 3 showed the weekly behavior of PM_{10} and SO_2.

At this condition, application of statistical significance shows that the cloud-to-ground lightning, sulfur dioxide and particulate matter were statistically significant to the level of the $p = 0.05$ and $p = 0.01$, in other words, 95% and 99% are certain that the weekly variation is not a coincidence for these variables. On the other hand, air temperature does not present statistical significance. These results suggest that air temperature does not have statistical significance. Table 1 presents the summary of the application test.

Based on these results, the storm flash rate in different particulate matter (PM_{10}) concentration levels was calculated, in order to analyze if the PM_{10} concentration has some influence on lightning distribution (Fig. 4) over the metropolitan region of

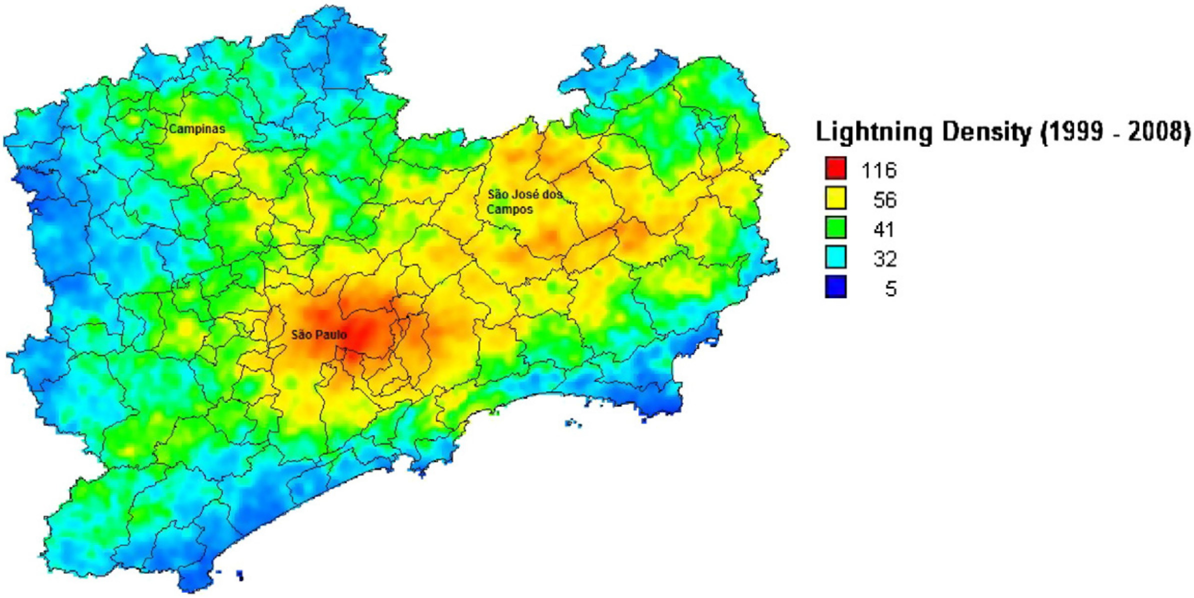

Fig. 1. Lightning density for the extended area involving the metropolitan regions of São Paulo, Campinas and São Jose dos Campos.

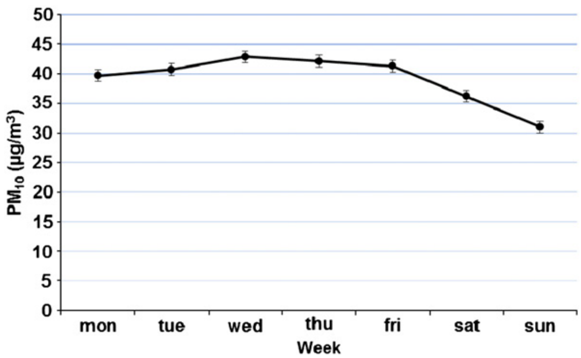

Fig. 2. Weekly distribution of PM_{10} to MRSP, Campinas and São Jose dos Campos.

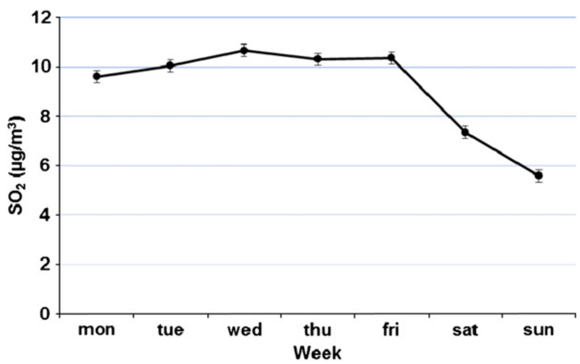

Fig. 3. Weekly distribution of SO_2 to MRSP, Campinas and São Jose dos Campos.

São Paulo. The average air temperature to the same particulate matter (PM_{10}) concentration levels (Fig. 5) was also calculated so as to evaluate the influence of air temperature in the phenomenon process. And as expected, the values for air temperature do not show variation on the different PM_{10} concentration levels.

Table 1
Summary of statistical significance test.

Variable	p	$p = 0.05$	$p = 0.01$
Num. of CG lightning	0.007	Approved	Approved
Particulate matter (PM_{10})	0.003	Approved	Approved
Sulfur dioxide (SO_2)	0.004	Approved	Approved
Air temperature	0.349	Disapproved	Disapproved

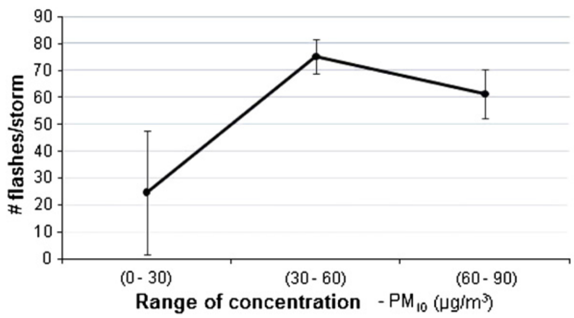

Fig. 4. Storm flash rate for different ranges of PM_{10} concentration.

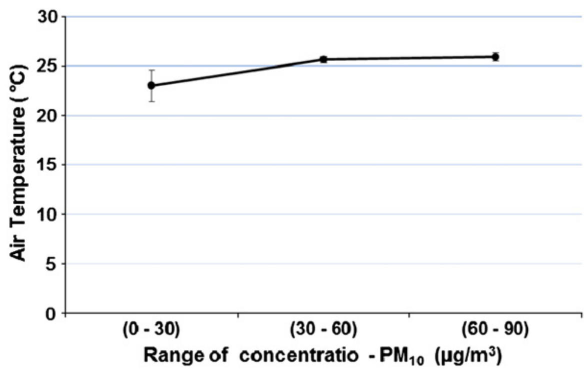

Fig. 5. Average air temperature to the different PM_{10} concentration levels.

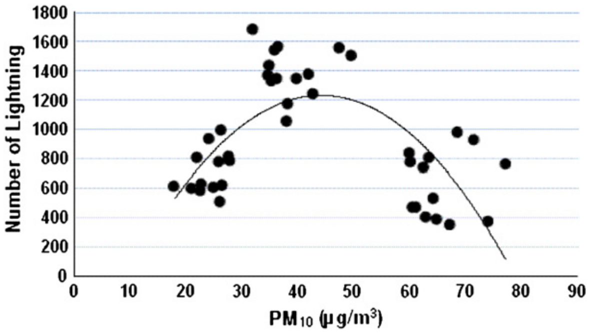

Fig. 6. Lightning dispersion as function of different PM_{10} concentration levels.

The storm flash rate graphic showed that there is a saturation trend of PM_{10} concentration on lightning activity intensification over the metropolitan region of São Paulo.

Other important result shows the behavior of the number of lightning for the selected days (Fig. 6). This behavior had already been seen by Altarazt et al. (2010) analyzing Aerosol Optical Thickness (AOT) due to aerosol smoke and lightning activity was provided by World-Wide Lightning Location Network (WWLLN) at the Amazonia region in an independent study. This result means that the number of lightning increases with PM_{10} concentration and decreases for bigger PM_{10} concentrations.

4. Conclusions

A weekly cycle for the statistically significant levels, $p = 0.05$ and $p = 0.01$, of cloud-to-ground lightning, sulfur dioxide (SO_2) and particulate matter (PM_{10}), was identified over the extended area involving the metropolitan regions of São Paulo, Campinas and São Jose dos Campos. It was also found that the storm flash rate increases until the second range of PM_{10} concentration (30–60 μg/m^3), and then decreases on the third range. It means that there is a saturation level of PM_{10} concentration at lightning activity intensification over the metropolitan region of São Paulo. For the selected days, it was observed that the average number of lightning increases as the PM_{10} concentration also increases until a saturation level is reached. After this level (bigger PM_{10} concentrations) the average number of lightning decreases, the same behavior had already been seen by Altarazt et al. (2010) analyzing Aerosol Optical Thickness (AOT).

Acknowledgments

We would like to thank the support of the CNPq, CETESB and BrasilDAT for providing data.

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