NEW FINDINGS ABOUT THE INFLUENCE OF SMOKE FROM FIRES ON THE CLOUD-TO-GROUND LIGHTNING CHARACTERISTICS IN THE AMAZON REGION

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ABSTRACT

In the last decade many authors have found evidence on the influence of smoke from fires on the cloud-to-ground (CG) lightning characteristics, both in the lifetime scale of individual storms and on a climatological scale. In general, the observations indicate that the peak current and percentage of positive flashes increase in thunderstorms injected with smoke, while the negative peak current decreases. This article investigates the validity of these findings in thunderstorms injected with large concentrations of smoke from fires in the Amazon region, comparing CG lightning characteristics in the dry (polluted) and wet (clean) seasons, as well as using a new methodology, based on results of a numerical simulation model of atmospheric transport of tracers coupled to a biomass burning emission model. The results confirm the previous findings and, in addition, give a first estimation of the sensitity of these parameters to changes in the smoke concentration.

1. INTRODUCTION

The influence of smoke from fires on the cloud-to-ground (CG) lightning characteristics has been investigated for many authors. Lyons et al. (1998) found a large increase in the percentage and peak current of positive flashes in association with thunderstorms over United States injected by smoke from fires in Mexico. For the same event, Murray et al. (2000) found a small decrease in the negative peak current of CG flashes. More recently, Pinto et al. (2006) found a decrease in the average negative peak current of CG flashes in the Southeastern Brazil during the months of August to October for the period from 1999 to 2004 coincident with an increase in the number of fires in these months, with no significant effect on the percentage and peak current of positive flashes. On the other hand, some authors have suggested that changes in lightning polarity and peak current may be related to drought conditions, i.e., high cloud bases and high levels of free convection and theta E values (Smith et al., 2000; Williams et al., 2005; Lang and Rutledge, 2006). Some authors argue that deep, dry daytime boundary layers favor high percentages of positive flashes as well as higher peak currents. The situation is complicated because biomass smoke and drought are often correlated.

Another important point is related to how aerosols might affect lightning. Although at the present time there is no sufficient information on this topic, some hypotheses are an increase in the condensation nuclei and/or an increase in ice nuclei. Related to this issue is the question if all types of aerosols may affect the lightning characteristics at the same way.

In this paper, it is investigated the effect of smoke from forest fires in the Amazon on the CG lightning characteristics. This region in the North part of Brazil is particularly interesting for this type of study, since large concentrations of particulate material covering vast areas are found in the atmosphere during the dry season in association with many deforestation and agricultural fires (Andreae et al., 2002; Silva Dias et al., 2002). The analysis is based on two years of lightning data obtained by a small network in the state of Rondônia and on the results of numerical simulations of the atmospheric transport model coupled with a biomass burning emission model.

2. DATA AND METHODOLOGY

The region of study in the Amazon is limited to 8° S and 14°S of latitude and 59°W and 66°W of longitude, including the total area of the state of Rondônia and, partially, the state of Mato Grosso and Bolivia. This area is showed in Figure 1. In this region, the concentration of aerosols is higher in August and September, decreasing from September to December. Therefore, the storms in August/September are formed in an atmosphere rich in smoke from fires, while those in October/December are formed in a cleaner atmosphere. The period of analysis is limited to data from August to December of 2002 and 2003 years.

The lightning data were obtained by a small network of four IMPACT sensors installed through an international collaboration between Brazil and United States (Blakeslee et al., 2003; Pinto et al., 2003). The sensors give the strike location, time, polarity, peak current and multiplicity. The data were corrected by a detection efficiency model provided by NASA (Blakeslee, private communication). Also, to prevent CG lightning contamination by intra-cloud flashes, positive flashes with peak current less than 20 kA (and not 10 kA as usual adopted - Cummins et al., 1998) were neglected, based on recent results presented by Biagi et al. (2006) suggesting that this contamination may extend to peak currents larger than 10 kA for this type of sensors. Despite of this fact, the results are not significantly modified if the 10 kA was adopted. More details on the lightning network can be found in Blakeslee et al. (2003) and Fernandes (2005).

The concentration of aerosols associated with smoke from fires was obtained from the Coupled Aerosol and Tracer Transport model to the Brazilian developments on Regional Atmospheric Modeling System. This system is coupled to a high resolution biomass burning emissions model, with diurnal and daily variability, developed for South America through a combination of remote-sensing products (land use and fire detection) with field observations such as emission and combustion factors and fuel loadings (Freitas et al., 2005). The model supplies the columnar integrated aerosol particles with diameter <2.5 μm in μg m^{-2} (hereafter referenced as PMINT2.5 – PMINT refers to Particulate Material Integrated) for eight daily UT times: 0, 3, 6, 9, 12, 15, 18 and 21, for a regional 40x40 km grid. The model has been applied to other studies in this region (Andreae et al., 2004) and has been validated with both direct and remote sensing observations. In particular, for the 2002 year, aerosol particle concentration from the model was successfully compared with surface level direct measurements using a tapered element oscillating mass balance instrument from 10 September to 03 November in Rondônia. A linear regression of the PMINT2.5 mass concentration observed values versus modeled values (r2 ≈ 0.7) shows that the measurements tend to be higher than the model by a constant value of approximately 12 μgm-3, which basically characterizes the background of mass particle concentration in the region.

In order to correlate the lightning parameters with the PMINT2.5, the former were grouped in the same space resolution of the model. For each UT time, flashes one and a half hour before and after were associated with this time. After that, for each grid of 40x40 km, the averages of the negative and positive peak current and of the percentage of positive flashes were computed. Only grids with 50 or more flashes were considered. The grids were then classified as a function of the PMINT2.5 values in three categories: polluted (PMINT2.5>30000 μg m^{-2}), moderate (30000>PMINT2.5>9000 μgm^{-2}) and clean (PMINT2.5<9000 μgm^{-2}). These values were adopted based on a comparative analysis between the model results and daily observations made by the tapered element oscillating mass balance instrument from 10 September to 03 November 2002 in Rondônia (Freitas et al., 2004). The average background value during this period was 12000 $\mu g.m^{-2}$. The value for the polluted category was arbitrarily adopted as 2.5 times larger than this value. Finally, for each category, average PMINT2.5 and lightning parameters were computed and compared to each other. To give a statistical meaning to the comparison, standard deviations were computed from monthly averages of the characteristics for each category. This approach was particularly important to avoid the large variability of individual peak current values.

3. RESULTS

CG lighting activity observed during the transition from the dry to the wet season in both years of study showed a tendency to an increase in the flash rate (Figure 2). Figures 3 and 4 show the time series of daily distribution of averages negative and positive peak current, respectively. While the average negative current peak presented a systematic increase during the period, the average positive peak current presented an apparent small decrease superposed on large variations. The percentage of positive CG flashes (Figure 5), in turn, shows no systematic variation, although large values were only observed in the dry (polluted) season, supporting the finding of Lyons et al. (1998). The analysis of Figures 3 to 5 suggest that while the negative peak current increases with the decrease of the concentration of aerosols, the characteristics of positive CG flashes show large daily variations. Such analysis, however, is limited by the fact that it is not possible to exclude other effects related to the changes in the large-scale atmospheric and land surface conditions from the dry to the wet season (Li and Fu, 2004).

In order to investigate in more details the results described above, the lightning data were compared with the concentration of aerosols following the methodology described in the previous section. Average daily values of vertically integrated PMINT2.5, as simulated by the model, are shown in Figure 6 for the years 2002 and 2003. Figure 7 shows the average negative peak current, positive peak current and percentage of positive flashes versus the average PMINT2.5 for each PMINT2.5 category, with their respectives standard deviations calculated as described before. It can be noted that the positive peak current and the percentage of positive lightning increase as the smoke aerosol loading increases, while the negative peak current decreases, in agreement with past observations. Figure 7 also shows linear regression fits to the lightning characteristics, which give an estimation of the sensitive of each characteristic to changes in the smoke concentration.

4. CONCLUSION

An analysis of the effect of smoke from fires upon the lightning characteristics of thunderstorms in the Amazon region was presented. The main effects observed were a decrease in the negative peak current and an increase in the peak current and percentage of positive flashes with the aerosol concentration, in agreement with previous findings of Lyons et al. (1998), Murray et al. (2000) and Pinto et al. (2006).

The results of a comparative analysis between lightning data and aerosol smoke loading estimated from the models suggest different sensitivies of negative and positive flashes to the effects of smoke from fires.

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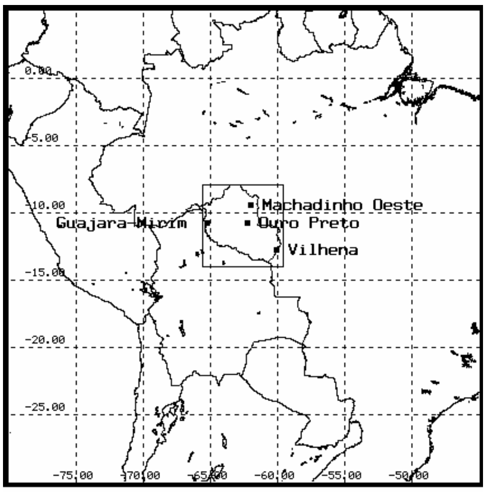

Figure 1

Figure 1 – Locations of the sensors in the north region of Brazil.

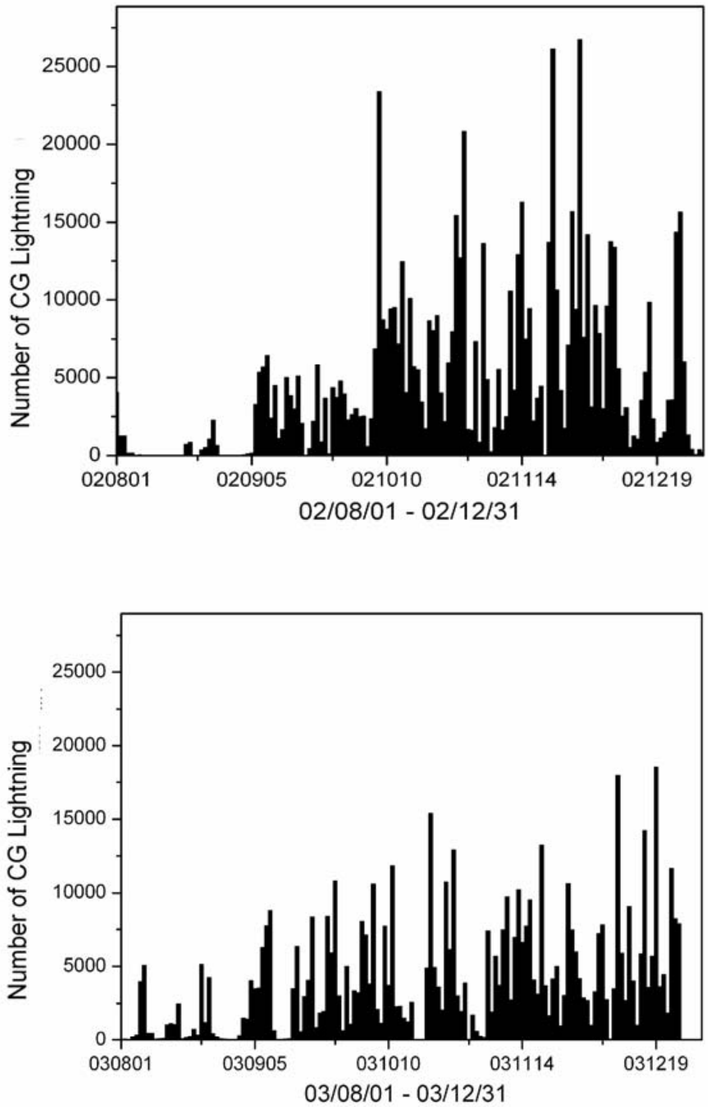

Figure 2

Figure 2 - Daily distribution of the CG lightning from August to December for (a) 2002 and (b) 2003.

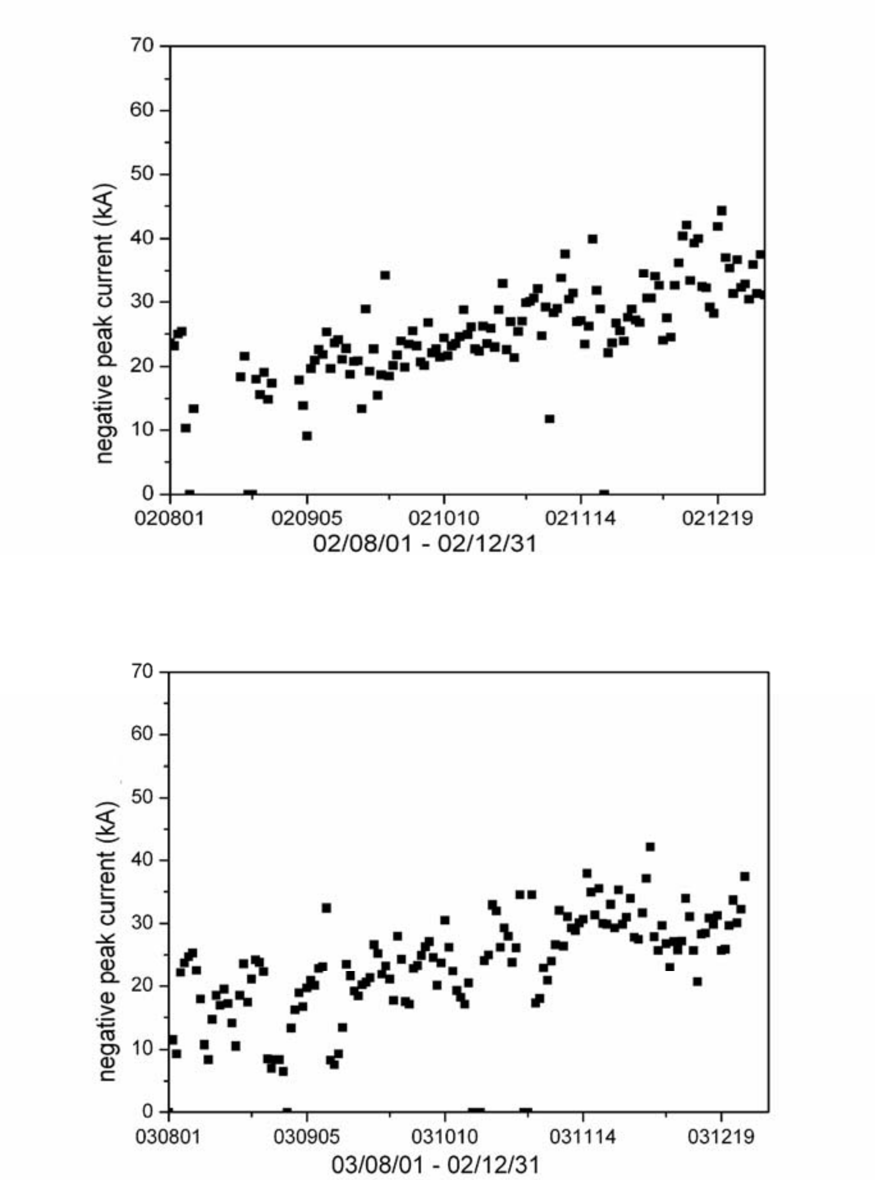

Figure 3

Figure 3 - Daily distribution of the negative peak current for (a) 2002 and (b) 2003.

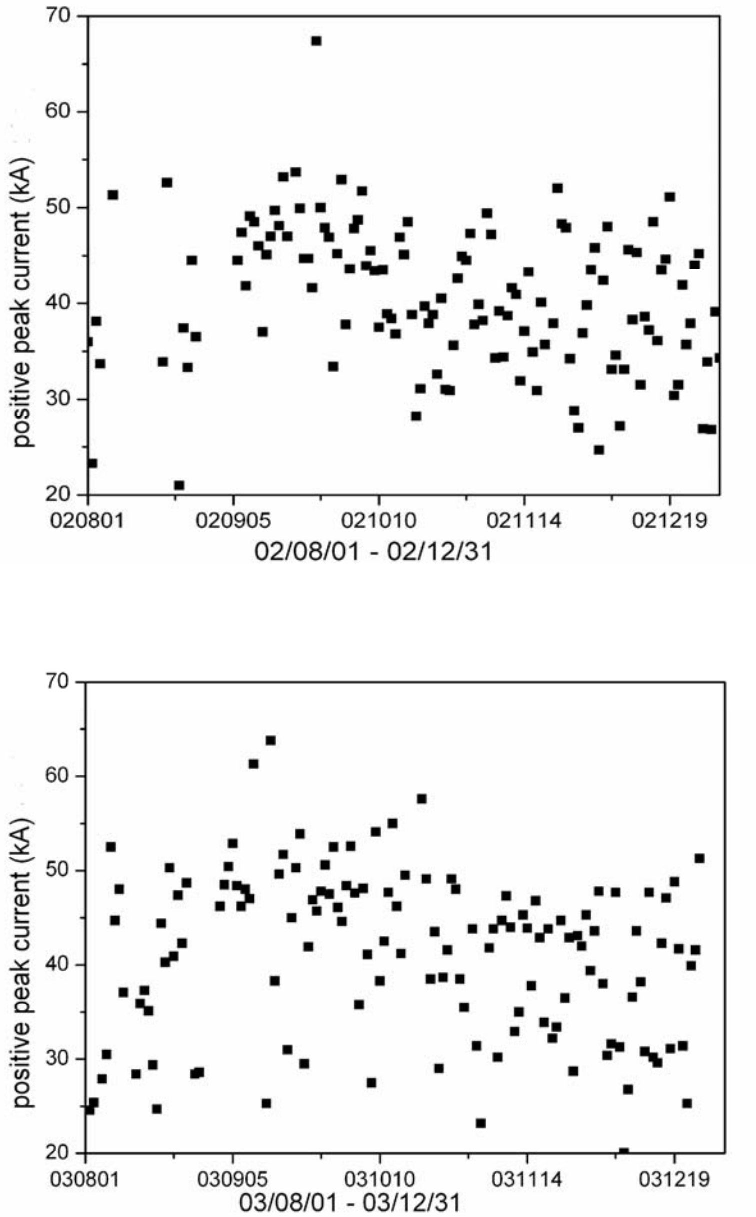

Figure 4

Figure 4 - Daily distribution of the positive peak current for (a) 2002 and (b) 2003.

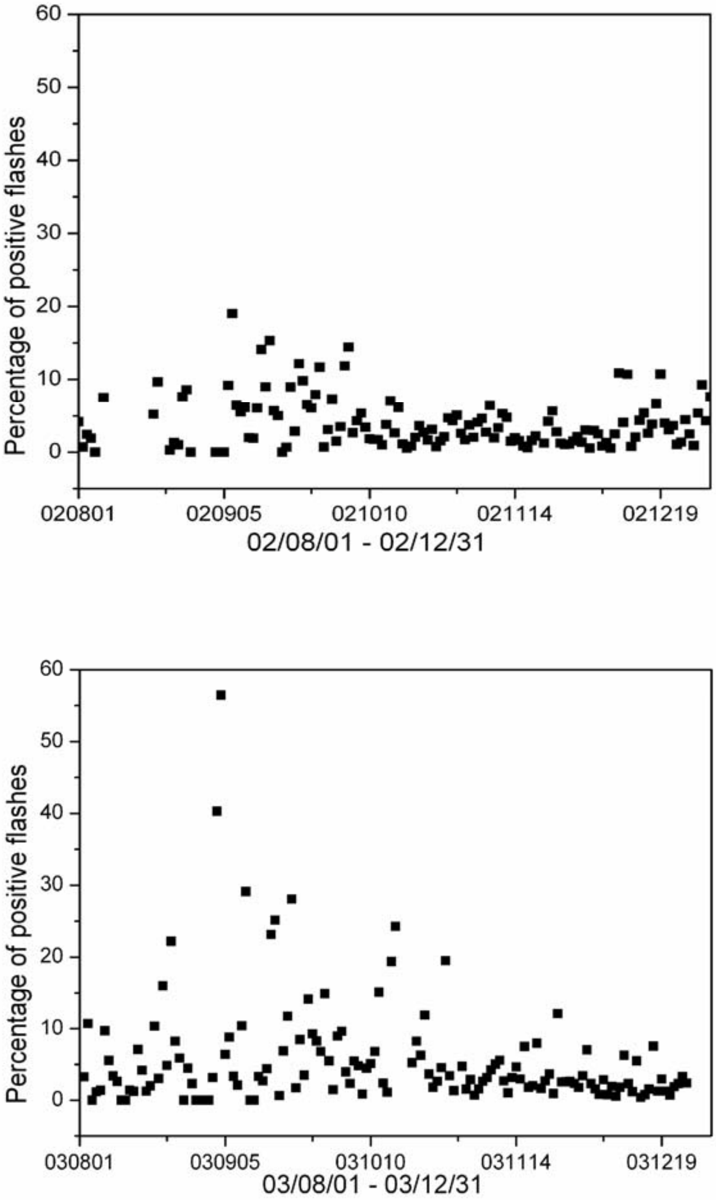

Figure 5

Figure 5 - Daily distribution of the percentage of positive CG lightning for (a) 2002 and (b) 2003.

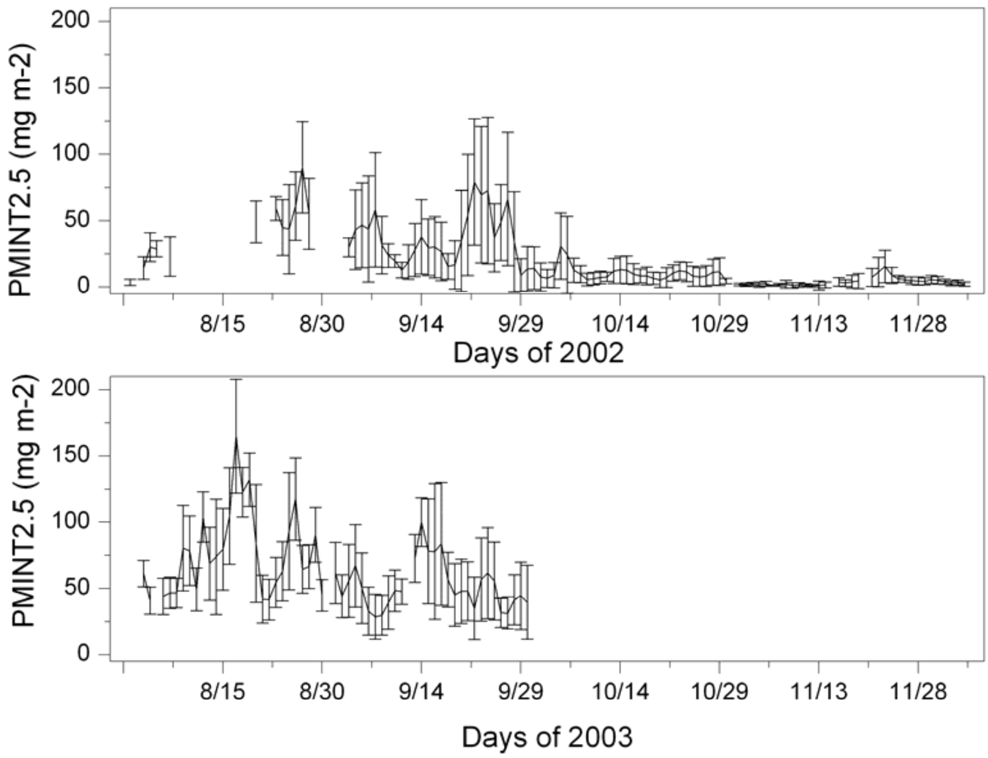

Figure 6

Figure 6 – Daily average model values of vertically integrated PMINT2.5 in mg.m^{-2} for the years 2002 and 2003. For 2003, model results were available up to end of September.

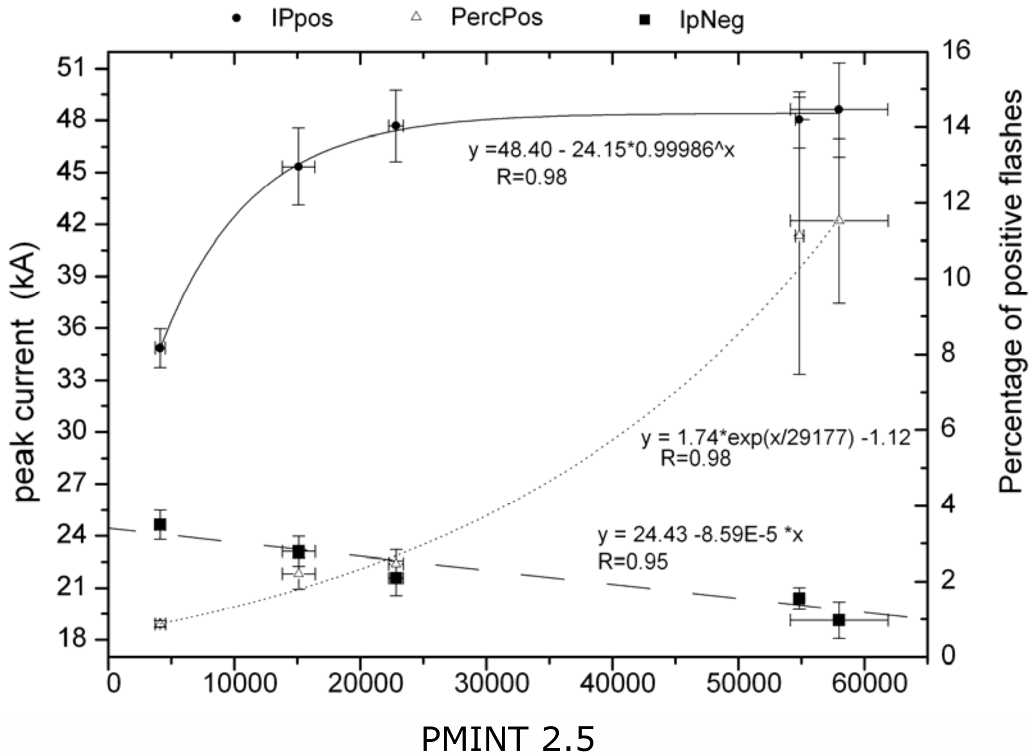

Figure 7

Figure 7 - Average of monthly values of the negative and positive peak current and the percentage of positive CG lightning for 2002 and 2003 as a function of the average PMINT2.5 for each PMINT2.5 category. Regression fits to arbitrary functions are indicated, with their respective correlation coefficients.