Impact of aerosols in cloud electrification: Results from cloud modeling and measurements at the Amazon region

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ABSTRACT: Amazonian convective systems have unique microphysical characteristics, varying from a maritime convective behavior (rainy season) to a continental behavior (wet-dry transition season), which modulates the electrification of these systems. The fact is that coincidentally or not this same modulation of precipitation regulates the period of farmer fires to prepare the pasture for cattle, releasing high concentrations of aerosols into the atmosphere. This work shows that convective storms of different sizes happened to have more positive CG lightning during the very polluted period of biomass burning, while this tendency was decreased with the establishment of the wet season and consequently less pollution.

1. INTRODUCTION

Several authors have been studying the percentage of positive and negative cloud-to-ground lightning (CG). Stolzenburg [1994] observed that summertime thunderstorms CG lightnings of positive polarity (+CG) can occur in high rates per minute, and sometimes all CGs can be positive during the initial formation of the thunderstorm. Carey and Rutledge [1998] found that the major number of +CGs were related to the presence of large hail. Lyons et al. [1998], Murray et al. [2000] and Smith et al. [2003] studied the relationship of the Mexican forest fires in the year of 1998 with the increase in the number of +CGs in Texas. Lyons et al. [1998] found that the percentage of +CGs was three times higher then the climatological mean, and they attributed this effect to the increase of cloud condensation nuclei (CCN) by affecting the cloud droplet spectra, which consequently can affect the charge separation mechanism. Murray et al. [2000] emphasized that this increase happened in isolated points, only where the biomass burning plumes inserted high quantities of aerosols. Smith et al. [2003] did not find any aerosol effect in the percentage of +CGs at a northwest USA biomass burning case, and they also pointed that the period of 1998 forest fires was anomaly dry and warm over the Central Plains which also lead to anomalies of high Convective Potential Available Energy (CAPE). However, Steiger et al. (2002) showed that the number of +CGs were climatologically diminishing over the city of Houston, pointing as reasons the heat island effect and the increase of CCN by pollution industry. Moreover, Fernandes et al. [2006] tried to make a relationship between the dry season biomass burning over the Amazon with the decrease of CGs and an...
aparently increase of the percentage of +CGs during this period.

Therefore, the relationship between the increase of CCN and the increase of +CGs is not well established. Other effects like the thermodynamics, topography and large-scale dynamics were also pointed as possible effects. The objective of this work is to investigate the role of aerosol into the electrification of thunderstorms, as well as the thermodynamic and large-scale effects over the Amazon region.

2. DATA AND RESULTS

The annual cloud-to-ground lightning cycle in the southwestern Amazon have two main peaks: the major one is between October and November and the second one is between December and January [Williams et al., 2002]. The data analyzed in this work is the data collected from September to November of 2002 at Rondonia, Brazil, which correspond the transition of the the dry-to-wet season in the southwestern Amazon and the major peak of the annual cycle. This season is also known by its peculiar social-economical situation of farmer fires to prepare the pasture for cattle, which releases high concentrations of aerosols into the atmosphere.

The instrumentation utilized here are: 1) the Brazilian Lightning Detection Network (BLDN), 2) the aerosol optical thickness measured by the AERONET at the Fazenda Nossa Senhora (FNS), 3) radiosondes launched also at the FNS, 4) S-band radar reflectivity located northwest of the FNS, 5) fire spots over the radar area (400km radius) detected by the NOAA-AVHRR, 6) NCEP reanalysis, and 7) an 1D electrified cloud model [Albrecht et al., 2007].

It can be seen from Figure 1 that the number of +CGs and -CGs detected by the BLDN over the state of Rondonia increased from September to November. This was a response of the atmosphere to the increase of humidity available for convection with the onset of the wet season, as it can be seen from the relative humidity in this same figure. Therefore, the increase in the number of lightnings are due to the increase of the number of thunderstorms. Figure 2 shows the AOT, CAPE and CINE (Convective Inhibition Energy) calculated from the radiosondes, and also the number of fires detected by the AVHRR satellite. It can be seen that the atmosphere was very polluted (AOT up to 6) during September and was cleaned with the onset of the wet season. The CAPE did not show a clear relationship with the number of CGs, however the frequency of both high CINE and high CAPE together occurs more often during September and October, which are special ingredients for explosive convections. Based on the AOT degree of pollution, the radar data was divided into three periods: Extremely Polluted (16/Sep-04/Oct), Polluted (05-25/Oct) and Clean (26/Oct-07/Nov). It was also sorted the precipitating systems by their life time duration using the FORTRACC software [Machado et al., 1998] (30-60, 60-120 and >120 min), and the results are presented in Figure 3. It can be seen that during the Extremely Polluted period there was in general more +CGs then -CGs for all life time classes considered. During the other two periods of pollution, the number of -CGs overcame the number of +CGs, and this feature was more evident for the Clean period.

Figure 4 shows the maximum Vertically Integrated Liquid (VIL – summation of the water content), the maximum reflectivity (Z) and the maximum echotop for 30 dBZ found for each precipitating system detected with the FORTRACC (not divided into classes). It is observed from this figure that there was a clear tendency of decreasing values of VIL, Z and echotop as
the onset of the wet season approached. Therefore, the storms are more vertically deep and severe during September, coincidentally the more polluted period. This increase in the deepness of the storms can be related to the fact of both high CINE and CAPE (which could lead into a deep convection), or the more CCNs and small droplets (which would increase cloud life time and give the cloud a change to grow into ice phase).

The 1D cloud model with non-inductive charge transfer and lightning parametrization was used to simulate a thunderstorm using a radiosonde from the Extremely Polluted period (09/24/2002 06 UTC). The non-inductive parametrization was based on the laboratory work of Avila and Pereyra (2000), which were similar to Takahashi (1978), except that they found a dependence with the mean supercooled droplet size. This dependence charges the graupel negatively in the presence of small droplets at colder temperatures. Figure 5 shows that, in the simulation with cloud droplets d=15 µm, the graupel+hail charging was always positive, resulting in an inverted bipolar system (negative over positive) during the initial time steps of the simulation (t<30min). This charge structure resulted in 37 cloud-to-cloud discharges (CC), with 86% of +CC. In the simulation using cloud droplets d=20 µm, the graupel+hail charging was positive in lower levels and negative in higher levels, this is because for larger droplets the inversion charging temperature is higher (Avila and Pereyra, 2000). In this case, it was generated a tripolar (negative between positives) until ~ 40 min of simulation, and 67 CC occurred with 70% of positive polarity.

3. CONCLUSIONS

This work shows that convective storms of different sizes happened to have more positive CG lightning during the very polluted period of biomass burning, while this tendency was decreased with the establishment of the wet season and consequently less pollution. Futher
studies are needed to understand how the thermodynamics of CAPE and CINE could explain an inverted dipole/tripole, however the increase of cloud life time by giving the cloud a chance to grow into ice phase is also a feature not discarded. Another possible reason could be addressed by the cloud simulations with charging dependence on supercooled cloud size spectra of Avila and Pereyra (2000).

Figure 3 – # of -CGs (red) and +CGs (black) divided by the total storm duration (y-1/min) by the normalized storm life time (x), for pollution periods and life times of 30-60, 60-120 and >120 minutes.

Figure 4 – Maximum VIL, Z and echotopo of 30 dBZ for the storms detected by the FORTRACC software.

Figure 5 – Temporal evolution of electric charges of graupel and hail (Qh+Qg), ice crystals and snow (Qs+ Qi), and electric field E with positive (black) and negative (gray) CC, d=15 (cima) e 20 (baixo) mm.

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