EFFECTS OF THE BIOMASS BURNING IN THE THUNDERSTORM DEVELOPMENT: AN ANALYSIS IN THE AMAZON BASIN

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1. INTRODUCTION

Cloud-to-ground lightning activity in thunderstorms are related to several environmental features that accounts to their development: microphysics (changes in droplet size distributions due to pollution, which consequently changes the life cycle and ice particles formation), thermodynamics (local convection) and large-scale forcings (seasonal humidity conditions and motions configurations, such as the South Atlantic Convergence Zone, squall lines that propagate through the Amazon, Bolivian high), as studied by Rosenfeld (1999), Petersen et al. (2001, 2002), Cifelli et al. (2002), Williams et al. (2002), among others. These features modify the development of thunderstorms that is observed in its life cycle and lightning flash density. This study investigates the impact of such dependencies on the development of the thunderstorms in the Amazon region based on four 4 years of cloud-to-ground lightning measurements over the state of Rondonia, Brazil. A special attention will be given between the dry and wet season (September to November), where biomass burning take place, and can contribute or not to the development of thunderstorms or even modify the electrical charge center.

2. DATA AND METHODOLOGY

Cloud-to-ground lightning (CG) data from 2000 to 2004 were collected by four Advanced Lightning Direction Finder (ALDF) sensors installed by the Marshall Space Flight Center/ NASA (MSFC/NASA) at the state of Rondonia as part of the Tropical Measuring Mission Ground Validation (TRMM/GV). During the RaCCI (Radiation, Clouds and Climate Interactions) and SMOCC (Smoke Clouds, and Climate – Andreae et al., 2004) campaigns at the state of Rondonia, Brazil, an unique set of data were collected representing the transition season from dry to wet conditions in the southwest Amazon, from September to November of 2002. The RaCCI campaign was part of the LBA (Large-Scale Biosphere-Atmosphere Experiment) project (Silva Dias et al., 2002). The campaigns instrumentation used in this work are presented in Figure 1, and they are:

- CAPPIs (Constant Altitude Plan Indicator) of 2 km horizontal and 1 km vertical resolutions, with a radius of 150km, from a Brazilian S-band Doppler radar, manufactured by the TECTELCOM company, installed just for the campaign (62.42W, 10.9S).
- Measurements of aerosol optical thickness (AOT) are taken by the AERONET (Aerosol Robotic Network)1 at the pasture site (Fazenda Nossa Senhora), since 1999 to nowadays. The AOT is defined as the extinction coefficient (partial radiance per wavelength, also called attenuation) integrated in a vertical column of unit section from the direct radiation beam in each wavelength (340, 380, 440, 500, 670, 870 e 1020 nm) based on the Beer-Bouguer's law (Procopio et al., 2004). Therefore, AOT gives the degree in which the aerosol blocks the sunlight transmission: higher the aerosol concentration in the atmospheric column, higher will be the blocking and higher will be the AOT value, indicating the degree of atmospheric pollution.
- Measurements of aerosol size distribution and cloud condensation nuclei (CCN) concentrations were taken at the pasture

1http://aeronet.gsfc.nasa.gov/
Radiosondes were launched every 3 hours at pasture site, measuring vertical profiles of temperature, humidity and wind velocity. CAPE (Convective Potential Available Energy), CINE (Convective Inhibition Energy) were calculated using these profiles of temperature and humidity (Bolton, 1980), as well as the warm cloud depth (WCD – the difference between the height of 0°C isotherm and the cloud base height).

3. RESULTS

Figure 2 shows the CG lightning detected over the state of Rondonia and the aerosol optical thickness from 2000 to 2004. It can be seen that the lightning activity has a major increase from September to November, that is, from the dry to the wet seasons. The AOT started to increase in the dry season, and continued high until the transition season. These high values of AOT are due to forest and pasture fires. Specially during the transition season, the local farmers burn their pastures to prepare them for cattle with the first rains of the wet season. Another interesting feature is the increase in the percentage of CGs with positive polarity (+CGs) during August and September for all 4 years studied (Figure 2a). We can see that the fact is that, coincidentally or not, this same modulation of precipitation and lightning activity (with an increase in the number of +CGs) regulates the period of fires, releasing high concentrations of aerosols into the atmosphere. Many authors have suggested the aerosols from biomass burning can be associated to changes in the polarity of CG lightnings (Lyons et al. 1998, Murray et al. 2000, Smith et al. 2003, Fernandes et al., 2006).

From September to November the aerosol pollution and number of fires decreases, which simulates conditions that vary from very polluted to clean environments. In order to study also the effect of the biomass burning over the precipitating systems, we divided the RaCCI campaign into three distinct periods of pollution and humidity, considering the period of the radar functionality (September 16 though 07 November):

- 16/Sep to 04/Oct: end of the dry season (DRY);
- 05/Sep to 25/Oct: transition between the dry and the wet seasons (TRANS);
- 26/Oct to 07/Nov: begging of the wet season (WET).

The thunderstorms that passed by the radar were divided into classes of lifetime duration (30-60 min, 60-120 min, and >120 min) and then normalized by their total time duration in a scale of 0 to 1. Therefore it is possible to compare different thunderstorms in the same life cycle stage, such as initiation, maturation, and decaying stages. This procedure was done using the a satellite cloud tracking algorithm called FORTRACC (Mathon and Laurent, 2001), modified to use radar reflectivity fields. To track the rain storms, a threshold of 20 dBZ is established to define the rain area clusters (clouds). The CG lightning measurements were navigated in the radar reflectivity maps and the thunderstorms were identified. Finally for each storm, the lightning rate was evaluated.

The panels in Figure 3 show the mean number of lightnings per system per time during the life cycle of the systems, represented by the normalized lifetime. We can see from Figure 3 that during the DRY periods the thunderstorms had more lightning of
Figure 2 – (a) CG strokes detected over Rondonia and the percentage of CGs with positive polarity (+CGs) (the dashed red line indicates the mean percentage) and (b) Aerosol Optical Thickness (AOT) measured over the Fazenda Nossa Senhora, from 2000 to 2004.

Figure 3 – Life cycle of the thunderstorms detected by the radar, divided into total time duration (30-60, 60-120, >120 minutes) and humidity/pollution period. Negative CGs are the blue lines, positive CGs are the red lines, and 'n=' are the number of cases studied.
positive polarity during all their life cycle for all total time duration families. In the thunderstorms that occurred during the other two periods (TRANS and WET), the number of negative CGs (-CGs) overcame the number of positive (+CGs), being this characteristic more strong during the clean period. This result indicates that the very dry and polluted environments could influenced not only in the number of CGs per thunderstorm, but also in their polarity.

More specific studies of how the thermodynamic can affect the CG polarity were conducted by Williams et al. (2005) and Cary and Buffalo (2007). Both studies found out that high cloud base heights may provide larger cloud water in the mixed phase, which is favorable for the positive charging of large ice particles that may result in storms with reversed polarity of its main dipole. Carey and Buffalo (2007) also found that positive storms occurred in environments associates with a drier low level mid-troposphere, higher cloud base, smaller warm cloud depth, and stronger conditional instability. They also pointed out that the differences in the warm cloud depth from negative to positive storm were the most dramatic one.

Following the above studies, we calculated the Lifting Condensation Level (LCL) - which is a measure of the cloud base height, the height of the $0^\circ$C isotherm and the Warm Cloud Depth (WCD), which corresponds to the depth between the height of the cloud base to the height of the $0^\circ$C isotherm. Figure 4 shows these variables from the pasture site radiosondes. It can be seen from this figure that there was a clear tendency of higher LCL during the dry period, while the T = $0^\circ$C height did not follow this tendency. This feature lead also to a tendency of lower WCD during the dry period. Considering that we had mainly

![Figure 4](image)

*Figure 4* – Lifting condensation level (LCL) height, height of $0^\circ$C isotherm, and Warm Cloud Depth (WCD). The horizontal lines correspond to the mean values.

![Figure 5](image)

*Figure 5* – Climatological percentage of +CGs from 2000-2004 during September, October and November.
positive storms at the dry season (Figures 2 and 3), our results agree with Williams et al. (2005), and specially with Carey and Buffalo (2007).

Figure 5 shows the spatial distribution +CGs percentages. As expected from the other results shown above, September shows an enhancement, followed by degrading decrease from October to November. However, the spatial configuration observed in September follows the map of deforestation. As seen in Figure 6, the changes in land cover that follow the construction of paved roads typically result in a so-called fishbone pattern of land-use: the construction of the main road, which is often followed by the development of numerous perpendicular secondary roads accompanied by intensive deforestation along the main axis and successive stripes of forested and deforested areas, depending on the distance from the secondary roads. Figure 7 shows the climatology of percentages of +CGs stratified by the land cover use of Figure 6. We can see that from August to October, +CGs occurs predominantly over deforested areas, and during September more than 30% of this type of lightning occurs over deforestation. This feature can be linked to changes in the thermodynamics of the atmospheric boundary layer (BL), such as more sensible heat and turbulence that elevates the top of the BL and consequently the cloud base heights, as discussed in Figure 4.

Figure 8 shows the mean aerosol size distributions measured at the pasture site (Fazenda Nossa Senhora) during events of clouds that were detected by the radar of RaCCI campaign. These clouds were divided by their electrification activity: those that did not produce lightning (Non-Thunderstorms), those that did produce lightning in general (Thunderstorms), and the storms that produced mainly +CGs (Positive Thunderstorms) and mainly -CGs (Negative Thunderstorms). It can be seen that during the DRY and more polluted period, there is no major differences in the size distributions of the aerosols, except at the size range of 0.005-0.02 μm: there was ~2000cm³ more aerosols during thunderstorms that produced more +CGs, and the negative and non-thunderstorms spectra are the same. Again, no major differences could be identified between

![Figure 6 - Deforestation status at Brazilian State of Rondonia, in southwestern Amazon, based on LANDSAT images (NPE, 2008).](image)

![Figure 7 – Percentage of the 2000-2004 +CGs that occurred over deforested, forest, water and other areas over the state of Rondonia, Brazil.](image)
non-thunderstorms and thunderstorms of either polarity. However, the aerosol size spectra during the WET and clean period presented interesting features: non-thunderstorm clouds were formed in more clean environments (with $\sim$6500 cm$^{-3}$ less total aerosols), while negative and positive thunderstorms presented $\sim$2500 and $\sim$6500 cm$^{-3}$ more total aerosols, respectively. Therefore, the aerosol may not affect the clouds electrification during the DRY and TRANS, but can be an import key during the clean and WET period.

4. CONCLUSIONS

Amazonian convective systems have unique microphysical characteristics, varying from a maritime convective behavior (rainy season) to a continental behavior (wet-dry transition season). These characteristics modulate the electrification of these systems, however it is not well understood which are the dominant processes that intensify the number of lightning from one season to another. The fact is that coincidentally or not the same modulation of the Amazonian precipitation regulates the period of farmer fires to prepare the pasture for cattle, releasing high concentrations of aerosols into the atmosphere.

The weather radar and lightning measurements at Southwest Amazon showed 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.

The thermodynamic analysis of the environment showed a smaller warm cloud depth, which is favorable for the positive charging of large ice particles that may result in storms with reversed polarity of its main dipole (Carey and Buffalo, 2007). This analysis also showed that the dry period had also more conditional instability, which could eventually produce deep convective systems if a low level forcing acts. The thermodynamic variability could also be associated to the land cover over Rondonia. We showed that +CGs occurred mainly over the deforested areas, where the top of the boundary layer can be higher and decrease the warm-cloud-depth, which have been reported as a condition for inverted polarity storms (Carey and Buffalo, 2007).

The aerosol effect on cloud formation and electrification is still not well established. We showed that the aerosol size distributions during thunderstorms and non-thunderstorms events do not differ during the DRY and TRANS periods. However, a major difference was found during the WET period, suggesting that thunderstorms only occur around a more polluted environment. Another aerosol effect that was not explored here is their...
composition. Jungwirth et al. (2005) found that biomass burning aerosols can change the molecular structure of the cloud ice crystals exposing more positive ions at their surface. More work is needed to be done in this field.

Acknowledgments
This work was supported by FAPESP (Fundação de Amparo a Pesquisa de São Paulo) on the grant number 04/09049-3.

REFERENCES


Silva Dias, and co-authors, 2002: Clouds and rain processes in a biosphere-atmosphere interaction context in the Amazon region, J. Geophys. Res., 107, 8072.


Williams, E., and co-authors, 2002: Contrasting convective regimes over the Amazon: Implications for cloud electrification, J. Geophys. Res., 107, 8082.