8A.3 LIGHTNING ACTIVITY ON THUNDERSTORMS RELATIVE TO THE MICROPHYSICS, THERMODYNAMICS AND LARGE-SCALE FEATURES IN THE AMAZON REGION

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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.

Our study investigates the development of the thunderstorms and their lightning activity as observed by a weather radar during the transition from dry-to-wet seasons over the Amazon region. The thunderstorms are divided into life time duration and their radar parameters are correlated to the thermodynamics derived parameters measured with the radiosondes, topography, and large-scale features inferred from NCEP reanalysis.

Furthermore, these thunderstorms are analyzed to decipt the pollution influence of the forest fires occurred during the dry-to-wet season in order to identify any influence into the cloud droplets formation and life cycle. Once the period chosen is influenced by biomass burning, the observed thunderstorms are analyzed to depict any changes in the life cycle and lightning polarity behavior that can be correlated to any changes in the cloud droplets formation.

2. DATA AND METHODOLOGY

The data analyzed here was collected during the RaCCI (Radiation, Clouds and Climate Interactions) campaign, at the state of Rondonia, Brazil, and occurred from September to November of 2002, which corresponds to the transition season from dry to wet conditions in the southwest Amazon. The RaCCI campaign was part of the LBA (Large-Scale Biosphere-Atmosphere Experiment) project (Silva Dias et al., 2002). The instrumentation of this campaign is resumed in Figure 1.

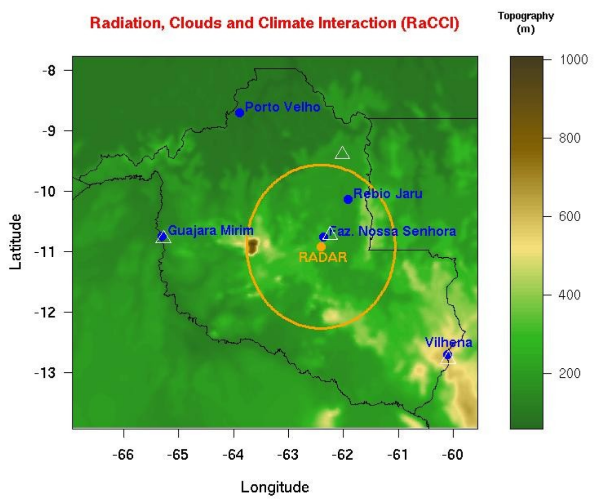

Figure 1 *– RaCCI field campaign instrumentation at Rodonia state, Brazil. The orange site represents the TECTELCOM weather radar location, and blue sites are the radiosonde sites. The Fazenda Nossa Senhora also held the aerosol and CCN counters. White triangles are the BLDN sensors.*

During this campaign, a Brazilian S-band Doppler radar, manufactured by the TECTELCOM company, was installed in Rondonia (62.42W, 10.9S, 433 m) to measure the convection characteristics. This data were collected in 10 minute sweepings with 24 elevations, which were converted into CAPPIs (Constant Altitude Plan Indicator) of 5 km horizontal and 1 km vertical resolutions.

Cloud-to-ground lightning data (CG) were collected with the Advanced Lightning Direction Finder sensors installed by the Marshall Space Flight Center at NASA (MSFC/NASA) and they are integrated into the Brazilian Lightning Detection

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Network (BLDN).

Measurements of aerosol optical thickness (AOT) were made by the AERONET (Aerosol Robotic Network) at the Fazenda Nossa Senhora. 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 Fazenda Nossa Senhora, by the Max Planck Institute for Chemistry. Radiosondes were also launched every 3 hours at this site, measuring vertical profiles of temperature, humidity and wind velocity. CAPE (Convective Potential Available Energy) and CINE (Convective Inhibition Energy) were calculated using these profiles of temperature and humidity (Bolton, 1980.). Large-scale characteristics were also analyzed using the the National Centers for Environmental Predictions (NCEP) reanalysis.

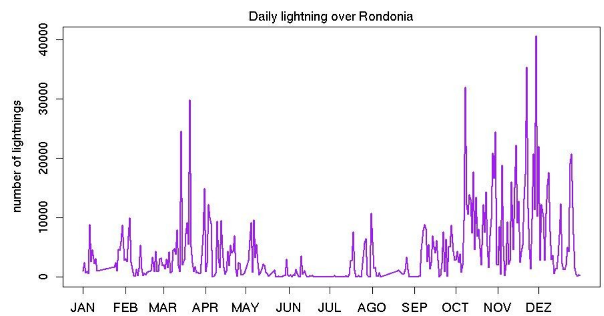
In order to characterize the thunderstorms, this study uses the cloud tracking algorithm developed by Mathon and Laurent (2001), which has been implemented at the National Space Research Institute (INPE) of Brazil, and it was named FORTRACC. In study, the method was modified to use radar reflectivity fields. To track the rain storms, a threshold of 20 dBZ is established to define the rain area

After these settings, the FORTRACC algorithm produces a temporal series of the main morphological characteristics of the rain storms, i.e.: size, location, major and minor ellipse axis and its inclination angle, radar reflectivity distribution, convective fraction, growth ratio and others. Further, 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.

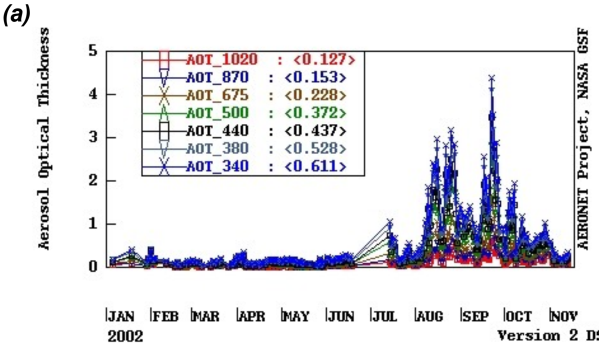
To analyzed the thunderstorms, they are divided in classes of lifetime duration (30-60, 60-120, >120 min), and the time is normalized by the total time duration. By using this procedure, it is possible to compare different thunderstorms in the same life cycle stage (initiation, maturation, and decaying).

3. RESULTS

Figure 2 shows the CG lightning detected over the state of Rondonia and the aerosol optical thickness for the year of 2002. It can be seen that the lightning activity had 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 were 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. We can see that the fact is that, coincidentally or not, this same modulation of precipitation regulates the period of fires, releasing high concentrations of aerosols into the atmosphere.



(a)



(b)

***Figure 2** – **(a)** 2002 lightning strokes detected by the BLDN. **(b)** Aerosol Optical Thickness (AOT) measured over the Fazenda Nossa Senhora during the year of 2002 (This figure was automatic generated by http://aeronet.gsfc.nasa.gov/).*

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 sytems, we divided the RaCCI campagin into three distinct periods of pollution, considering the period of the radar functionality (September 16 though 07 November):

- 16/Sep to 04/Oct: *Extremely Polluted (EP)*;
- 05/Sep to 25/Oct: *Polluted (PL)*;
- 26/Oct to 07/Nov: *Clean (CL)*;

Figure 3 shows the mean relative humidity over the state of Rondonia calculated from the NCEP reanalysis, superposed with the number of lightning of positive and negative polarities that occurred over the same area. It can be seen that both the humidity and the number of lightning increased from September to November following the onset of the wet season. One interesting feature observed in Figure 3 is that there was only a large number of lightning (>500) when the isoline of 60% of relative humidity (yellow color on the panel) was above the height of 800 hPa. In the begging of the campaign (mid September) there was some isolated days with more than 60% of relative humidity above the level of 850 hPa. During the end of September until mid October there was a predominance of less humidity available over high altitudes. Finally, from mid October to November the humidity increased up to the heights of 550 hPa.

This situation of very humid low levels and drier upper levels is a perfect environment for convective condition instability. The convective condition instability is an instability that occurs if the thermal parcels can break the boundary layer stability. This scenario can be observed over the CAPE and CINE time series presented in Figure 4. There was high values of CINE that the convective parcels needed to break until mid October (end of dry season). CAPE was also high (>1000 J/kg) or moderate (500-1000 J/kg) during the whole campaign, specially during the dry (10-30/Sep) and wet (15/Oct-07/Nov) periods. However, with the low CINE during the wet period, the number of clouds are higher than during the dry period, when clouds needed to break the high stability of high CINE.

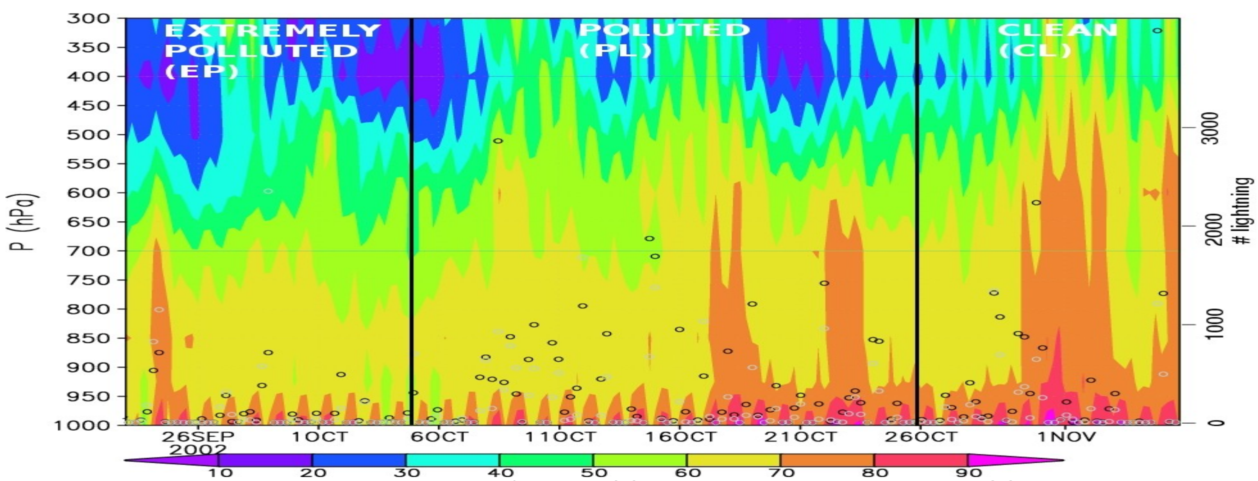


Figure 3 *– Mean relative humidity (shaded – left axis), +CGs (gray circles – right axis) and -CGs (black circles – right axis) over the Rondonia. The black solid lines represents, the division of the 3 pollution periods.*

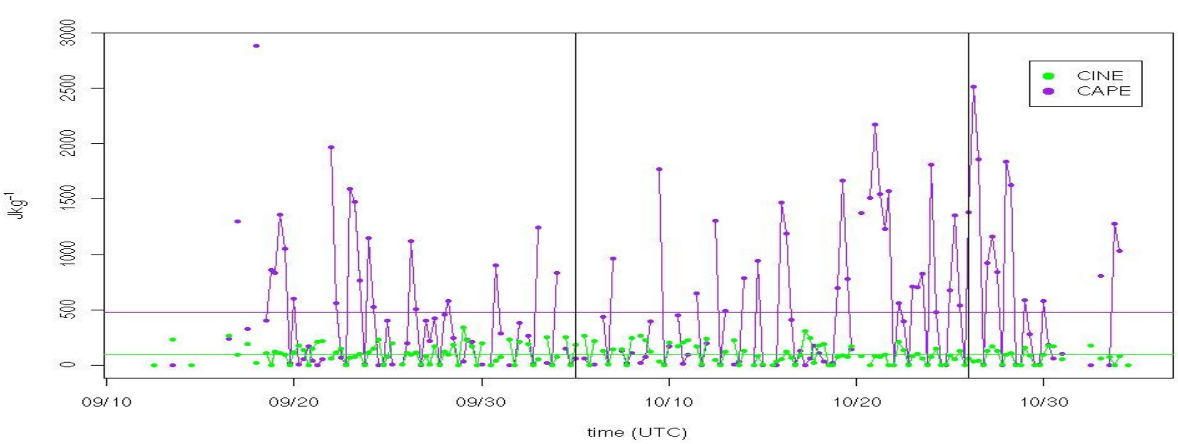


Figure 4 *– Convective Available Potencial Energy (CAPE) and Concentration Inhibition Energy (CINE). The horizontal lines correspond to the mean values.*

In order to investigate how the clouds could break this convection inhibition, we computed in Figure 5 the mean topography (Figure 1) height under the convective cells that produced lightnings at their initial stage, for the end of the dry, transition and wet seasons. It can be seen that the mean topography height of all thunder cells was 400 m. However, only 50% of the dry period cells were initiated with a topography of 300 m, while this percentage was 80% for the wet season and 100% for the transition season.

Therefore, during the dry period, when a convective parcel could find a topography difference of 50 to 100 m which could forced it to be elevated, the parcel could find an instable upper environment with high CAPE. In this case, the parcel could "explode" into a well vertically developed storm producing more lightning.

Apparently, this is what happened in Figure 6. Figure 6 shows the maximum Vertically Integrated Liquid (VIL) of the clouds over the radar area. The VIL was calculated from the radar CAPPIs by integrating in altitude liquid water content (LWC):

$$LWC_i = 3.4\times10^{-3}\left(10^{\frac{Z_i}{10}}\right)^{\frac{4}{7}} \quad (1)$$

$$VIL = \sum_1^{18}\left(LWC_i\, dh\right) \quad (2)$$

where Z_i is the reflectivity (dBZ) at the height *i* and dh = 1 km. It is observed from this figure that there was a clear tendency of decreasing values of VIL as the onset of the wet season approached. Therefore, the storms are more vertically deep and severe during the dry season, coincidentally the more polluted period.

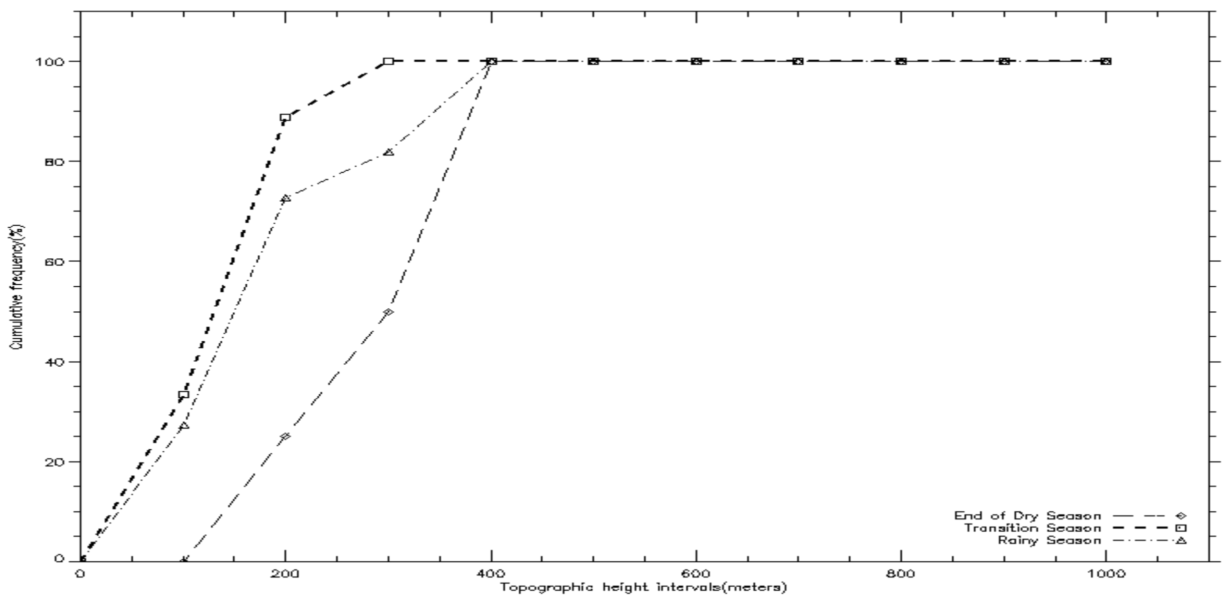


***Figure 5** – Cumulative frequency of topography height under the initial convective systems that produced lightning.*

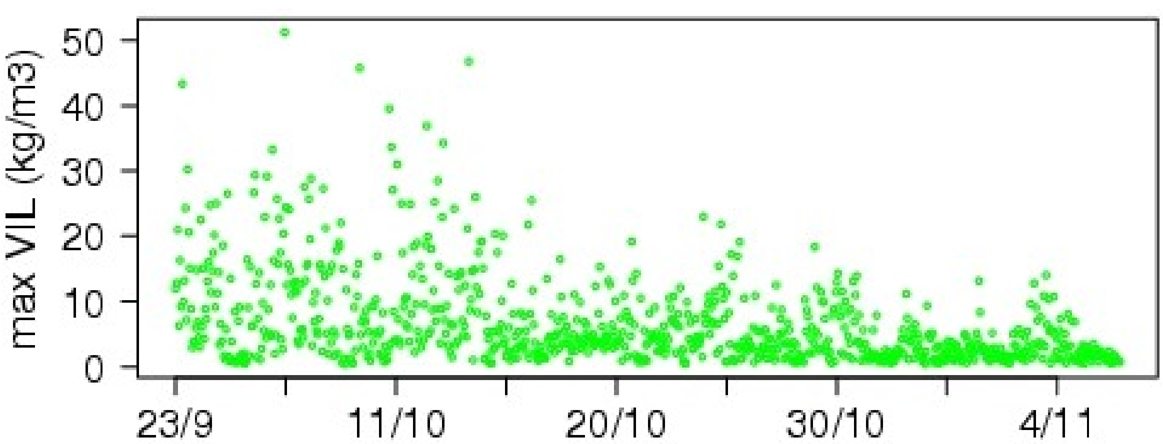


***Figure 6** – Maximum Vertically Integrated Liquid (VIL) for all systems detected by the radar*

The clouds that passed over the radar area where then tracked by the FORTRACC software and divided into 3 classes of total time duration (30 to 60, 60 to 120 and greater than 120 minutes, representing local to meso-scale convective systems), and 3 classes of pollution (EP, PL, and CL). The panels in Figure 3 show the mean number of lightnings per system per time (10 minutes of radar images) during the life cycle of the systems, represented by the normalized time. We can see from Figure 3 that during the EP period the thunderstorms had more lightning of positive polarity during all their life cycle for all total time duration families. In the thunderstorms that occurred during the other two periods (PL and CL), the number of negative CGs overcame the number of positive, 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 midtroposphere, 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 0ºC isotherm and the Warm Cloud Depth (WCD), which corresponds to the depth between the height of the cloud base to the height of the 0ºC isotherm. Figure 8 shows these variables from the Fazenda Nossa Senhora radiosondes. It can be seen from this figure that there was a clear tendency of higher LCL during the dry period, while the T= 0ºC 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 positive storms at the dry season (Figure 7), our results agree with Williams et al. (1995), and specially with Carey and Buffalo (2007).

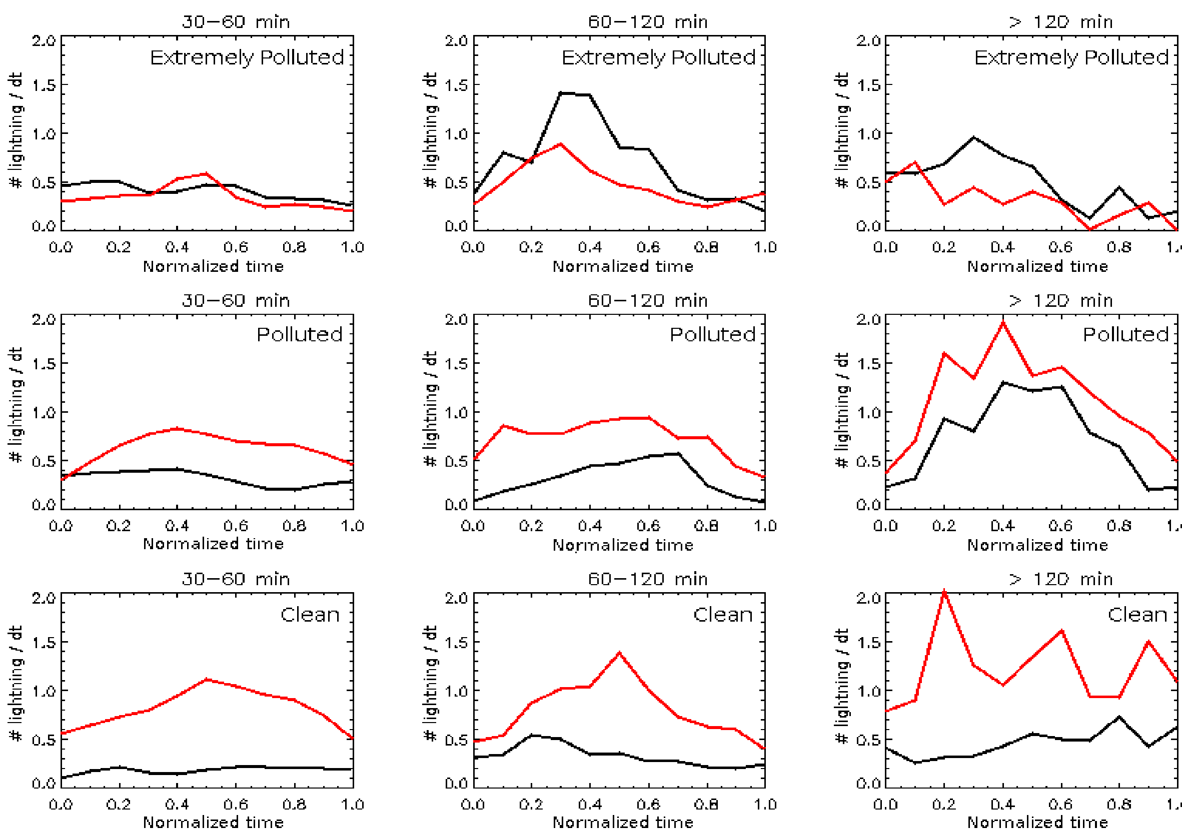


***Figure 7** – Life cycle of the thunderstorms detected by the radar, divided into total time duration(30-60, 60-120, >120 minutes) and pollution period. Negative storms are the red lines and positive storms are the black lines.*

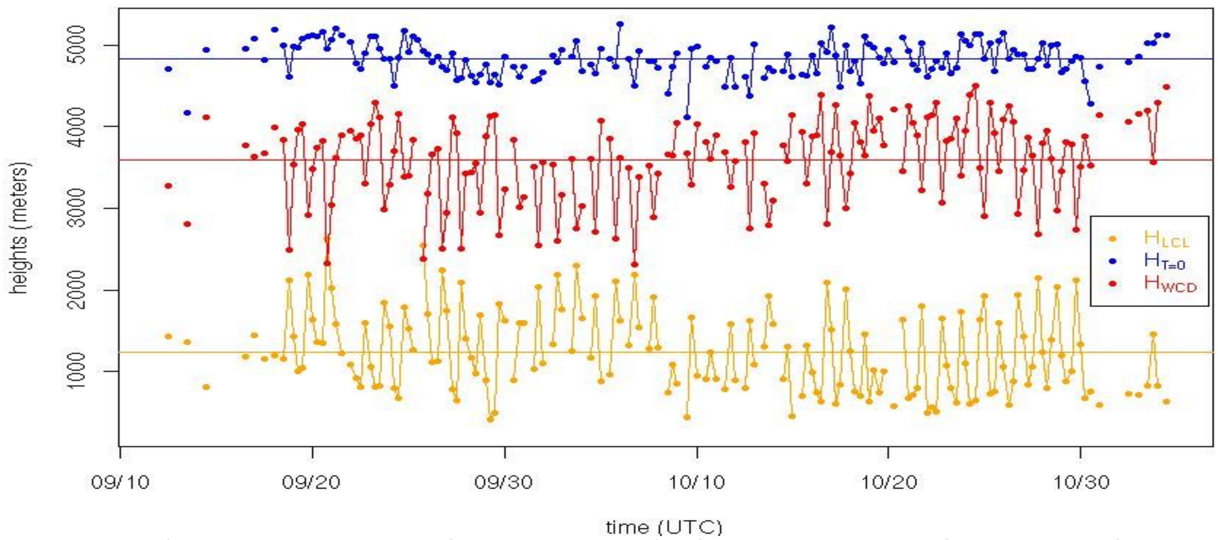


Figure 8 *– Lifting condensation level (LCL) height, height of 0oC isotherm, and Warm Cloud Depth (WCD). The horizontal lines correspond to the mean values.*

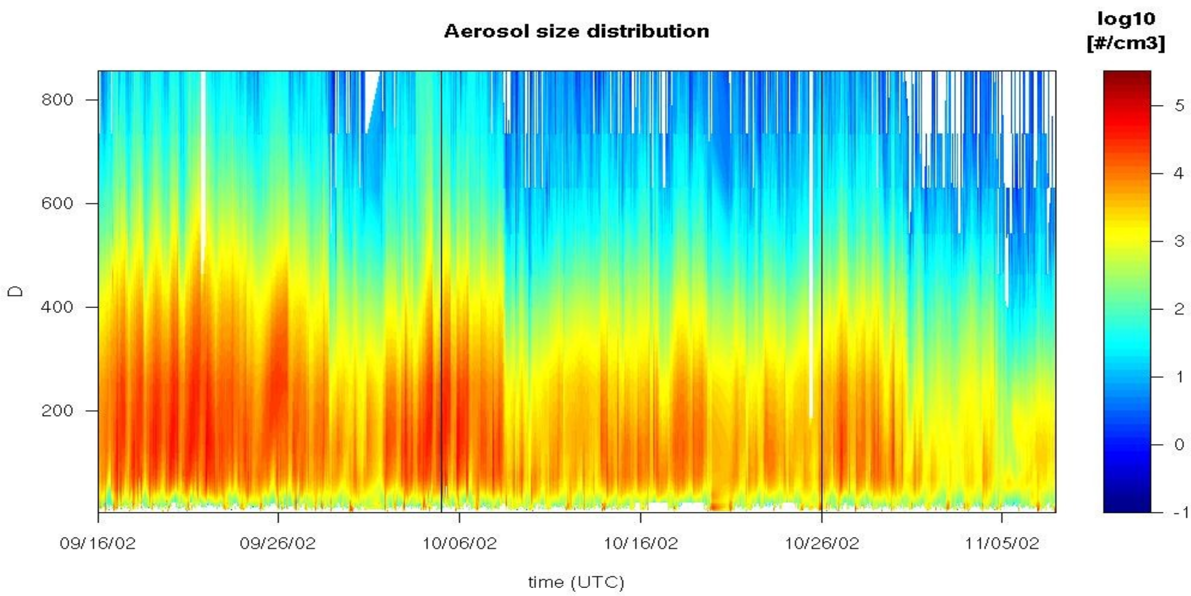


Figure 9 *– Aerossol size distribuition measured at the Fazenda Nossa Senhora.*

The coincidence of the extremely polluted period (Figure 2b) with the occurrence of positive storms (Figure 7) is also intriguer. Lyons et al. (1998), Murray et al. (2000), and Smith et al. (2003) studied the relationship between the Mexican forest fires of 1998 and the enhancement in the number of +CGs in the state of Texas, United States. Lyons et al. (1998) found that the percentage of +CGs was three times higher than the climatological mean. Murray et al. (2000) emphasized that this enhancement was in isolated points, and only where the biomass burning plumes inserted a high quantity of aerosols in the atmosphere. These authors attributed this effect to the enhancement of the CCNs. This is known as the aerosol hypothesis for cloud electrification (Rosenfeld and Lensky, 1998; Williams et al., 2001; Williams et al., 2002): air from clean (dirty) atmospheric boundary layer will have a low (high) number of large (small) droplets, which can prevail the coalescence and precipitation activation, diminishing the cloud water that can be injected at the mixed phase of the cloud, where the lightning is generated.

Figure 9 shows the aerosol size distribution and concentration during the RaCCI campaign. We can see that there was much more large concentration of aerosols of all sizes during the dry period. The CCN concentrations also followed the same behavior of higher concentrations at the dry period to lower concentrations at the onset of the wet period (not shown). Figure 10 shows the relationship of CCN concentration with the supersaturation of the environment representative of the polluted and clean periods. We can see a dramatic difference between the PL to the CL periods at high supersaturaions: for S=1.12% there was a difference of more than 4000 cm^{-3} of activated CCNs. However, this value of S is not realizable at nature, where we can achieve maximums of only 0.2% at very large vertical velocities (~20 ms^{-1}). At S=0.2% the difference between the number of PL and CL activated CCNs decreased to ~ 1200 cm^{-3}.

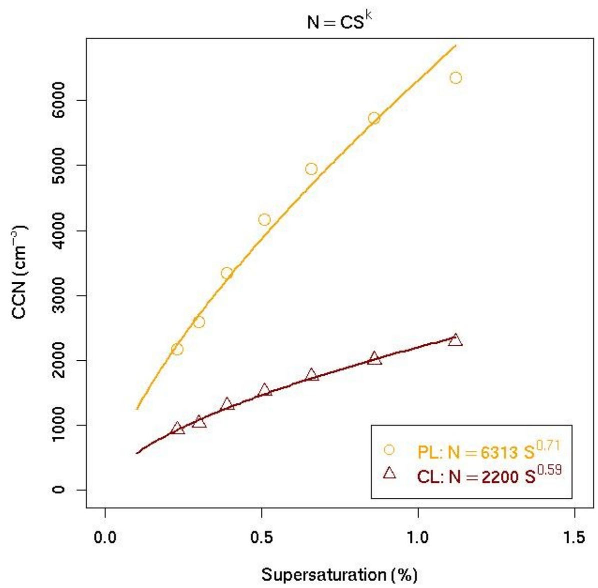


Figure 10 *– Mean cloud condensation nuclei (CCN) activated by the supersaturation indicated inside the counters of Max Planck Institute for Chemistry installed at the Fazenda Nossa Senhora. The polluted period (PL) is represented by 25 October 2002, and the clean period (CL) by 14 November 2002.*

Considering the not so dramatic difference between number of CCNs at the conditions found in nature (Figure 10), and that the number of available aerosols as CCN candidates is larger during the EP and PL than during CL for *all* diameter sizes (Figure 9), we can speculate three additional scenarios despite the aerosol hypothesis:

(1) If the CCN distribution follow the number and size of aerosols distribution, and assuming that the larger CCNs are activated first due to a lower critical radius (Pruppacher and Klett, 1997), we would have that during the very polluted periods more droplets could be activated by larger CCNs. These clouds would have a greater number of large droplets (and not small droplets as the aerosol hypothesis). The cloud droplets would also grow faster and not develop a deep mixed phase, which would decrease the electrification of the clouds.

(2) Assuming (1) and that there would be a moderate difference in the number of CCN (as the one in Figure 10 for lower supersaturations), both polluted and clean periods could activate the same size distribution of CCNs, which would lead to clouds with same cloud spectra but with more droplets of all sizes in the polluted case. The PL and CL clouds would then have just a difference in the life duration (with the PL cloud behind in the life cycle) but not in the electrification.

(3) The small aerosols and CCNs could play as a humidity "stealer", drying up the upper boundary layer, which will make the atmosphere more conditionally instable. This characteristic could make the EP and PL clouds more electrically efficient due to the strong convection updrafts.

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 low level forcing was found to be the topography, that despite of the not so accidentally terrain at Rondonia (Figure 1), the clouds during the dry period formed over a difference of 50-100 meters of height. The large-scale onset of the wet season insert more humidity into the atmosphere which facilitate the convection.

The aerosol effect on cloud formation and electrification is still not well established. It was speculated here three additional scenarios of how aerosols can play depending on how they are activated as CCN: (1) they can produce polluted clouds with larger droplets and less lightning (improbable), (2) polluted and clean environments can produce similar clouds with similar electrification, but with a delay in the polluted cloud life cycle, and (3) they can dry up the atmosphere and be a second player in the thermodynamic.

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

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REFERENCES

Bolton, 1980: The computation of equivalent potential temperature, *Mon. Wea. Rev.*, **108**, 1046-1053.

Carey, L., and K. Buffalo, 2007: Environmental control of cloud-to-ground lighting polarity in severe storms, *Mon. Wea. Rev.*, **135**, 1327-1353.

Cifelli, R. W.A. Petersen, L.D. Carey, and S.A. Rutledge, 2002: Radar Observations of the Kinematic, Microphysical, and Precipitation Characteristics of Two MCSs in TRMM-LBA. *J. Geophys. Res*, **29**, 8077.

Jungwirth, P., D. Rosenfeld and V. Buch, 2005: A possible new molecular mechanism of thundercloud electrification, *Atmos. Res.*, **76**, 190-205.

Lyons, W.A., T.E. Nelson, E.R. Williams, J. A. Cramer, and T.R. Turner, 1998: Enhanced Positive Cloud-to-Ground Lightning in Thunderstorms Ingesting Smoke from Fires, *Science*, **2**, 77-80, 1998.

Machado, L. A. T., W. Rossow, R. L. Guedes, and A. Walker, 1998: Life Cycle Variations Of Mesoscale Convective Systems Over The Americas, *Mon. Wea. Rev.*, **126**, 1630-1654.

Mathon, V. and H. Laurent, 2001: Life Cycle of the Sahelian convective cloud systems, *Quart. Royal. Meteor. Soc.*, **127**, 377-406.

Murray, N. D., R. E. Orville, and G. R. Huffines, 2000: Effect of pollution from Central American fires on cloud-to-ground lightning in May 1998, *Geophys. Res. Lett.*, **27**, 2249-2252.

Petersen, W.A., and S.A. Rutledge, 2001: Regional Variability in Tropical Convection: Observations from TRMM. *J. Climate,* , **14**, 3566-3585

Petersen, W.A., S.W. Nesbitt, R.J. Blakeslee, R. Cifelli, P. Hein, and S.A. Rutledge, 2002: TRMM Observations of Intraseasonal Variability in Convective Regimes Over the Amazon. *J. Climate,* **15**, 1278-1294.

Procopio, A.S., Artaxo, P., Kaufman, Y.J., Remer, L.A., Schafer, J.S., Holben, B.N., 2004: Multiyear analysis of amazonian biomass burning smoke radiative forcing of climate, *Geophys. Res. Lett.*, **31**, 3108-3112.

Pruppacher, H. R., e J. D. Klett, 1997: *Microphysics of Clouds and Precipitation*, D. Reidel, Dordrecht, Holland, 714 pp., 1997.

Rosenfeld, D., and M. Lensky, 1998: Satellite-based insights into precipitaion formation processes in continental and maritime convective clouds, *Bull. Amer. Meteor. Soc.*, **79**, 2457-2476.

Rosenfeld, D, 1999: TRMM observed first direct evidence of smoke from forest fires inhibiting rainfall, *Geophys. Res. Lett.*, **26**, 3105-3108.

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

Smith, J. A., M. B. Baker, and J. A. Weiman, 2003: Do forest fires affect lightning?, *Quart. J. Royal Meteor. Soc.*, **129**, 2651-2670.

Williams, E., D. Rosenfeld, N. Madden, C. Labrada, J. Gerlach, and L. Atkinson, 1999: The role of boundary layer aerosol in the vertical development of precipitation and electrification: Another look at the contrast between lightning over land and over ocean, Preprints, *11th International Conference on Atmospheric Electricity*, Gunstersville, AL, 754-757.

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

Williams, E., V. Mushtak, D. Rosenfeld, S. Goodman, and D. Boccippio, 2005: Thermodynamic conditions favorable to superlative thunderstorm updraft, mixed phase microphysics and lightning flash rate, *Atm. Res.*, **76**, 288-306.