UNDERSTANDING THE ELETRIFICATION PROCESSES: A CONTRIBUTION OF CHUVA PROJECT

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ABSTRACT: The CHUVA Project, a Brazilian campaign that aims to validate the rainfall estimation from the Tropical Rainfall Measuring Mission (TRMM) and Global Precipitation Measurement (GPM) is conducting several field campaigns over Brazil since 2010. In each field campaign in addition to the rain measurements, CHUVA is measuring the vertical electrical field and lightning activity. Those measurements are being employed to understand the electrification processes observed in the different regions of Brazil. To understand these processes, we have developed a methodology that retrieves the charge centers based on field mills and radar reflectivity measurements. During the field campaigns of Bélem and Vale do Paraiba we found a paradox, i.e, where Vale do Paraiba thunderstorm had a maximum electrical field of 2 kV/m while in Belém it was above 4 kV/m, but Belém experienced less lightning activity than Vale do Paraiba thunderstorms. When retrieving the charger centers of 2 selected thunderstorms it was found a dipole solution with Belém having a negative charge center between at 3-5 km height and positive at 7 km with charges varying from 100-500 C. For Vale do Paraiba though, we found a positive charge center at 3-5 km and a negative at 7-9 km with charges varying from 10-80C.

INTRODUCTION

During the year of 2011, CHUVA project (***C***loud processes of t***H***e main precipitation systems in Brazil: A contrib***U***tion to cloud resol***V***ing modeling and to the GPM (Glob***A***l Precipitation Measurement) [Machado et al., 2014], conducted 3 field campaigns in Brazil: Fortaleza (April), Belém (June) and Vale do Paraíba (November/December), where polarimetric weather radar and lightning measurements were conducted. Lightning measurements were

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performed STARNET (Sferics Timing and Ranging Network) [Morales et al., 2011] during the 3 CHUVA field campaigns, Figure 1, and it is possible to observe from daily time series that Fortaleza had the weakest lightning activity followed by Belém and Vale do Paraiba. Fortaleza and Belém are coastal cities in northeast of Brazil and have a mix of warm rain and ITCZ deep convection that penetrates inland, while Vale do Paraíba, southeast Brazil, combines localized deep convection, frontal systems and squall lines with sea breeze and montain-valey circulations. As a consequence, we would expect less lightning activity in the northeast than in the southeast that is clear in Figure 1, once the first two are more oceanic type of storms. Moreover, Vale do Paraíba shows 3 to 10 times more lightning flashes than the northeastern cities, although Belém presents almost daily thunderstorms all year long [Morales et al., 2014].

(a) (b)

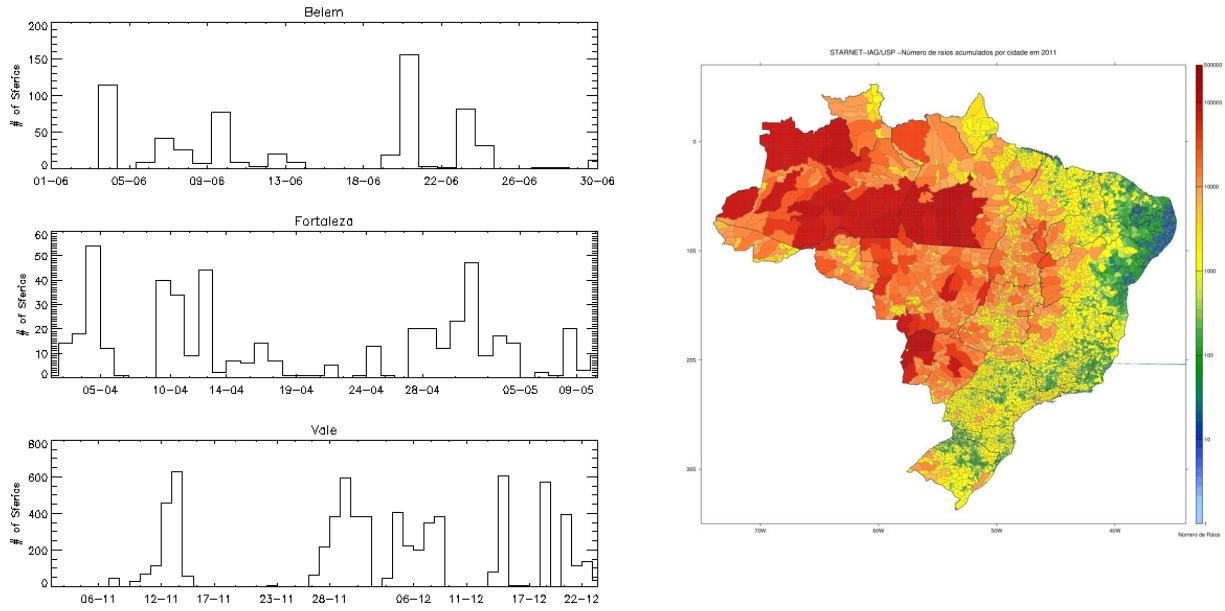


Figure 1. (a) STARNET Daily sferics measurements observed in the 2011 CHUVA field campaigns and (b) STARNET annual lightning activity in 2011.

To understand why we observed such lightning activity differences, we initially looked into the polarimetric measurements from CHUVA X Band weather radar and to the vertical electrical field (Ez) measurements. Finally, Ez observations were used to retrive the charge centers and hypotesize about these lightning activity.

THUNDERSTORM STRUCTURE

During the CHUVA field campaigns, a polarimetric Doppler X-Band weather radar was conducting continuous volume and Range Height Indicator (RHI) scanning every 6 minutes. The RHIs were performed over the supersites, where several rainfall measurements were taken since CHUVA aims to validate Global Precipitation Mission (GPM) program [Machado et al., 2014]. Around the super sites of Belém and Vale do Paraíba we have deployed a network of 3 field mills that were sampling Ez every 0.1 (Boltek) and 1 (Campbell) second.

Based on the thunder days of Figure 1, we selected all RHI measurements within 50 km from the radar and analyzed the mean radar reflectivity (Z) and liquid/ice water content (LWC/IC) profiles (Figure 2).The mean thunderstorm vertical profiles show that Belém has the highest Z values followed by Vale do Paraíba and Fortaleza below 10^{o}C, but when we looked for the Z and IC profiles above the melting layer though, it is possible to observe that Vale do Paraíba has higher values between 0 ^{o}C and -15 ^{o}C while Belém between -15 ^{o}C and -50^{o}C. These results indicate that in Vale do Paraíba we would expect the predominance of accretion while at Belém aggregation. As a consequence, Vale do Paraiba would have more graupel and hail while Belém more ice and snow particles, which agrees with the lightning observations because the graupel/hail/ice collisions are more efficient in transferring charges than ice/snow particles, so we would expect more lightning discharges in Vale do Paraíba than in Belém. Fortaleza profiles present two particular signatures: first a weak bright band followed by an increase in Z and LWC between 0 ^{o}C and 20^{o}C and second a sudden slight increase of Z between -15 ^{o}C and -25 ^{o}C. This is a characteristic of the presence of snowflakes that are produced aloft that precipitate and melt and then coalesce as it becomes water.

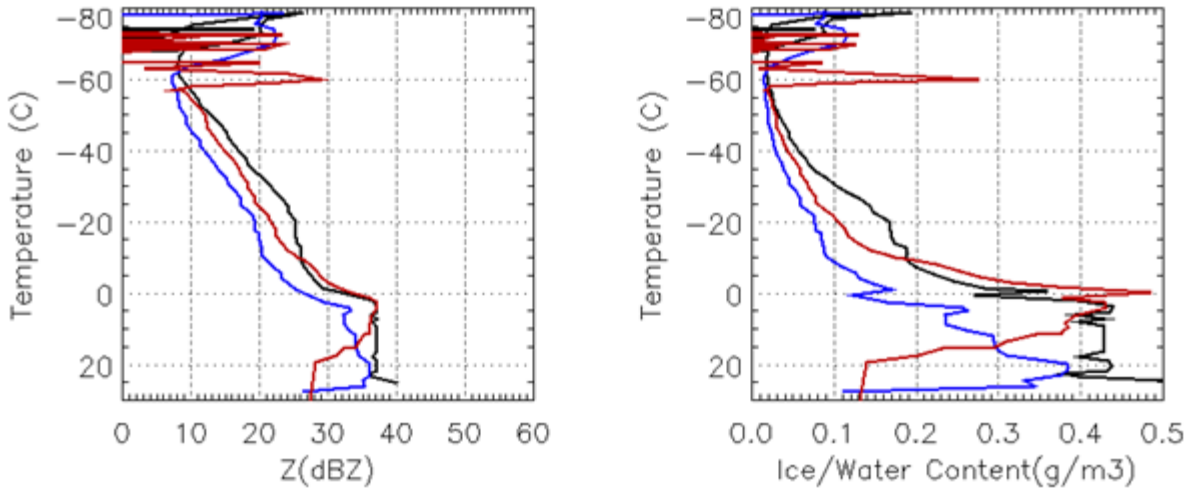


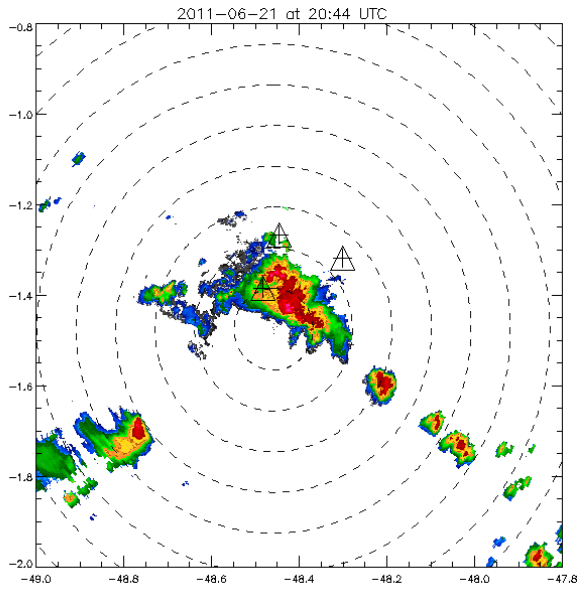
Figure 2. (a) Mean radar reflectivity and (b) liquid and ice content profiles for thunderstorms observed in Fortaleza, Belém and Vale do Paraiba.

CHARGE CENTERS

To explore the electrification process and understand some of the lightning features observed during the CHUVA field campaigns, we now analyze radar and field mill measurements for 2 cases: one in Belém (Figure 4) and one in Vale do Paraíba (Figure 5). Later we apply the inverse problem of Coulomb´s Law methodology to retrieve the vertical charge centers [Lacerda et al. ,2012].

In Belém, a squall line propagating E – W crossed 3 field mill sensors (Airport, Benevides and Outeiro), Figure 3a. All sensors present an Ez increase as the storm approaches followed by some reversal polarity and decaying Ez followed by fair air weather conditions, Figure 4a. All sensors observed a positive field indicating a negative charge in the lower part of the storm. As the storm approachs Outeiro (northern sensor), Ez values reached 4kV/m while in the other 2 sensors, less than 2 kV/m. Cross sections over the storm as it crossed Outeiro shows a vertical development reaching 15 km. In the mixed zone that extended from 0 ^{o}C to -35 ^{o}C we found the presence of low density graupel and ice crystals and aggregates aloft. Below 0 ^{o}C rain and high density graupel that could be small hail. The extended layer in the mixed zone, almost a depth of 5km and the presence of small hail melting could explain the high values of Ez and few lightning flashes (Figure 1, Figure 4a), because we might have a large positive charge region bounded by a strong negative region near the melting layer that carries these charges as it precipitates.

(a) Belém



(b) Vale do Paraíba

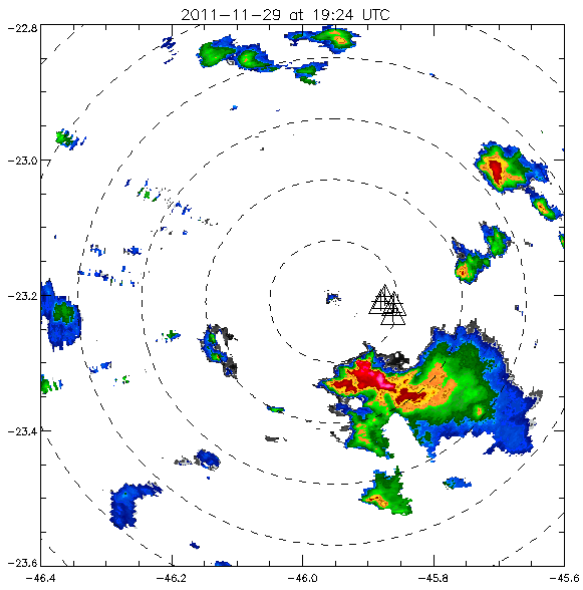


Figure 3. Radar reflectivity PPI 0.5 degrees elevation at Belém during 21st June 2011 (a) and Vale do Paraíba on 29th November 2011 (b).

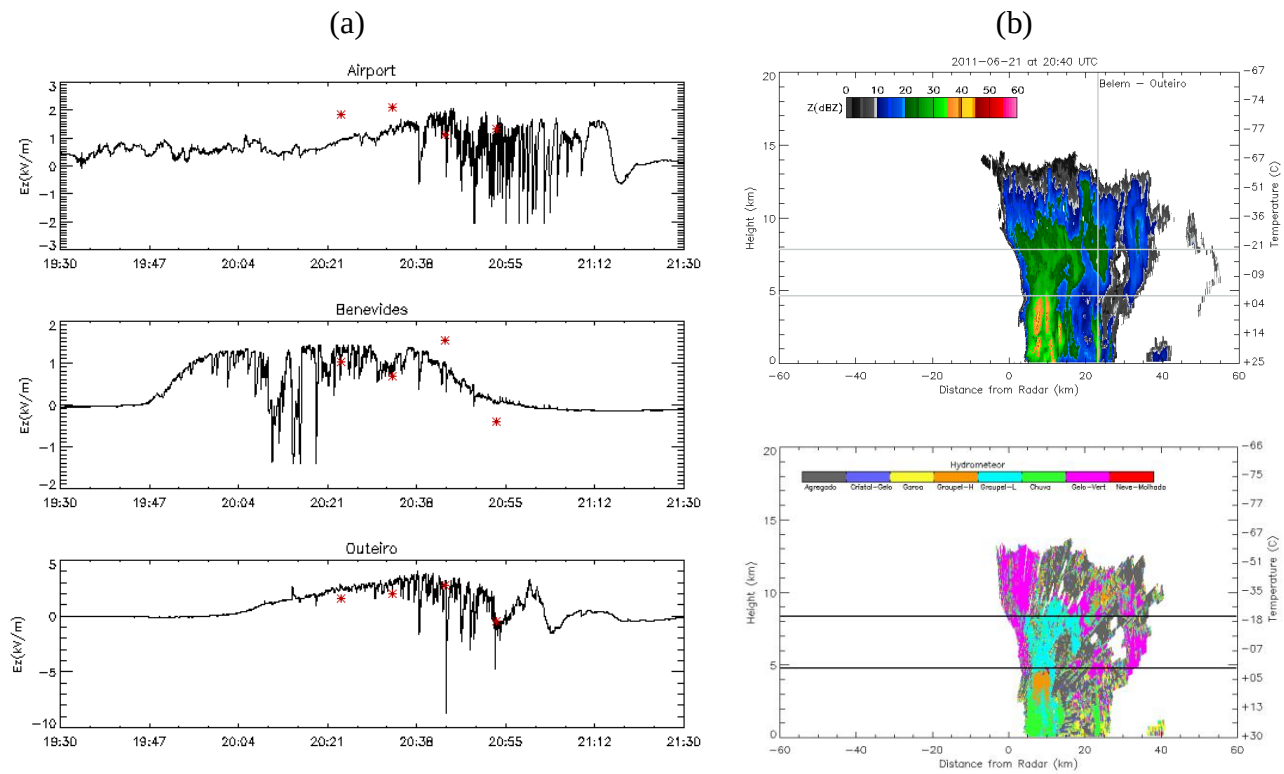


Figure 4. Temporal evolution of the vertical electrical field observed on 21st June 2011 at CHUVA Belém field campaign at the sites of Airpot, Benevides and Outeiro (a); and (b) radar reflectivity RHI and correspondent hydrometeor classification of a RHI over Outeiro at 20:40 UTC on 21st June 2011

In Vale do Paraíba campaign, Figure 3b, a precipitating system was propagating from SW to NE and passed near the sites on 29th November 2011. The field mill records, Figure 5a, show that as the storm approach the Ez became negative and after its passage it turned positive. These features would indicate a lower positive charge bounded aloft by a negative charge region. Differently from Belém, Ez measurements barely reach 1 kV/m but it showed high lightning activity (Figure 1 and 5a). By looking at the RHI, Figure 5b, we do see a deep storm reaching as high as 13km but in the mixed region, defined by the isotherm of 0°C and -20°C, we found weak echoes that are associated with aggregates and low density graupel and ice particles aloft. Below the melting layer we observe rain but not so intense. These characteristics are reasonable to explain the low Ez values observed but not the lightning activity that is 3 times more than in Belém.

Table 1 shows the solution of the inverse problem of Coulomb´s law on the above measurements. It is possible to observe that negative/positive dipole of Belém thunderstorm and positive/negative dipole of Vale do Paraíba. In Belém the negative charge is in between 3-5 km while in Vale do Paraíba it goes from 5-9 km. The positive charge region in Belém is at 7 km and in Vale do Paraíba varies from 3 to 5km. Charge wise, Belém showed values from 100 to 500C while Vale do Paraíba from 10 to 80 C. Those numbers are consistent with the Ez values

measured, but the lightning activity no because Belém has the highest Ez values but low lightning flashes. One hypothesis for these lightning differences could arise from the fact that in Belém the 100-500 C charge center is spread over a layer that extends from 5 up to 10 km thus having more intra-cloud discharges (20-100 C/km) and few cloud to ground while in Vale do Paraíba the charge centers are confined in shallow layers that facilitate the break down and consequently having more lightning activity.

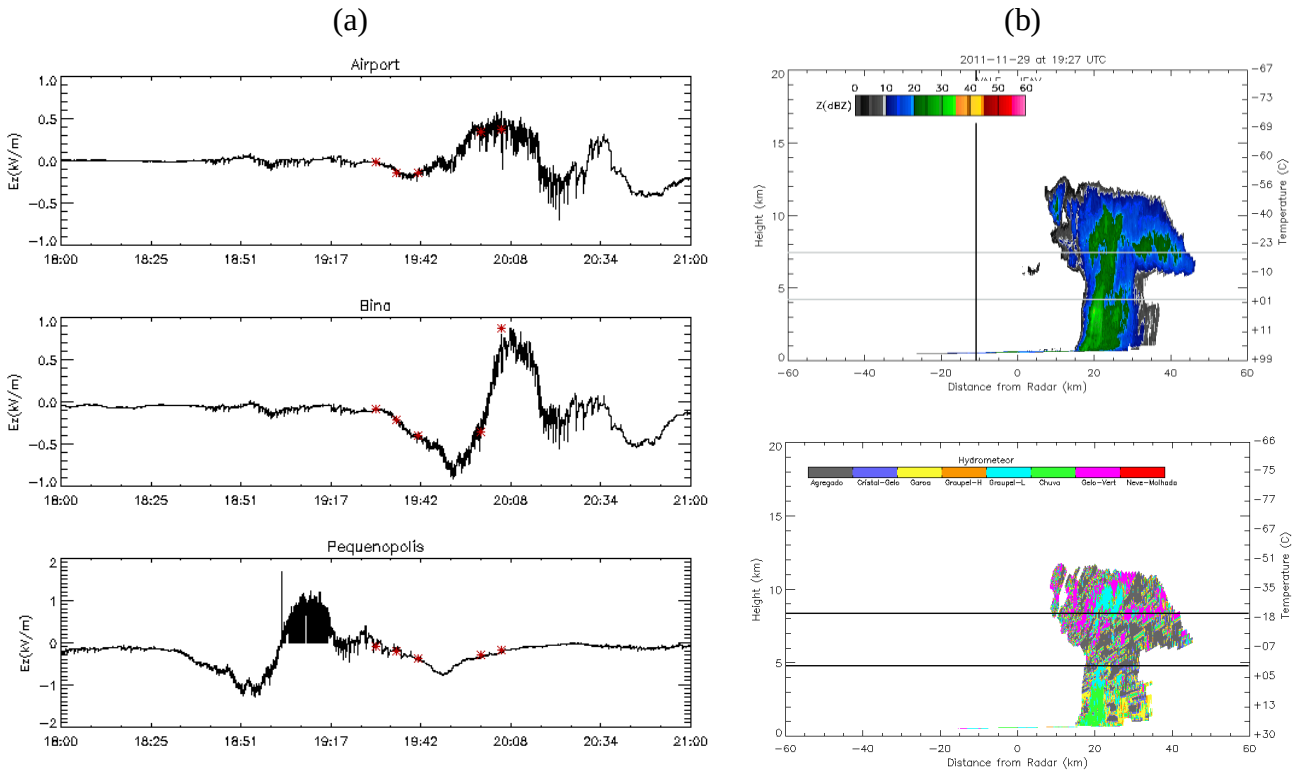


Figure 5. Temporal evolution of the vertical electrical field observed on 29 November 2011 at CHUVA Vale do Paraíbafield campaign at the sites of Airport, Bina and Pequenópolis (a); and (b) radar reflectivity RHI and correspondent hydrometeor classification of a RHI over IEAV at 19:27 UTC on 29 November 2011

Table 1. Charge distribution computed for the storms observed in Belém and Vale do Paraíba

(a) Belém

21/06/2011	*Low Charge Center*		*High Charge Center*	
Time	**Height (km)**	**Charge (C)**	**Height (km)**	**Charge (C)**
20:24	**5**	**- 528**	**7**	**+ 527**
20:34	**3**	**- 511**	**7**	**+ 352**
20:44	**3**	**- 112**	**7**	**+ 194**
20:54	**3**	**+128**	**7**	**- 98**

(b) Vale do Paraíba

29/11/2011	*Low Charge Center*		*High Charge Center*	
Time	**Height (km)**	**Charge (C)**	**Height (km)**	**Charge (C)**
19:30	**4**	**+ 54**	**6.5**	**- 40**
19:36	**4.6**	**+ 17**	**6.5**	**- 17**
19:42	**5**	**+ 88**	**7.9**	**- 79**
20:00	**2.8**	**+ 15**	**4.8**	**- 13**
20:06	**3**	**+ 15**	**9**	**- 13**

CONCLUSIONS

This study presented some of the measurements of CHUVA field campaigns that are being used to understand the electrification processes of the observed thunderstorms. It has been observed that the lightning activity is more pronounced as the region has less oceanic influence, although they presented deep development. Polarimentric weather radar measurements showed that coastal thunderstorms (Belém and Fortaleza) have been characterized by the predominance of aggregation processes while more inland (Vale do Paraíba) it was observed accretion. Thus we would expect more lightning in Vale than the other 2 campaigns as STARNET measurements confirms. Moreover, we would expect negative charge centers as snow/small hail are melting and positive as snow and aggregates are melting which was confirmed also by the electrical field measurements. Finally, vertical electrical field measurements showed that Belém storms presented 4 kV/m while in Vale do Paraíba it did not reach 2 kV/m which is a paradox taking into account the lightning activity observed. Considering the magnitude of charge centers retrieved by the inverse problem and depth of the mixed zone with the observed hydrometeors it seems that in Belém storms we find a competition inside the extended charge center while at Vale do Paraíba as shallow layer would benefit the break down and consequently more lightning discharges.

ACKNOWLEDGMENTS

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