7.4 THUNDERSTORM CHARACTERISTICS DURING THE 2002 RACCI/LBA FIELD CAMPAIGN

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1. INTRODUCTION

The tropical convection is in general organized by cloud clusters known as Mesoescale Convective Systems (MCS) [Cotton and Anthes, 1989 or Houze, 1993], which are responsible for most of total rain volume in these areas Nevertheless, numerical weather prediction models still need a better physical description of these systems.

Global analyses of MCS are mainly done by satellite measurements, since weather radars are not available everywhere. Due to the observation frequency of geostationary satellites, infrared and visible images are used to track the life cycle of convective systems [Maddox, 1980, Mapes and Houze, 1993, Chen et al., 1996, Hodges and Thorncroft, 1997, Machado et al., 1998, Mathon and Laurent, 2001]. By tracking the convective systems, several studies were able to characterize the MCSs in several regions of the globe: South America [Velasco and Fritsch, 1987, Machado et al., 1998]; West Pacific [Miller and Fritsch (1991)]; Africa [Laing and Fritsch (1993)]; Australia [Mapes and Houze (1992)]; and the globe [Machado e Rossow (1993)].

Later in time, the tracking algorithms were employed to analyze the MCS life cycle [Machado et al. (1998), Mathon and Laurent (2002)]. In those analyses, these authors used a technique that described the temporal evolution of the convective systems (CS), and were able to understand the temporal/spatial development of those systems. Later, Morales et al. (2002) combined these techniques with the precipitation radar on board the Tropical Rainfall Measuring Mission (TRMM), and found that the size of the convective systems are a function of the amount of ice in the upper level during the initial development of the storms.

Based on the previous findings, this study tries to identify the origin of the atmospheric discharges during the CS development. To seek this goal, this work uses the data collected during the Dry-To-Wet/LBA field campaign from September to November of 2002, in the western part of the Amazon region, mainly the Rondonia State. The characterizations of the CS are done by the use of infrared satellite images from GOES-8 satellite and cloud-to-ground measurements.

2. DATA SET

This section describes the data set used to characterize the observed convective systems during September 12th to October 10th in the Dry-to-Wet/LBA field campaign of 2002. Figure 1 illustrates the instruments position deployed during that field campaign.

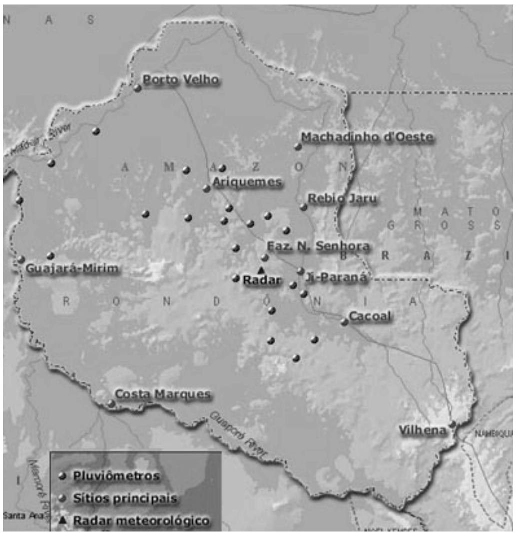

Figure 1. Instruments location during the Dry-to-Wet field campaign in 2002 as part of the RACCI/LBA project.

2.1 Infrared Satellite Images

The infrared (channel 4 –11 μm) images of GOES-8 satellite were processed by CPTEC/INPE. During this processing, the raw data was converted to brightness temperature in a regular grid of 4x4 km. During the field campaign, the images were available every 30 minutes.

2.2 Cloud-to-Ground Lightning

A lightning network consisting of 4 Advanced Lightning Direction Finder (ALDF) sensors were installed by Marshall Space Flight Center (MSFC) of NASA during the TRMM/LBA field campaign of 1999. The sensors are installed in Guajara Mirim, Ouro Preto, Machadinho do Oeste e Vilhena, Figure 1.

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3. METHODOLOGY

In order to characterize the convective systems (CS), this study applies the CS tracking method developed by [Mathon and Laurent [2000]. This method assumes that the cold brightness temperature observed in the infrared channel is associated with deep convection. This hypothesis is valid for tracking tropical CS during the entire life cycle, since thick Cirrus clouds are formed during the deep convection.

Therefore, we selected a temperature threshold of 235 K to define the cloud area according to the methodology defined by Laurent et al. [2002]. This version of the algorithm was implemented by CPTEC and it is operational since August 2003, and it is known as FORTRACC (Forecasting and Tracking Convective Clouds), http://moara.cptec.inpe.br. The CS is then defined by a cloud with a minimum of 100 pixels, i.e., ~ 1.600 km^2.

After these settings, the FORTRACC algorithm produces a temporal series of the main morphological characteristics of the CSs, i.e.: size, location, major and minor ellipse axis and its inclination angle, temperature distribution, convective fraction, growth ratio and others. Figure 2 presents an infrared satellite image after FORTRACC processing, where the colors represent the lifetime stage of the CS (red – initial; yellow – mature; green – dissipation), and Figure 3 presents the temporal evolution of a selected CS over Figure 3.

In order to understand the electrical characteristics observed in the CS during the Dry-to-Wet field campaign, only the CSs observed in the area coverage by the lightning network are analyzed. With this criteria, we were able to observed 83 CS, of those 41 of them had lightning discharges and 42 did not present any cloud-to-ground lightning during its entire lifecycle.

4. RESULTS

This section presents the main observed characteristics for the CS with lightning and without lightning during its lifecycle. In our analysis we investigate the dependency of the CS size with its duration, the lifecycle behavior as a function of the CS size, and finally how the lightning density varies as a function of CS size.

4.1 CS Size X CS Lifetime Duration

According to Laurent et al. (2002), the maximum CS size is related to the maximum lifetime duration. Since the maximum size is found during its mature stage, it is possible to predict how long it will last a CS after it reaches the mature stage. In another hand, it is expected that CS that produce lightning have a differentiated vertical development than those without lightning. Therefore, we present on Figure 4, a scattering diagram of the maximum observed CS size and its lifetime duration for those with lightning (Figure 4a) and without lightning (Figure 4b).

It can be noted in Figures 4a and 4b that the CSs that have lightning present longer duration and are larger. By the regression line, the angular coefficient shows that CS with lightning (0.22) present a large increase with time duration, and the linear coefficient show the CS with lightning (659) are bigger than those without lightning (438).

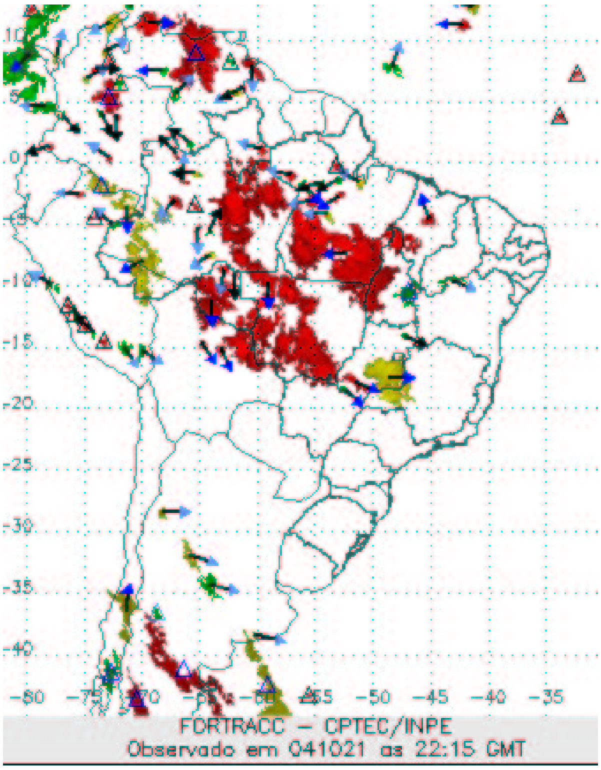

Figure 2. CS observed by FORTRACC. Red clouds in initial development, Yellow clouds are in mature stage, and Green cloud in dissipation process.

As a next step we categorize the CS as small, medium and large system. Figure 5 shows the CS distribution according to these categories. The classes are defined as: 100-1,000; 1,000-10,000 e > 10,000 pixels. As observed in Figure 4, the CS without lightning do not present systems above 10,000 pixels, but due to the low sample gathered, we can not say that the large CS (> 10,000 pixels) will always have lightning. In another hand, it is expected that those systems do present lightning, since the presence of lightning discharges are associated with the present of ice, and as observed by Morales et al. (2002), the large CS have large amount of ice during its initial and mature development.

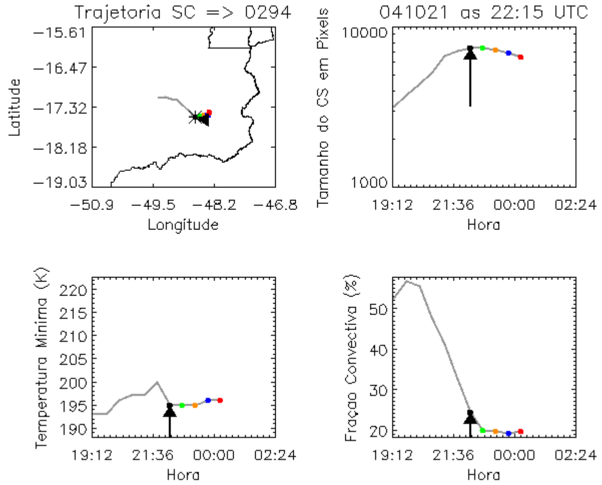

Figure 3. Temporal evolution of location, area, brightness temperature and convective fraction of a CS observed in Figure 2.

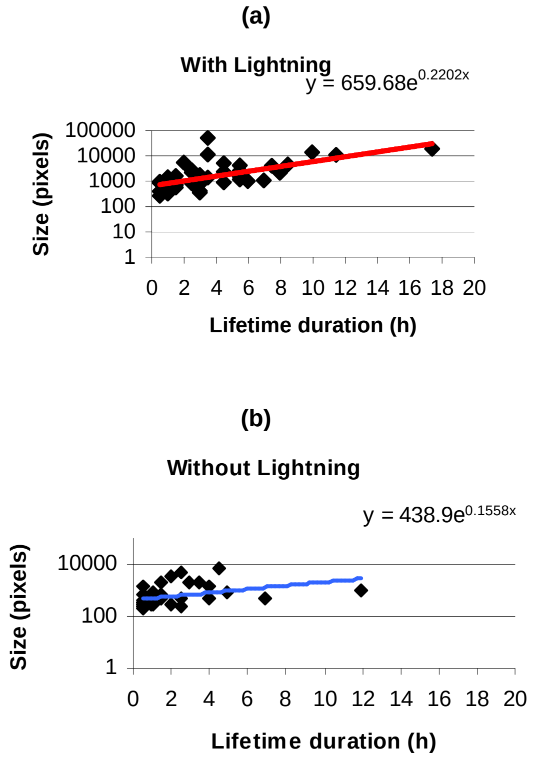

Figure 4. Maximum CS size in pixels versus lifetime duration for CS with lightning (a) and without lightning (b).

4.2 CS lifecycle

The analyses of CS lifecycle can be used to understand the different dynamical processes involved during the CS development, and therefore, it could indicate whether some systems present or not lightning, or why the thunderstorms have larger area. In order to seek these mechanisms, the CSs were separated in 3 size classes as shown in Figure 5, and its lifetime duration is normalized between 0 and 1, i.e., the maximum lifetime duration represents 1. So, this normalization can show the mean behavior of CS for the different classes.

Figure 6 presents the mean life cycle for the 3 classes interval for CS with and without lightning. Additionally, we add the mean cloud-to-ground lightning observed in the CS with lightning. The next sub-sections discuss the main characteristics observed in these results of Figure 6.

4.2a)100-1,000 pixels

The CS with lightning present a larger area during its entire life cycle when compared with without lightning. Moreover, the CS with lightning show clearly the initiation, mature and dissipation stages, while the CS without lightning have a steady development. The frequency of lightning increases as the CS reaches the mature stage, and decreases during the dissipation phase.

4.2b) 1,000-10,000 pixels

The CSs without lightning are bigger during the initiation stage and they reach earlier the mature stage than the CS with lightning. Afterwards, the CS without lightning dissipate faster than with lightning. In another hand, the growth ratio (time expansion) of CS with lightning is higher than those without lightning, The CSs with lightning reach its mature stage after half of the lifecycle. Additionally, it can be noted that the lightning frequency follows the area expansion, where the highest development is correlated with the highest lightning frequency. Furthermore, it is also noted that there are 2 peaks of lightning frequency, one in the initial and the other before the mature stage. It is possible to speculate that the increase in lightning frequency is linked to the intense updrafts during the initial development, and presence of downdrafts during its mature phase. Finally, the decrease of lightning intensity is associated with the dissipation of the CS.

4.2c) Larger than 10,000 pixels

All the CS larger than 10,000 pixels present lightning discharges. As pointed earlier due to the small sample of CSs gathered, it is not possible to guarantee that all the CSs larger than this size have lightning. Nevertheless, the results show that the area expansion and compression is higher than the CS with small sizes. The highest lightning frequency is observed in between the initial and mature stages.

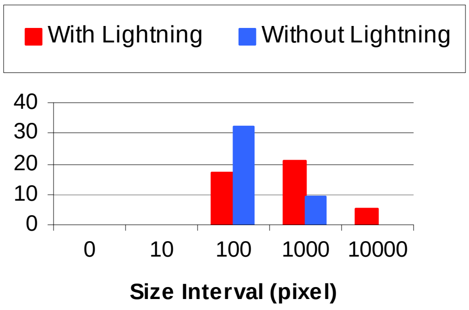

Figure 5. Distribution of CS with lightning (red) and without lightning (blue) as a function maximum size observed.

4.3 Lightning Density

The lightning density is used in this section to identify which CSs are more lightning producers or lightning efficient, mainly we are trying to verify if the large CS have a lot of lightning because they are lightning efficient or because they are large. For this inspection, we define the lightning density as the lightning frequency normalized by the area of the CS and by the time step.

In Figure 7, we present the temporal evolution of the lightning frequency during the entire normalized lifecycle for each CS size category. By analyzing this figure we can conclude the following:

- In the small CS (100-1,000 pixels), Figure 7a, it is noted that the lightning density is maximum during its initial stage and it decreases afterwards;
- For the medium CS (1,000-10,000 pixels), Figure 7b, it is noted that the lightning density has 2 peaks during the initial development and before the mature stage;

The larger CS (> 10,000 pixels), Figure 7c, have the same behavior as the medium CS, but the peaks are more pronounced;

The CS size intercomparison reveals that highest lightning frequency occurs for the small CS. This finding can be correlated to size of the convective cores, since the large CSs have more than 80% of stratiform area. Therefore, diluting the lightning production. Nevertheless, it is important to note that the large CSs are responsible for most of the lightning activity during its entire lifecycle, Figure 6.

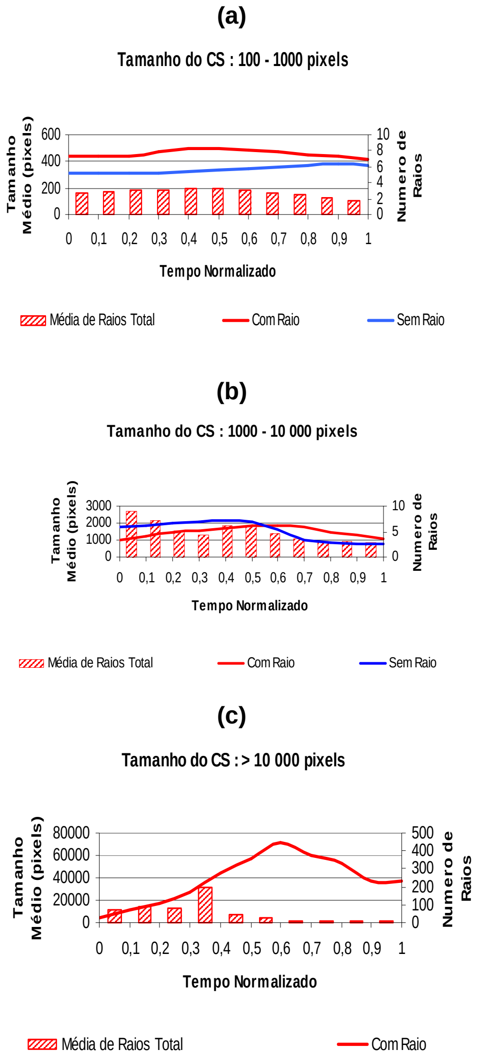

Figure 6: Mean lifecycle of the CSs with lightning (red) and without lightning (blue) for different size categories (a) 100 and 1,000 pixels; (b) 1,000 and 10,000 pixels and (c) larger than 10,000 pixels. The red stripe bar show the lightning frequency.

It can be also note that the medium and large CSs present an increase of lightning density, while the small SC tend to decrease. These results imply that the small SCs reach its mature phase and enter in the dissipation state, i.e., the updrafts/downdraft are less intense and the ice content above the 0^oC isotherm reduces, which are the main ingredients for the atmospheric discharges generation.

Besides that, the medium and large CS present 2 frequency density peaks, and we can argue that during the initial development there is a predominance of the updrafts, which can induce the higher amount of lightning. Later, the atmospheric discharges decrease until the appearance of the downdrafts, which will provoke the second increase of lightning frequency during its mature phase.

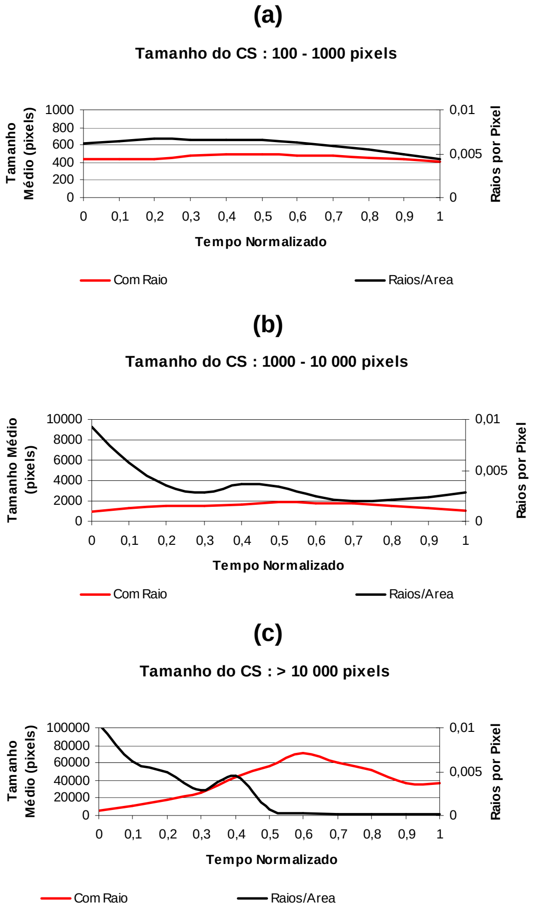

Figure 7: Lightning density temporal evolution for the CS as a function of size categories: (a) 100 and 1,000 pixels; (b) 1,000 and 10,000 pixels and (c) large than 10,000 pixels.

5. CONCLUSION

Most of the CSs without lightning analyzed have maximum size in the categories of 100 to 1,000 pixels, while the ones with lightning are in the range of 1,000 and 10,000 pixels.

Of all the CS gathered during our analyses, it was verified that all the large CS, greater than 10,000 pixels, have lightning and they persist for longtime duration. These results show that large systems present lightning due to the strong vertical development that is favorable for the development of ice, which is necessary for the electrical activity formation. Though, the small and medium CSs also present this vertical development, but the size, intensity and duration of the systems are dictated by the growth ratio during it initial development.

All the CSs with lightning present higher growth ratio than those without lightning. The CS without lightning after they reach the mature stage, dissipate faster than those with lightning. The CS with lightning have a longer maturation stage and dissipate slower. Therefore, these results imply that it should have a responsible process for this CS feeding, which will determine its characteristics like the size and the presence of lightning discharges. In all the size categories, it was verified that, in the presence of lightning, the systems reach large size, and therefore have longer duration. The systems without lightning did not present this growth and duration behavior.

The temporal evolution, development, maturation and dissipation, are more pronounce for the CS with lightning. The process of initial development until the mature stage is more efficient in the CS with lightning, while the dissipation process is more efficient for the systems without lightning.

The lightning discharges in the small systems are almost constant until the maturation. For the median and large CS, the lightning activity presents 2 distinct maximums, the first one when there is the predominance of updrafts, initial development, and the second one when the downdrafts dominate, initial stages of the maturation.

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