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Lightning Activity in Mesoscale Convective System associated with Different Synoptic Situations over Southern South America

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***Abstract* — Two Mesoscale Convective System (MCS) events that occurred in the southern portion of South America will be analyzed in order to characterize the local lightning activity related with different synoptic situations. On December 10-11, 2012, a MCS, originated by a cyclone centered over the Atlantic Ocean, presented an organized convective activity moving northeastward. This MCS formed in an area of baroclinic flow in the vanguard of a cold front. This feature was trivial in determining MCS displacement velocity, and consequently lightning density in the region. The other MCS that occurred on December 12-13, 2012 was generated by a low pressure area located in the central region of South America (Chaco Low), and showed disorganized convective activity moving (northwestward). This MCS formed due mainly thermodynamic factors in the lower troposphere and divergence in the upper troposphere by the interaction of the subtropical jet. In both MCSs lightning density in the region was influenced by the synoptic situation which the MCS was formed. Being influenced by the velocity and direction of MCS displacement. The rate of occurrence and polarity of lightning as well as the IC/CG and CG+/CG- rates were not affected by the different conditions that the MCSs were formed.The data set used in the present study will consider: (1) lightning location and polarity from BrasilDAT, (2) analysis and forecasts from WRF model, and (3) infrared channel data from Satellite GOES-12.**

Keywords: Lightning; Mesoscale Convective Systems; Synoptic Analysis

I. INTRODUCTION

Mesoscale Convective Systems (MCSs) are large convective systems that are organized on a larger scale, with rainfall area of ~100km or more in one direction [Houze, 2004].

MCSs are worldwide studied more than 30 years [Maddox, 1980; Machado, 1998; Laing, 1999; Salio, 2007; Anabor, 2008; Jain, 2010; Lang, 2010]. MCSs may have intense precipitation, strong winds, hail and lightning. MCSs in the southeastern region of South America are responsible for severe weather [Brooks, et al. 2003] and a region with one of the largest worldwide occurrences of lightning [Christian, et al. 2003].

Most electrical discharges in the atmosphere occurs within the clouds (IC), however, a portion of the discharge out of the cloud towards the ground, which is called cloud-to-ground (CG). These lightning which hit the ground, can damage electrical power grids, deaths and fires [Pinto Jr, 2008].

Synoptic Meteorology involves the study of phenomena on a large scale and indicates that the passage of cyclones along with jets of high and low tropospheric levels favors the generation of MCSs in southeastern South America.

This paper investigates the electrical activity by lightning relative to MCSs formed by different synoptic situations in southeastern South America using lightning location and polarity date, WRF model simulation and cloud top temperature from geostationary satellite. In this way, the characteristics of the electrical activity of these MCSs could indicate own characteristic patterns.

Section 2 describes an overview about the work, data and methodology used in the work. Section 3 presents the meteorological scenario characteristic in South America responsible for the formation of MCSs in the study region. Also, the synoptic analysis involved in the formation and development of MCSs analyzed. Section 4 presents the characteristics of the lightning activity of MCSs studied: density, trajectory, rate and peak current. Section 5 discusses the main results and conclusions are presented in Section 6.

II. DATA SET AND METHODOLOGY

A. Overview

Figure 1 shows selected area for this study. Region is located in the southeast of South America and occupies the grid 25°S - 35°S and 49.5°W - 60.5°W. The available instrumentation included lightning detection network, forecast model output and geostationary satellite observations. Each component of the observing network will be discussed individually.

Two MCSs that occurred in this grid were studied. MCSs occurred in four consecutive days:

- 10-11/December/2012 *(days/month/year)*: 10-11/Dec MCS;

- 12-13/December/2012 *(days/month/year)*: 12-13/Dec MCS.

B. Analysis and Forecasts from WRF Model

The Weather Research and Forecasting Model (WRF) output data was used to diagnose the synoptic atmospheric conditions. Data analysis used in input/initialization of the model are from the Global Forecast System (GFS). Data generated for the days 10-11/Dec used analysis of 12UTC 09/Dec/2012 to 60 hours of simulation. And for days 12-13/Dec used analysis of 12UTC 11/Dec/2012 to 60 hours of simulation. Simulation was performed for the entire period at hours 00UTC and 12UTC. Grid simulation occupies the area 12°S/42°S and 38°W/66°W. The spatial resolution is 15 km and 10 vertical levels.

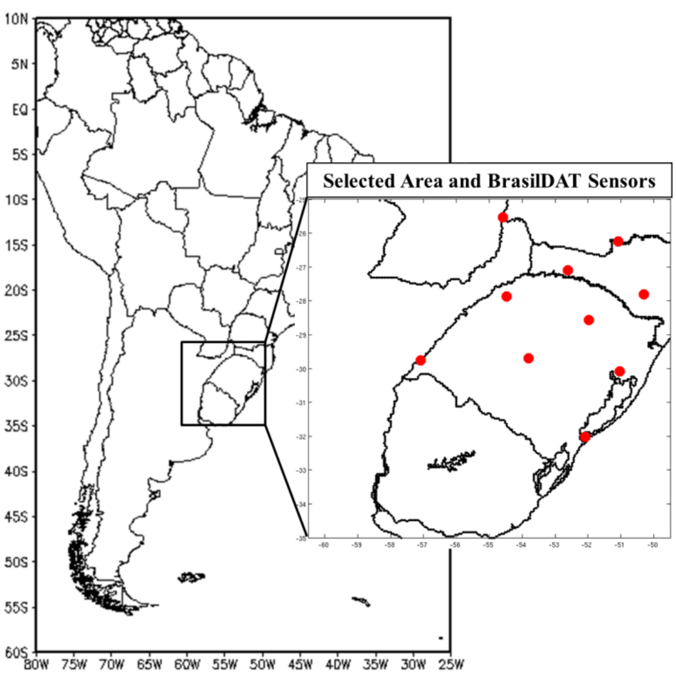

Figure 1. South America; selected area for the lightning study and location of lightning detection sensors from BrasilDAT (red dot).

C. Lightning Location Data

Brazilian Lightning Detection Network (BrasilDAT) strokelevel data were used. BrasilDAT is based on the *EarthNetworks* Total Lightning System (ENTLS) and can classify intracloud (IC) discharges, cloud-to-ground (CG) discharges and polarity (+CGs and -CGs). BrasilDAT operates at Low Frequency (LF) and Very Low Frequency (VLF), and is composed of 10 sensors covering the grid of interest in this work.

There are no studies on the effectiveness of BrasilDAT for the study region. BrasilDAT currently has detection efficiency of 85% to 90% for GC and 50% to 60% for IC in southeastern Brazil [Naccarato et al. 2012].

Lightning selection considered the data entered in the grid of interest, shown in Figure 1. Identification and analysis of the trajectory and rate of lightning was selected 7.5 minutes before and after satellite data (temporal resolution of 15 minutes). BrasilDAT efficiency reaches 90% for CG and 40% for IC. These efficiency values were used for correction of the rate of occurrence of lightning in section III-C.

D. Cloud Top Temperature

For visual analysis and determination of the area of the MCSs we used data from cloud top temperature in infrared channel (10.2-11.2µm) from Geostationary Operational Environmental Satellite 12 (GOES 12 - IR). GOES-12 is scheduled to scan South America every 15 min. These data were provided by the Brazilian Center for Weather Forecast and Climate Studies, CPTEC/INPE.

The temperature thresholds used to define the SCM differ in literature, but most authors use a threshold of less than -28 ° C [Maddox, 1980; Machado et al. 1998; Anabor et al. 2008; Fiolleau, 2010]. In this work we use the -30°C isotherm to define the area occupied by the MCSs.

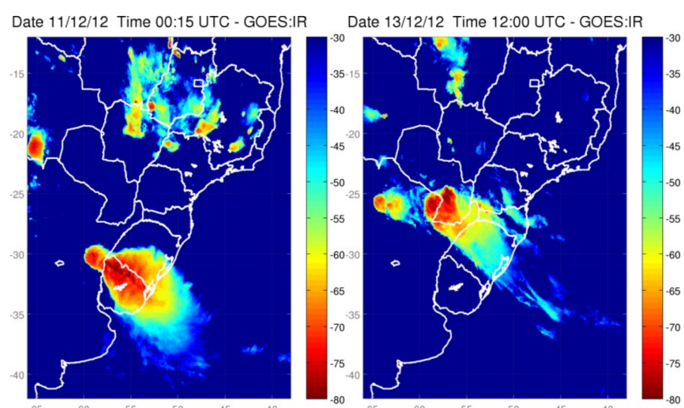

Figure 2. Cloudtop temperature maps of the South America MCSs.

III. METEOROLOGICAL SCENARIO

A. South America General Features

Southeastern South America is a region with high potential for occurrence of MCSs [Anabor et al. 2008] and in some cases associated with severe storms [Maddox et al. 1982]. Nascimento et al. [2005] defined as severe storms convective systems capable of producing hail (≥2 cm in diameter), wind gusts ≥26m/s and lightning activity (thunderstorm). Brooks et al. [2003] performed a global climatology using NCEP/NCAR reanalysis data to identify regions where such severe storms are most likely to develop. For Southern South America (where MCSs developed) >50 days per year had atmospheric conditions that favored the development of severe storms.

Meteorological features in mesoscale and synoptic scale that manifest dynamic and thermodynamic manner are responsible for the MCSs occurence in Southern South America. Subtropical region of South America there is the passage of cyclones responsible for frontal systems throughout the year. Mattos et al. [2003] classifies the cold front in South America according to the area (range) and lifetime. MCS in 10-11/Dec the cold front dissipates over southern Brazil not exceeding the Paraná state (Brazil). This cold front causes precipitation and temperature decline, regardless of the season, before dissipating over the South Atlantic Ocean. This type of cold front also brings rainfall and lightning over southeastern South America, especially when preceded by mesoscale convective complexes over Paraguay [Mattos et al. 2003]. 12-13/Dec MCS the cold front is typical of late spring, summer and early fall [Mattos et al. 2003]. MCS associated with this cold front is induced by the presence of Chaco Low [Oliveira et al. 1986].

The Chaco Low is a low pressure system that preferentially occupies northern Argentina and Paraguay. Responds to the warming of the lower and middle troposphere. Heating the tropospheric column is due to the positive heat balance in the soil, by the latent heat flux due to convection. Troposphere is a vertically extended and presents a structure barotropic [Seluchi et al. 2010]. This meteorological pattern was observed in 12-13/Dec MCS.

An important feature of South America was observed on days 10-11/Dec, is the South America Low Level Jet (SALLJ). The SALLJ transports warm moist air from the Amazon regions to high latitudes [Marengo et al. 2002]. In this case, SALLJ reaches 12 m/s or more at 850 hPa, the shear between 850 hPa and 700 hPa is at least 6 m/s, in agreement with Bonner et al. [1968]. The SALLJ presence allows an occasional coupling between lows and highs level jet which represents an important dynamic mechanism for the development of MCSs [Nascimento et al. 2005]. The equatorial entrance of high level jet is a favorable region to MCS formation [Uccellini et al. 1979]. Evaporation of Uruguay, Paraguay and Paraná rivers and local circulation generates a favoring occurrence of convective systems generated mainly by thermodynamic forcings [Salio et al. 2007].

B. Synoptic Analysis

This section will not show all the maps generated by the simulation. Maps will be described, but follow in Figures 3, 4, 5 and 6 maps relating to time: 00UTC 11/Dec (left); 12UTC 13/Dec (right). These maps are in the same time at satellite images shown in Figure 2.

00UTC 10/Dec (~24h before the first MCS) at low levels a ridge over southeast South America was observed due to a center of high pressure over the Atlantic Ocean (27°S, 44°W). Same region has limited availability of humidity. At midlevel in the region is a ridge indicating subsidence. At South America we observe a flux (in 850mb) of air with a speed exceeding 12m/s (SALLJ) between southern Bolivia and northern Argentina, indicating advection of warm, moist air to regions of higher latitude. Note the presence of a cyclone centered in 998mb (40°S; 64°W). This cyclone and the SALLJ will be fundamental in MCSs formation.

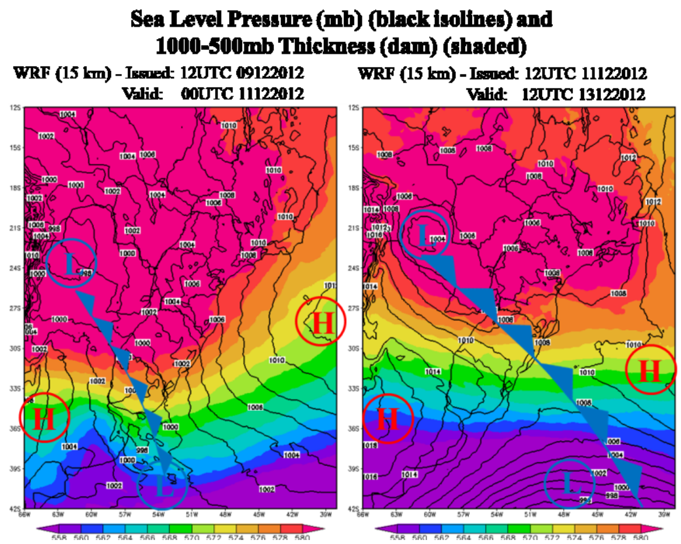

Figure 3. Symbol indicates the location of the cold front, the letter H (red) indicates high pressure and the letter L (blue) indicates low pressure.

12UTC 10/Dec (~12h before the first MCS) conditions in our region of interest are the same as described above, stable. At low levels the advection of warm moist air is kept by SALLJ to high-latitude regions. Cyclone prior centered at 40°S; 64°W moves northeastward (39°S; 60°W). On midlevel there is a trough from the west indicating a positive vorticity advection to be trivial in the formation and displacement of MCS.

00UTC 11/Dec MCS formed at the leading edge of the cold front with advancing cyclone identified from the first simulation shifting to the northeast. Location of the cold front is evidenced by the strong thermal gradient between Argentina and Uruguay and trough into the surface. Location of the cold front is indicated on the low level maps in Figures 3 and 4 (left). The central region of Argentina passes the influence of a ridge of high pressure center indicated by the letter H (Figure 3 left). While the trough surface is at the forefront of the trough in midlevel cyclone moves rapidly under the influence of positive vorticity advection. The position of the trough on midlevel (dashed line) are shown in Figure 5 (left). These characteristics indicate baroclinicity in the region of MCS formation. MCS was in the equatorial entry of the subtropical jet, shown in Figure 6 (left), resulting in divergence at high levels favoring the intensification of MCS.

12UTC 11/Dec cyclone now moves to the east and the cold front is on Santa Catarina (Brazil). Temperature advection becomes weak and barotropic flow. After the fast displacement of the cold front, cyclone occludes. Feature observed when they are superimposed: surface trough, trough at 500mb and the core of the jet at high levels. At that time the MCS is fragmented.

00UTC 12/Dec (~12h before the second MCS) cyclone moves over the ocean favoring the flow of humidity in southeastern Brazil. Study area is now with the influence of high pressure center in Argentina, quoted since the simulation of 00UTC 11/Dec. This feature stabilizes the weather not favoring the formation of convective clouds. The Chaco Low center in Paraguay 998mb (22°S; 58°W) favors the flux of warm moist air to northern Argentina and north of Rio Grande do Sul. This feature will be trivial in the formation of the second MCS.

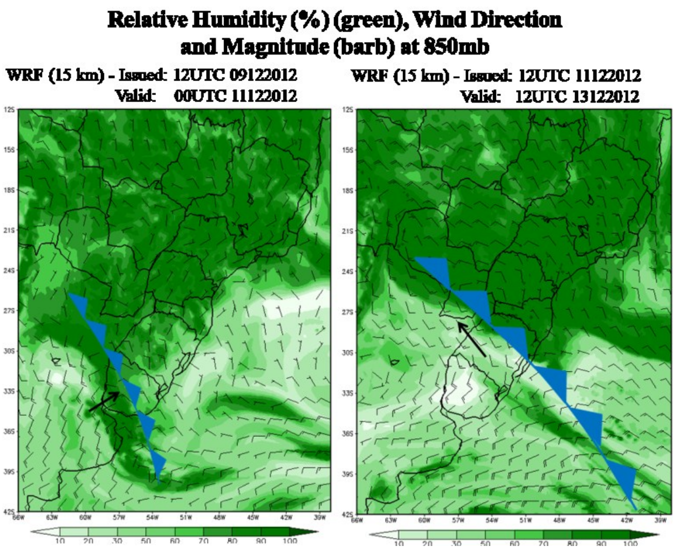

Figure 4. Symbol indicates the location of the cold front and the black arrows indicate the direction of MCSs propagation.

12UTC 12/Dec due the trough surface (Chaco Low centered in 996mb (25°S; 57°W)), the first convective systems occur. At high levels the system is in the entrance equatorial from subtropical jet, favoring the intensification of the system. At the southern tip of South America there is a cyclone (55°S; 60°W) and a cold front starting displacement towards northeast, similar to that seen on 10/Dec.

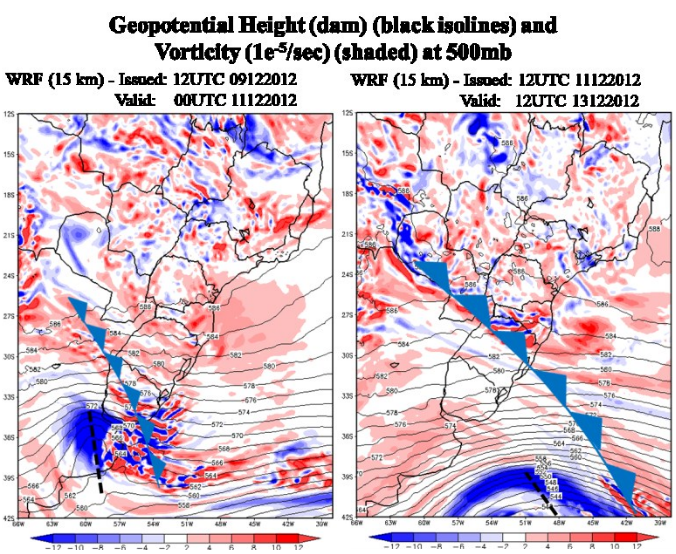

Figura 5. Symbol indicates the location of the cold front and the black lines indicate the position of the troughs in 500mb.

00UTC 13/Dec study area continues the influence of a trough generated by the Chaco Low in Paraguay (25°S; 50°W). MCS is intensified mainly by the divergence at high levels. A cold front mentioned earlier is located between Argentina and Uruguay. A ridge in Argentina due to a new high pressure centered 1020mb (25°S; 50°W).

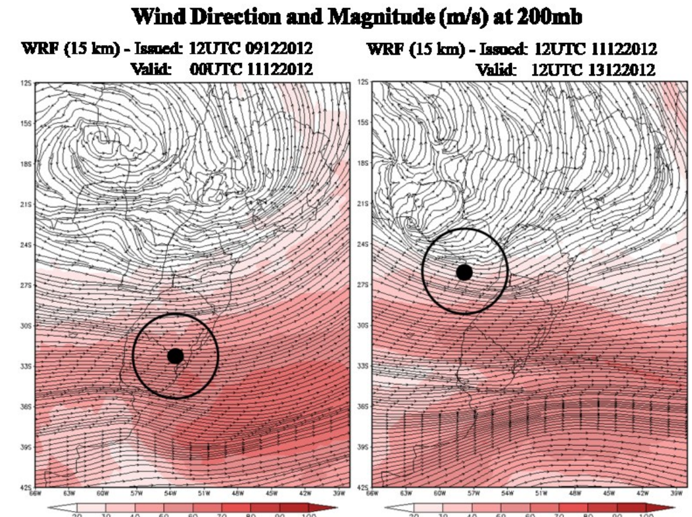

Figura 6. Symbol indicates divergence in the equatorial entrance of core jet at 200mb.

12UTC 13/Dec cyclone before centered in 984mb (47°S; 50°W) is now centered in 982mb (46°S; 44°W) and cold front is in the Rio Grande do Sul. The position of the cold front at low levels is indicated on the maps shown in Figures 3 and 4 (right). The ridge on Argentina reaches southern Brazil and northern Argentina. The high (H red) and low (L blue) pressure is shown in Figure 3 (right). The pattern anticyclonic of the high (Argentina) and cyclonic of the low pressure (Paraguay) causes the displacement of the MCS in the northwest direction. The wind direction is shown by the black arrow in Figure 3 (right). At high levels the position of the jet core favors the intensification of MCS. The divergence at high levels is shown in Figure 6 (right), located in the entrance equatorial jet.

00UTC 14/Dec high pressure reaches the entire area of interest leaving the weather stable. The cold front moves east due to the movement of the cyclone.

IV. LIGHTNING ACTIVITY

A. Total Lightning Trajectory

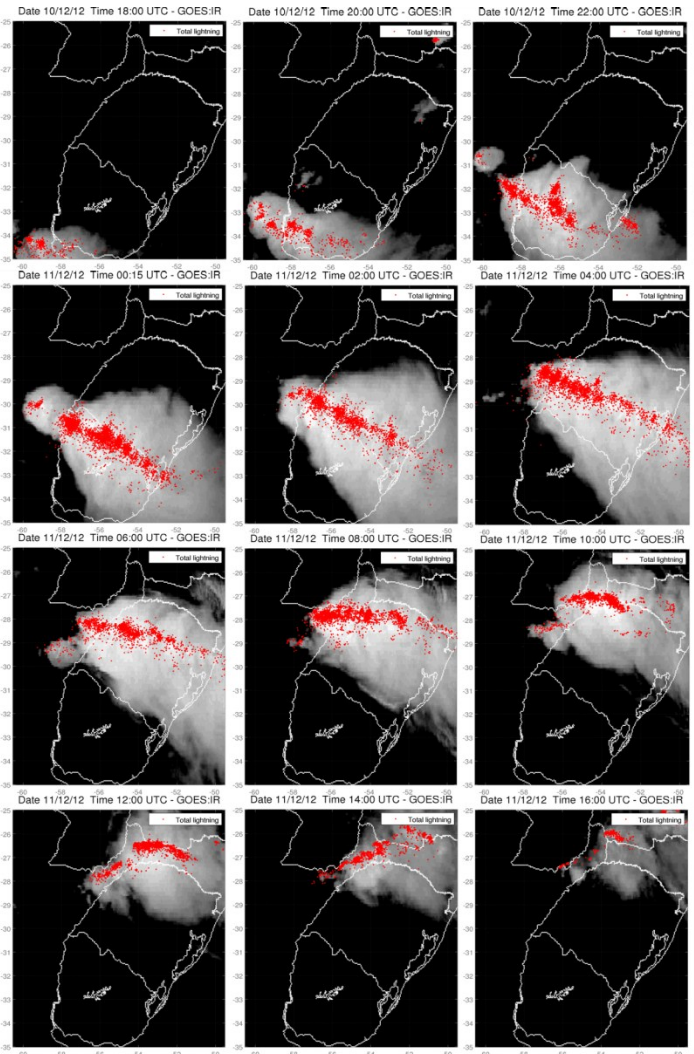

Figure 7. Satellite GOES 12-IR with total lightning $(15\text{min})^{-1}$ (red dot) every 2 hours.

The mosaic of satellite images in Figure 7 and 8 show the accumulated lightning every 15 minutes. 10-11/Dec SCM first lightning occurred 14UTC 12/Dec in the grid. The first image (18UTC - 10/Dec) shows the lightning between Argentina and Uruguay. In the following image (20UTC - 10/Dec) the convective cells begin to organize themselves online and move in the northeast direction. This feature remains until 04UTC 11/Dec. Between 18UTC (10/Dec) and 04UTC (11/Dec) the lightning moved from Argentina to northern Rio Grande do Sul. This displacement occurred in only 10hours, ie MCS moved with high velocity. From the image of 06UTC (11/Dec) lightning occupy northern Argentina and north of Rio Grande do Sul. The period between 06UTC and 16UTC, lightning did not move, indicating lowest velocity of MCS. These characteristics cited as the velocity associated with synoptic analysis indicates a rapid advancement of the electrical activity of the MCS along with the advance of the cold front. Discussed in the previous section, while the frontal system was at the forefront in the trough midlevel, MCS moved fast. From the moment the cyclone moves over the ocean, with the decrease of positive vorticity advection that the velocity of the MCS decreases. The cyclone passes to move eastward than northeastward and MCS fragments, remaining over northeastern Argentina, northwest of Rio Grande do Sul and west Santa Catarina.

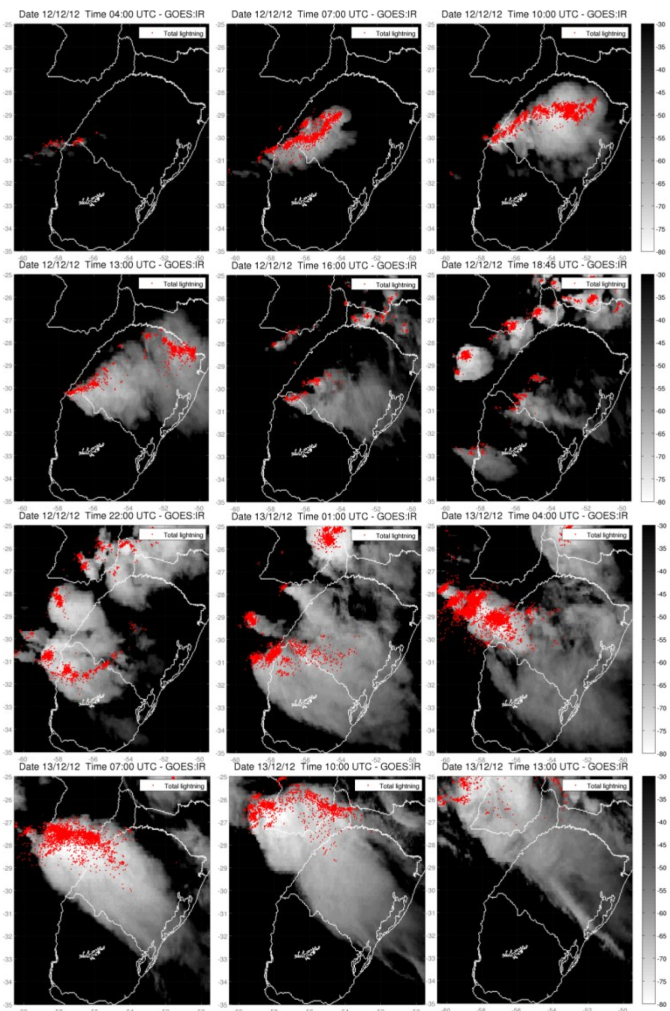

Figura 8. Satellite GOES 12-IR with total lightning $(15\text{min})^{-1}$ (red dot) every 3 hours.

In the second MCS (Figure 8) the electrical activity began at 03UTC 12/Dec. The sequence of images between 04UTC and 10UTC the lightning intensifies moving eastwards, occupying the state of Rio Grande do Sul. 13UTC 12/12 lightning activity decreases with MCS disintensification. From 16 UTC 12/Dec new lightning convective systems develop individually in northern Argentina, Paraguay and southern Brazil. 04UTC 13/Dec lightning organize and no displacement of MCS. From 07UTC 13/Dec MCS moves towards northeast with lightning in the forefront. Considering the synoptic analysis described in section III-B, MCS is on the edge of a surface trough. In general, MCS displacement was initially east and after remained in the same location. A cold front moved from southern South America and reached the MCS. The resulting MCS displacement is due to high and low pressure on the continent. MCS propagates against the flow seen by the satellite image in Figure 2 (right).

B. Total Lightning Density

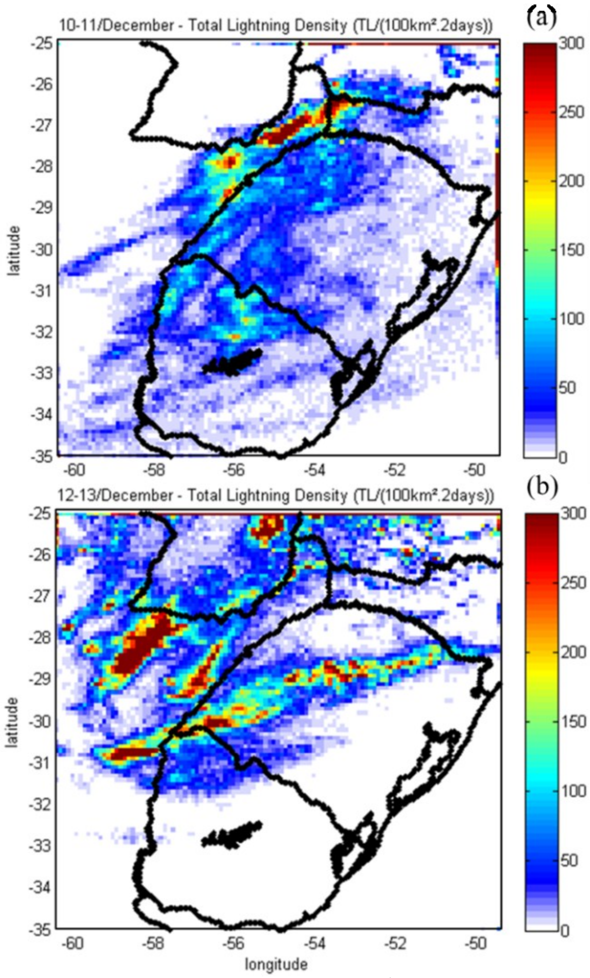

Figure 9. Total lightning density (100km².2days)$^{-1}$: (a) 10-11/December/2012; (b) 12-13/December/2012.

Figure 9 (a) shows the density of total lightnings 10-11/Dec. The maximum lightning density was in western Santa Catarina and northern Argentina. Density values were greater than 300 lightning strokes per 10km². Density values remained higher in the west of Rio Grande do Sul. These high density values agree with the results already observed for the displacement and velocity of the MCS. When the cyclone passes to occlude MCS moves at a slower velocity. MCS is fragmented and keeps part on the region with the highest density of lightning. Other high density values were observed in Uruguay before the border with Brazil.

Figure 9 (b) shows the density of lightnings 12-13/Dec. Density values larger than 300 lightning per 10km² occurred in several locations. Values with higher density are located when the MCS showed little velocity, before the passage of the cold front. After the cold front reaches the MCS system moves to the northwest and the densities are low.

C. Peak Current and Lightning Rate

Table 1. Lightning features in MCSs with correction efficiency.

Lightning Features (Efficience CG 90%; IC 40%)			
Total Lightning TL: 1.094.632			
Intracloud IC: 73,21 %			
Cloud-to-Ground CG: 26,79%			
Cloud-to-Ground Negative CG-: 82,93%			
Mean Peak Current Mpk- CG-: -29,11 kA			
Cloud-to-Ground Positive CG+: 17,07%			
Mean Peak Current Mpk+ CG+: +33,32 kA			
Date	**10-11/Dec/2012**	**Date**	**12-13/Dec/2012**
TL	422.933	TL	671.698
IC	73,66%	IC	72,92%
CG	26,34%	CG	27,08%
Total CG	**111.403**	**Total CG**	**181.873**
CG-	83,38%	CG-	82,66%
Mpk-	-30,97 kA	Mpk-	-27,96 kA
CG+	16,62%	CG+	17,34%
Mpk+	+35,1 kA	Mpk+	+32,27 kA

Table 1 shows the characteristics and percentage of lightning. In four days of study the number of lightning was approximately 1 lightning stroke per km² in the analysis grid. The IC/CG ratio was approximately 2.8. The percentage of the lightning CG+ was ~20%. The total lightning was higher on 12-13/Dec.

Considering the different synoptic situations/different MCSs the rate of occurrence of CG+ and CG- no differences in values. And also the average peak current in the MCSs was practically the same. 10-11/Dec MCS maximum area was in the first half of the time that the system showed electrical activity. The biggest IC/CG ratio was after the maximum area of the MCS at 01UTC. After the MCS maximum area IC/CG and CG+/CG- ratio increase, indicating greater activity of IC and CG+ lightning. Most lightning occurred before maximum area of MCS. This result indicates a larger convective activity in the early hours of the MCS and after the maximum area stratiform region was increased, resulting an increase of CG+ lightning.

In the second synoptic situation (the second MCS) 12-13/Dec MCS between 00UTC and 16UTC the first convective system showed the same feature described above. Before the MCS maximum area had the highest rate of lightning and further increased the rate of CG+/CG-, indicating the same increase in positive polarity of lightning. Between 16UTC and 02UTC many convective systems begin and dissipate and each system has a particular life cycle contributing to change the characteristics of MCS. Also influencing the characteristics of the electrical activity of the MCS. 02UTC MCS organize and start the displacement in the northwest direction. The maximum area was the 03UTC and maximum electrical activity was 04:30UTC. After both decrease until the end of the MCS.

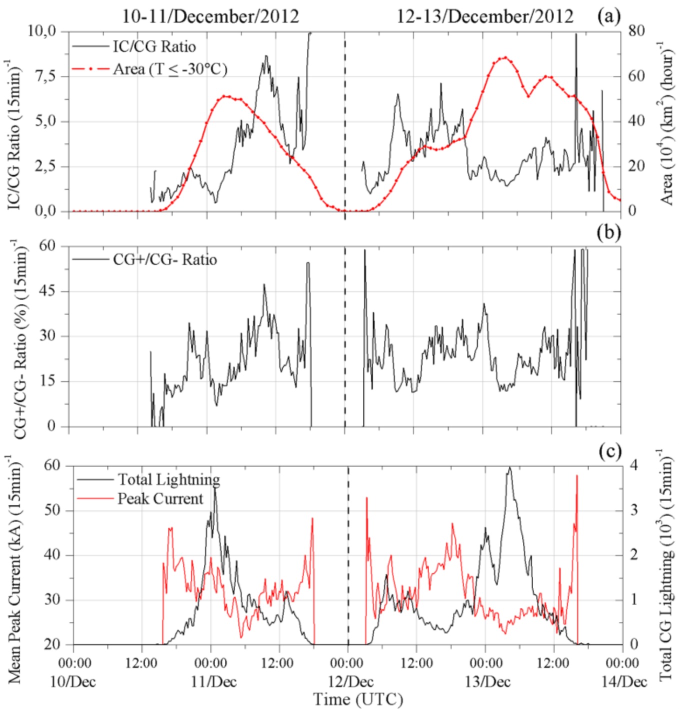

Figure 10. (a) Ratio between intracloud (IC) and cloud-to-ground (CG) discharges $(15\text{min})^{-1}$ and Area with cloud top temperature ≤ -30°C (10^4 km².hour^{-1}); (b) Ratio between positive (CG+) and negative (CG-) cloud-to-ground discharges (%) $(15\text{min})^{-1}$; (c) Total lightning rate $(15\text{min})^{-1}$ and mean peak current $(15\text{min})^{-1}$.

V. CONCLUSION

In this work we made the synoptic analysis for days 10, 11, 12 and 13 December 2012. Two MCSs in this period occurred in the southeastern region of South America. The characteristics of electrical activity in these systems was analyzed: total lightning trajectory and density; lightning rate and peak current.

10-11/Dec MCS formed at the leading edge of a cold front presenting features of baroclinicity. Formed by a cyclone as it moves along the South Atlantic following the coast of South America to the northeast. This MCS presented characteristics have formed due to dynamic factors. The electrical activity of MCS moves towards the northeast. With occlusion of the cyclone MCS fragmented and the part that remains on the continent not move. Lightning density in the region was influenced by the synoptic situation which the MCS was formed. Being influenced by the velocity and direction of displacement of the MCS.

12-13/Dec MCS formed from the union of several individual convective systems that were initiated by thermodynamic factors, warm and moist air in the lower troposphere. Formed in the trough of low Chaco, barotropic low pressure meteorological system. While the convective systems are separated not moving. After uniting the MCS moved in the northwest direction. This displacement is the response of synoptic event condition. The circulation of Chaco low and high pressure in Argentina causes the displacement of the MCS against the flow of the cold front.

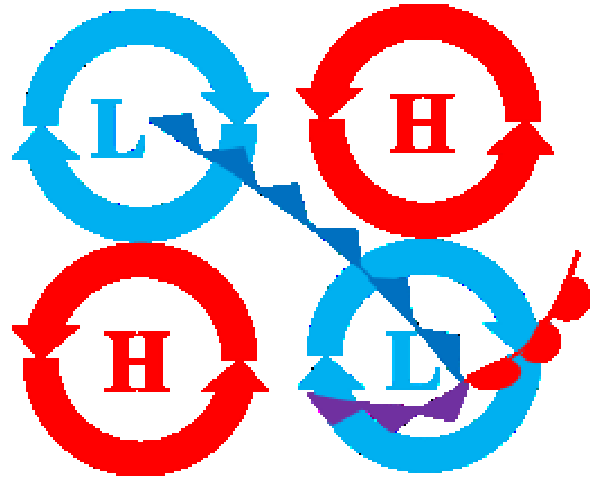

Figure 11. Schematic location of MCSs in relative with high (red H) and low (blue L) pressure. Position of the frontal system is indicated by the symbols: cold front (blue), warm front (red) and occlusion (purple).

Figure 11 shows where the MCSs occurred in relation with areas of high and low pressure and the cold front position. 10-11/Dec MCS occurred in the baroclinic zone of the cold front located on the low pressure represented by the letter L in the lower right of the Figure 12. 12-13/Dec MCS occurred over the trough of the Chaco Low barotropic feature, represented by the letter L in the upper left of the Figure 12;

The rate of occurrence and polarity of lightning as well as the IC/CG and CG+/CG- rates were not affected by the different conditions that the MCSs were formed.

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