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Lightning activity associated with Amazonian coastal squall lines: a case study

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***Abstract*—This work analyzes the electrical activity produced during the life cycle of coastal Amazon Squall Lines (ASL) observed on 23 June, 2011 and monitored by GLD360, a VLF Lightning Detection Networks. The VLF-network detected lightning diurnal distribution presented three strong peaks of activity: corresponding to the intensification of some cells storm. By tracking the main stroke clusters in time, it was observed that the ASL was first mainly expanded towards the west. When the dominant cell storm reached the Amazon River, the ASL changed its drift direction. Next, the ASL was mainly expanded towards the Southwest and the dominant cell storm seemed to follow the Amazon River side. The cell storm direction and its intensification suggest an influence of the river-breeze.**

***Keywords*— Lightning activity; lightning detection; coastal Amazon Squall Lines.**

I. INTRODUCTION

The Amazon region presents a strong lightning activity. Indeed, the optical measurements of lightning from space with the Optical Transient Detector (OTD) and the Lightning Imaging Sensor (LIS) on the Tropical Rainfall Measuring Mission (TRMM) satellite show that 78% of the lightings occur in tropical thunderstorms [Christian et al., 2003]. Moreover, in the eastern Amazon, the analysis of ground base lightning measurements with the SIPAM´s Lightning Detection Network (LDN-SIPAM) show in this region Cloud-to-Ground (CG) lightning density values of up to 11 events/km2/year with strong peak currents values (7% was determined to be between 100 and 250 kA) [Almeida et al., 2012].

Coastal Amazon Squall Lines (ASLs) are aligned clusters of cumulonimbus form along Brazil's northern coast associated with deep convection and the sea breeze front [Cohen et al. 1995] and [Alcântara et al., 2011]. The lines are propagated inland, across the Amazon basin with velocity of 50–60 km/h, an average length between 1000 and 2000 km and an average width of around 200 km [Alcântara et al., 2011]. According to Garstang et al. [1994], the ASLs contain intensifying convective elements and the top of the clouds reaches very low temperatures <-70 º C and heights from 16-17 km. As the electrical activity in thunderstorms is related to deep convective clouds with reference to several parameters, such as cloud height [Williams et al., 1985] and [Altaratz et al., 2010], or updraft velocity [Ushio et al., 2001], or ice phase precipitation [Carey and Rutledge, 2000] and [Yoshida et al., 2009], thus, the Squalls Lines are embedded in a strong electrical activity. Previous studies show that the lightning activity goes through various phases during the life cycle of a Squall Line (Mazur and Rust [1983] and Nielsen et al. [1994]).

The goal of this study is to analyze the electrical activity produced by the coastal ASL observed by the Centro de Previsão de Tempo e Estudos Climáticos (CPTEC) on the 23rd June of 2011 over the region of Belém (Brazil). The electrical activity was measured by one Very Low Frequency (VLF) Lightning Detecting Networks: the GLD360. The registered strokes was clustered and tracking over a regional scale to follow the ASL developing and moving.

II. GLD360 LIGHTNING DETECTION NETWORK DESCRIPTION

VLF Lightning Detection Network is based on radio antennas which record the radio noise emitted by lightning discharges (cloud-to-ground or intra-cloud lightning) in the Very Low Frequency range (3-30 kHz). The radio wave, propagated and law attenuated in the Earth-Ionosphere Waveguide (EIWG), which are called also Sferics, can be measured at great distances from the stroke and allows a spacing of the receiver sites of thousands of kilometers.

The Vaisala GLD360 network operates since September 2009 and the station distribution provides a worldwide coverage. GLD360 receivers are equipped by orthogonally oriented magnetic loop antennas and synchronized timing by GPS. The stations are measure continuously the magnetic field and extracts Sferics waveforms that are compared to expected waveform shapes stored in a database to estimate the propagation distance and accurately determine the arrival time [Said et al., 2011]. A combination of arrival time, arrival azimuth, range estimation, and amplitude is used to measure the discharge time, peak current, and location [Said et al., 2010]. Over the continental U.S., the GLD360 has a stroke Detection Efficiency (DE) of 40-60% with a Location Accuracy (LA) of 1-4 km, based on a comparison with the National Lightning Detection Network (NLDN) [Said et al., 2010]. Moreover the use of large air-core loop antennas with a well-matched preamplifier aids in the detection of Sferics from low peak current discharges at large distances [Said et al., 2011].

III. METHODS

During the coastal Amazon Squall Lines, the electric activity was measured by the GLD360 network. The collected set of strokes data enabled us to focus the study on regional scale corresponding to the ASL developing and moving zone. This regional scale is selected as a rectangular area, limited by [-3, 1] º S of latitude and [52, 46] º W of longitude (see Figure 3).

Strauss and Stephany [2011] show a correlation between the trajectories of the centroids of the nuclei of electrical activity resulting from the clustering and the centroids of the precipitation nuclei derived from the CAPPI radar images. These stroke clusters located in the expansion boundary of the ASL correspond to the intense convective region of the thunderstorm. Thus, for each time window of 10 minutes, the strokes registered by the GLD360 network in the regional area are clustered by geographic location to track the main cells of the thunderstorm. The stroke clusters are calculated by the K-Means method [Seber, 1984] and limited by a number of 6 clusters per time window. Two clusters with a common area are merging. Each stroke cluster is next defined by its time window, the location of its centroid (latitude and longitude) and its weight which is proportional to the number of strokes belonging to the cluster. As the average velocity of the ASL is around 50–60 km/h [Alcântara et al., 2011], a series of consecutive time stroke clusters with a distance < 10 km is clearly related to the same cell storm. Considering a maximum velocity of 90 km/h, a train of stroke clusters is defined as consecutive time clusters with a distance < 15 km.

IV. RESULTS AND DISCUSSION

A. *Strokes diurnal distribution*

The stroke diurnal distribution, presented Figure 1 is calculated by 10 minutes range from the GLD360 dataset limited by [-3 1] º S in latitude and [52 46] º W in longitude. This dataset is formed by a total of 5,711 strokes. Next, the stroke diurnal distribution is discriminated by ranges of estimated peak current (Figure 2).

The stroke distribution showed that the electrical activity began at 1300 UTC and increased slowly until 1820 UTC, the rate of strokes with estimate peak current >100 kA was high. At 1830 UTC the lightning activity increased suddenly and stayed intense until 2100 UTC. During this period, 3 peaks of strokes could be observed: the first one, the strongest, at 1840 UTC, the second one at 1940 UTC and the third one, the smallest, at 2110 UTC. This period present also a high rate of weak peak current (<20 kA). Finally, the number of strokes decreased continually until 2400 UTC. More generally, the characteristics of lightning activity during the life cycling of Mesoscale Convective Systems (MCS) was first described by Goodman and MacGorman [1986] who found that the most electrically active period is between the development and mature phase. More recently, studying 720 MCSs life cycles in Brazil, Mattos and Machado [2011] found that the average lightning life cycle exhibited a maximum close to maturation, while the maximum average lightning density occurred in the initial life cycle stage.

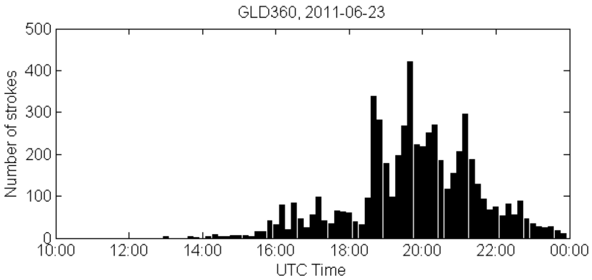

Figure. 1. Strokes diurnal distribution.

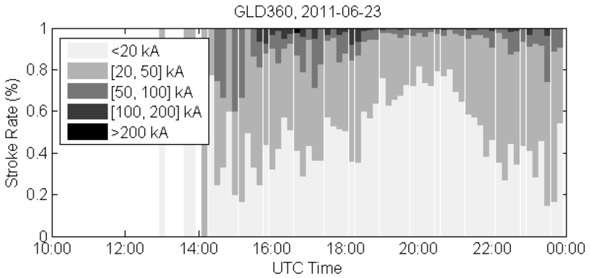

Figure. 2. Strokes diurnal distribution discriminated by ranges of estimated peak current.

B. *Stroke clusters shifting*

The strokes, registered by the VLF network were organized by clusters related to the nuclei of precipitation of the storm cells. Figure 3 shows all the stroke clusters calculated from the GLD360 database. Each cluster is represented by a circle whose diameter is proportional to the number of lightning events and whose color corresponds to the time window. Two consecutive time clusters with distance <15km are linked by a dashed line and related to the same storm cell. Even if the ASL cloud is moving like a single entity, the trajectory of the dominant storm cells appears though the stroke clustering. The results show that before 1800 UTC (the ASL genesis phase), the stroke clusters were small (<80 strokes) and mainly located in the area limited by [-3 -1] º S and [48.5 46] º W. The biggest cluster of this phase, 77 strokes, occurred at 1630 UTC and was centered in -1.76º S 46.93º W. This cluster was in the fifth position of a clusters train composed by 7 clusters, beginning at 1550 UTC in -1.87º S, 46.71º W and ending at 1650 UTC in -1.80º S 47.04º W. This train of stroke clusters suggests that the ASL was mainly expanded towards the west with a velocity around 40 km/h.

Between 1830 and 1900 UTC two simultaneous strong trains of stroke clusters occurred, corresponding to the strongest peak of the GLD360 diurnal distribution (Figure 1). The first one was a series of 4 clusters (with the respective weights 45, 186, 42, 28 strokes) which began at 1830 UTC at -1.64º S, 47.78º W and ended at 1900 UTC at -1.61ºS, 47.95ºW. The second one was a series of 3 clusters (with the respective weights 93, 169, 102 stroke) which began at 1840 UTC at -2.09º S 47.89º W and ended at 1900 UTC at -2.10º S, 47.99º W. The two cell storm velocities were respectively around 39 km/h and 37 km/h towards the river.

Next, between 1900 UTC and 2200 UTC appeared a long and dominant cell storm, whose the convective region seemed to follow the river side. The way of the convective region was tracking through the stroke clusters and can be observed in detail on Figure 4. This train had three big stroke clusters (> 200): the first two at 1930 UTC and 1940 UTC corresponded to the second peak of strokes in the diurnal distribution (Figure 1); the third one at 2110 UTC, which has the biggest weight (255 strokes) corresponded to the last and the smallest peak of lightning events, marking the maturation phase of the ASL. The cluster train began at 1930 UTC at -1.49º S, -48.24º W and ended at 2140 UTC at -1.88º S, 49.22º W. This cell storm had traveled around 117 km in 2 hours and 10 minutes, given a velocity of 54 km/h. After 2200 UTC the stroke clusters were small again (<50 strokes) but the convective region of the cell storm continued to follow the river side towards the west.

Following the stroke clusters on Figure 3, before 1930 UTC, the ASL was mainly expanded towards the West and after 1930 UTC towards the Southwest following the river side. The local river-breeze circulation, which occurs during the daytime from the river to the continent, may have an influence on the ASL main cell direction and intensifies along the riverside. Indeed, Molion & Dallarosa [1990] have suggested that river-breeze convergence may depress rainfall along the river and enhance it inland. The river-breeze influences increase with the width of the river such as in the Manaus region [Oliveira and Fitzjarrald, 1993] and the Santarem region [Fitzjarrald et al., 2008] in Brazil.

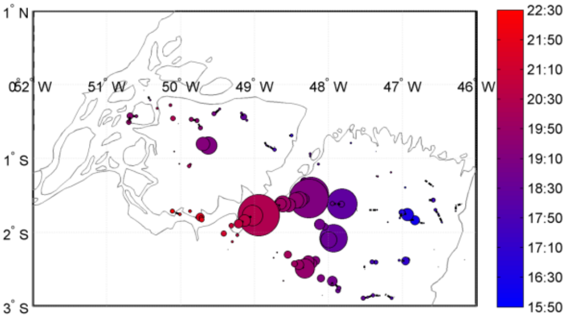

Figure. 3. Stroke clusters from GLD360 as a function of weight and time from 1550 to 2330.

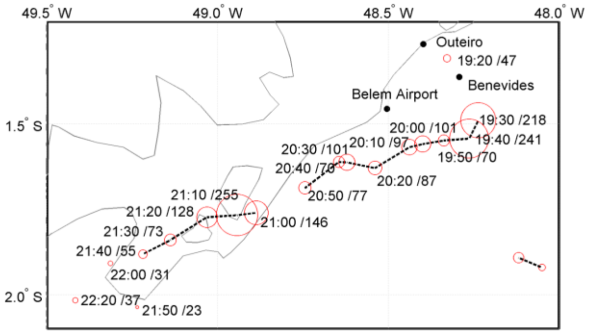

Figure. 4. Stroke clusters from GLD360 embedded with time window and weight (minute:second /number of lightning).

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REFERENCES

Alcântara, C. R., M. A. Silva Dias, E. P. Souza and Cohen, J. C. (2011), Verification of the role of the low level jets in Amazon squall lines Atmospheric Research, 100(1), 36–44, doi: 10.1016/j.atmosres.2010.12.023.

Almeida, A. C., B. R. Rocha, J. R. Souza, J. A .Sá and J. A. Pissolato Filho (2012), Cloud-to-ground lightning observations over the eastern Amazon Region, Atmospheric Research , 117, 86-90, doi: 10.1016/j.atmosres.2011.08.015.

Altaratz, O., I. Koren, Y. Yair and C. Price (2010), Lightning response to smoke from Amazonian fires, Geophys. Res. Lett., 37(7), doi: 10.1029/2010GL042679.

Carey, L. D. and S. A. Rutledge (2000), The Relationship between Precipitation and Lightning in Tropical Island Convection: A C-Band Polarimetric Radar Study, Mon. Wea. Rev., 128(8), 2687-2710, doi: 10.1175/1520-0493(2000)128<2687:TRBPAL>2.0.CO;2

Christian, H. J., R. J. Blakeslee, D. J. Boccippio, W. L. Boeck, D. E. Buechler, K. T. Driscoll, S. J. Goodman, J. M. Hall, W. J. Koshak, D. M. Mach, M. F. Stewart (2003), Global frequency and distribution of lightning as observed from space by the Optical Transient Detector, J. Geophys. Res., 108(D1), ACL 4-1–ACL 4-15, doi: 10.1029/2002JD002347.

Cohen, J. C. P., M. A. F. Silva Dias, C.A. Nobre, (1995), Environmental conditions associated with Amazonian Squall Lines: a case study, Mon. Weather Rev., 123(11), 3163 - 3174, doi: 10.1175/1520-0493(1995)123<3163:ECAWAS>2.0.CO;2.

Fitzjarrald, D. R., R. K. Sakai, O. L. Moraes, R. Cosme de Oliveira, O. C. Acevedo, M. J. Czikowsky, T. Beldini (2008), Spatial and temporal rainfall variability near the Amazon-Tapajós confluence, J. Geophys. Res., 113(G1), doi: 10.1029/2007JG000596.

Garstang, M., H. Massie, J. Halverson, S. Greco and J. Scala (1994), Amazon coastal squall lines. Part I: Structure and kinematics, Mon. Weather Rev., 122, 608-622, doi: 10.1175/1520-0493(1994)122<0608:ACSLPI>2.0.CO;2.

Goodman, S. J., and D. R. MacGorman (1986), Cloud-to-ground lightning activity in Mesoscale Complexes Convective, Mon. Weather Rev., 114, 2320–2328, doi: 10.1175/1520-0493(1986)114<2320:CTGLAI>2.0.CO;2.

Mattos, E. V. and L. A. Machado (2011), Cloud-to-ground lightning and Mesoscale Convective Systems, Atmospheric Research, 99(3-4), 377–390, 10.1016/j.atmosres.2010.11.007.

Mazur, V. and W. Rust (1983), Lightning propagation and flash density in Squall Lines as determined with radar, J. Geophys. Res., 88(C2), 1495–1502, doi: 10.1029/JC088iC02p01495.

Molion, L. C., and R. L. Dallarosa (1990), Pluviometria da Amazônia: são os dados confiáveis? Climanálise - Boletim de Monitoramento e Análise Climática, 5, 40-42.

Nielsen, K., R. Maddox and S. Vasiloff (1994). The evolution of cloud-to-ground lightning within a portion of the 10–11 June 1985 Squall Line, Mon. Weather Rev., 122, 1809–1817, doi: 10.1175/1520-0493(1994)122<1809:TEOCTG>2.0.CO;2.

Oliveira, A. P. and D. R. Fitzjarrald (1993), The Amazon river breeze and the local boundary layer: I – Observations, Boundary Layer Meteorology , 63(1), 141-162, doi: 10.1007/BF00705380.

Said, R. K., M. J. Murphy, N. W. Demetriades, K. L. Cummins and U. S. Inan (2011), Methodology and Performance Estimates of the GLD360 Lightning Detection Network paper presented at XIV International Conference on Atmospheric Electricity, Rio de Janeiro, Brazil.

Said R. K., U. S. Inan, K. L. Cummins (2010), Long‐range lightning geolocation using a VLF radio atmospheric waveform bank, J. Geophys. Res., 113(D23108), doi:10.1029/2010JD013863,

Seber, G. A. (1984), Multivariate Observations, John Wiley & Sons Inc., Hoboken, NJ.

Strauss, C. and S. Stephany (2011), Sliding window-based spatio-temporal clustering of lightning data, paper presented at XIV International Conference on Atmospheric Electricity, Rio de Janeiro, Brazil.

Ushio, T., S. J. Heckman, D. J. Boccippio, H. J. Christian, Z. Kawasaki, (2001), A survey of thunderstorm flash rates compared to cloud top height using TRMM satellite data, Journal of Geophysical Research, 24, 89–24.

Williams, E. R. (1985), Large-scale charge separation in thunderclouds, Journal of Geophysical Research , 90, 6013–6025.

Yoshida, S., T. Morimoto, T. Ushio, Z. Kawasaki (2009), A fifth-power relationship for lightning activity from Tropical rainfall measuring mission satellite observations, Journal of Geophysical Research , 114.