The Catatumbo Lightnings: A Review

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ABSTRACT: The Catatumbo Lightnings is the local name of a set of electric storms that takes place mainly in the southwestern quadrant of the Maracaibo Lake Basin (MLB), in Venezuela, between the Bravo and Catatumbo riverbeds. Recently, this place has been reported to be the location with the highest flash (lightning) density in the world, as evidenced by LIS/TRMM data. Several local factors help trigger the formation of the thunderstorms in the zone, namely the topography configuration, moisture availability, wind circulation and orographic convection. From a regional point of view, the monthly lightning anomaly in the Catatumbo zone evidence a modal cycle which follows the Inter Tropical Convergence Zone (ITCZ) migrations, with a minimum in January and a maximum in August-September, the latter in correspondence with minimal yearly values of meridional winds and the Caribbean Low Level Jet (CLLJ) seasonal weakening. Thus the meridional wind intensity in the MLB seems to play a very important role in the lightning formation, with an inverse correlation: high hurricane activity years (e.g. 2005) provide a mean decrease of southwards wind velocity along the Venezuelan coasts, enabling suitable conditions to convection activity in the MLB Southwestern region. A characterization of the seasonal behavior of the Catatumbo Lightnings has also been done recently in terms of the Convective Available Potential Energy, and suggests a specific range for occurrence of lightning and a plausible way to establish an Early Warning System for thunderstorm in the zone.

1. INTRODUCTION

The Catatumbo Lightnings phenomenon has been reported to be the set of electric storms with the highest flash (lightning) density on Earth [Stock et al., 2011; Albrecht et al., 2009]. In the last decade, the Lighthouse of Maracaibo, as is locally known, has been object of renewed interest in the scientific community due to its inherent characteristics and also for the lack of information on its occurrence and behavior. These electric storms possess an inter-annual variability ranging from 180 to 260 nights per year throughout the Maracaibo Lake Basin (MLB) although they are mainly concentrated to its southwest portion near the Catatumbo river mouth. The appearance of this electro-atmospheric event has been recurrently reported for approximately 500 hundred years [Zavrotsky, 1991].

Several authors have suggested in the past different explanations about the CL origin [Zavrostky, 1991 and references therein]. In particular, Falcón et al. [2000] have suggested a microphysical model based on the symmetry properties of methane gas and its critical concentration on the upper side of the storm cell, but such a model must be carefully revisited due to the fact that the proposed mechanism is not viable if updraft and downdraft circulations within the clouds are considered.

On the other hand, Stock et al. [2011] and Albrecht et al. [2009] have reported the phenomenology of the CL in terms of satellite observations using the Lightning Imaging Sensor-LIS [Boccipio et al., 2002]. Meanwhile, Díaz and Muñoz [2011] have studied the spatial and temporal evolution of the kinetic and convective available potential energy in the MLB.

In the following pages a brief review of several recent developments is presented.

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2. THE MARACAIBO LAKE BASIN

The region of interest (8N-12N and 73W-70W) is dominated by two important geographic phenomena (Figure 1). The first one is the Andes Range which is divided, in Venezuela, into two well defined arms: the Perijá Range (extending along the Venezuela-Colombia border) and the Venezuelan Andes (extending to the Northwest until disappearing in front of the Caribbean Sea). With mean heights between 1500 m and 3700 m, both arms encircle almost completely the second phenomenon: the Maracaibo Lake, the biggest in South America. In the Southwestern quadrant of the MLB is placed the Catatumbo River, the most important one for the Maracaibo Lake hydrodynamics. The location of the MLB is affected by several global-to-regional climatic phenomena, e.g. El Niño-Southern Oscillation (ENOS), the Inter Tropical Convergence Zone (ITCZ) migrations, intrusions of high tropospheric troughs from Northern Hemisphere, synoptic perturbations, the trade winds and the Caribbean Low Level Jet (CLLJ) seasonal variability [Amador, 2008; Pulwarty et al., 1998]. Locally, the wind circulation and convection activity on the MLB is defined by the orographic configuration, the influence of the trade winds, the lake breezes and occlusion between cold air masses coming from the Andes and Perijá Cordillera, and warmer air masses coming from the Lake and the Caribbean.

![Figure 1. Orographic configuration of the zone.](image)

![Figure 2. Flash rate for southern Maracaibo Lake.](image)

3. PHENOMENOLOGICAL ASPECTS

The time series detected by LIS of annual flashes/day in the region of interest between 1995 and 2005 is shown in Figure 2. Using granule LIS data for each quadrant of the MLB, Stock et al. [2011] report that annual flash minima take place in January and maxima in September (Figure 3). This behavior seems to be related with the intensity of meridional wind component in the region (again, Figure 3): there is a maximum for in January-February (about -1 m/s) and a minimum between May and September (-0.1 to +0.2 m/s).

![Figure 3. Flash mean frequency (left) for each Cartesian quadrant over the MLB (after Stock et al., 2011) and meridional winds climatology in m/s (right) using NOSA30k [Muñoz and Recalde, 2010].](image)
The reported flash density for the region as measured by LIS for the period 1998-2008 is 181 flashes/km²/year [Stock et al., 2011]. Stock et al. [2011] also mention, based on Centro de Modelado Científico (CMC) field campaigns observations between 2002 and 2010, that the most frequent electrical activity in the Catatumbo region is intra-cloud (IC). New evidence using a Boltek StormTracker lightning detector located at CMC shows that approximately the 52% of 2011’s March-April discharges in the MLB are IC+, and that maximum lightning activity tends to occur daily between 22 hr and 4 hr (local solar hours).

4. RETROSPECTIVE MODELING

A numerical simulation over the 1998-2008 period for MLB employing the WRF model [Skamarock et al., 2005] has been used to study the physical behaviour of several variables. The dataset, known as NOSA30k, was produced by the Andean Observatory [Muñoz et al., 2010] and is freely available at the IRIDL (for details see Muñoz and Recalde, [2010]). From this, convective available potential energy (CAPE) estimates have been analyzed [Díaz and Muñoz, 2011]. The results for the least active month (January) and the most active (September) are shown in Figure 4.

![Figure 4. 1998-2008 CAPE (J/kg) climatology for January (left) and September (right). The black square shows the highest lightning activity region (see main text).](image)

Along the year, the wind circulation (counterclockwise) in the MBL advects moisture and energy in a specific zone (black square in Figure 4), defining a region with the basin’s highest convective activity. This is partly why the Juan Manuel National Park, located in that zone, is mostly a marshland.

The highest monthly CAPE for the studied period happens in 2005, a very active hurricane year, with a peak of 2427 J/kg and very weak mean meridional surface winds. In contrast, CAPE’s climatological January and September’s maxima for the black square in Figure 4 are in the order of 600 J/kg and 1800 J/kg, respectively. For further results and discussion the reader is exhorted to see [Díaz and Muñoz, 2011].

5. CONCLUDING REMARKS

The Catatumbo Lightnings are a set of very active electrical storms taking place in the MLB, especially in its Southwestern quadrant, near the Catatumbo River mouth. They present a mean modal behavior in the flash density variability along the year, with a minimum in January and a maximum in September, with a mean value of 181 flashes/km²/year. As it has recently been reported by two different authors [Stock et al.,
Northwestern South America possesses the highest flash rate in the planet, and specifically it is located in the MLB. The convection processes are modulated in the region by the effect of the ITCZ migrations, the trade winds, the CLLJ and local topography.

From a local point of view, even when the Falcón et al. [2000] model must be reconsidered carefully, we think that methane gas could still be facilitating the electric discharge occurrence. Indeed, an anomalous concentration of methane in the storm cell will disperse itself more or less evenly inside the cumulonimbus due to the updrafts and downdrafts. The total dielectric constant of the medium being modified, it diminishes the electrical field needed to produce the air electrical rupture, providing more frequent lightning.

The recent studies of Díaz and Muñoz [2011] using CAPE and normalized CAPE suggest typical values that can be useful for defining an Early Warning System in the region, forecasting available potential energy for convection maps by means of the WRF model.

REFERENCES


