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HIGH ALTITUDE LEADERS MAPPED BY THE COLOMBIA LIGHTNING MAPPING ARRAY

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***Abstract*—On April 2015 a Lightning Mapping Array network (COLMA) was installed at the north of Colombia. This network provides 3D mapping of the development of lightning leaders. For the first time such network has been setup in the tropics. That allows us to investigate the high altitude development of lightning leaders. Here we present the results of the first measurements to confirm that negative leaders at altitudes of 15 km are common in the observed thunderstorms.**

1 - INTRODUCTION

During the last few decades, the development of lightning leaders has been investigated by means of VHF lightning mapping systems (e.g. [1-3]). The use of remote sensing techniques have been helpful since most of leaders occur within the thundercloud and are not visible.

The Lightning Mapping Array (LMA) system locates RF emissions in the VHF range (60-66 MHz) in three dimensions by a time-of-arrival technique using at least five stations. Each station samples the maximum RF power amplitude and its GPS derived precise time over 80 µs intervals. Typically, two to three thousand sources per second are located during lightning flashes and power in dBW is available for every located source (see [3-4]).

LMA systems have been used to investigate properties of lightning and thunderstorms (e.g. [5-7]). Electrical charge structure can be identified from leader propagation. However, most of these studies correspond to mid-latitude thunderstorms and few studies have been developed in tropical areas, where the lightning activity has one of the highest values in the world, e.g. the tropical zone dubbed "Catatumbo" and composed by the upper area of Magdalena river valley in Colombia and the Maracaibo lake in Venezuela. This region has been identified by several authors [15-16] as one of the regions in the world with highest lightning activity, in fact, a recent study developed by Torres et al. [14] using local and global lightning data in tropical regions of America shows that the highest lightning activity zones in South America are located between latitudes 8° and 10° where the Catatumbo area is located. This area has a Ground Flash Density up to 53 flashes/km^2 - year such as shown in Fig. 1 (Ground Flash Density map).

On the other hand, nowadays a new field of study in physics has been developed around of high dissipate energy at higher atmosphere: Transient Luminous Events (TLEs) and Terrestrial Gamma-ray Flashes (TGFs). It is thought that TGFs are produced by several electrical properties of thunderstorms such as its electrical charge structure, vertical potential distribution that allow electrons to run away in the intense fields of lightning leaders pointing upwards. Space-based detections of global TGFs distribution have shown the tropical regions as the most active zones of TGFs. E.g. Fabro et al. [18] presented a recent analysis of global TGFs distribution where South America was characterized by significant amount of TGFs.

In this work, we present the first time LMA data of the recently deployed network in Colombia (COLMA). Differences between lightning at tropical regions and mid-latitudes (Europe) are discussed.

2 - LIGHTNING ACTIVITY IN COLOMBIA

Several studies about lightning activity in Colombia have been developed during the last years. In 1990 it was published a Keraunic level map [15] by the Colombian Weather Service and the National University of Colombia. This parameter helped to define the temporal and spatial lightning behavior in Colombia. Values between 100 - 160 thunderstorms days per year were computed in the regions of the river valleys of Magdalena and Cauca; and Catatumbo and Pacífico. At the same time, a bi-modal behavior of thunderstorms occurrence was found at the centre of Colombia.

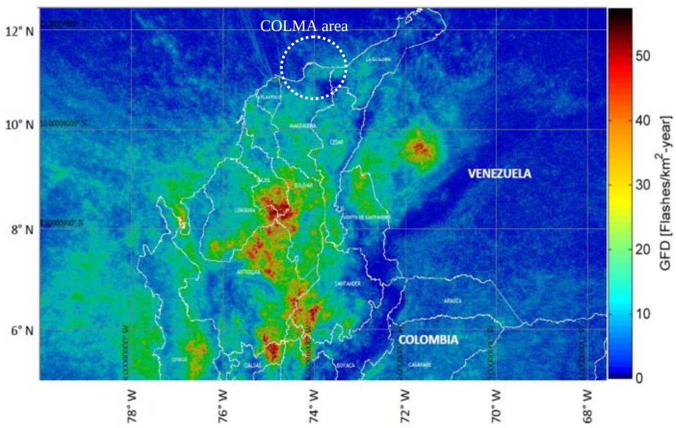

Figure 1 - Ground Flash Density at the north of Colombia derived from the Colombian LINET network. (Adapted from [14]).

Regarding the GFD, in 2002 the first GFD map was published by Younes [19]. In that map it was found values between 20 to 30 flashes/km^2 - year using the Local

Lightning Location Network - RECMA. Those results were consistent with Keraunic Level report previously published. In 2010 a new GFD map was computed by Gallego [20]. Figure 1 shows the most recent GFD map published by Aranguren et al. [16] using the Total Lightning Location Network - LINET installed in Colombia. As shown in Figure 1, values between 15 to 25 flashes/km^2 - year are the most commonly reported and the maximum value up to 55 flashes/km^2 – year. In the area of interest where the COLMA is installed the GFD was estimated between 15 to 20 flashes/km2-year and the annual thunderstorm days of 100.

3 - COLOMBIA LIGHTNING MAPPING ARRAY

In April 2015 a Lightning Mapping Array-LMA network was installed in Colombia (COLMA) in the frame of Atmosphere Space Interactions Monitor-ASIM mission [8]. The COLMA is composed by six sensors with a baseline between 5 to 20 kilometers. The area of interest is located in Santa Marta region at the north of Colombia. It covers a small littoral zone of the Atlantic ocean, the Santa Marta city and the western foothills of the Sierra Nevada de Santa Marta mountain, the most highest and isolated mountain in Colombia with a maximum altitude value of 5700 m.a.s.l (see Fig. 2).

Figure 2- Colombia Lightning Mapping Array (COLMA) network.

4- DATA

A total of 10 thunderstorms have been recorded and analyzed from September to November 2015. More than 7000 individual flashes and up to 480000 flashes sources have been registered. Simultaneously, the LMA data obtained from Ebro Lightning Mapping Array - ELMA in Spain between 2011 to 2015 were employed in order to compare the altitudes of lightning leaders in Colombia and Spain.

Figure 3 shows an example of 10 minutes of lightning activity during the 16th of November of 2015. From the figure it can be noted a significant leader activity at altitudes above 12 km which corresponds to the typical top altitude for most of the thunderstorms observed by the ELMA in Spain [9-10]. This finding confirms that: lightning leaders in the tropics can development at high altitudes due to the vertical extension of tropical storms.

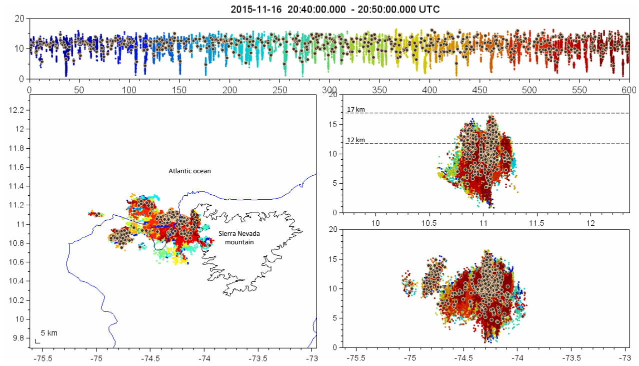

Figure 3- Ten minutes of lightning activity during the 20151116 storm (Temporal occurrence and height sources distribution are shown at the top. The bottom view shows the lightning sources locations).

The individual flash in Figure 4 shows negative leader development reaching heights of ~15 km. Assuming that negative leaders develop in positive charge regions and positive leaders in the opposite polarity regions, the flash revealed a mid-level negative charge region below ~6 km and an upper positive charge region extending up to ~15 km.

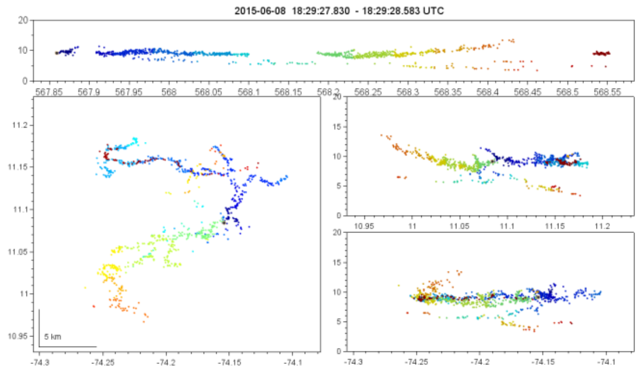

Figure 4- Lightning flash of the 20150608 at 18:29:28 UT.

5 - RESULTS

5.1 - ELECTRICAL CHARGE DISTRIBUTION

The heights of the sources could help to identify the electrical charge distribution in the cloud (simple inspection analysis). Using this analysis, the 3-dimensional sources location suggest that, the electrical charge structure presented a tripolar distribution centred at 5 km, 8 km and 10.5 km of height and could represent the lower positive charge region, negative charge region and upper positive charge region, respectively (see Fig. 5).

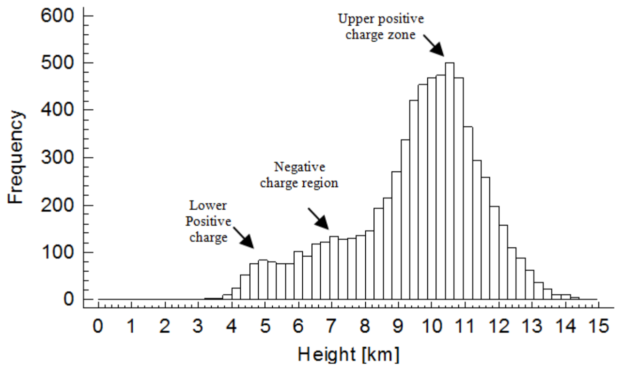

Figure 5- Median height distribution of the lightning sources (electrical charge distribution)

Figure 6 Compares the heights of the lightning sources in Colombia and Spain.

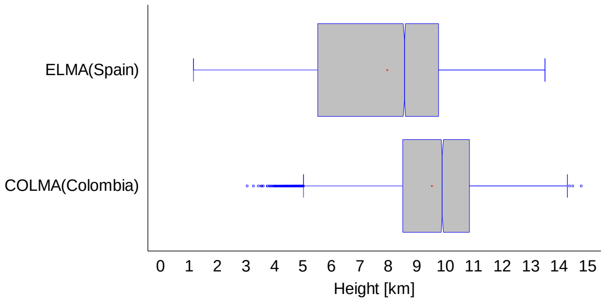

Figure 6- Box plots of the height distributions of Colombia COLMA and Spain ELMA

The box plot shows that the median height of the lightning sources in Spain is located at 8 km; 2 km below to the median value in case of Colombia, which is located at 10 km. An analysis of the maximum altitude of lightning sources for each individual flash was computed. A 50% of these sources were located above 12.5 km and 70 % have altitude above 13.5 kilometers. These results could be a measure of the vertical extension in the tropical storms.

5.2 - TIME EVOLUTION OF LIGHTNING SOURCES DURING A STORM

Time evolution of the electrical charge distribution was analyzed during a case study on 16 November 2015. The COLMA sources are plotted in a time-altitude density map (density map).

Three clusters which high values of VHF sources (more than 3000 sources) were identified between 19:30 to 20:20; 20:30 to 21:00 and 21:10 to 21:30 UT (figure 7). At the same time, the maximum values of lightning sources were located at 8 km during the first interval and 10 km during the last two intervals. In addition, at 20:50 UT was identified the most active flash rate, with more than 7000 lightning sources, these sources have an altitude range from 3 to 14 kilometer of altitude. Sources were located closer than 40 km of distance from the center of the network.

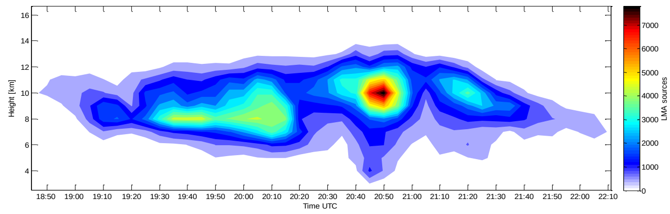

Figure 7- Time-altitud lightning sources evolution.

6 - CONCLUSION

We presented first data of VHF measurements of radio emissions from lightning leaders in Colombia (tropical region) using the Colombia Lightning Mapping Array network - COLMA the first 3D-VHF system operating in a tropical region.

700 individual flashes from September to November 2015 have been analyzed, and up to 480000 sources have been processed. The median height distribution of lightning sources (see Fig. 5), suggests that, the majority of flashes (lightning leaders) in Colombia were initiated at 10 km of height, more than 2 km above compared to Spain. At the same time, the vertical extension of tropical storms have been identified between 3 to 15 km and a tripolar distribution of lightning sources has been identified, with values centred at 5 km, 8 km and 10.5 km of height by the lower positive charge region, mid-level negative charge region and upper positive charge region, respectively. Regarding the time evolution of lightning sources, it has been possible to identify the active cells and its maximum lightning source occurrence, also the variation of the electrical charge structure as a function of time-altitude incidence.

Some findings confirm what we expected, lightning leaders can propagate at higher altitudes. The differences in altitude between the flashes in tropical and mid-latitude storms is due to the tropopause height in the tropics (~17 km). The presence of lightning leaders at higher altitudes might favour the production of the highly energetic Terrestrial Gamma-ray Flashes (TGF) observed from space.

The information presented here has several implications because, the COLMA network is the first VHF 3-D system installed in the tropical region and this information will allow us to analyze and continue investigating the electrical properties of tropical storms such as, spatial distribution, intra cloud ratio, duration, altitude of the electrical charge, lightning leader information.

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