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Quarterly Analysis of Total Lightning Activity in Colombia

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***Abstract*— This paper presents spatial and temporal variations of the distribution of total lightning activity in Colombia based on data provided by satellite observations from the NASA TRMM LIS mission. The dataset used is a recent update with a better-gridded resolution ranging for sixteen years of total lightning observations. The results show some areas of the Colombian territory with flash rate densities (FRD) up to 252 flashes per square kilometer per year and around 65 percent of its mainland with an FRD above 10 flashes per square kilometer per year. The lightning activity hotspots are located mostly in the north part of the country around the Atrató, Cauca, and Magdalena River basins and the foothills of the three main Cordilleras and several other Serranías (e.g., Baudó, San Lucas and, Perijá). All these areas have continuous lightning activity nearly throughout the year. These results highlight that lightning activity in Colombia takes place mainly in the north part of the country with one peak of activity around mid-year. In the rest of the territory, there are two peaks of activity, although some regions with a less marked transition between the periods.**

***Keywords*—Lightning; Colombia; TRMM LIS; Andes mountains; Rainy season; Intertropical convergence zone.**

I. Introduction

NASA Global Hydrology Resource Center periodically, release updated lightning observation data on its website. The repository is a collection of datasets from several satellite platforms. For this work, it is of interest a dataset from the Lightning Imaging Sensor (LIS) that was on board of the NASA Tropical Rainfall Measuring Mission (TRMM/LIS). This sensor recorded total lightning activity for the latitudes between 38º N and 38º S. The data includes total lightning activity, namely, cloud to cloud (CC), intracloud (IC) and, cloud to ground (CG) flashes. In reference [1] there is a complete description of these dataset and other related products. Using the mentioned datasets, Albrecht developed a new version by improving its resolution [2]. As a result, the datasets, contain information of 16 years (1998-2013) of lightning observations from TRMM/LIS gridded to a resolution of 0.1º x 0.1º [3].

With this improved resolution, every sample of the datasets gives information about an area of roughly 121 km^2. This is true for Colombia because of its near-equator location. For the aim of this study, the information in all datasets was limited by the coordinates 13º N and 4.3º S and 79.1º W and 66.3º W, that encompasses the whole of the continental area of Colombia but also include parts of bordering countries (Panama, Ecuador, Venezuela, Peru and Brazil), and a portion of open waters (the Caribbean Sea and the Pacific Ocean). Thus, to remove the data from these areas, a spatial filter was developed by the authors. In this way, the filtered data only pertain to Colombian mainland increasing the accuracy of the results.

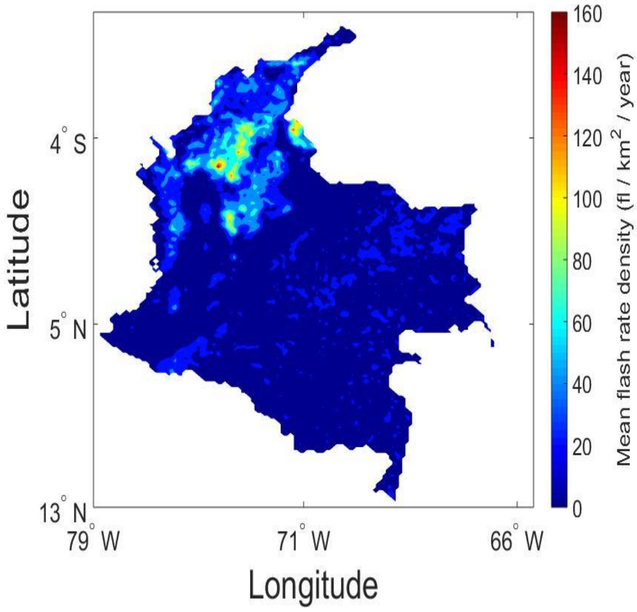

Fig 1: Mean total flash rate density climatology for 16 years (1998-2013) over Colombia from TRMM/LIS datasets. About 65% of the territory has a flash rate density over 10 flashes km^{-2} yr^{-1} and about 15% of the territory has a flash rate density over 70 flashes km^{-2} yr^{-1}.

II. Geography and climate of Colombia

Colombia is situated in the northwest of South America with an approximate extension of 1,142,000 km^2. It has coastlines on both the Pacific and the Atlantic Oceans, and its geographical diversity is due to the presence of three parallel mountain ranges that extend south-north direction through the territory. They belong to the Andes Mountains; where locally they are named Western, Central and Eastern Cordilleras. In these mountains, there are altitudes above 5,000 m.a.s.l., in addition to elongated valleys and Andean high plateaus between the mountain ranges. Cauca River basin divides the Western and Central Cordilleras, and Magdalena River basin the Central and Eastern Cordilleras. There are also several smaller valleys located between these Cordilleras and other low to middle altitude mountain ranges (Serranías). This varied topography creates well differentiated five natural geographic regions: the Andean region, the Pacific region, the Caribbean region, the Amazon region, and the Orinoquia region. Each of these regions has well differentiated geographical and climatic features such as coastlands, plains, highlands, forest, and Andean plateaus.

In connection to the climate, it goes from the tropical along coastlines and eastern plains (mean temperature over 24º C) to the colder in highlands (mean temperature close to 2º C). The three main factors influencing the climate in Colombia are topography, wind regimes, and air moisture. The first factor has addressed previously. Wind regimes involve both global and local patterns, namely, seasonal migration of the Inter-Tropical Convergence Zone (ITCZ) [4]; the interaction with northeast and southeast trade winds [5], the presence of inland and offshore Mesoscale Convective Systems (MCSs) [6], [7] the El Niño-Southern Oscillation (ENSO) [8], the Atlantic Multidecadal Oscillation (AMO), the Pacific Decadal Oscillation (PDO), low-level jets [9] and Caribbean cold fronts [10], among others. The third factor, the presence of moisture over the country, depends on interactions between four primary sources of humidity: the Atlantic and Pacific Oceans, and the Orinoco River and Amazon River basins [11], [12]. These factors configure a wide spatial and temporal variability in Colombian climate with one or two rainy seasons where the precipitations concentrate particularly at medium altitudes in the foothills of Serranías and Cordilleras [13]. Depending on the methodology, researchers can identify up to seventeen climates throughout the country [9], [14].

III. SPATIAL DISTRIBUTION OF LIGHTNING ACTIVITY

The mean annual flash rate density (FRD) of Colombia, for 16 years is shown in Fig. 1. In this image, the lightning activity concentrates in the north part of the country, which corresponds to most of the Caribbean region and the northern part of the Andean and the Pacific region. The activity is also intense in the interAndean valleys that correspond to the Atrató, Cauca and Magdalena River basins. The two subregions with the highest values of FRD are the Depresion Momposina in the Caribbean region and the Catatumbo region in the Andean region. The latter belongs to the Maracaibo Lake basin where is located the site with the highest lightning activity on Earth [2]. Despite the valuable information of this image, there is a limitation because it does not provide details about the temporal evolution of the lightning activity in the country. Given that, the authors also found some temporal variations of the lightning activity. The results are presented as follows.

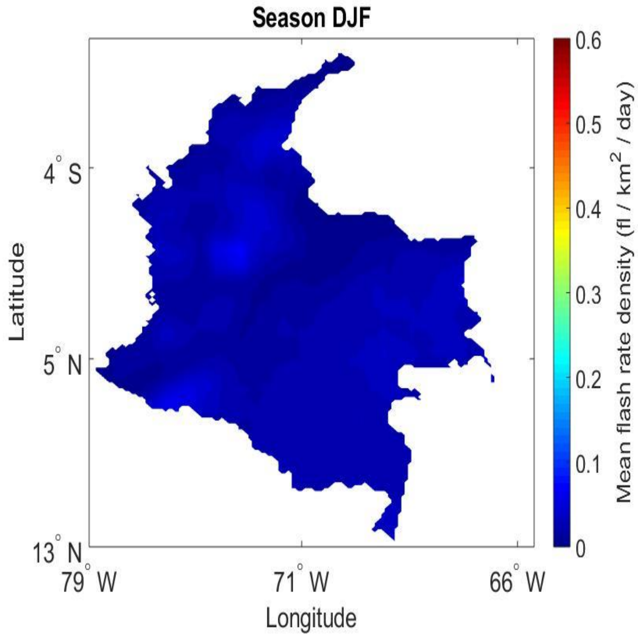

Fig 2: Mean FRD per day (flashes km^{-2} day^{-1}) of the first quarter (December, January, February) for the period from 1998-2013 in Colombia.

IV. QUATERLY VARIATION OF LIGHTNING ACTIVITY

The information available in the datasets divide the year into four seasons, namely, December, January, February for the first season; March, April, May for the second season; June, July, August for the third season and September, October, November for the fourth season. For each season the reported results correspond to the mean FRD per day. To begin with, the mean FRD per day of the first quarter (December, January and, February) is shown in Fig. 2. The image evidences a generalized low-intensity lightning activity over the territory that coincides with the annual dry season in Colombia. During this quarter the ICTZ is in its further south equator localization. With very low values of FRD, the lightning hotspots during this quarter are the middle part of the Magdalena River basin and to a lesser extent the Sibundoy valley in the Amazon region and Catatumbo region.

For the second quarter (March, April, and May) the mean FRD per day is shown in Fig. 3. During this period the ITCZ starts to move north of the equator, passing over the Colombian mainland. This displacement causes an intensification of rain, reaching a peak around April. The lightning activity starts to increase up to get a moderate intensity (0.1 flash km^{-2} day^{-1}) in most of the territory. Although some areas in the north of the country experiences FRD above 0.3 flash km^{-2} day^{-1}. These areas correspond to the far north of the Andean, Pacific, and most of the Caribbean regions. The subregions Depresion Momposina and Catatumbo region have the highest FRD values. Other areas with high FRD are the Meta River basin and the high plains in the Orinoquia region; Pubenza valley and Sibundoy valley in the Andean and Amazon regions, respectively.

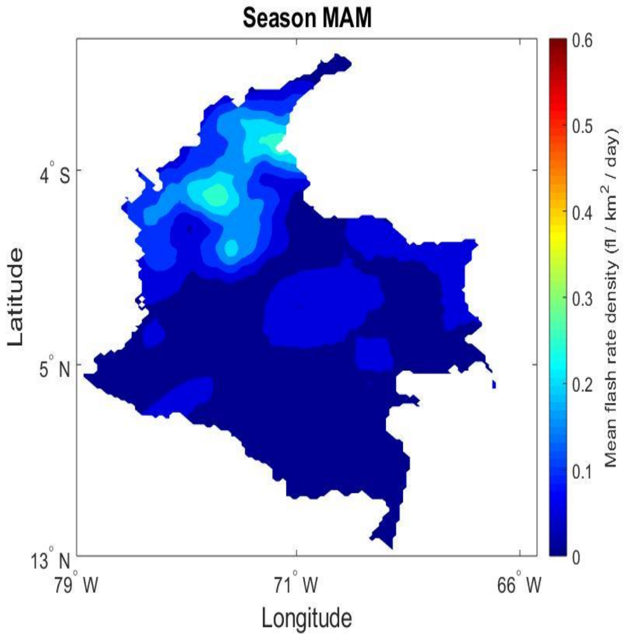

Fig 3: Mean FRD per day (flashes km^{-2} day^{-1}) of the second quarter (March, April, May) for the period from 1998-2013 in Colombia.

For the third quarter (June, July, August) the mean FRD per day is shown in Fig. 4. During this quarter, there is a general reduction of lightning activity except in the north part of the country where it keeps high. The more significant decrease occurs in most of the Andean region, and to a lesser extent, in the southern part of the Pacific region and the foothills of the Amazon region near to the Western Cordillera. As was previously stated, the activity remains high in the northern part of the Andean and the Pacific region and the entire Caribbean region. It is interesting to note that the only exception to the intense lightning activity in the Caribbean region is the subregion of the Alta Guajira where there is a desert-like area. However, during this quarter, the lightning activity in this subregion has its peak of activity.

Finally, for the fourth quarter (September, October, November) the mean FRD density per day is shown in Fig. 5. During this quarter occurs the second rainy season in most of the territory. Regarding lightning activity, this has an almost generalized second peak of activity. The lightning activity in the Caribbean still high. In the same way, the lightning activity is high in most of the Orinoquia and the Amazon region. During this quarter the lightning hotspots are in the Caribbean region, middle Magdalena River basin and Catatumbo region.

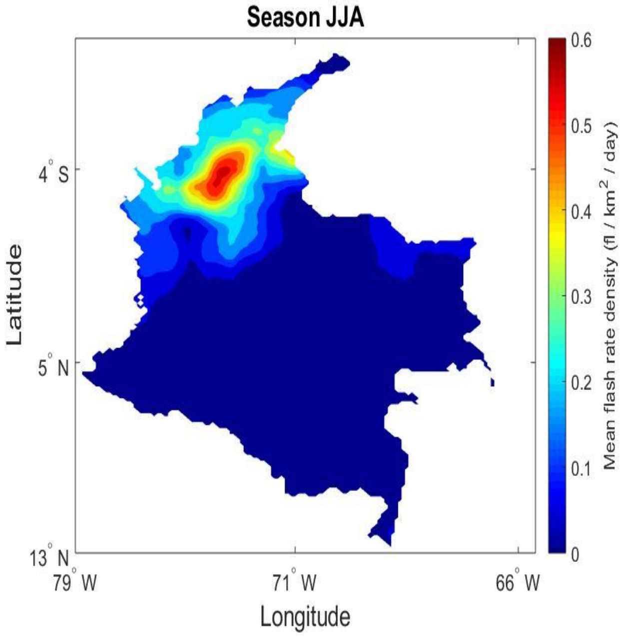

Fig 4: Mean FRD per day (flashes km^{-2} day^{-1}) of the third quarter (June, July, August) for the period from 1998-2013 in Colombia.

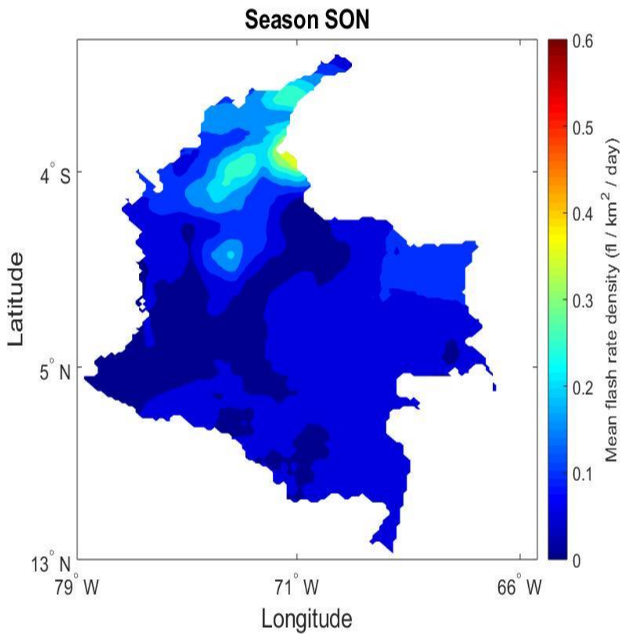

Fig 5: Mean FRD per day (flashes km^{-2} day^{-1}) of the fourth quarter (September, October, November) for the period from 1998-2013 in Colombia.

V. CONCLUSIONS

Together the present findings suggest that the northern part of both Andean and Pacific regions; and most of the Caribbean region have the highest values of lightning activity in Colombian territory. The areas with the highest values of lightning density have an almost continuous lightning activity throughout the year; this means a unimodal pattern with a peak around August. This can be seen in the behavior of lightning activity in the Caribbean region where the lightning activity is almost present during three quarters, only decreasing at the beginning of the year. The lightning activity in Andean and Pacific regions follows a bimodal pattern with peaks of activity around April and September, with a smooth transition between the two seasons, this means, there is no a marked decreased in lightning activity around mid-year. The Amazon and Orinoquia regions also follow a bimodal pattern, but unlike later, they have a well-marked transition between seasons, meaning a sharp decline around mid-year. Additionally, there are some isolated subregions worth to mention because of its moderate lightning activity are the Pubenza, Aburrá, and Sibundoy valleys.

The sites with moderate and high lightning activity share similar conditions because they mainly take place in the foothills of mountain systems belonging to rivers basins.

Satellite-based data used in this study suffer from limitations related to the short observation time of the low orbit satellite over an area, as well as, the efficiency of the optical sensor, especially for thunderstorms in daylight. Nonetheless, all the findings are consistent with previous studies that used both satellite and ground-based data.

Additional work is necessary to find the factors that may influence the intense lightning activity in certain areas, especially environmental factors such as humidity, winds patterns, and solar radiation.

Currently, the authors are further extending this work to cast additional light about spatial distributions and temporal variations of total lightning activity in Colombia.

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