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Daniel Aranguren, Jesús López, Joan Montanyà, Horacio Torres. (2018) Natural observatories for lightning research in Colombia. 20th International Conference on Electromagnetics in Advanced Applications, Cartagena de Indias, Colombia, Sept. 10 - 14, 2018: IEEE, 2018. Pp. 279-283 Doi: 10.1109/ICEAA.2018.8520371.

Daniel Aranguren, Jesús López, Joan Montanyà, Horacio Torres. (2018) Natural observatories for lightning research in Colombia. 20th International Conference on Electromagnetics in Advanced Applications, Cartagena de Indias, Colombia, Sept. 10 - 14, 2018: IEEE, 2018. Pp. 279-283 Doi: 10.1109/ICEAA.2018.8520371.

Natural Observatories for Lightning Research in Colombia

Daniel Aranguren
Keraunos SAS, and
Research Group of Acquisition and Analysis of Signals - PAAS
National University of Colombia, and
Bogotá, Colombia
daranguren@keraunos.co

Jesus López
Lightning Research Group - LRG
Technical University of Catalonia
Terrassa (Barcelone), Spain
jesus.alberto.lopez@upc.edu

Joan Montanyà
Lightning Research Group - LRG
Technical University of Catalonia
Terrassa (Barcelone), Spain
montanya@ee.upc.edu

Horacio Torres
Keraunos SAS, and
Research Group of Acquisition and Analysis of Signals - PAAS
National University of Colombia, and
Bogotá, Colombia
htorress@keraunos.co

***Abstract*— This paper presents a selected, not exhaustive, description of lightning research in Colombia over time, based on natural observatories for experimentation and measurement; and introduces the DABEIBA Lightning Research Center as a new institutional cooperation to concentrate several instruments such as Lightning Mapping Array - LMA, high speed cameras, high energy detectors, by different scientific parties in a single area for tropical lightning research.**

Keywords—Lightning research center, tropical zone

I. Introduction

Systematic experimental lightning research works have been carried out in Colombia since the 80s, involving many types of techniques and instruments, from the first low frequency lightning counters (called RSA-10) [1-2] to the most recent high frequency lightning mapping arrays (called LMA) [3]. The entire long list of contributions cannot be described in detail, but beyond that, this paper focuses on some research efforts made to implement natural laboratories in very especial locations in the heart of some of the most lightning active areas in the world, where several instruments were arranged to measure both physical lightning parameters and lightning-caused effects on sensitive systems such as electric ones.

Nowadays, a new experimental observatory is developed in Colombia, based on contributions from national and international research institutions that allowed conforming the DABEIBA Lightning Research Center, where an important set of specialized equipment such as Lightning Mapping Array – LMA, high-energy detectors, electric field mills, high speed and sensitive cameras, and many others are deployed.

II. Background

Measurements of lightning induced voltages and currents were initially developed in experimental medium voltage systems in order to find explanations for the extremely high failure rates of power distribution transformers in several rural areas [5-9]. Outstanding research measurement deployments are described in Fig. 1. Improved prototypes of distribution transformers were produced as a result of the first long-term measurement and observation campaigns on real networks in 1997. High voltage transient meters were installed along overhead medium voltage networks during different campaigns starting in 1999, 2002 and 2006 at different locations [6, 7-9]. A 60m-height instrumented tower (35m-height in an initial stage) was deployed in 1998 in one of the highest lightning active area in Colombia; plate antennas and various other instruments were used as a complement of direct measurements. Local electric field mill networks have been used in natural laboratories since 2006. Unfortunately, most of those research facilities were interrupted due to funding limitations, and political and social factors; however, some statistically representative measurements were provided by induced overvoltage meters and others.

III. First Deployments: Experiments with Power Distribution Transformers

Since 1989, the research group PAAS of the National University of Colombia focused its efforts on finding solutions for the high mortality of power distribution transformers due to lightning in Colombia (official figures show an annual rate around 25.000 destroyed transformers) [1]. An integral analysis that includes the environment, the transformer modeling (the high frequency behavior), the installation and transportation conditions, among many others, was realized.

In 1997 an experimental medium voltage circuit, in a rural area where the mean life cycle of power transformers was 2.5 years, was used to install 14 improved power transformers with structural changes in its internal construction in order to control the lightning transferred pulses from the high to the low voltage side and increase its insulation level (BIL – Basic Insulation Level). The improved construction was designed by the PAAS group and the transformer prototypes were built by the company SIEMENS [1-2]. This initial test deployment is shown in Fig. 1 in the location Topaipí, where the Ground Flash Density - GFD is close to 30 flashes/km^{2}year. After four years, the lightning location system that was operating at that time (based on LPATS technology) detected more than 130 CG flashes at distances closer than 100 m to the experimental system and only two failure cases were reported.

This initial experience was used to develop other experimental systems, such as in Samaná in 1999 (Fig. 1) where 15 new prototypes of power transformers were tested in a real medium voltage overhead system, under a regime of

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GFD around 55 flashes/km^{2}year. In all cases, the life cycles were extended to more than 8 years. More details about the modeling, new designs, and experiments are given by Torres [1-2].

IV. Contributions on Lightning Measurements

A. Experience with instrumented towers

In 1998, Torres [1-2, 5] installed a 35-m instrumented tower in Samaná (Fig. 1), called Ilyapa, with several current sensors in the bottom. The expected number of direct strikes on the tower was 1.3 per year, taking into account the general Ground Stroke Density - GSD provided by the LLS at that time (the Detection Efficiency was probably lower than 50% as described by Torres [2]), computed on wide calculation grids for the neighboring area, around 35 strokes/km^{2}year (recent data suggest that the real GFD in this area is higher than 45 flashes/km^{2}year as described in Fig. 1). Few years later the tower was moved to Puerto Berrio (Fig. 1) and increased in height up to 60 m. Data of today shows that the GFD is around 37 flashes/km^{2}year in this area. Fig 2 gives an example of a direct current measurement in 2002. Some lightning current signals, as reported by Torres et al [11], were possible in the period before 2005 when the measurement program was stopped, unfortunately not enough to be considered as statistically representative.

The more precise and efficient LLSs of today allow observing more specific local lightning hotspots, even inside one of the highest lightning hotspots in the world as Samaná (it was recently identified by Albrech et al [12] based on the historical detection data provided by the satellite detector LIS). Some recent analyses show that high lightning active areas in Colombia expose also an inhomogeneous behavior of GFD, as smaller computation grids are used. The Ilyapa instrumented tower was located in a very high lightning active area but not necessarily matching a local lightning hotspot. Additionally, the high altitudes of cloud charge centers in the tropics, as recently presented by Lopez et al [13] using a LMA network in Colombia, produces that tall structures do not interact with cloud charges as in high latitudes, where upward lightning is usual. Therefore, the real expected number of direct strikes could be very different to the initial estimated.

Current research is focused on finding local hotspots inside very lightning active areas in Colombia, where existing towers with demonstrated high direct lightning strike rate could be instrumented, in order to continue the measurement program started with the Ilyapa station.

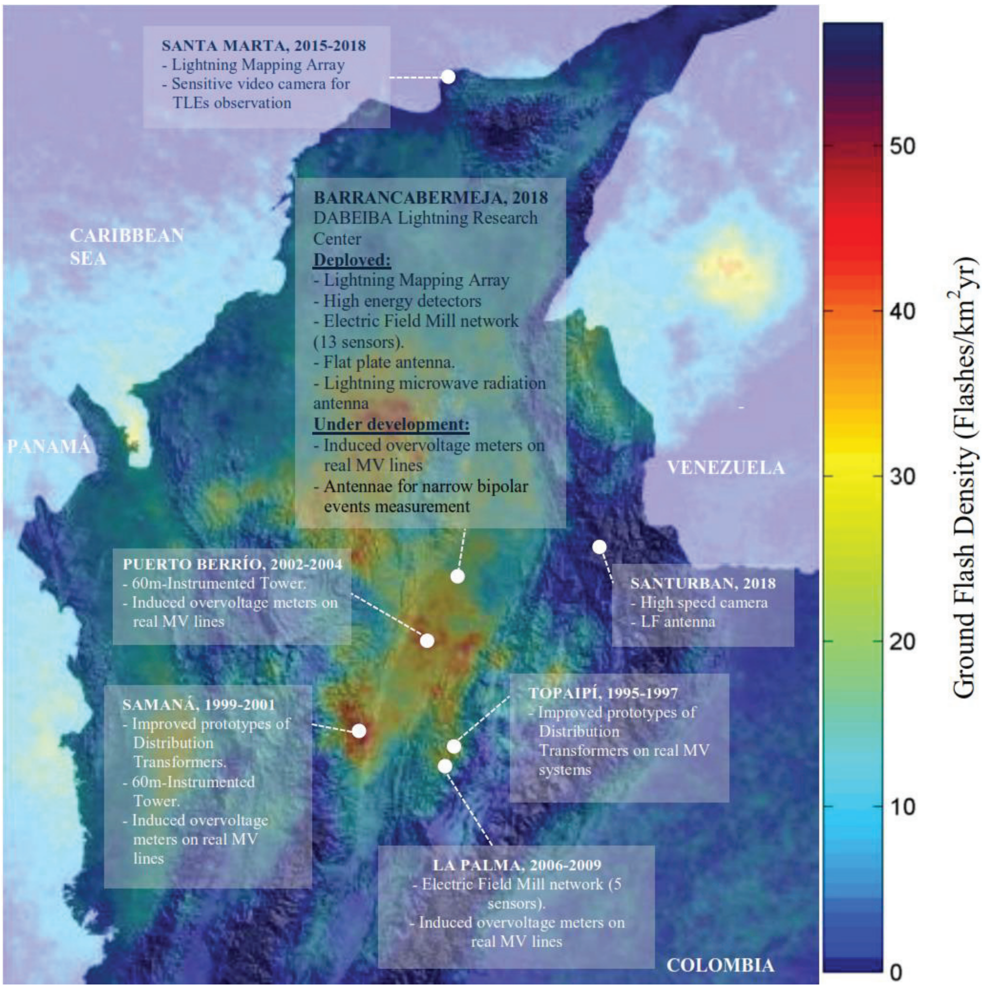

Fig. 1. Measurement instrument deployments in Colombia as natural lightning laborabatories

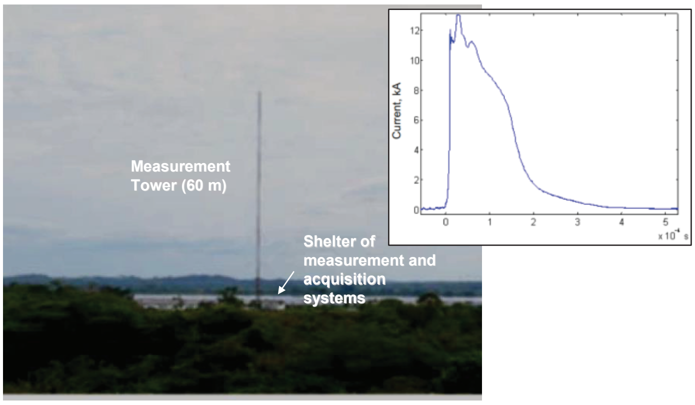

Fig. 2. Measurement instrument deployments in Colombia as natural lightning laborabatories

B. *Measurement of lightning induced overvoltages*

Theoretical studies on lightning induced overvoltages were started in Colombia in 1999 [14]. A first experimental deployment was carried out in 2000 by Salgado [15], who built and installed three transient overvoltage meters in a 200-km real medium voltage network in Samaná (Fig. 1). More than 200 lightning induced overvoltages were simultaneously measured at the three points in this campaign [15-16]. In 2005, improved measurement systems were installed in Puerto Berrio (Fig. 1) on a short overhead medium voltage network, right next to the Ilyapa instrumented tower. The design and deployment of those instruments were carried out by Perez [10] as the experimental validation for computational models later introduced in specialized software. The last experimental lightning induced overvoltage measurements were carried out in La Palma (Fig. 1) in 2008. In this case, five measurement stations, as shown in Fig. 3, were installed along a 260-km rural distribution system. Results are presented by Aranguren et al [8]. Measured lightning induced overvoltages in the last three experiments are not directly comparable due to the used overhead electric systems are different. Conclusive results from the experiment in La Palma (Aranguren et al [8]) show that the mean amplitude of the induced transients was 37 kV at the medium voltage level and 55 kV in the low voltage one, in addition, the mean duration of the electromagnetic transients were around 400 µs, with maximum values up to 700 µs.

The knowledge developed in the described experiments have contributed to program specialized simulation tools, which are used today for studying the reliability levels of large power distribution systems in the order of thousands of kilometers of length (Perez et al. [17]).

Overvoltage measurement connection

Overvoltage measurement components

Fig. 3. Measurement system of ligtning induced overvoltages

C. *Measurement of atmospheric electrostatic field*

Some deployments of electric field mills were developed for experimental campaigns in Bogotá (2004), Bogotá, Medellín and Manizales (2006), La Palma (2006), and others. Electric field mills in La Palma (Fig. 1) were located right in the area where lightning induced overvoltage meters have been installed. All used devices were based on the prototype built by Aranguren in 2004 and its improvements in the following years [18]. Based on these systems Aranguren et al [19, 20] studied the electrical structures of thunderstorms. A bipolar charge solution was found in Bogotá using storm episodes in 2010 with a first charge of -22 C at 5.86 km height and a second charge of 6.8 C at 3.76 km height (respecting local altitude: 2,555 MSL). Similar analyses at lower altitude areas, as La Palma, confirmed that the main negative charges are located at altitudes of 8.5 km or more. Effects of orography were also investigated.

Electric field mills in La Palma coordinated with lightning location data and induced overvoltage measurements were used to study the thunderstorm severity related to power outages [8, 9]. Described research evolved to adapted thunderstorm warning systems which are currently used in several industrial applications.

V. DABEIBA LIGHTNING RESEARCH CENTER

In 2015 a scientific cooperation coordinated by Technical University of Catalonia – UPC, Keraunos SAS (spin-off company linked to the National University of Colombia), and University of Magdalena, installed the first Lightning Mapping Array - LMA network in the tropics. This system was implemented with the main object to contribute to the European ASIM project [4]. The COLLMA network is composed by six VHF detectors with a baseline from 5 to 20 km. The area of interest covered a small littoral zone of the Caribbean Sea, the Santa Marta city and the western foothills of the Sierra Nevada de Santa Marta mountain, the highest coastline mountain in the world. Fig. 4 gives an example of lightning leader mapping in a period of 10 minutes when at least five Cloud-to-Ground flashes are identified. CG detection provided by the Colombian Total Lightning Detection System - CTLDS [21] (give as X in Fig. 4) exposed a very good correlation in space and time. As shown in Fig. 4 the emissions are detected at altitudes up to 15 km. Continuous measurements from 2015 to 2018 allowed checking that lightning leaders reach high altitudes in tropical thunderstorms favoring the production of Transient Gamma Flashes – TGF [4].

The positive experience in Santa Marta encourages to re-locate the LMA to a higher lighting density area in Colombia. It was moved in 2018 to Barrancabermeja (Fig. 1), where severe thunderstorms are common during most of the year and several other instruments are available such as a 13-sensors electric field mill network, a meteorological radar, and others. The GFD in this area is around 30 flashes/km^{2}year. Fig. 5 illustrate the location of electric field mills, LMA antennae, a LINET antenna of the CTLDS and, the meteorological radar. Other experimental instruments as a high energy detector, and microwave and flat antennae were installed in Barrancabermeja (in the Industrial University of Santander - UIS).

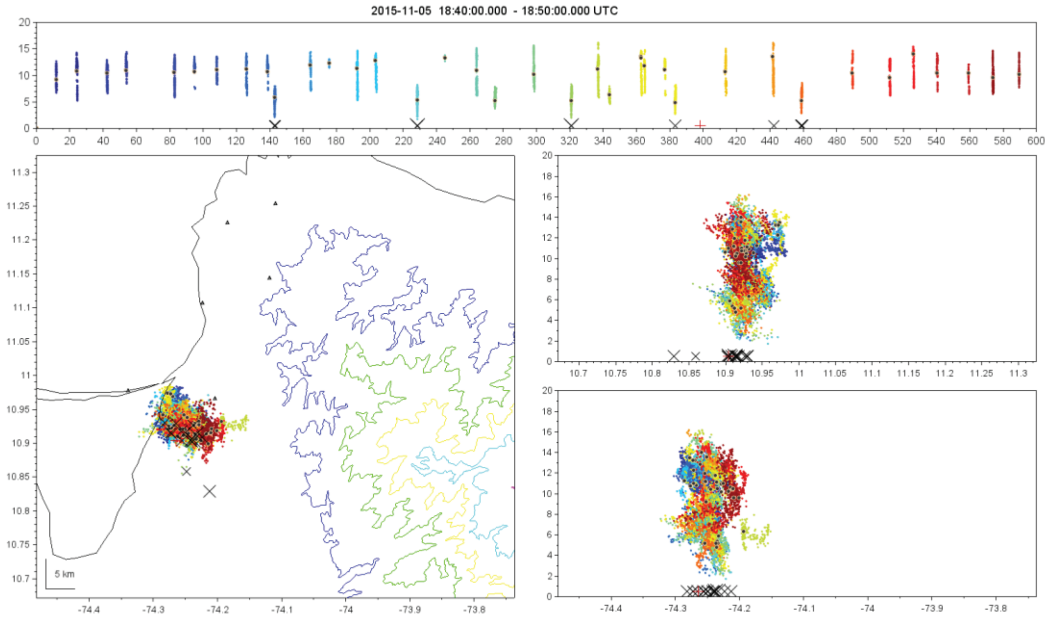

Fig. 4. LMA record in Santa Marta on November 5 2015. Emissions related to Intracloud and Cloud-to-Ground activity in a 10 min period. The X show Cloud-to-Ground stroke detections provided by the Colombian Total Lightning Detection System (Based on LINET technology)

Last deployment includes an optical observation set up in San Turban Mountain, at an altitude higher than 3500 MSL (Fig. 1). It is a strategical location chosen for its sky quality, its altitude and the distance to the LMA network. Observing Transient Luminous Events – TLEs is the main expectation.

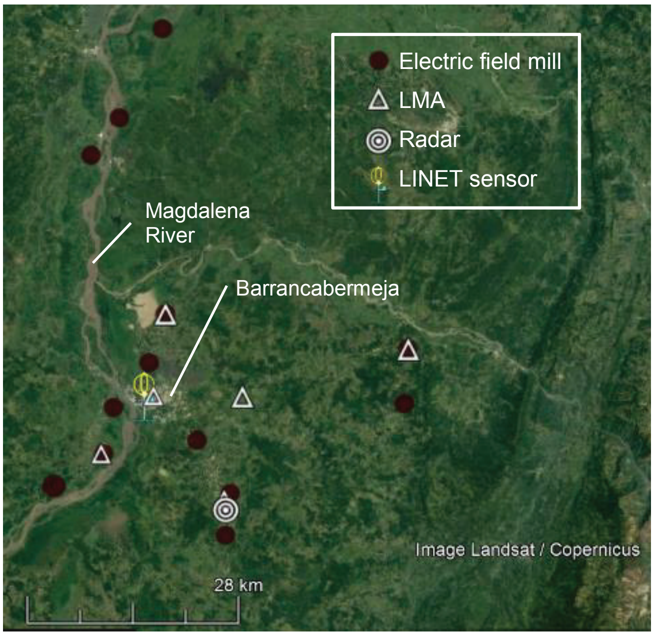

Fig. 5. Dabeiba Lightning Reasearch Center

The described implementation of lightning measurement instruments has been called Dabeiba (inspired in the Dabeiba goodness of the Katia indigenous culture), and it is expected that most of the measurement developments started in previous natural laboratories in other places of Colombia could be continued in this new area. Analyses of local lightning hotspots inside Dabeiba have allowed identifying existing tall objects (telecom towers), where lighting direct measurement is viable. In addition, throughout this area there is a large overhead power electric system of more than 600 km that supplies very sensitive industrial loads (oil industry), where lightning-caused disturbances produce a very significant operative effect

VI. Conclusions

Some of the most relevant experimental efforts carried out in Colombia for lightning research over natural laboratories has been presented. Many other measurements for a wide number of lightning-related objects, not discussed here, have been developed in Colombia by several scientists, however, this paper focuses on the historical experimental facts that lead to the implementation of the Dabeiba Lightning Research Center.

The first experimental studies conducted to find solutions for a critical problem of damages of power distribution transformers motivated the deployment of more specialized and complex measurements in instrumented tall towers and instrumented overhead power lines. Founding limitations and other local factors did not allow conducting long-term experiments and relative short and medium periods of measurements were finally available. The number of experimental deployments in very high lightning active areas is notable.

In order to study the electrical and physical structures of thunderstorms in tropical areas, which can be related to the production of TLEs and TGFs, the first LMA in a tropical region was deployed. The first detections confirmed the recurrence of thunderclouds of greater vertical development.

The Dabeiba Lightning Research Center was planned and arranged to host the LMA system and coordinate its measurements with complementary information from the CTLDS, electric field mills, radar and others. Several topics about lightning such as the behavior of CG strikes on tall structures, the effects on power distribution systems, the behavior of severe storms and many others are now under development.

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