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BrasilDAT$_{Dataset}$: COMBINING DATA FROM DIFFERENT LIGHTNING LOCATING SYSTEMS TO OBTAIN MORE PRECISE LIGHTNING INFORMATION

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***Abstract*— Lightning locating systems (LLS) operating in VLF-LF and VLF frequency ranges have been operating in Brazil for many years. In the last seven years we have compared data of three different systems for events where we have some independent lightning information. We found that an adequate combination of all data in a unique dataset provide more reliable information than the data of each network separately. We call this dataset BrasilDAT Dataset. Examples of use of BrasilDAT Dataset in the analysis of lightning striking a power line, an instrumented tower, a building and persons will be presented.**

Keywords—lightning location systems; lightning in Brazil

I. INTRODUCTION

Brazil is the largest tropical country of the World and, as a direct consequence, has the largest absolute incidence of cloud-to-ground flashes estimated in about 50 to 100 million flashes per year. This huge number of flashes is responsible for more than one billion dollar of damage to properties and systems and more than 100 fatalities every year. In spite of this reality, lightning research in Brazil begun only at the end of the 1970s in the Brazilian Institute of Space Research (INPE). This research led the creation of the Atmospheric Electricity Group (ELAT) at INPE in 1987 [Pinto, 2009]. More details about the history of this research along the last 40 years can be found elsewhere [Pinto and Pinto, 2017].

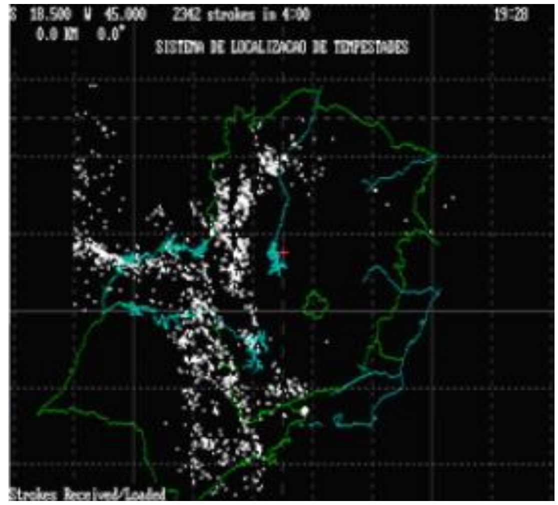
Lightning locating systems (LLS) operating in VLF-LF frequency range have been operating in Brazil in the last 30 years. The first system was deployed in November of 1988 by the CEMIG power company. The system, acquired from an American company called ARSI, was called Thunderstorm Location System (TLS) and it was composed by four LF LPATS-3 sensors installed in the state of Minas Gerais and communicating to a central processor through a satellite link. For the first time it was possible to see in a screen where lightning was occurring in Brazil in real time. Tens of thousands of flashes were recorded in several days during the summer of 1999. At that time we do not have an idea of how many flashes occur in Brazil every year and what was the actual area monitored by the system. To answer these questions we realize that we need to compare TLS data with other independent source of lightning data. At first, we tried to compare TLS data with the observations at the instrumented tower located at the Morro do Cachimbo station, almost in the center of the area were the LPATS-3 sensors were installed. The comparison, however, was found to be very difficult because only a few flashes strike the tower every year and the time of the occurrence of the flashes were not synchronized with the TLS time system. The solution was search for other source of data. As a result, in the spring of 1989 we compare TLS data with observations made by electric field sensors on board stratospheric balloons flying above the thunderstorms using the GPS system which, at that time, was already in use by the TLS. We found that TLS detected only 50% of the flashes in the South region of the state of Minas Gerais and less than 10% of the flashes in the border of the Minas Gerais state with the state of São Paulo. This result encourages CEMIG to install two more sensors in 1992 and cooperates with the Brazilian Institute of Space Research (INPE) to install one more sensor in the state of São Paulo in 1997. In 1999, two other institutions (Furnas and Simepar) installed sensors in other two states (Rio de Janeiro and Paraná) forming the first national network, now known as National Integrated Lightning Detection Network (RINDAT). In 2004 the first VLF LLS with sensors installed in Brazil and other countries in South America provided lightning location data. In 2011 other VLF-LF system called Brazilian Lightning Detection Network

(BrasilDAT) was deployed in Brazil operated by INPE. BrasilDAT provides also intracloud data and extending the coverage area of RINDAT. In the last seven years we have compared data of the three systems for events where we have some independent lightning information. We found that an adequate combination of all data in a unique dataset provide more reliable information that the data of each network separately. We call this dataset BrasilDAT Dataset. Examples of use of BrasilDAT Dataset data in the analysis of lightning striking a power line, an instrumented tower, a building and persons will be presented.

II. THE BEGINNING OF LIGHTNING LOCATING SYSTEMS IN BRAZI AND THE ORIGIN OF BRASILDAT DATASET

In November 1988, the CEMIG Power Company deployed a Lightning Locating Systems (LLS) in the VLF-LF frequency range to monitor lightning in real time. The system, acquired from an American company called ARSI, was called Thunderstorm Location System (TLS) and it was composed by four LPATS-3 sensors installed in the state of Minas Gerais and communicating to a central processor through a satellite link. For the first time we saw in a screen using software called VIS (installed in a microcomputer using the DOS operational system) where lightning was occurring in almost real time. Tens of thousands of flashes were recorded in several days during the summer of 1989 (see Fig. 1). At that time, however, we do not have an idea of how many flashes occur in Brazil every year and what was the actual area monitored by the system. To answer these questions we realize that we need to compare TLS data with other independent source of lightning data. At first, we tried to compare TLS data with the observations at a 60-m instrumented tower located at the Morro do Cachimbo station, almost in the center of the area were the LPATS-3 sensors were installed (see Fig. 2).

(a)



(b)

Fig. 1. (a) LPATS-3 sensors and (b) the first screen with almost real time lightning locations..

The comparison, however, was found to be very difficult because only a few flashes strike the tower every year and the time of the occurrence of the flashes recorded in the station were not synchronized with the TLS time system. The solution was, then, to compare the lightning data with the electric field data on stratospheric balloons that fly above the thunderstorms and recording flashes along their trajectories. In 1989 and 1990 we launched several balloons and comparing the data we found that TLS detected only 50% of the flashes in the south part of the state of Minas Gerais and less than 10% of the flashes in the border of the state with the state of São Paulo.

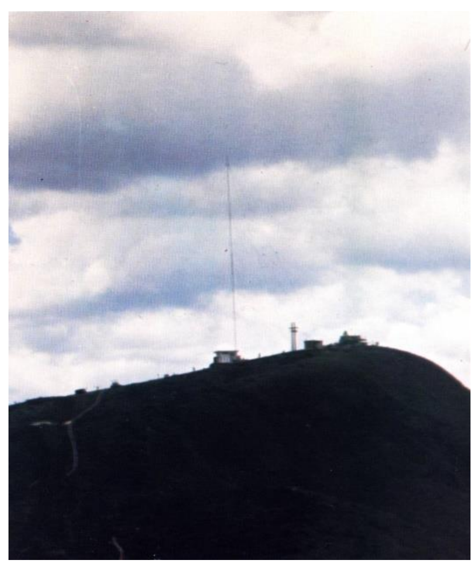


Fig. 2. Instrumented tower at the Morro do Cachimbo Station.

This result encourages the company to install two more sensors in 1996, At that time a new sensor called IMPACT was acquired. Differently of the LPATS sensor it detects both the electric and magnetic field components of the lightning radiation. In 1997, one additional sensor was installed by INPE in the state of São Paulo (see Fig. 3) and six sensors were installed in the state of Paraná. The information get by the sensors now are running in a new operational system called Solaris and we can see the flashes in a much better screen resolution (Fig 4).

Fig. 3. IMPACT sensor installed in Cachoeira Palista, state of São Paulo in 1997.

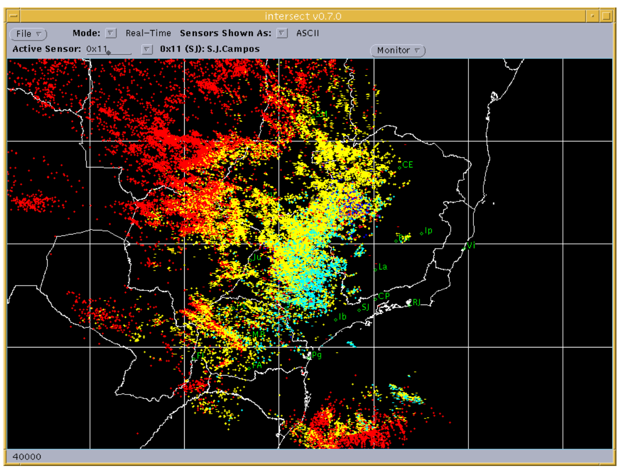


Fig. 4. Lightning in real time in a much better screen resolution of a worstation.

In 1998, Furnas Centrais Elétricas begun to install more sensors in the states of Rio de Janeiro, Paraná, Espírito Santo and São Paulo forming the first national network, now known as National Integrated Lightning Detection Network (RINDAT). Fig. 5 shows the evolution of the number of sensors of RINDAT from 1988 to 1998, when it was composed by 20 sensors.

With the emergence of RINDAT in 1998 two other activities with the goal to validate the LLS data were developed in Brazil. One activity was the beginning of rocket triggered lightning observations in a site located inside INPE in Cachoeira Paulista, state of São Paulo in 1999. Fig. 6 shows the platform to launch the rockets and the first triggered lightning using the altitude method in November 1999. The observations allow to estimate the errors in the peak current estimates by RINDAT, as well as to verify the location accuracy. The observations end in 2007, after trigger more than 30 flashes. The other activity was lightning observations by high speed cameras. High speed camera observations begun in 2000 motivated by the possibility to record triggered flashes and are still in use to record downward and upward natural flashes. However, very soon we realize that we can record natural flashes and install a camera in an observatory in São José dos Campos (see Fig. 7). At present time we recorded more than 3000 natural flashes and can use these observations to estimate the real detection efficiency and location accuracy of the lightning location system. Beginning in 2012 more than 150 upward flashes have been recorded by the high speed cameras in the city of São Paulo and the observations have also been used for the same purpose.

In 2004 we begin the lightning detection and location using a VLF LLS with a installation of a VLF sensor in the INPE facilities in São José dos Campos, state of São Paulo, as part of a VLF LLS called World Wide Lightning Detection Network (WWLLN) (see Fig. 8). At present time the WWLLN has 10 sensors installed in South America. Considering that this system record the sky wave instead the ground wave recorded by VLF-LF LLS, the sensors triangulate at thousands of kilometers range instead of hundreds of kilometers in the case of VLF-LF systems. The lower number of sensors necessary to cover a given region, however, has as a consequence lower detection efficiency and location accuracy.

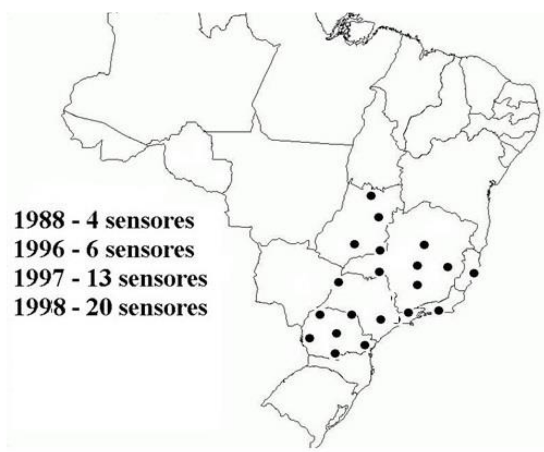


Fig. 5. RINDAT sensors from 1988 to 1998.

(a)

(b)

Fig. 6. (a) Triggered lightning facility in Cachoeira Paulista, state of São Paulo, and (b) the first triggered lightning in Brazil in November 1999.

(a)

(b)

Fig. 7. (a) First speed camera used to recorded lightning flashes in Brazil with a 3000 fps and (b) the tower were the camera made most observations since 2000.

Fig. 8. Sensor of the VLF WWLLN.

In 2011 we began to detect intracloud flashes using other technology. Fig. 9 shows one sensor of this technology. Then, we create a new VLF-LF LLS called Brazilian Lightning

Detection System (BrasilDAT). Differently of RINDAT, BrasilDAT is operated exclusively by ELAT/INPE.

Fig. 9. Sensor to detect intracloud flashes from BrasilDAT.

After using data from the three different technologies for six years (2011 to 2017), we realize that all systems measured part of the flashes that really happens and in most cases they are complementary each other. Motivate by this finding we decide to join data from the three different technologies in just one dataset, following some specific criteria. This dataset is called BrasilDAT Dataset. It combines data from more than 110 sensors. The stroke data are combined using a grouping method based on some criteria which involves time-of-event, location uncertainty, stroke type and peak current. Strokes with time differences lower than a pre-defined Δt are considered the same stroke if your location error overlap. The location error of VLF LLS is considered dependent on the number of sensors involved in the solution. The value of Δt is different when compare two VLF-LF LLS and when compare a VLF-LF LLS with a VLF LLS. It is assumed that VLF LLS detected only clod-to-ground strokes and that VLF-LF LLS detected cloud-to-ground strokes above a peak current threshold. Also, if one network classified the stroke as cloud-to-ground stroke it is assumed that it is a cloud-to-ground stroke. Finally, peak currents are averaged if both VLF-LF LLS detected the stroke or is considered the VLF-LF LLS value in the case the stroke is detected by one VLF-LF LLS and by the VLF LLS. If only VLF LLS detected the stroke the peak current is estimated based on a relation (spatial-dependent) with the number of sensors involved in the solution. Afterwards we describe the BrasilDAT Dataset data for a few lightning-related events.

Some examples of application of BrasilDAT Dataset are as follow:

- In 25 February 2015 a four-stroke flash struck the 60-m tower in the Cachimbo station in Belo Horizonte, Southeast Brazil. One network detected two stokes striking the tower; one network detected a stroke near the tower; and the other network did not detect any stroke at the time of the struck recorded by the tower instruments. Peak currents estimated had errors less than 20% compared with direct measurements.
- In 27 January 2016 a 7-stroke flash struck a lightning rod in the top of a 50-m common building in São Paulo. One network detected five strokes, one striking the building and four near the building; one network detected two strokes striking the building; and the other network detected one stroke near the building at the time the building was struck. Peak currents estimated had errors less than 20% compared with direct measurements.
- In 29 December 2014 four bathers were killed by lightning in a beach in the Southeast Brazil. Several witnesses saw a stroke striking water and others striking the beach sand. One network detected a stroke on the water; one network detected a stroke striking the beach sand; and the other network did not detect any stroke near the approximate time of the event.
- In 04 June 2017 one of the two shielding cable of 500 kV Blumenau - Campos Novos TL in the South of Brazil was disrupted. One network detected a stroke string the cable; one network detected 5 strokes near the cable; and the other network detected a stroke near the cable at the time of the disruption. It was probably a six-stroke flash.

After the analysis of a large number of events we found that this dataset can explain in details more than 90% of the lightning-related events like transmission line faults, lightning fatalities, lightning strikes to towers and buildings or lightning damages to property that happened in the last two years.

III. Conclusion

In this article we describe briefly the history of lightning detection and location in Brazil since 1998 up to 2018. We can say that along this time we learn a lot about lightning detection and location. One of the main knowledge that we learn is that there is no system that detect all flashes with their proper characteristics. All systems have limitations that in general are not easy to find in the literature, in part for commercial reasons. Based on this fact, the simultaneous use of data from different systems, combined properly based on independent validation studies, is the best way to have more precise lightning information.

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