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BASIC LIGHTNING FLASH PROPERTIES DERIVED FROM LIGHTNING MAPPING ARRAY DATA

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Abstract – The size and duration of lightning flashes are examined. Data from the Ebro Valley Laboratory Lightning Mapping Array is used as reference. Additional data from the VLF/LF LINET network is included. In the analysis, each flash is simplified by a confidence ellipse fitting most of the detected sources. The major axis of the ellipse is adopted as the flash length. Flash durations are computed too. The analysis of 778 flashes results in a median flash length of ~14 km with a median duration of ~0.3 s. The results presented, besides characterizing the storm activity, they can be useful to define stroke grouping criteria, lightning flash density calculations and lightning warning purposes.

1 - INTRODUCTION

Lightning is characterized by a large number of parameters. Most of these parameters have been obtained remotely by the measurement of associate electromagnetic fields, optically and directly by means instrumented towers and rockets. Despite of the efforts to provide statistics of lightning parameters for many decades, technological improvements can still help to provide and update most of them.

Two basic parameters as flash duration and size are addressed in this paper. Flash durations were treated by Brook and Kitagawa [1] by means of electric field measurements. In their work the total duration was defined as 'the time interval between the first burst of pulse activity and the last detectable R- or K-change pulse'. The analysis of 784 dischargers revealed a median duration of 0.5 s which was twice as large as the durations given by Bruce and Golde [2], Schonland [3] and Pierce [4]. Later Ogawa and Brook [5] also found an average duration of 0.5 s for cloud flashes.

Recently three-dimensional lightning mapping systems have been used to calculate the total length of lightning channels in order to estimate NOx per flash and other lightning properties [6-7].

There are some fields in which knowing the flash size and duration is very useful. For example, in lightning protection applications, lightning flash characteristics are necessary when addressing risk assessment. Lightning flash data is generally obtained by operational lightning location systems. Those systems mainly detect cloud-to-ground (CG) strokes. In order to determine flash properties and to obtain lightning flash densities, the strokes need to be grouped into flashes. The grouping of strokes is based on a space-time criterion [8]. To do so, flash size and duration must be known. On the other hand, many procedures of lightning warning use the lightning distance as part of alarm decision [9]. In such case it is important to know how large lightning flashes are.

In this paper we present the statistics of flash duration and size computed from the detections by the Lightning Mapping Array operating in the Ebro Valley Laboratory (north east of Spain). Moreover, the same analysis is done for the detections of the VLF/LF LINET network data.

2 - DATA

In 2011 a Lightning Mapping Array (LMA) system [10-11] was deployed at the area of the Ebro Valley Laboratory in the North East of Spain. The arrival times of impulsive radiation events in the 60–66 MHz VHF band are measured at six to twelve ground-based stations and are used to determine the development of individual lightning discharges in three-dimensional space and time. Differences in the radiation and propagation characteristics of negative and positive breakdown are used to determine the polarity of the lightning channels [10] and to infer the charge structure [12]. The same area is covered by the European VLF/LF lightning detection network LINET [13]. This network provides CG stroke locations and intracloud (IC) emissions in VLF/LF. The IC detections are located in altitude too. Figure 1 shows and example of the combined LMA and LINET data of an individual flash.

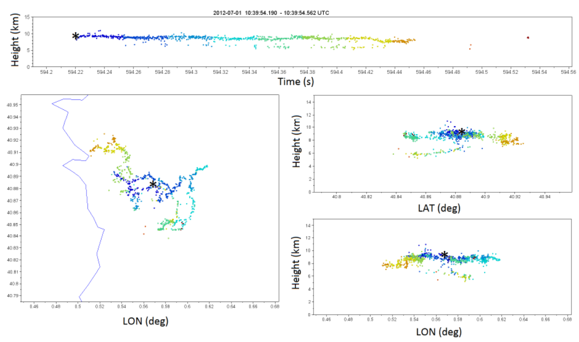

Figure 1- Example of an IC flash. Top: Height vs. time; Bot: side and top projections. Detections are colored by time. LINET detections are represented by ∗.

3 – FLASH COMPUTATION

Lightning flashes can show very complex leader structures. In addition, the LMA data can be noisy too. Then, to compute automatically the total size of a data large sample can be tedious. A simple procedure to compute the size of a flash is presented in this paper. The method fits the LMA sources of each individual flash into an ellipse. As a result, the flash can be described using three simple parameters: major axis, minor axis and inclination of the ellipse. Figure 2 shows an example.

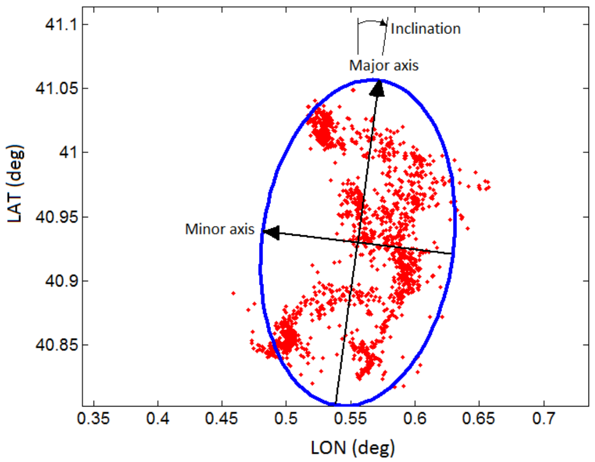

Figure 2- Flash fitted to an ellipse. The three parameters that defines the ellipse are indicated.

The ellipse represents a confidence region defined by certain standard deviation. By setting properly the standard deviation, the confidence ellipse will enclose most of the LMA sources that forms the flash structure while scattered noisy sources will have less influence in the fitting. Figure 3 displays the same flash fitted by ellipses with 1.5 and 2 standard deviations.

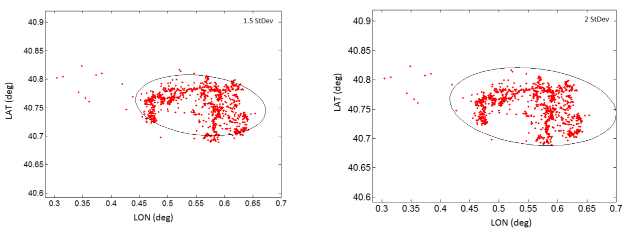

Figure 3- Ellipse fitting data containing 1.5 standard deviations (left) and 2 standard deviations (right).

The same procedure as described above has been applied to LINET detections of individual flashes. Figure 4 plots a flash with LMA and LINET detections and their fittings.

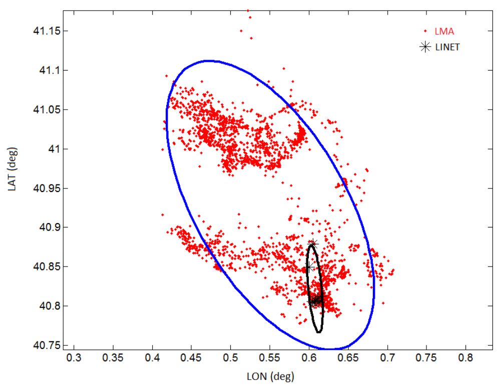

Figure 4- LMA and LINET detections and their fitted ellipses with a standard deviation of 1.5.

While the procedure has been automatized; in this work each fitted flash has been manually validated in order to reject uncertain cases.

4 – RESULTS

Firstly, the spatial extension of lightning flashes is estimated by the distribution of the lengths of the major axis of the ellipses. Figure 5 presents the distribution of a 778 flashes during two storms passing over the LMA network.

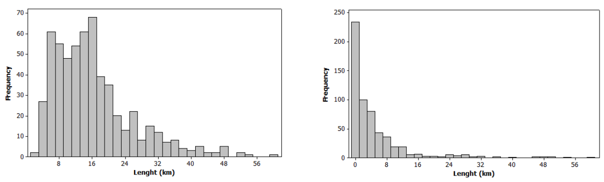

Figure 5- Distributions of flash lengths with LMA sources (left) and LINET detections (right).

The flash length distribution by means of the LMA data presents a median of ~14 km whereas by the computation of LINET it results in ~2.2 km.

Secondly, the shape of the lightning flash can be analyzed by means of the distribution of the major axis to minor axis ratio. Figure 6 plots the distribution for the LMA flashes.

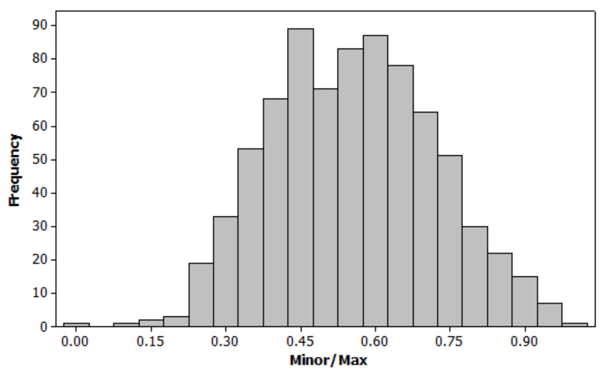

Figure 6- Distribution of the minor/major axis ratio for the LMA flashes.

The ratio of minor to major axis has a median of 0.55, indicating that lightning flashes are typically described by an ellipse with its major axis doubling its minor axis.

Thirdly, flash durations are easily estimated by computing the time differences between the first and the last detections of the flash. Figure 7 depicts the distributions of the flash durations obtained.

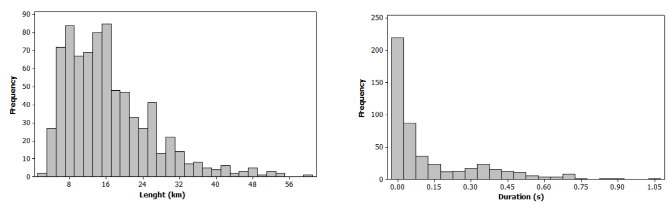

Figure 7- Flash durations according to LMA (left) and LINET (right).

The median and mean of the durations for the LMA flashes are 0.33 s and 0.37 s, respectively. In the case of

LINET, the median and mean durations are 35 ms and 0.13 s, respectively.

It is worthy to plot the flash length versus duration. Figure 8 displays the LMA flash length versus the duration.

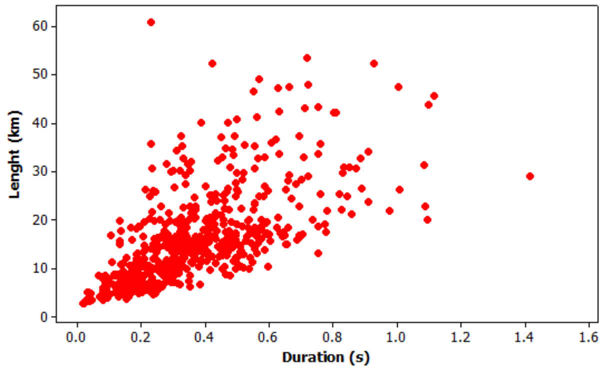

Figure 8- LMA flash length versus duration.

Finally, figure 9 displays the vertical extension of the analyzed flashes. The vertical extension here is the distance between the groups of the 10 % highest sources and the 10 % lowest.

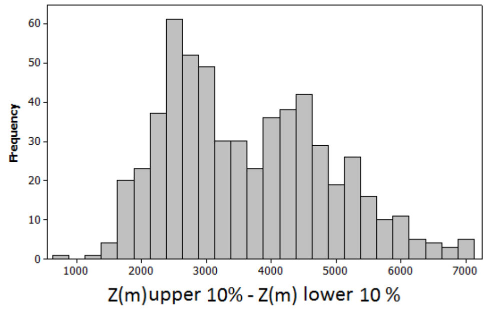

Figure 9- Vertical distribution of the flashes. The height corresponds to the difference between the average altitude of the 10 % highest and the 10 % lowest.

5 – DISCUSSION

Median length of lightning flashes computed by LMA data resulted in ~14 km with maximum cases above 50 km whereas the median length by LINET is much shorter (~2.2 km). However it is interesting to see how in this case the maximum lengths are similar and higher than 50 km.

A similar behavior occurs with the durations, LMA median and average durations are much higher than in the case of LINET, but both present cases with maximum durations above 1 second. The differences between both networks are mainly due to the different lightning processes that each network detects. The LMA detections correspond to lightning leaders, specially those negative, whereas LINET detects CG and IC 'strokes'.

In order to provide more representative statistics, the sample must include as much as different storm types and conditions as possible. There are several factors that can determine the flash size and duration. In the same storm, flashes in the convective region tend to be more compact whereas flashes in stratiform areas can be very large. Dramatic differences between convective and stratiform flashes can appear in mesoscale convective systems (MCS). Then, it is desirable that the sample includes a representation of small convective storms, large storm systems and supercells. In addition the reduced range of detection of the LMA systems makes difficult to have all the storm life time in the range. So that is limited to a small set of cases.

The information presented here has several implications. First, the duration of the flashes and their size give information related to the storm activity and extension. It is shown in figure 8 how duration and size are related to each other. Second, the statistics of size and durations have implication in the calculation of lightning flash densities and stroke grouping criteria, as changing these parameters will have an effect on the number of flashes and consequently in the flash densities. Current criteria for grouping strokes are a maximum distance of 10 km between strokes, a maximum duration of 1 s and a maximum inter-stroke interval of 500 ms (e.g. [8]). The elementary parameters presented here can also help to decide a grid size when computing lightning flash densities. Finally, the statistical knowledge of flash size can be also used as reference for lightning warning purposes where the distance between lightning occurrence and the target to be warned provides some lead time for preventive actions and to recover the non-alarm status. The results indicate the convenience of combining lightning and radar data. As previously pointed in previous works [14], lightning in convective cells tend to be frequent and compact but contrary, lightning in stratiform regions can be very large but less frequent.

6 – CONCLUSIONS

In this paper elemental lightning flash characteristics like size and duration of a CG flash have been presented, based on data from modern lightning mapping systems. The analysis has been done using flash detections recorded by the Ebro Valley Lightning Mapping Array (LMA) and the VLF/LF European network LINET. The LMA provides a wide range of sources per flash that allows distinguishing the detailed flash structure. In order to simplify the flash geometry and reduce the effect of noise, confidence ellipses are proposed as a simple method to characterize the spatial extension of a flash. The same method has been applied to the LINET detections.

In this work, the results obtained from a sample of 778 flashes are presented. To sum up, the median length of a flash is about 14 km while its duration is 0.33 s. In the sample, the maximum flash length is over 50 km with maximum duration over 1 second. Even though these values do not correspond to an extensive analysis of data, they can be taken into account when strokes are grouped into flashes and lightning flash densities. That is the case when data from operational grade lightning location systems are used.

Future work will include radar data in order to check the relationship between size of flashes and the extensions of the radar reflectivity fields. Besides, time evolution of both can provide very valuable information for storm characterization and warning purposes. Moreover, CG and IC flashes will be distinguished in the analysis.

8 - REFERENCES

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