EARTH NETWORKS LIGHTNING NETWORK PERFORMANCE (Abstract 58)

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ABSTRACT

The Earth Networks Total Lightning Network (ENTLN) is a global lighting detection network that has been operational since 2009. The ENTLN sensors are broadband electric field sensors that detect both intra-cloud (IC) and cloud-to-ground (CG) flashes and provide timing, location, classification, and peak current measurements. ENTLN consists of roughly 1600 wideband sensors deployed globally. Since its initial deployment, several improvements were made over the years to enhance its performance and usability. Notable ones are the addition of many new sensors each year to improve detection efficiency and extend global coverage. Firmware improvements have also been made to further increase sensitivity. A multi-parameter algorithm was incorporated to enhance IC and CG classification. To validate these improvements, Earth Networks has sponsored several studies to provide valuable feedback on performance improvements. This presentation will highlight two such studies. The first was performed at the Lightning Observatory in Gainesville (LOG), Florida using a combination of high-speed cameras and electric field sensors. For the 608 flashes in this study, a flash detection efficiency (DE) of 99% was found. Also, 97% of the flashes classified as CG by ENTLN algorithms were confirmed as CG via the measurements at LOG. The second study was performed at Langmuir Laboratory in New Mexico. In this study, 546 flashes were analyzed from three separate storms and ENTLN data was compared to simultaneously acquired interferometer (INTF) and electric field change array data (LEFA). Results show a total DE of 97.5%. Ninety one percent of flashes categorized at CG by EN were suggested to be CG by correlation of the LEFA+INTF data. Where EN determined the flash to be IC, LEFA+INTF agreed in 84% of cases.

ACRONYMS AND SYMBOLS

CG: Cloud-to-ground
ENTLN: Earth Networks Total Lightning Network
IC: Intra-cloud
INTF: Broadband Lightning .Interferometer
LEFA: Langmuir Electric Field Array
LOG: Lightning Observatory in Gainesville

Introduction

Lightning data has become an integral part of weather observation and public safety, especially when it comes to nowcasting. The importance of lighting data is evidenced by the amount of effort that is going into location/observing systems, with ground networks continuously growing globally as well as with recently launched satellite lightning sensors. The ENTLN, a ground-based network, is continuously being enhanced to improve the performance of the system. In 2015, the processor was upgraded, which handles the time-of-arrival location and classification of lightning from the raw sensor data. One of the primary changes was to the classifier, which featured a new algorithm that uses multiple waveform parameters (e.g., rise-time, peak width) to distinguish between IC and CG flashes. The goal of this study is to highlight two studies that analyze the performance of the ENTLN.

Data

ENTLN

ENTLN continuously measures lightning stroke occurrence time, location, type (IC and CG), polarity, and peak current, at over 1,600 ground-based stations around the world. ENTLN is comprised of wideband sensors to detect and classify both IC and CG flashes (Ref. 2).

LOG

The LOG is a multi-sensor facility dedicated to lightning research. Used in this study are a high-speed video camera, electric field, and electric field change sensors as ground truth data. (Ref. 6).

LEFA

The LEFA is network of eight electric field change antennas that operate at low frequencies. These sensors sample at 50 kHz and have three channels with varying sensitivities, sensitive (S), medium (M), insensitive (I), which effectively improves the dynamic range of each sensor (Ref. 1).

INTF

The INTF consists of three broadband radio frequency antennas that operate between 20-80 MHz. The system directly samples RF at 180 million samples per second and uses cross-correlation techniques to map lightning in two dimensions. The high speed and large number of sources located makes INTFs effective at measuring both the negative and positive leader within a lightning flash, as well as fast processes like K-waves (Ref. 4, 7). While RF can be detected to several tens of kilometers, the best resolution is obtained for flashes within 20 km of the INTF. Withing this range, the detection efficiency of an INTF (much like an LMA) is effectively 100%.

Methods

In the first part of this paper, we highlight recent improvements to ENTLN as well as published results that quantify these improvements. A study performed in 2017 by Zhu et al [Ref. 6] looked at natural and triggered CG lighting around the Lightning Observatory in Gainsville (LOG). The goal of this study was to estimate the improvements from a processor upgrade that was released by Earth Networks in August of 2015. The data used to determine the truth set of CG flashes/strokes was a combination of electric field, electric field derivative, and high-speed video. High-speed video was used to observe the discharge directly and estimate a location. Electric field and and electric field derivative data then confirmed the timing and and polarity. A detection was defined to occur when there was an ENTLN flash/stroke within +/- 1 ms and if that ENTLN location was within 40 km from the LOG. A correct ENTLN classification meant the event was classified correctly as a CG with the same polarity as given by the electric field sensors.

The second study that this paper will discuss was performed at Langmuir Laboratories near Socorro, NM. In this study, data from the Langmuir INTF and LEFA were used to determine the detection efficiency and classification accuracy of ENTLN. Each of the ENTLN flashes were synchronized with LEFA data and INTF data. LEFA provided the direction of change of the electric field, its rate of change, and as well as particular characteristics of CG strokes (e.g. dI/dt component will tend to appear on more distant CGs, while nearby CGs will primarily show the ΔQ term (Ref. 5)). Corresponding INTF data was used to identify stepped leaders, as well as the elevation of the flash. Particular attention was paid to vertical stripes in INTF elevation vs. time images (these denote rapid elevation changes characteristic of K-leaders and dart leaders). If the vertical feature ends below 10 degrees elevation, it is considered a low elevation (and it is reasonably likely that the leader continued to ground). If all the points in a vertical line appear above 10 degrees, then it is considered that this represents an IC K-process. Also, in many cases the INTF shows more slowly descending leaders. Depending on final elevation these are classified as either CG stepped leaders or a purely IC process.

If the direction of change of the electric field that corresponds to the feature detected by ENTLN is the same for all stations, we refer to that as ”same polarity” changes, and these are an indicator that it was likely a CG flash since they do not exhibit a field reversal at increasing distances, unlike like IC flashes (Ref. 3). If at least one of the stations differs in the direction of change of the feature of interest to EN, we call this ”opposite polarity” and consider it an indicator of an IC flash.

Based on these considerations, six parameters were defined to systematize the determination by a human analyst on whether a given flash was an IC or CG: LEFA Polarity, LEFA Stepped leader, LEFA dI/dt component, E-field Slow Variation, INTF elevation, and INTF Leader. Human judgment based on data inspection assigned each of these parameters a zero if it was “CG-like” or a one if it was “IC-like”. An average of these parameter values allowed us to calculate an ”IC Tendency”. If the IC Tendency was greater than 0.5 the flash was classified as an IC, if the average was less than 0.5, it was classified as a CG. (Visual inspection of data by multiple analysts was used to verify that this numerical system reproduced judgment of expert analysts familiar with both LEFA and INTF measurements.)

Results

The results obtained in the Florida LOG study are summarized in Table 1. Both processors were applied to the same waveforms that occurred during the time of the 219 flashes and 608 strokes, and their outputs were then analyzed separately. They found that the classification accuracy (CA) from the new processor increased significantly, especially for strokes, while the DE remained high or improved. This shows that the new processor is an improvement over the old processor. It should be noted that the results in Table 1 apply to CG flashes and strokes only.

TABLE I. SUMMARY OF THE ENTLN PERFORMANCE CHARACTERISTICS EVALUATED USING

	P2014	*P2015*
Flash DE	99%	99%
Flash CA	91%	97%
Stroke DE	97%	96%
Stroke CA	68%	91%

In the Langmuir Laboratory study, a total of 546 flashes were analyzed, of which ENTLN detected 535 and 11 cases where the INTF detected lightning, but ENTLN did not. That results in a DE of 98% for total (IC+CG) lightning. The flashes missed by ENTLN were observed at the beginning and end of the 3 storms analyzed. In these cases, the electric field records were unusually featureless, which suggests why ENTLN did not detect anything. All of the missed events were IC flashes, resulting in an IC and CG DE of 97.7% and 100%, respectively. From the 535 flashes detected by ENTLN, 470 were classified by EN as IC from which 400 were classified correctly. (Correctly means consistent with the determination of “IC Tendency” from the LEFA+INTF analysis). The classification accuracy for IC flashes is 85%. Sixty-five of the flashes detected by ENTLN were classified as CG. Fifty-nine of them were classified correctly. The classification accuracy for CG flashes is 91%. The overall classification accuracy is 86%.

Next we present examples of three flashes within this study to provide a more detailed look at the analysis performed. The INTF azimuth and elevation vs time can be seen in Fig. 1 top and bottom panels, respectively, while the LEFA data is in the middle panel. The vertical lines illustrate the times of ENTLN detections, with solid lines being CGs and dotted being ICs. This ENTLN flash was recorded at 21:39:04.6 UTC and is classified as an IC. The IC tendency for this flash was 1, meaning for all the checks, it seems to be an IC flash. That is, the LEFA stations show opposite polarity (see Fig. 2), there is no evidence of a stepped leader or a dI/dt component visible in the LEFA data, and the INTF shows only high elevation sources and no leader to ground. Therefore data agrees with the classification of ENTLN as an IC.

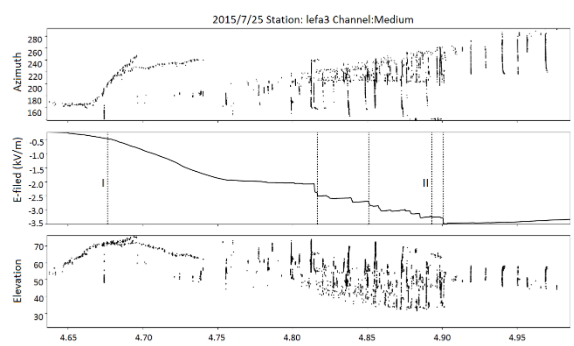

Fig. 1. Flash recorded at 21:39:04 UTC. The data results in an IC tendency of 1, which agrees with the ENTLN classification as an IC.

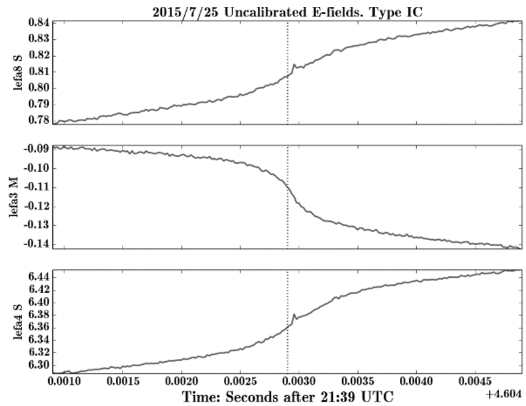

Fig. 2. Flash recorded at 21:39:04 UTC, zoomed view of event I. LEFA stations show opposite polarity, which implies an IC.

The second example is shown in Fig. 3. The IC tendency for this flash was 0, meaning for all the checks, it seems to be an CG flash. That is, the LEFA stations show the same polarity (see Fig. 2), there is evidence of a stepped leader (both LEFA3 and LEFA8) and a dI/dt component (LEFA8) visible in the LEFA data, and the INTF shows low elevation sources and a clear leader to ground. Therefore data agrees with the classification of ENTLN as a CG.

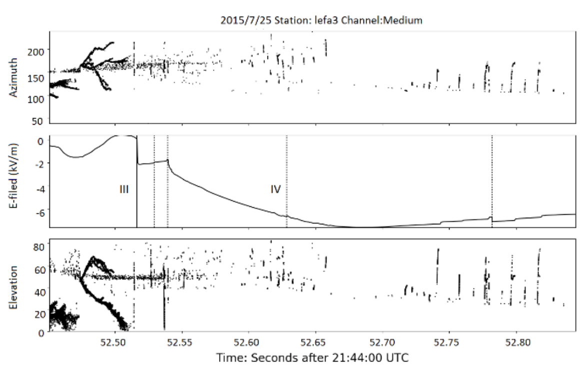

Fig. 3. Flash recorded at 21:44:52 UTC. The data results in an IC tendency of 0, which agrees with the ENTLN classification as a CG.

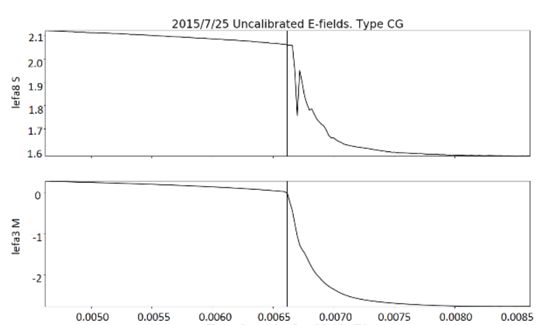

Fig. 4. Flash recorded at 21:44:52.5 UTC, zoomed in on event III. LEFA stations show the same polarity as well as a dI/dt signature (LEFA8), which implies a CG.

The final example is shown in Fig. 5 and was recorded at 23:08:06.5 UTC. This is an example of a flash that the ENTLN missed altogether. As is evidenced by the LEFA data, there is very little impulsive electrical activity, as well as no relatively fast charge motion, which would be seen as rapid elevation changes in the elevation vs time plot. This is a relatively uneventful IC flash occurring near the end of the storm, which explains why the ENTLN did not detect it.

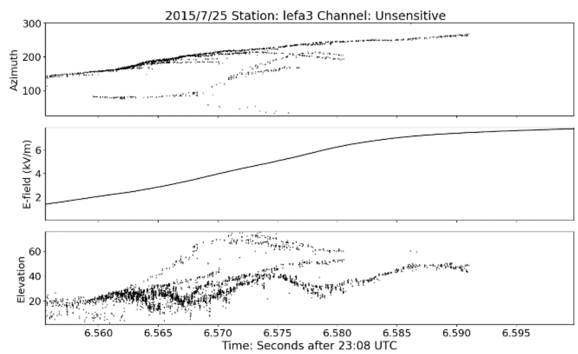

Fig. 5. Flash recorded at 23:08:06 UTC. There is no evident leader to ground and no dI/dt signature, suggesting this is an IC flash. There are no K-changes, suggesting why the ENTLN missed this flash.

CONCLUSIONS

The ENTLN network has recently undergone improvements to increase its accuracy and effectiveness globally. The goal of this paper is to quantitatively measure these improvements and provide a general overview of the networks current capabilities. Past studies as well as this study have shown that ENTLN has continued to improve over the years. Two studies were highlighted to quantify these improvements.

The first study, performed in Florida at the LOG, found a flash detection efficiency and CG classification accuracy of 99% and 97%, respectively. Specifically, the upgrade in the processor in 2015 significantly increases the CA of both flashes and strokes, while also slightly improving the DE.

The second study, performed at Langmuir Laboratory, found a total (IC+CG) flash detection efficiency of 98% and classification accuracy for IC and CG flashes of 85% and 91%, respectively.

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