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PERFORMANCE CHARACTERISTICS OF THREE DISTINCT LIGHTNING DETECTION NETWORKS COVERING BELGIUM

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ABSTRACT — In this paper, we report results from electric field measurements, coupled to high-speed camera observations to test the performance of lightning location networks in terms of its detection efficiency and location accuracy. The measurements were carried out during August 2011 in Belgium, during which 57 negative cloud-to-ground flashes, with a total of 210 strokes, were recorded. Data from the Belgian lightning network, the European Cooperation for Lightning Detection EUCLID and Vaisala's Global Lightning Detection network GLD360 are evaluated against this ground-truth data set.

1. INTRODUCTION

Lightning Location Systems (LLSs) are used for more than 20 years. These LLSs can use different types of sensors, e.g., SAFIR, IMPACT, LPATS, LS, or a combination of them; enabling the user to detect cloud-to-ground (CG) lightning and/or intracloud (IC) electrical activity. Depending on the available sensor information, either direction finding, a time-of-arrival (TOA) technique, or a combination of them can be used to process the raw sensor data into valid locations.

Various methods can be applied to investigate the performance of a lightning location network. For instance, lightning detections could be linked to outage reports of high-voltage transmission lines or damage/insurance claims (e.g., Diendorfer et al. 2003). In addition, data from different LLSs can be intercompared when having an over-lapping region in common (e.g., Poelman 2011). However, the most straightforward way to determine the performance of a LLS is through the use of ground-truth data. Such data can be gathered by means of observations of lightning to towers (e.g., Diendorfer 2010), measurements of rocket-triggered lightning (e.g., Jerauld et al. 2005; Nag et al. 2011) or via video and electric field (E-field) measurements (e.g., Schulz et al. 2010). Nevertheless, there are differences between tower/triggered and video/E-field measurements. For instance, observations of lightning to towers are restricted to the tower position, unlike E-field and video measurements. Thus, results coming from tower data are solely valid for the position of the tower. In addition, observations of tower and triggered lightnings give the location accuracy (LA) directly and also show a potential systematic error. E-field and video measurements in their turn give solely an upper limit to the LA, as one cannot be undoubtedly sure whether the channel has the same ground striking point for all the strokes in a flash (Biagi et al. 2007).

In this paper, we present for the first time results of the performance of three different lightning detection networks covering Belgium, based on a ground-truth campaign during August 2011 using E-field and high-speed camera observations. In Section 2 the measurement set-up is described together with the collected data. The networks for which we determine the performance are presented in Section 3. We report on the resulting performance characteristics in Section 4, and summarize in Section 5.

2. MEASUREMENTS AND DATA

A GPS synchronized field measurement (FM) system is used, consisting out of a flat plate electric field antenna, an integrator, a fiber optic link and a high-speed camera. In this way, the change of the electric field during lightning activity up to a few tens of kilometers

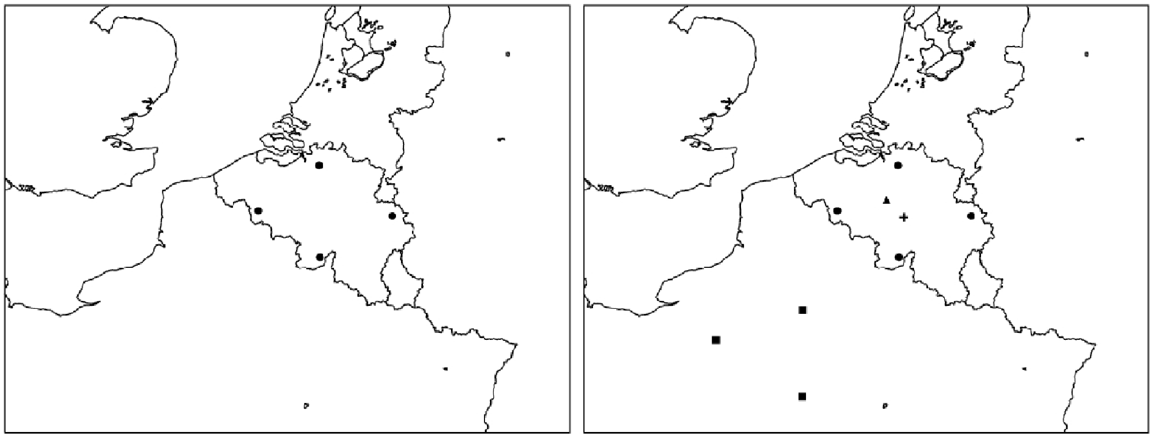

Fig. 1: Sensor positions of OP (*left*) and TP (*right*). In addition to the four SAFIR sensors of OP (*dots*), TP uses data from an extra fifth SAFIR sensor (*triangle*), an LS7001 (*cross*) and three LS8000 sensors (*squares*).

away is recorded continuously. The camera records 200 frames per second, enough to separate the individual strokes that exist in a multi-stroke flash. For more details on the operational and technical aspects of the FM system, we refer the interested reader to Schulz et al. (2005, 2009).

The measurements were carried out during August 2011 in Belgium, during which only four storm days occurred. However, only data from the 22nd, 23rd and 26th of August are found to be of sufficient quality for further investigation. In the data set we find 57 negative flashes, with a total of 210 strokes that are accepted for additional analysis. All of the flashes have clear CG field waveforms and/or apparent CG channels in the camera's field of view. Note that only flashes are used of which we have complete knowledge of all the occurred strokes. This means that we discard flashes that do not have a clear lightning channel to ground in the video and the related E-field cannot be clearly identified as coming from the CG flash. In the following, we evaluate solely the performance of the networks against negative CGs, since not enough data is available to make valuable statistics for positive CGs.

3. NETWORKS

3.1 *Belgian lightning detection network*

The Royal Meteorological Institute of Belgium (RMI) has been operating a SAFIR (Système d'Alèrte Foudre par Interférométrie Radioélec-trique) lightning detection system since 1992. The operational SAFIR network consists out of four sensors of type SAFIR-3000 in Dourbes, Oelegem, La Gileppe and Mourcourt, see Fig.1. Within the current operational processor (OP) the localisation of lightning discharges is operated in the VHF band, and uses solely the latter four sensors. An interferometric lightning location retrieval method for VHF signals is used to retrieve after triangulation the location of the sources. In addition, the sensors are equipped with an E-field antenna detecting the high-current LF return stroke signature, allowing the discrimination between IC and CG electrical signals. Once a LF signal is detected, the CG stroke is assigned a location using the position of a time-correlated VHF signal.

Besides OP, RMI is running in parallel Vaisala's Total Lightning Processor (TLP) as a processor in test-phase (TP). TP in its turn uses a combination of TOA and magnetic direction finding to locate CG discharges. Note that not only does the method differ for locating CGs between OP and TP, but also the amount of sensors that can contribute to a valid solution. Besides the former four SAFIR sensors used by OP, TP receives raw data from an extra fifth SAFIR sensor positioned in Ukkel. In addition, at the time of the campaign, TP shared data with Vaisala's demo-network around Paris in cooperation with Météorage. This non-operational network provides TP with lightning data from three LS8000 sensors in Evreux, Compiègne and Renardières. An extra LS7001 is placed in Ernage/Belgium for study purposes, but was only operational from August 26th onwards, bringing the total available sensors to nine for TP.

3.2 *EUCLID*

In 2001 several countries, i.e., Austria, France, Germany, Italy, Norway and Slovenia,

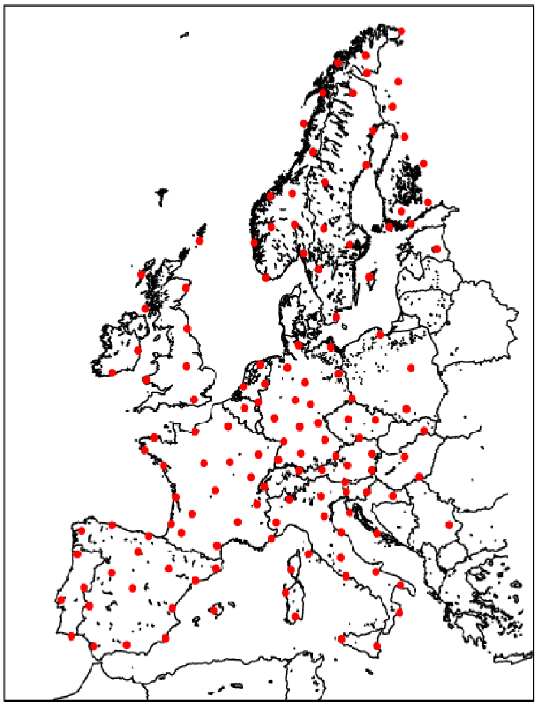

Fig. 2: Sensor positions of EUCLID (*dots*), plotted in red for clarity.

started EUCLID, a EUropean Cooperation for Lightning Detection, with the goal to provide European wide lightning data with nearly homogeneous quality. Subsequently Spain, Portugal, Finland and Sweden joined EUCLID as well. EUCLID is special in the sense that the individual partners are highly motivated to run their individual networks with state-of-the-art lightning sensors. As of August 2011 the EUCLID network employs 142 sensors, see Fig. 2, of which 4 are of type LPATS III, 13 LPATS IV, 1 SAFIR, 16 IMPACT, 42 IMPACT ES/ESP and 66 LS7000 sensors (oldest to newest), all operating over the same frequency range with individually-calibrated gains and sensitivities. Data from all these sensors are processed in real-time using a single common central processor, which also produces daily performance analysis for each of the sensors. This assures that the resulting data are as consistent as possible throughout Europe. In fact, the Europe-wide data produced by EUCLID is frequently of higher quality than the data produced by individual country networks, due to the implicit redundancy produced by shared sensor information.

3.3 GLD360

Vaisala's new global lightning detection network GLD360 was developed in collaboration with Stanford University and is operational since the beginning of 2010. In short, it employs a set of sensors with orthogonal magnetic loop antennas operating at very-low-frequencies (VLF) enabling to measure the arrival azimuth. A clever method is then applied that makes use of the received waveforms at different sensors and cross-correlates them to a so-called waveform bank, containing a catalogue of empirical wave-forms. Propagation effects are taken into account to subsequently obtain the arrival time and distance estimates to each sensor. The final coordinates and peak currents of the lightning discharge are found by minimizing a cost function, containing the azimuth, arrival time and distance estimates. A more thorough description of the network is found in Said et al. (2010, 2011).

4. ANALYSIS

The final dataset includes 57 flashes, containing a total of 210 strokes. From this a mean multiplicity of 3.7 strokes per flash is found. Note that 21% of the observed flashes are composed out of a single stroke only. The mean/median time difference between subsequent strokes within a flash is 0.096s/0.058s, with a maximum interstroke interval of 0.46s. One flash has been observed with a continuing current of about one second. This is to our knowledge one of the longest continuing currents ever observed of natural CG lightning.

A flash/stroke detection efficiency (DE) is found of 93/70%, 90/64%, 100/84%, and 98/70% for OP, TP, EUCLID and GLD360, respectively. To determine the LA of the different systems, only strokes are used which follow the same stroke channel as seen in the images. A limited number of 8 flashes have been observed from which we can clearly identify that the strokes follow the same channel. Note that not all of the networks observe all these flashes and/or strokes. We find an upper limit for the median LA of 6.1, 1.0, 0.6, 0.9km for OP, TP, EUCLID and GLD360, respectively. In addition, one can correlate the locations of the 210 individual strokes between two different systems. When doing so, a median difference of 9.9, 10.4, 10.9, 1.0, 2.0 and 1.4km between OP-TP, OP-EUCLID, OP-GLD360, TP-EUCLID, TP-

GLD360 and EUCLID-GLD360 is found, respectively. Besides location coordinates, the different networks provide an estimate of the peak current of each individual stroke. A median stroke peak current of -55.2kA, -19.0kA, -18.2kA, -18.3kA is found for OP, TP, EUCLID and GLD360, respectively. Performance values as described above for the different networks and distances between positions of corresponding strokes are listed in Table 1 and 2, respectively.

TABLE 1
PERFORMANCE CHARACTERISTICS

	Stroke DE [%]	Flash DE [%]	LA [km]	Number of strokes[a]	Median peak current [kA]
OP	70	93	6.1	13	-55.2
TP	64	90	1.0	12	-19.0
EUCLID	84	100	0.6	23	-18.2
GLD360	70	98	0.9	22	-18.3

[a] This amount of strokes, which follow the same path, are used to estimate the LA.

TABLE 2
CORRELATION OF STROKE POSITIONS

	Median location difference [km]	Number of strokes[b]
OP vs TP	9.9	118
OP vs EUCLID	10.4	134
OP vs GLD360	10.9	108
TP vs EUCLID	1.0	126
TP vs GLD360	2.0	103
EUCLID vs GLD360	1.4	134

[b] Amount of strokes both detected by the two networks.

5. SUMMARY AND DISCUSSION

E-field and high-speed camera observations were recorded during three thunderstorm days in Belgium. The data is used to determine the LA and DE of three different networks. At the level of flashes, all the networks perform well with a DE of over 90%. Larger differences are found between the stroke DEs. EUCLID is the network with the highest overall DE.

The LA of OP is rather poor. This is probably related to the location algorithm which uses the position of a time-correlated VHF signal as the CG striking point. This VHF emission can be transmitted from high above ground or in the cloud, and potentially leads to a large difference compared to the true ground striking point. The LA of TP and GLD360 is ~1km, a few hundred meters more than what is found for EUCLID. Note that when correlating the positions of mutual observed strokes between two networks, TP locates strokes on average closer to the EUCLID strokes then does GLD360.

On the level of the measured currents, it is noteworthy to mention that GLD360, using a completely different technology, reports the same median peak current as what is found by EUCLID and TP. On the other hand, OP shows a large deviation by a factor of three in the observed median peak current compared to the other lightning location systems. The latter could due to the fact that the SAFIR sensors are not well enough calibrated to ensure accurate peak measurements.

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