

# Validation of the EUCLID LLS during HyMeX SOP1

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**Abstract**—This paper deals with performance evaluation of the European lightning location system EUCLID in France during the HyMeX [1] Special Observation Period 1 (SOP1) in 2012. Beside other instruments a Lightning Mapping Array (HyLMA) and a mobile Video and Field Recording System (VFRS) was deployed in the south of France. The data of those independent systems are used to determine the performance of the EUCLID lightning location system (LLS) in terms of detection efficiency (DE) and location accuracy (LA) for both CG and IC flashes.

Based on VFRS records of 161 flashes, we determined a negative/positive flash DE of 90/87% and negative/positive strokes DE of 87/84%. The negative flash DE is quite low compared to the usual performance noticed on similar LLS because during two days of the VFRS measurements, where a significant amount of the negative flashes was recorded, a nearby sensor was out of order. The positive flash DE is low because the criteria to determine if a stroke was correctly detected by the operational LLS are quite strict. In fact only one positive stroke out of 56 strokes was not detected by the LLS.

The HyLMA data gave us the opportunity to objectively determine for the first time an intra-cloud (IC) DE for a network in Europe. We analyzed the IC-DE for so called isolated ICs. Isolated ICs are IC discharges which are not related to any cloud to ground stroke. For one isolated storm we found a surprisingly good IC-DE of 47%. Unfortunately we also realized that the LA of the IC discharges is not as good as for CG strokes.

**Keywords**—Lightning location systems; performance evaluation; E-Field measurements, video measurements; intra-cloud detection efficiency

## I. INTRODUCTION

The EUCLID (EUropean Cooperation for LIghtning Detection) lightning location system (LLS) was established in 2001 as a cooperation of six countries (Austria, France, Germany, Italy, Norway and Slovenia) and subsequently other countries as Spain, Portugal, Finland and Sweden also joined this cooperation. As of December 2013 the EUCLID network employs 146 sensors, 8 LPATS, 16 IMPACT, 33 IMPACT

ES/ESP and 89 LS7000 sensors, when listed in order from the oldest to the newest sensor version. EUCLID is one of the LLS worldwide with most validation studies done so far. Validation of the EUCLID network (see Fig. 1) was primarily done with independent ground truth data, e.g. tower measurements and video and field measurement data. Most of the validation in terms of location accuracy (LA) and detection efficiency (DE) was done in Austria [2], [3], [4] but in 2011 also an experiment in Belgium took place [5].



Fig. 1: EUCLID network layout in 2012

During the HyMeX SOP 1 (HYdrological cycle in Mediterranean EXperiment Special Observation Period 1) [1] several instruments were setup to provide high quality description of electrical state of thunderstorms over the Northwestern Mediterranean basin (Figure 2). In addition to a Lightning Mapping Array (HyLMA), four independent European operational lightning detection networks and other research instruments such as micro-barometer and microphone

arrays, induction rings, field mills and a Video and Field Recording System (VFRS) were used for the experiment. The data from the VFRS was used to validate the EUCLID system in the region as detailed in the following.

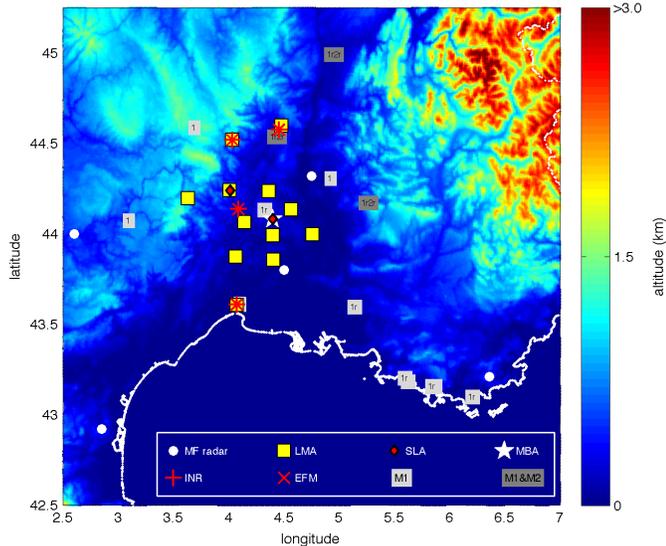


Fig. 2: Locations of the VFRS deployment with recording (1r) and without recording (1) during the 2 months of operation. Locations of other instruments sensitive to lightning occurrence are also indicated: it includes the Lightning Mapping Array (HyLMA), two slow antennas (SLA), microbarometer and microphone array (MBA), induction rings (INR), and electric field mills (EFM). A second fast camera (M2) was operated few days at the same location as M1 during the field campaign with few videos.

## II. METHODOLOGY

In our experiment a measuring system consisting of a flat plate antenna, an integrator, a fiber optic link and a high speed camera was employed, which is described in detail in [6] and [7]. The recorded video and E-Field data sets are complementing each other because sometimes it happens that strokes can be identified only either on the video or in the E-field data and sometimes the strokes can be clearly identified in both data sets.

Such a dataset allows a straight forward correlation of each individual stroke detected from the LLS to a field signature and a video frame. After the correlation of the data it is possible to determine the Flash Detection Efficiency (DE) and the Stroke-DE. It is further possible to evaluate if the LLS categorized the field signals detected by the LLS sensors correctly as cloud-to-ground stroke or cloud discharge. The accuracy of the LLS can be estimated by searching for multiple strokes in a flash following the same channel. Assuming that the strokes which are following the same visible channel to ground attach to the same ground strike point the LLS should locate those strokes at the same place. In reality there are differences of the individual stroke coordinates which reflect the location accuracy of the LLS. By calculating the distances of those strokes to the location of the first stroke it is possible to estimate the accuracy of the LLS. As stated in [8] there is a possibility that the

channel geometry and/or the actual ground contact location varied slightly from stroke to stroke and were not resolved by the video camera. Therefore the differences determined by this method should be regarded as upper bounds of the actual position differences.

The installed HyLMA gives us the possibility to analyze the DE of intra-cloud (IC) discharges for a LF-LLS for the first time in Europe. To evaluate IC detection we focus on IC flashes not connected in time and space to a cloud-to-ground (CG) flash – in our terminology we call those flashes isolated ICs. It is important to detect isolated ICs because those provide key information to the end user (e.g. MET services) and additional potential products (e.g. early warning products). Non isolated ICs – often called bursts – only add additional data to an existing CG flash.

## III. DATA

During HyMeX SOP 1 (2012) a total of 114 negative cloud-to ground (CG) flashes and 47 positive CG flashes during 8 storms (see Table 1) were recorded with VFRS.

TABLE I: Number of recorded flashes

	Neg. flashes	Pos. flashes
20120924	13	-
20120926	13	31
20120929	12	7
20121011	37	-
20121021	8	4
20121022	2	2
20121023	-	2
20121026	29	1
Total	114	47

The E-field and video records were taken at different places in the main region of the SOP 1 (see Fig. 2). The mean distance of all negative/positive strokes to the location of the recording system was 30/23 km (maximum distance 93/61 km and minimum distance 2/6 km). The grouping of strokes to flashes was basically done applying the same criteria as normally used for lightning location systems: a maximum distance between the stroke locations of 10 km and a maximum flash duration of 1s. No maximum interstroke interval criterion was applied.

For the analysis of the isolated IC-DE we analyzed data recorded on 2012-09-05 for a 2-hour storm with moderate lightning activity located close to the HyLMA network. 55 flashes out of a total of about 150 flashes for the entire storm (the HyLMA data analysis was performed by hand) appear to be isolated ICs, i.e. without any connection to the ground.

## IV. RESULTS

Fig. 3 presents an example of concurrent observations for flash #048 recorded during the 26 September 2012 storm. The discharge started with a positive CG stroke which is clearly visible in the E-Field data but caused only minor light variations in the video data. 268 ms after the positive CG a negative CG occurred. A clearly observable channel connecting to the ground was recorded with the 5-ms VFRS

camera (Fig. 2a). 13 ms after the first negative CG another negative CG occurred which was visible in the camera data. Both EUCLID and HyLMA reported consistent time and space locations of the flash. Little vertical description of the flash was available from HyLMA as the flash was relatively far away from the HyLMA center. All ground strokes reported by VFRS were recorded by EUCLID. Further there were several IC discharges reported by EUCLID while VHF radiation was reported by the HyLMA. One additional +CG stroke was reported by EUCLID during the life of the flash where it is not totally clear from the E-field whether the categorization as CG is correct.

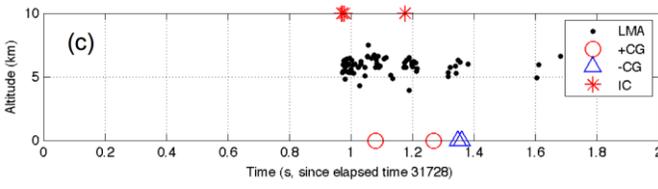
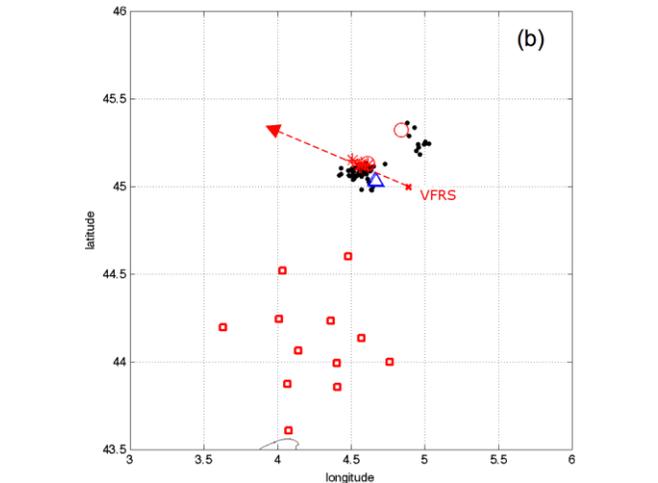
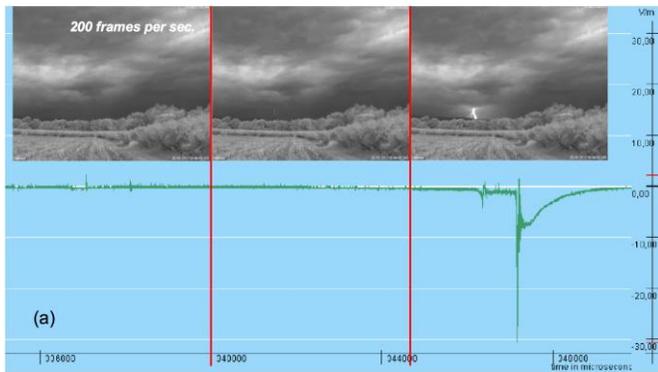


Fig.3: Example of concurrent observations during 2 seconds with (a) observations collected by the VFRS during the first stroke of the negative cloud-to-ground flash, (b) ground projections of the strokes as located by EUCLID as well as the VHF sources simultaneously located by LMA, (c) time-height of the HyLMA sources as well as times of EUCLID records with IC records set to an arbitrary altitude of 10 km.

The peak current for the recorded strokes was determined from the EUCLID lightning location system. The median peak current of all the negative/positive cloud-to-ground strokes was

-17/51 kA, the smallest peak current was -5/8.8 kA and the largest was -145/150 kA. We have to note that there exists no peak current calibration of the lightning location data for negative first strokes and for positive strokes [2] and therefore the values given above are rough estimates.

Out of the 114/47 negative/positive flashes captured by our video and field measurement system, the LLS detected 103/41 flashes (flash detection efficiency 90%/87%) and out of the 321/56 negative/positive strokes the system detected 279/47 (stroke detection efficiency 87%/84%). The criteria to determine if a stroke was detected by the LLS are quite strict because not only the location has to be provided with certain quality criteria but also the CG/IC categorization has to be correct. Basically only one positive stroke was not detected.

Due to bad visibility during our entire measurement campaign we found only videos with 14 strokes in the same channel as a previous stroke. The calculated median LA for those strokes is 250 m.

For the evaluation of the IC detection we analyzed one storm on the 2012-09-05. The EUCLID LLS detected 26 (47%) of those isolated ICs. The polarity of all the discharges was determined correctly.

Interestingly we realized that often the intra-cloud discharges were somewhat misplaced relative to the HyLMA discharges. Fig. 4 shows an example of such a misplaced IC.

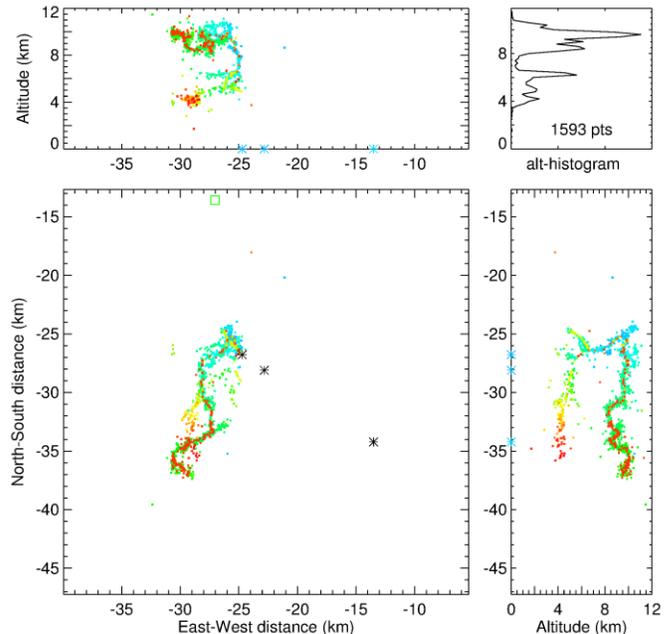


Fig. 4: Example of misplaced IC. The stars in the figure are the locations of the IC given by the EUCLID LLS

To quantify the location accuracy of the EUCLID LLS for IC discharges we calculated the mean location for all the HyLMA sources within +/- 1 ms of the EUCLID stroke time. Then we calculated the distance between the IC location given by EUCLID and this mean LMA source location. The median distance of the EUCLID ICs to their corresponding mean LMA sources is 4.8 km (mean 6.4 km). This location accuracy is

significant worse compared to the location accuracy for CG strokes although all sensors around were working correctly. However note that the number of distances (86 IC discharges were analyzed) used for this statistics is rather low and consequently concurrent records for other storms have to be analyzed.

In general the reason for the bad LA is related to the small peak currents of the IC discharges. The median peak current of the isolated ICs is 6 kA compared to -17 kA and 51 kA for the negative and positive CG strokes respectively. Those small IC peak currents result in a small average number of sensors reporting (ANSR) of 2.6 compared to negative CG strokes (ANSR = 14.5) and positive CG strokes (ANSR = 30.9) and strokes located with such a small number of sensors are of course more poorly located compared to strokes with a larger number of sensors (see e.g. [9]).

## V. DISCUSSION

In this paper we present detailed results about the performance of the European LLS EUCLID in the southern part of France.

The estimated DE of the EUCLID LLS for negative flashes/strokes is 90%/87% and the DE for positive flashes/strokes is 87%/84%. Because the EUCLID LLS performance suffered during the observation period due to the outage of a close sensor, the estimated DEs are similar to results from measurements in Austria [4] and Belgium [5].

Misclassification of 14% (8/56) for positive strokes is significantly worse compared to Austria where only 5% (6/119) of the strokes were misclassified. Right now it is unclear why more strokes were misclassified in France, maybe there is a relation to the measurement because a significant amount of recorded strokes occurred over the sea.

For the first time in Europe the DE for intra-cloud discharges is analyzed. During one storm the EUCLID LLS detected 47% of all isolated ICs. More investigations on other SOP1 storms will be performed to evaluate EUCLID IC DE and LA performances.

## ACKNOWLEDGMENT

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