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PERFORMANCE VALIDATION OF THE EUROPEAN LIGHTNING LOCATION SYSTEM EUCLID

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SUMMARY

In this paper we present a performance analysis of the European lightning location system EUCLID in terms of location accuracy (LA), detection efficiency (DE) and peak current estimation. The performance analysis is based on ground truth data from direct lightning current measurements at the Gaisberg Tower (GBT) and data from E-field and video recordings. The E-field and video recordings were taken in three different regions in Europe, in Austria, in Belgium and in France. The analysis shows a significant improvement of the LA over the past seven years. Currently the median LA is in the range of 100 m. The observed DE in Austria and Belgium is similar yet a slightly lower value is found in France because during the measurement period in France a nearby lightning location sensor was out of order. The accuracy of the lightning location system (LLS) peak current estimation for subsequent strokes is reasonable keeping in mind that the LLS estimated peak currents are determined from the radiated electromagnetic fields assuming a constant return stroke speed.

The results presented in this paper can be used to estimate the performance of the EUCLID network for regions with similar sensor baseline and sensor technology.

KEYWORDS

Lightning, Lightning Location Systems, Performance Evaluation, Detection Efficiency, Location Accuracy.

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1. INTRODUCTION

Lightning location data are used by power utilities for more than 20 years. The data are important to support the network operator in order to increase the power system security and to provide warning information for maintenance crews in case of approaching thunderstorms. For all applications of lightning data it is important to know the performance of the employed lightning location system (LLS) in terms of location accuracy (LA) and detection efficiency (DE). Often it is tried to determine the performance of an LLS by network cross comparison with data from another LLS [1], [2] but such comparisons typically do not provide any clear results. Therefore a direct comparison of LLS data with ground truth data is the best way to validate the performance of an LLS.

Different approaches to collect ground truth data of lightning discharges are used:

(A) Lightning to instrumented towers
(B) Rocket-triggered lightning
(C) Video and E-field records of lightning discharges

Each of these methods have different advantages and limitations (for more details see [3]). During the last years several validation campaigns were carried out in Europe, e.g. in Slovenia, where LLS data were compared to data from GPS synchronized flash counters installed on mobile phone towers [4], and in France, where video surveys were used to determine the actual network performance of the French LLS [5]. In this paper we are using a ground truth data collection approach (A) with data from the direct lightning current measurement at the Gaisberg Tower (GBT) [6] and approach (C) with lightning data collected in three different regions in Europe [7] to evaluate the performance of the EUCLID (EUropean Cooperation for LIghtning Detection) LLS in terms of location accuracy, detection efficiency and the accuracy of the peak current estimate.

In the following section we provide detailed results from a comparison of EUCLID data with direct lightning current measurements on an instrumented tower in Austria and with video and E-field records of lightning discharges in Austria, Belgium and France. Those measurements should be representative for all regions in Europe covered by the EUCLID network with similar sensor baselines.

2. EUCLID NETWORK

In 2001 several countries (Austria, France, Germany, Italy, Norway and Slovenia) started a cooperation called EUCLID (EUropean Cooperation for LIghtning Detection). It is the goal of this cooperation to provide European wide lightning data of high and nearly homogeneous quality. In the meanwhile also Spain, Portugal, Finland and Sweden joined EUCLID. The EUCLID cooperation is special in the sense that the individual partners are highly motivated to run their individual networks with state-of-the-art lightning sensors. All the partners employ dedicated technicians to supervise and maintain the network and to react in short time in any case of sensor or communication problems. 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. All sensors are operating in the same frequency range with individually calibrated sensor gains and sensitivities in order to account for any local sensor site conditions. Figure 1 shows the EUCLID network configuration as of 2012. In this figure also three areas labelled Region1, Region 2, and Region 3, respectively, are indicated. In these areas video and E-field records of lightning discharges were collected.

Fig. 1: EUCLID network configuration for 2012. Sensor locations are shown as red dots.

Data from all of these sensors are processed in real-time using a single common central processor, which also provides daily performance analyses reports for each of the sensors. This assures that the resulting lightning data are as consistent as possible throughout Europe. In fact, the European wide data provided by EUCLID is frequently of higher quality than the data produced by individual country networks, being sub-networks of EUCLID. This is due to the implicit higher redundancy in EUCLID as a result of participation of sensors in the lightning location, which are located outside the national borders in a neighbouring country. We note that there is a full backup EUCLID processing center in Germany with independent data connection to all sensors. Further, the transnational EUCLID cooperation also acts as a platform for knowledge exchange related to lightning location technology and LLS data applications. Since the beginning of the cooperation the performance of the EUCLID network has been steadily improved, as a result of employing improved location algorithms, of installing state of the art sensor technology and by adapting sensor positions because of bad sites (e.g. local electromagnetic noise). Over the next 1-2 years, at least 10 of the older sensors are expected to be upgraded to the newest sensor type (LS700x).

3. INSTRUMENTATION

3.1 Gaisberg Tower (GBT)

Since 1998 direct lightning strikes to a radio tower have been measured at Gaisberg, a mountain next to the city of Salzburg in Austria [8]. This 100 m high tower is located on the top of the mountain Gaisberg (1287 m ASL). Lightning flashes to the tower occur in summer as well as during winter time. The overall current waveforms are measured at the base of the air terminal installed on the top of the tower with a current-viewing shunt resistor of 0.25 mΩ having a bandwidth of 0 Hz to 3.2 MHz. A fiber optic link is used for transmission of the shunt output signal to a digital recorder installed in the building next to the tower. The signals were recorded by an 8 bit digitizing board installed in a personal computer. The trigger threshold of the recording system was set to 200 A with a pre-trigger recording time of 15 ms. The lower measurement limit given by the 8 bit digitizer resolution was about 15 A. A digital low pass filter with an upper frequency of 250 kHz and offset correction is applied to the current records before the lightning parameters (peak current, charge transfer, action integral) are determined. More details about the Gaisberg measurement system can be found in [8].

3.2 Video and field recording system (VFRS)

To collect video and E-field data of individual lightning discharges we are employing a mobile video and field recording system (VFRS) consisting of a flat plate antenna, an integrator, a fiber optic link and a camera. The system is described in detail in [9], [10], and [11].

4. DATA

The lightning data used in this analysis were collected in three different regions covered by the EUCLID LLS (see Fig. 1).

- Region 1 (Fig. 2A): During summer periods from 2009 to 2012 measurements with the VFRS were carried out at various locations in Austria. In addition direct lightning current measurements are performed at the instrumented GBT, close to the city of Salzburg, since 2000.
- Region 2 (Fig. 2B): In August 2011 ground truth data were collected with the VFRS in Belgium.
- Region 3 (Fig. 2C): In 2012, during the HyMeX project [12], ground truth data were collected with the VFRS in southern France.

The measurement locations for those regions are given in Fig. 2. In Fig. 2A the location of the GBT in Austria is especially indicated.

A) B) C)

Fig. 2: Measurement locations for A) Austria B) Belgium C) France

At the GBT a total of 487 flashes were recorded between 2005 and 2012, the vast majority of them being upward initiated discharges. A detailed analysis of these tower initiated flashes is given in [8], 133 flashes containing 434 return strokes, are used as ground truth reference in this paper. The remaining flashes to the tower contained either initial continuous current (ICC) only or an ICC with superimposed pulses (ICC pulses), which are either not detectable by LLS or not representative for strokes in natural downward lightning.

During 30 days we recorded 442 negative and during 21 days 156 positive flashes (see Table 1) with the VFRS in three distinct regions. All these recordings were carried out at 35 different locations. Unfortunately in Belgium no positive flashes were recorded.

Table 1: Total number of flashes recorded with the VFRS

	Neg. flashes	Pos. flashes
Austria (2008-2012)	271	109
Belgium (2011)	57	-
France (2012)	114	47
TOTAL	442	156

5. RESULTS

5.1 Location accuracy

For the analysis of the LLS LA based on data from the GBT measurements (Region 1) only data from return strokes were used. The median LA for the years 2005-2012 is 211 m. Over this eight year time period we observe a steadily improvement of the LA as a result of the following changes in the LLS:

- Implementation of an improved location algorithm which better selects the sensor messages for a return stroke
- Implementation of sensor based onset time calculations [13]
- Implementation of a better estimate of the field propagation velocity
- Introduction of angle and distance dependent propagation corrections for each individual sensor [14]

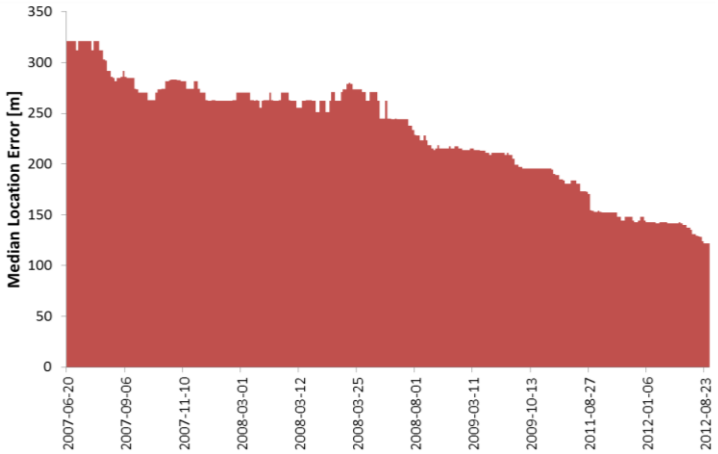


Fig. 2: Median location error over time calculated as moving average over the last 100 return strokes to the GBT.

The improvement of the LA over time can also be seen in Fig.2. This figure shows the moving average of the location error over the last 100 return strokes directly measured at the GBT. The plot starts with 20.6.2007 because in the period from 1.1.2005 to 20.6.2007 the 100 strokes occurred, which are needed to start the moving average calculation. The last recorded stroke during the period of interest occurred on 23.8.2012.

To determine the LA with the VFRS we have to search for strokes that occurred in the same return stroke channel. Due to the reason that almost no positive flashes with multiple strokes in the same channel exist, the LA is determined with negative flashes only. The method to estimate the LLS accuracy based on multi-stroke flashes is described in [3] and [15] and the LLS location error determined with this method is an upper limit because the return stroke channel is not always seen all the way down to the ground strike point of each return stroke.

Table 2: Median LA in Austria (Region 1) determined with the VFRS and the number of strokes they are based on

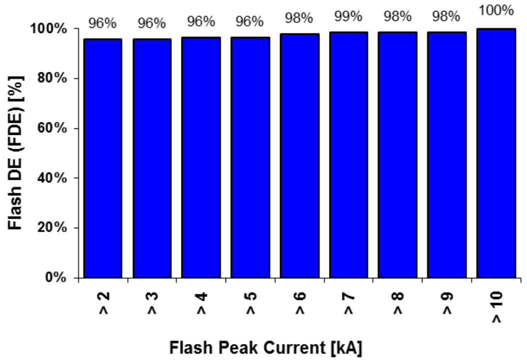
2009-2010	2012	Total
326 m (N=119)	126 m (N=108)	259 m (N=227)

The median LA in Belgium (Region 2) determined in 2011was 600 m and in France (Region 3) determined in 2012 was 256 m. Those values are based on 25 strokes (Region 2) and 14 strokes (Region 3) only.

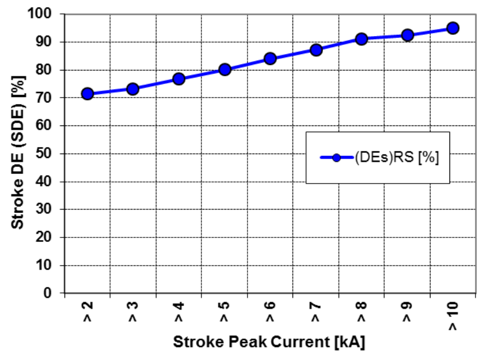
5.2 Detection efficiency

In general it can be shown that the flash/stroke DE increases with increasing peak current. EUCLID flash DE based on the GBT measurements is shown to be greater than 96% if one of the return strokes in a flash had a peak current greater than 2 kA (Fig. 3A). Flashes containing at least one stroke above 10 kA are always detected (DE=100%). As usual stroke DEs are lower than the corresponding flash DEs. For peak currents greater than 2 kA the stroke DE is 71% (Fig. 3B)

One has to keep in mind that the analysis of the GBT measurements is made for negative subsequent strokes in upward initiated flashes only (no first stroke data are available from tower measurements). Taking into account that first strokes in natural downward lightning normally have greater peak currents than subsequent strokes, the determined overall flash DE of 96 % (in Fig. 3A) should be interpreted as a lower limit.



A)



B)

Fig. 3: Flash DE A) and stroke DE B) determined for negative return strokes at the GBT.

DE determined from VFRS records: Due to the reason that the DE did not vary in Austria from 2009 to 2012 we present only the average DEs for all the years where data were recorded with the VFRS.

Table 3: Flash and stroke DEs determined from VFRS data. The number of flashes/strokes recorded during each of the campaigns is given in the parenthesis.

	Flash DE		Stroke DE		Median of stroke peak currents	
	positive	negative	positive	negative	positive	negative
Austria (Region 1)	97 % (109)	98 % (271)	92 % (119)	84 % (928)	34 kA	-12 kA
Belgium (Region 2)	-	100 % (57)	-	84 % (110)	-	-18 kA
France (Region 3)	87 % (47)	90 % (114)	84 % (56)	87 % (321)	46 kA	-16 kA

The criteria used in Table 1 to determine whether a stroke was detected by the LLS or not are quite strict because not only the stroke location has to be provided with certain quality criteria but also the cloud-to-ground/intra-cloud classification has to be correct.

As we have discussed before, the DE depends on peak current and therefore we give in Table 3 also the median peak current for negative and positive strokes in the three regions. The median values are based on LLS estimated peak currents.

5.3 Peak current estimates

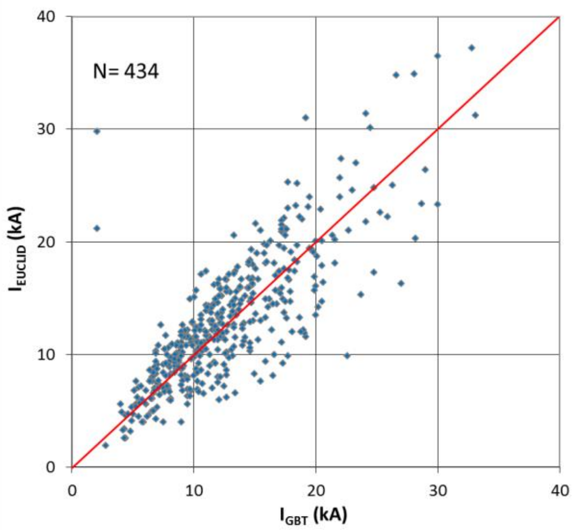


Fig. 4: EUCLID peak current estimates plotted versus directly measured stroke peak currents at the GBT during the time period 2005–2012.

The EUCLID peak current estimates are only compared with the direct current measurements to the GBT in Fig. 4 because no information regarding peak current is available from the VFRS data records. In Fig. 4 ideally all data points should be on the red line. Due to different return stroke speed, propagation paths from the tower to the LLS sensors the resulting EUCLID peak current estimation scatters around this line. Nevertheless the overall accuracy seems to be reasonable. 80% of the absolute peak current deviations are below 3.8 kA.

6. DISCUSSION

LA from GBT measurements was determined for negative subsequent strokes only. Furthermore we cannot obtain any information regarding the LA of positive flashes from VFRS measurements because positive flashes with subsequent strokes in the same channel are rare. Nevertheless we do not see any reason why the LA for negative first strokes and positive flashes should be different from the validated LA of negative subsequent strokes.

We observed a continuous improvement of the LA of the EUCLID network during the last years due to several technology improvements (see chapter 5.1). Keeping in mind that the LA determined with the VFRS data is a kind of upper limit of the LA (see chapter 5.1), the agreement between LA determined from GBT data and VFRS data in Austria is surprisingly good.

The relatively low LA in Belgium has several reasons. During the time of the VFRS measurements there were still several sensors of outdated technology installed around Belgium which have a negative effect on the LA and the number of samples to determine the LA is relatively low. Meanwhile the old sensors installed around Belgium have been upgraded.

The DE determined with data from the GBT is in good agreement with the DE determined with VFRS data in Austria considering that the DE from GBT data is based on subsequent strokes only and first strokes normally exhibit peak currents greater than subsequent strokes.

The lower DE for negative flashes in France is a result of a temporary outage of a nearby sensor during September 2012 when the measurements were carried out. During this time period nine single stroke flashes were missed. The low DE for positive flashes is caused by the very strict criteria we applied for the analysis. We rate misclassified strokes as not detected by the LLS. Eight positive CG strokes were actually located but classified as IC (5 single stroke flashes). In fact only one positive flash was not detected at all.

The results presented in this paper are assumed to be representative for the performance of the EUCLID network in other regions with similar sensor baseline and sensor technology.

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