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Thunderstorm warning systems : why lightning detection networks should be considered as one of the most relevant solution in Western Europe ?

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Abstract— This paper presents a performance analysis of the European lightning detection network (EUCLID) with respect to warnings of cloud-to-ground lightning in western Europe.
These warnings allow to prevent accidents due to thunderstorms electrical activity, and can be employed in several domains such as industry, utility networks, leisure activities, transport, civil protection, …
In these sectors, a reliable and efficient warning is considered as vital, according to the risk of human and assets losses.
Based on a standard configuration, we have evaluated the EUCLID warning system's efficiency and obtained some convincing results with 96% of probability of detection (POD) and with a 20 minutes' lead time in more than 80% of the cases. Upon conclusion of the study, these results were compared to some previous studies which had evaluated the electric field mills' efficiency.

Keywords—lightning warnings; thunderstorm warning systems; probability of detection; lead time; Euclid; Meteorage; field mills.

I. Introduction

Since the past five years, some lightning locating system (LLS) have proven their high efficiency in terms of location accuracy and detection efficiency. In Europe, for example, the EUCLID network has reached a detection efficiency (DE) greater than 96% for flashes higher than 2 kA, and a median location accuracy of 100 m on most of the area [Schulz et al. 2015].
Beyond their ability of detecting lightning discharges, one of the most relevant interests of LLS is their capacity to provide early warnings.
The work presented in this document intends to evaluate the efficiency of LLS for early warnings, and to compare them to electric field mills (EFM) which are categorized as "class I", by the European standard EN50536 "Protection against lightning – Thunderstorms warning systems".

We have focused our analysis on 105 random locations all over western Europe, and used lightning data collected over a 5 years' period ranging from October 2010 to September 2015 in order to calculate some standard indicators often used in such an evaluation protocol.
The probability of detection (POD) was thus determined, but we have also computed the lead time (LT).
We have considered a relevant warning delivery as a process able to warn before the appearance of a lightning discharge in the vicinity, with a sufficient lead time to allow the end user to apply the procedures defined to protect people and assets.
The false alarm ratio (FAR) was also calculated.

II. Method

A. *Lightning warnings provided by a lightning detection network : basic principles*

Lightning activity is certainly one of the sole meteorological phenomenon to be localized in real time, using lightning detection networks, contrary to the others phenomenons measured through weather radars or satellites which are sequenced every 5 minutes or more.
As there are only a few seconds between the occurrence of a lightning event and its detection, an efficient warning system based on real time lightning observation is possible.
As shown in figure 1, a virtual monitoring area (MA) is created around the site to be protected and the alarm is triggered as soon as a lightning event, intra-cloud or cloud-to-ground flash, is detected within the MA.
The alarm will last for at least a pre-defined time, named dwell time (DT) and any lightning event detected inside the MA whilst the alarm is active, will extend the alarm for an additional DT.
A lead time (LT), corresponding to the period to establish the appropriate safety procedures, can be calculated if a cloud-to-ground (CG) strokes is detected within the AOC or the TA.

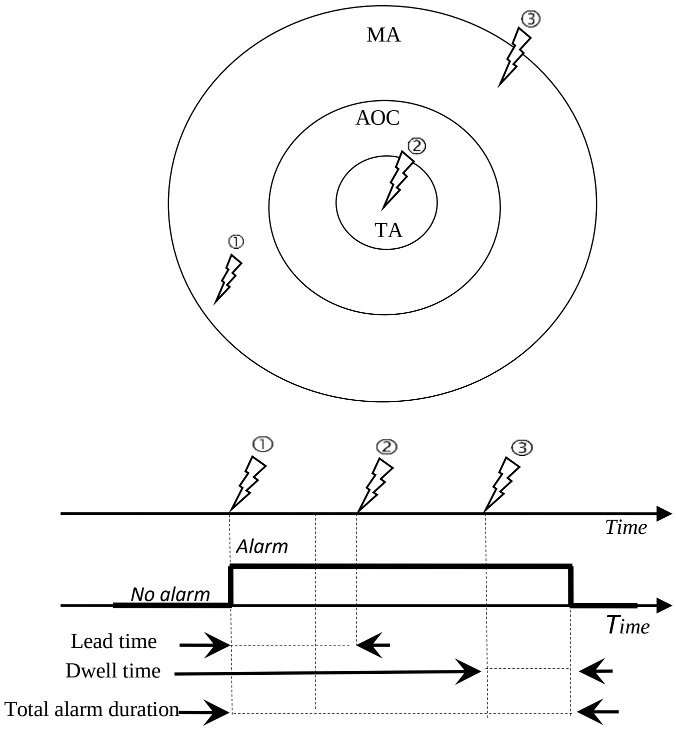

Figure 1 : principles

B. *Evaluation methodology*

For the current study we have considered a 20 km radius circle for MA and a dwell time of 60 minutes, which are very common parameters.

We have randomly selected 105 specific locations all over western Europe as seen in Figure 2 below.

Figure 2. Maps of random locations used for the current study

For each location, we have defined:

- a target area (TA), characterized by a 2 km radius circle centered on the site
- an area of concern (AOC), characterized by a 5 km (AOC5) or a 10 km (AOC10) radius circle centered on the site, especially to compare our results with some others studies using some similar areas.
- a monitoring area (MA), used to trigger an alarm, characterized by a 20 km radius circle centered on the site.

Then, we have analyzed all the cloud-to-ground (CG) strokes detected in the various areas, for a 5 years' period (2010-2015), including the dating and localization of each of them.

Therefore, it was possible to determine each time an event was detected in the TA, if it was preceded by a lightning flash into the monitoring area, and if so, to calculate the time interval between these 2 occurrences.

In case of lightning related event (LRE) with more than 1 CG in the target area, we have considered the calculation of the lead time until the 1st CG and have not considered the other ones in order not to over evaluate the performances.

All the LRE were analyzed thanks to a specific statistical tool developed by Meteorage, which has allowed to calculate an efficiency based on the following parameters:

- the number of effective alarms (EA): alarms correctly triggered before a LRE is detected within the TA or AOC.
- The number of failures to warn (FTW): occurrence of a LRE within the TA or AOC without previous alarm. The failure to warn is measured through the failure to warn ratio (FTWR) that is equal to 1-POD
- the probability of detection (POD) of a thunderstorm, the ratio of EA to the total number of LRE within the TA or AOC.
- The number of efficient alarms, alarms triggered before a LRE is detected within the TA or AOC and with a sufficient lead time. For the current study we have considered a 20 minutes' period (EA20').
- the probability of detection with a 20 minutes' lead time (POD20') of a thunderstorm; ratio of efficient alarms to the total number of events with a LRE within the TA or AOC.
- The number of false alarms (FA); alarms triggered but not followed by a LRE into the AOC. The FA is measured through the false alarm ratio (FAR).

The main statistical metrics are resumed below:

$$POD = \frac{EA}{EA+FTW} \qquad (1)$$

$$POD20' = \frac{EA20'}{EA20'+EA+FTW} \qquad (2)$$

$$FAR = \frac{FA}{EA+FA} \qquad (3)$$

III. RESULTS

A. POD

If we consider the system's ability to warn before the occurrence of a CG in the target area, our system would have sent 1845 effective alarms (EA) for 72 failures to warn, that being more than 96% of successful warnings.

We have also calculated this metric for both areas (see table 1), essentially to compare with some previous studies.

Table 1: Efficiency in terms of POD calculated on various areas

	TA (2km)	AOC5	AOC10
CG	4412	27930	111601
EA	1845	5032	8718
FTW	72	476	1947
POD	**96,24%**	**91,36%**	**81,74%**

For 3 of the target areas there were no CG detected during the study period. Thus the POD for the TA was calculated for 102 sites instead of 105.

54 locations have reached a POD TA of 100%, and 88 locations (86% of the population) obtained a result higher than 90%.

In order to avoid weak statistical results due to a lack of data (e.g location 12 in UK obtained a 50% POD but only with 2 CG), a second study was done after removing sites with less than 10 lightning strokes. This study shows no result under 80% (see Fig. 2).

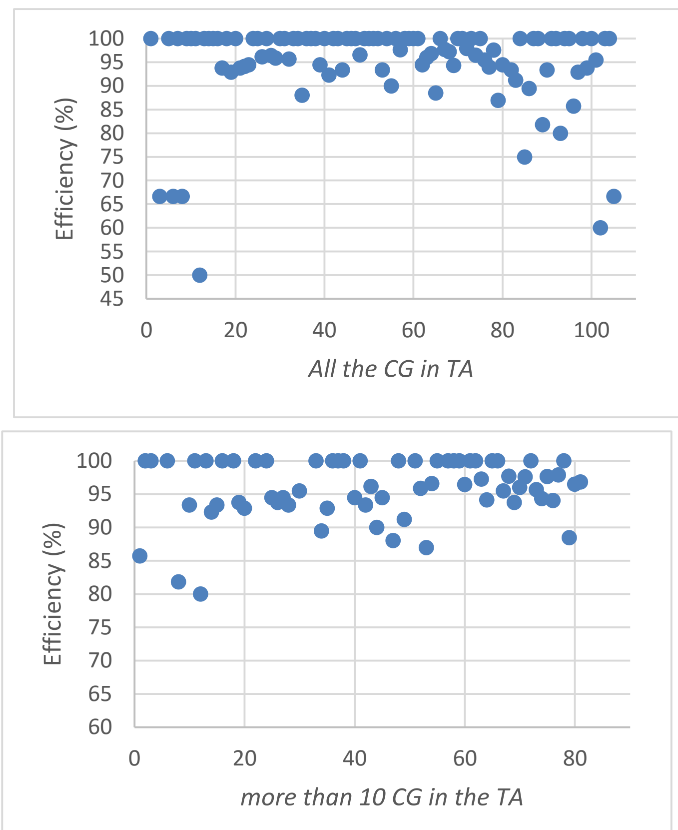

Figure 2: Efficiency in terms of POD (target area)

B. POD20'

Based on our operational users' feedback, we have used a 20 minutes' lead time, assuming it was sufficient for the user to apply its safety procedures in case of thunderstorm.

The POD20' was calculated for each LRE on the TA, and we obtained values above 81%.

Despite some variation, the POD20' is better than 80% in 57 locations out of 102, and if we remove locations with less than 10 CG to avoid some potentially unrepresentative statistics, the POD20' is always higher than 60% (Figure 3).

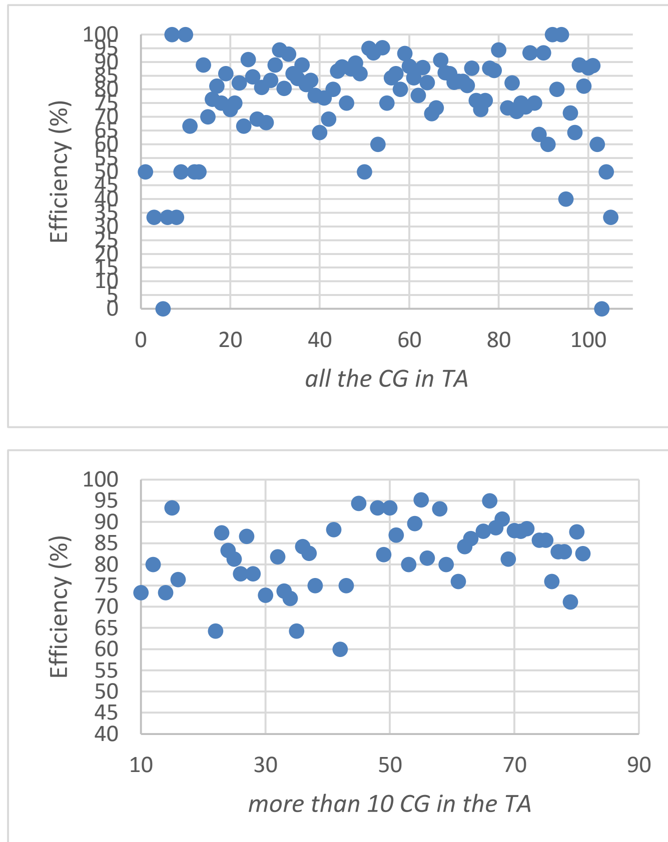

Figure 3: Efficiency in terms of POD20'

C. FAR

The third metric to consider is the false alarm ratio (FAR), measuring alarms never followed by a CG in the TA or AOC.

The false alarm (FA) concept should probably be clarified, in particular because of the various causes of false alarms.

Some systems deduce the existence of a thunderstorm by analyzing the electric field, they can induce some alarms generated by some external events such as dust storms, blowing sand and snow as mentioned for example in Murphy et al., [2008].

The consequence of such a false alarm will certainly be different than an alarm not followed by a CG in the TA, in particular because the user will not be able to consider this second case as a false alarm before a retrospective analysis of the event.

These precisions on the false alarm concept should not disguise the consideration that if the number of alarms is too high, even in case of a real lightning activity, it will probably hinder the vigilance of the user.

Nevertheless, with an average of 46 warnings per site and per year, we consider these figures as acceptable in an operational configuration.

As shown in figure 4, 5 sites have obtained an average number of alarms per year greater than 100, but they are located in very active thunderstorm areas (e.g with location 71 in Italy where the average number of CG per year in the TA is 35).

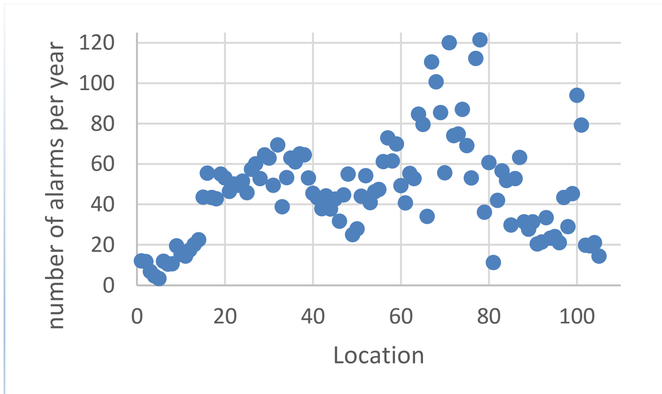

Figure 4: Average number of warnings per year

As LLS systematically deliver a warning in presence of a thunderstorm because the alarm is triggered when a CG occurs, we could almost consider a 0% FAR although we should take into account the LLS detection efficiency.

In an another way, we could also consider that, if there were no CG in the target area, the event could also be qualified as a false alarm. In this case, we must admit that, for the current study, the FAR would reach 92,5%.

The FAR was then calculated on various areas in order to put these results into perspective, and show as an average value, that less than 1 thunderstorm out of 10 will lead to a CG in the target area, 1 out of 5 in the AOC5, and approximately 1 out of 3 in the AOC10.

Table 2. False alarm rate in function of the AOC size

AOC	FAR
2 km (TA)	92,5%
5 km	79,6%
10 km	64,6%
20 km	0%

D. *Results per country*

Except Portugal and Ireland where a lack of data seems to be responsible of the lower result, 9 countries of western Europe have an average value higher than 90% in terms of POD, and 5 countries have reached a POD20’ higher than 80%.

We assume those results as representative for a large part of western Europe although some specific studies could be made in a future work to determine if these results could be reached for Portugal and Ireland.

Table 3: results per country
(metrics calculated on TA events)

Country	EA	EA20'	FTW	POD	POD20’
France	525	449	16	97%	83%
Italy	484	420	16	97%	84%
Spain	301	259	18	94%	81%
Germany	285	233	9	97%	79%
Austria	68	62	3	96%	87%
Switzerland	57	47	1	98%	81%
NL	42	33	1	98%	77%
Belgium	39	28	1	98%	70%
UK	30	21	3	91%	64%
Portugal	10	6	3	77%	46%
Ireland	4	2	1	80%	40%

IV. COMPARISON WITH EFM RESULTS

Some standards seem to imply that field mills provide the most relevant warning systems as they are theoretically able to react during the polarization phase, that is before the occurrence of a lightning discharge.

For example, the EN 50536 standard has even categorized EFM as “class I”, supposedly the most efficient system, considering that they are able to analyze the whole lightning lifecycle.

Some previous studies evaluating EFM efficiency with a 1 kv/m threshold [Murphy et al, 2008, Aranguren et al, 2009, Da Silva Ferro et al, 2011], provide the following results:

- a POD comprised between 34 et 61%,
- a FAR comprised between 41 et 87%
- a lead time, when calculated, never exceeding 13 minutes.

The present study shows some clearly better results for LLS regarding POD as resumed in table 4.

Moreover, the short range of EFM seems to be incompatible for users who needs a lead time higher than 10 minutes when LLS do not seem to suffer from this limitation for a large part of western Europe.

V. Conclusions

The purpose of this present study is to determine the efficiency of warning systems based on LLS lightning data, and to discuss some common categorization used in some standards such as EN50536.

The convincing results confirm that LLS provide a reliable system, with an average POD higher than 96% in western Europe, allowing to reach a 20 minutes LT in more than 81% of the cases.

These results are also in accordance with some previous studies where LLS had obtained some good results in terms of warnings. For example, Holle et al. [2014] had used some similar parameters than the present study excepting for dwell time and obtained a 95% POD and a 86% FAR

Some results certainly deserve to be put into perspective for some countries (Portugal, Ireland, and to a lesser extend Belgium and the Netherlands) where a lack of events does not allow to calculate some truly representative metrics.

However, these results seem valid for a large part of Europe, where the POD's analysis matches the situation where thunderstorms evolve in large fronts gradually moving from MA to the TA, as, for more than 80% of the events, lightning discharge firstly occurred between 10 and 20 kilometers, then between 5 and 10.

This is symptomatic for location 51 in France for example, where only 2,4% of the CG had appeared within a 10 km area without any previous alarm.

Finally, the system performances are already high but will probably be enhanced by some future works based on a cell identification method, especially to reduce the number of false alarms but also to characterize the thunderstorm severity.

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Table 4. Resume comparing studies in the literature

	POD			FAR			
	AOC 2 km	AOC 5km	AOC 10km	AOC 2 km	AOC 5km	AOC 10km	TWS
Murphy et al. (2008)	-	-	34,4%		-	74,1%	EFM
Aranguren et al. (2009)	-		37,5%			87,0%	EFM
Da Silva et al. (2011)	-	61,0%	58,0%		58,0%	41,0%	EFM
Holle et al. (2014)	95,0%			86,0%			LLS
Present study	96,2%	91,4%	81,8%	92,5%	79,6%	64,6%	LLS