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A cross-comparison of the GLD360 and Météorage networks over France

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***Abstract*—The performance of the Vaisala's long range lightning locating system (LLS), so called GLD360, has been studied over USA and Brazil. In Europe, despite two recent studies have been performed by [Poelman et al., 2013] and [Makela et al., 2012] it was important for Météo France to determine the quality of this new lightning dataset over France to evaluate the coverage of overseas areas.**

This paper presents the comparison between GLD30 and Météorage, the French national LLS which is a high resolution network with well-known performances being taken as a reference. In the first part, both datasets are analysed and some descriptive statistics are presented. Then, we explain the method and criteria used to define the coincident events taken in account in the comparison. To finish we present the results of a statistical and spatial study.

We have compared data over a two years period ranging from May 2011 until December 2012. The global relative detection efficiency (RDE) of the GLD360 in respect to Météorage for CG strokes is of 48% but for those exhibiting a peak current amplitude larger than 15 kA, the RDE raises up to nearly 60%. The analyse of the peak current amplitudes for coincident strokes shows in average an overestimation of 15% for GLD360 and a polarity discrimination error of 13%. Concerning the location accuracy, the analysis of the semi-major axis of the confidence ellipsis shows the theoretical stroke location error is 6.1 km. However, the computed distance between coincident strokes has a median value of 2.7 km, a mean of 5.5 km and remains below 8 km in 75% of the cases. We note the spatial distribution of these errors is not uniform: on the east of the Pyrénées and on the east of France location errors distance are higher between 8 and 10 km in average and we haven't yet found a plausible explanation

Keywords—Lightning Locating Systems (LLS); lightning detection systems cross-comparison;

I. Introduction

Vaisala Global Lightning Dataset (GLD360) service was launched in 2009 based on a worldwide VLF lightning detection network. The performance of this new global network has been evaluated over USA, Brazil and Europe where two recent studies were performed. The first one [1] has compared GLD360 data to high speed camera observations and E-field measurements during a campaign in Belgium on August 2011. As a result the GLD60 detected more than 90% of the observed flashes and around 70% of the strokes with a location accuracy around 1 km. The second study [3] has compared GLD360 and EUCLID data, the latter being the European lightning locating system (LLS). It is the fruits of cooperation between several national LLS operators and covers all Western Europe. According to the results of the study, EUCLID seems to have a better detection of weak events. Vaisala claims 70% of flash detection efficiency (DE) and results gives 48% over Austria for strokes. Vaisala claims (flash DE > 70%) are confirmed. Diurnal variation looks similar for both networks meaning the GLD360 seems to suffer in a lesser extent from diurnal variations compared to other VLF networks. The mean location accuracy error is of 3.8 km, with a median of 1.5 km where Vaisala claims this error is in the range of 2 to 5 km. These good results offer good perspectives to use such data on areas not covered with high resolution networks.

Meteo France has acquired a good expertise of lightning activity since several years over France with data from the Météorage network. As GLD360 can provide data over non covered area by high resolution networks, it is important for us to check GLD360 performances to assess the quality of this new dataset. Indeed, Météo France has some concerns in overseas regions where no high resolution LLS are installed. Therefore the GLD360 data could be a response to weather applications in such areas. This paper presents the results of the comparison between GLD360 and Météorage LLS the latter being taken as a reference.

In the first part, the two datasets are analysed and presented. Then, we explain the method and criteria used to define coincident or matching events. To finish we present the results of a statistical and spatial study based on the matched events.

II. Datasets

A. GLD360

Vaisala has operated the GLD360 system since 2009. This network uses VLF sensors to detect Cloud-to-Ground (CG) lightning strokes. Direction finding and Time Of Arrival technologies are used and combined with waveform recognition thank to comparisons to a waveforms bank [5]. The GLD360 provides CG return strokes but it is assumed that 5 to 8% are not CG strokes but some strong Intra-Cloud (IC). On another hand, the system cannot discriminate the type of strokes. GLD360 delivers also the polarity and peak current estimates.

B. *Météorage*

Météorage, the company, operates the French national network since 1987. As shown in figure 1, France is nowadays covered by LS7001 sensors from Vaisala belonging to Météorage. Exchange agreements with neighbouring countries allow getting additional foreign sensors making the all area uniformly covered.

Fig1 – Météorage sensors

Fig 2 – Comparison domain

Météorage network provides return strokes CG and flashes but also IC strokes which are discriminated from CG strokes. Because of rather short sensor baselines in France, the Météorage network detects a significant proportion of IC flashes.

C. *Data*

Figure 2 shows the comparison domain which covers all France except Corsica. Vaisala provided us with GLD360 data between 05 May 2011 and 31 December 2012. This long period covers two summer seasons which is usually the season where the lightning activity is high in France. The dataset includes the date (with accuracy to the microsecond), location, peak current amplitude, polarity and semi-major axis of the confidence ellipsis describing the theoretical location error. This latter parameter was set available only after the 17th of November 2011.

III. STATISTICAL ANALYSIS OF EACH DATASET METHOD

The spatial distributions of the number of strokes based on the GLD360 and Météorage datasets are presented on plots in fig. 3. We can notice on the maps that in south-east and on the Pyrenees (mountains at the border of Spain and France), Météorage detects more flashes than the GLD360 does. On the opposite, in the north and west of France the GLD360 locates more lightning events compared to Météorage that is surprizing according to the high level of performances reached by the latter.

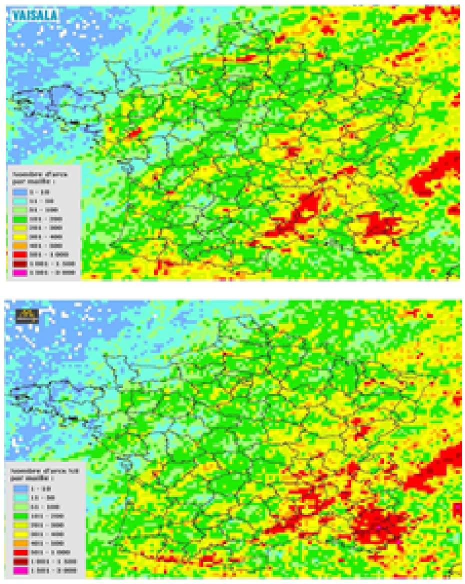

Fig 3 – Plots of datasets on all period
On top GLD360, down Météorage

On all the period of the study, a total of 2 357 660 strokes were detected by the GLD360 whereas Météorage detected 2 430 843 CG strokes and 2 386 357 IC strokes. We notice that the number of CG events is comparable for both systems taking into account the GLD360 dataset may contain up to 5 to 8% of IC according to Vaisala.

A. *Stroke peak current amplitude*

The distribution of the stroke peak current amplitudes (see figure 4) shows a proportion of positive strokes of 34% for GLD360 whereas Météorage presents only 13% of positive CG strokes.

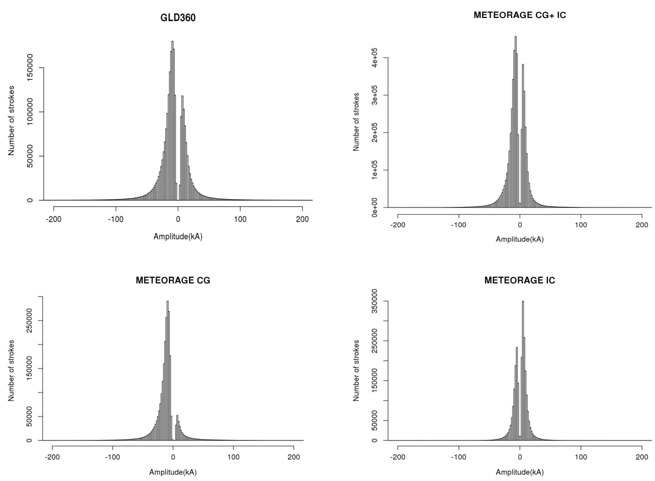

Fig 4 – Histogram of amplitudes

Assuming the GLD360 contains a maximum of 8% of IC the GLD360 still detects 13% of positive strokes more than Météorage. Several reasons can explain this big discrepancy: the discrimination between IC and CG is sometimes incorrect in the Météorage network leading to a transfer of CG to IC; GLD360 detects in reality more than the 8% of IC claimed by Vaisala, GLD360 misclassifies negative strokes to positives strokes.

The median values of both systems are of the same order (GLD360: -13.7 kA and +11.5 kA, Météorage CG strokes: -12.1 kA and +12.4 kA) but maximum values are higher for GLD360: around 1000 kA for GLD360 and 800 kA for Météorage. Of course we think so high values in stroke peak current are not realistic and mainly due to a limitation in the stroke peak current model in use in both LLS.

Looking at the spatial distribution of the absolute value of stroke peak current amplitudes (see fig 5) one can notice that GLD360 seems to report higher values compared to Météorage illustrating lower detection efficiency for the weakest peak current strokes.

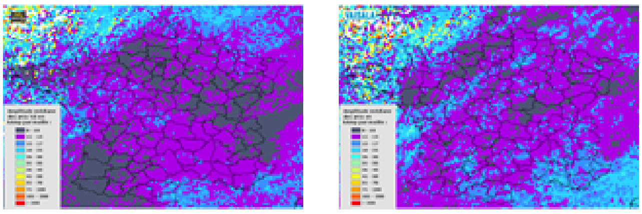

Fig 5 – Median value of absolute amplitude in kA by bin, Météorage on left side, GLD360 on right one

B. *Location accuracy*

GLD360 and Météorage systems report for every stroke an estimation of the location accuracy. The latter is defined by an ellipsis which semi major axis (SMA) represents the theoretical location error [8]. Distributions of SMA for both systems are shown in figure 6.

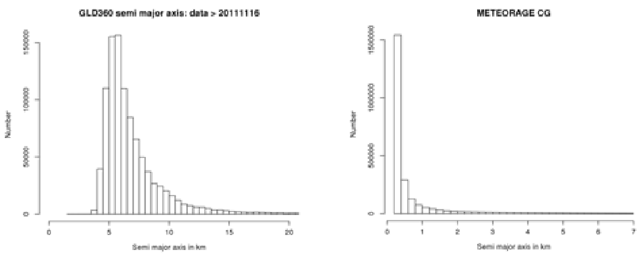

Fig 6 - Histogram of semi-major axes

The limits of the distributions are different because of the settings of the systems. Météorage rejects any stroke with a SMA greater than 7 km whereas GLD360 keeps strokes with a SMA up to 99.9 km. For a better reading the distribution presented on figure 6 cut at 20 km. As a result, the median value for the CG strokes located by Météorage is about 300 m to be compared to 6.1 km for the GLD360. A look at the spatial distribution indicates that Météorage is homogeneous on the studied region. For GLD360 (Fig 7), the network seems more accurate on north of France.

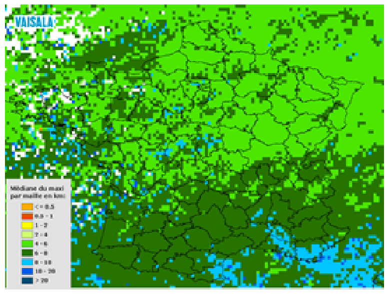

Fig 7 – Spatial distribution of GLD360 SMA

C. *Diurnal variation*

Most often time, long range detection networks using ionosphere guide have lower detection efficiency during the night. According to our findings, it seems the GLD360 hold a consistent level of detection all along the day and is not suffering that much from this day/night effect.

IV. METHODOLOGY TO DEFINE MATCHED OR COINCIDENT STROKES.

To be able to compute the Relative Detection Efficiency (RDE) of GLD360 versus Météorage we must define a new dataset composed of coincident strokes detected by both systems. To do this, we took in account all Météorage strokes (CG+IC) in order to evaluate the part of IC detected by GLD360. To match coincident strokes, we applied the following spatial and temporal criteria:

- Maximum delay between GLD360 and Meteorage strokes is 0.1 millisecond
- Maximum stroke separation distance of 30 km.

Several tries were made to assess the best separation distance value between time coincident strokes and finally 30 km was chosen because it allows a maximum of matches without associating strokes from different stormy cells (with a distance of 15km, we get 10% less of coincident strokes). This value takes in account the bigger location accuracy errors in GLD360. When several strokes are fitting the criteria, the first stroke of the sequence is selected.

V. RESULTS

63% of GLD360 strokes have found a coincident Météorage stroke, and we notice that 21% of them are associated with an IC detected by Météorage. This result shows GLD360 may actually detect more than 8% of IC but it is difficult to make any decision since Météorage network is perhaps not a perfect reference considering discrimination between CG and IC.

The median value for interstroke delay is 7µs and in 75% of the cases it is lower than 17µs (for a maximum interstroke delay value of 100µs).

A. Relative Detection Efficiency (RDE)

We took the definition to calculate the RDE from [7]. According to this definition, the RDE of GLD360 compared to Météorage is the ratio between the number of coincident strokes and the initial number of strokes detected by Météorage.

If we consider only CG detected by the Météorage network, the RDE is close to 50% (Tab. 1). This result is consistent with a previous comparison over Austria [3]. We also checked how the RDE can be influenced by the level of the daily activity or by the season and we can say that there are no seasonal effects and no link with the lightning daily activity.

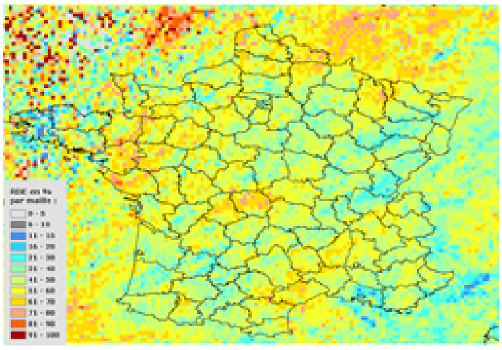

Fig 8 – Spatial distribution of RDE GLD360/Météorage CG

On Fig. 8, we can see that RDE GLD360/Météorage is not completely uniform: on south west and around Paris, the Météorage' sensors baselines are shorter than elsewhere in France and we think that weak events are likely to be more detected in this region compared to the rest of the network. On the western part of France, lightning locations are less numerous (see fig 3) and the spatial distribution is not relevant. But on south east, mainly around Marseille where the level of lightning activity is high, we notice the RDE can decrease down to 20%.

Tab 1: RDE for strokes, Météorage=CG+IC

	Stroke RDE
GLD360/Météorage	**31 %**
Météorage/GLD360	**63 %**
GLD360/Météorage CG	**48 %**
Météorage CG/GLD360	**49 %**

To go further, we studied the RDE as a function of the peak current amplitude. On figure 9, we can see the distribution for values under 30 kA (purple bars: strokes detected by Météorage, blue bars: common strokes and green curve: RDE with RDE scale on the right). As expected, for small values of amplitude, the RDE is very poor. On figure 10, the RDE is plotted on all the range of amplitudes. We can see that the curve rises from small values and above 15 kA the curve is quite flat around 60% of RDE.

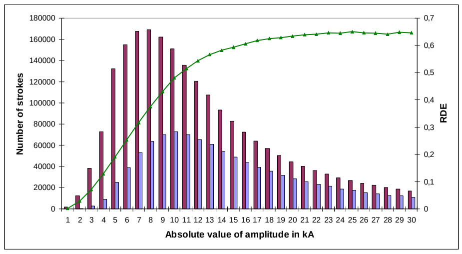

Fig 9 – RDE as a function of peak current amplitude: focus on amplitude < 30kA

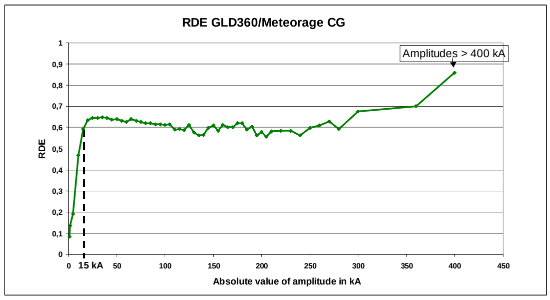

Fig 10 – RDE as a function of peak current amplitude

To have a better understanding of this result, we analysed the amplitude of coincident strokes. Figure 11 shows the correlation of amplitudes. If both systems agreed on the peak current estimation all the data should be plotted following a y=x line, but for a small part it's not the case.

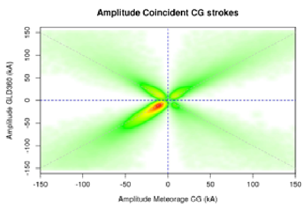

Fig 11–Correlation of stroke amplitudes for coincident CG

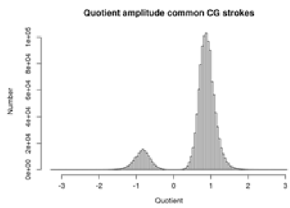

Fig 12–Ratios of stroke amplitudes

Figure 12 represents the same but the ratio of the two amplitudes is considered. If we take in account only data with same polarity, the linear correlation is strong (r=0.96) and gives the following regression:

$$GLD360_{Ip} = 1.15\ Météorage_{Ip} - 0.47$$

The analysis of residuals indicates that 50% are between -2.3 kA and 3 kA. These results tend to prove the GLD360 overestimates peak current amplitudes by a factor of 15% according to our dataset.

B. Inversion of polarity

On figure 12, the negative ratios represent coincident strokes with inconsistent polarities, meaning both systems disagree on the stroke peak current polarity. Météorage is known to be very efficient in stroke polarity assignment because it uses electromagnetic ground waves to determine the sign of the stroke current. From this statement, one can consider that the GLD360 is misclassifying about 13% of the strokes with a wrong polarity. Out of this, 83% are assigned with a negative polarity by Météorage explaining the high rate of positive strokes (34%) in GLD360 compared to Météorage.

C. *Location accuracy of coincident strokes:*

In the first analysis of the datasets, we focussed on the distribution of the SMA on the global datasets and for both networks. We compute now the distance between individual coincident strokes representing the relative location error. To be sure of the quality of the location accuracy of our reference dataset, we consider only the coincident strokes where Météorage SMA is lower than 500 m.

As shown in figure 13, in 75% of the cases, the distance between coincident strokes is lower than 8 km. It is noticeable that the SMA statistical distribution (left side of fig. 13) is less spread than the distribution of distances (right side of fig. 13) with respective median values of 6.1 km and 2.1. This demonstrates the GLD360, most of the time, overestimates the location error committed by the system.

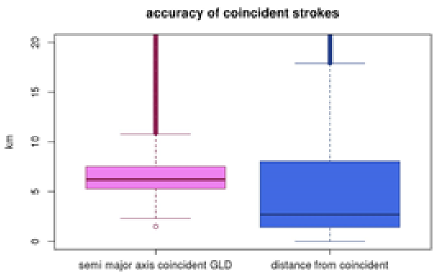

Fig 13– right boxplot: distance between coincident strokes (having for Météorage less than 500m of SMA); left boxplot: SMA of coincident GLD360 strokes

These results for location errors are rather good showing GLD360 seems to be more accurate than expected with the first analyse of theoretical error computed in SMA.

If we consider the spatial distribution of these separation distances in order to check the spatial accuracy of the detection, we can see on figure 14 that in most of the areas, values are in the order of 4 to 5 km, but on the east side of Pyrenees and on east side of France, errors are greater than 7 km.

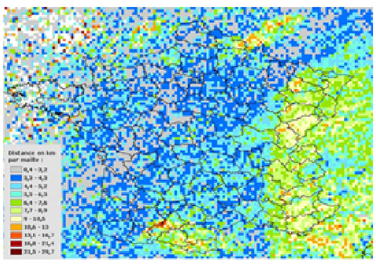

Fig 14– spatial distribution of distance between coincident strokes, average by bin of 1km.

If we compare figure 14 to figure 7, we see that SMA are increasing from north to south which is surprisingly not from west to east! We haven't found any plausible explanations to this result yet.

VI. Conclusion.

The aim of this study was the comparison between the GLD360 and Météorage lightning network over France in order to determine GLD360 performances. To do this, Météorage was used as a reference.

The first part of this work analyses the two datasets and notices some statistical differences. The number of CG events is comparable for both systems taking into account the GLD360 dataset may contain up to 5 to 8% of IC according to Vaisala. But GLD360 detects a higher proportion of positive event (34%) than Météorage. Considering the theoretical location accuracy, the GLD360 exhibits a SMA median value of 6.1 km whereas it is 300 m for Météorage. We notice also that GLD360 seems to be more accurate on north than south of France.

Very often long range network presents a lower detection during the night but according to our study the GLD360 seems to be affected in a lesser extend compared to similar systems.

After these statistical considerations, we define a new data set composed of coincident strokes that allows us to compute RDE. The RDE of the GLD360 in respect to Météorage CG is of 48%. But the study of this RDE as a function of amplitude shows clearly that GLD360 has a poor detection of strokes lower than 15 kA. For strokes over 15 kA, the RDE is increasing to around 60% and this result seems consistent with other results [3]. Having in mind this result represents a relative DE we can think that the given manufacturer DE of 70% seems realistic.

We haven't found RDE variations due to the level of activity or season.

For amplitude, GLD360 and Météorage have a strong correlation but GLD360 overestimates values by 15%. We notice also that 13% of coincident strokes are assigned by GLD360 with a wrong polarity out of which 83% correspond to positive strokes.

GLD360 being a long range lightning detection network is less performing than a high resolution national network as Météorage. But the separation distances between coincident strokes have a median value of 2.7 km and 75% of these distances are smaller than 8 km. When compared with the median SMA of 6.1 km, these results tend to prove the GLD360 overestimates the actual location errors. As a result, the location error committed by the GLD360 is nicely small over France and surprisingly good for a long range lightning detection network.

Over France, GLD360 has in general a uniform level of detection but we have noticed that the level of location accuracy drops on the East part of France.

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