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Analysis of the French lightning locating system location accuracy

Impact of the recent technological upgrades on performances

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Abstract— **The location accuracy is one of the important parameters characterizing the performance of a lightning location system. It is also one of the most difficult to determine as the actual location of the discharge being located must be accurately known to achieve a reliable assessment of the real error. Among all the measurement techniques which can be used to collect such ground truth data, none can cover large area preventing the estimation of the location accuracy at a regional or national scale. Trying to get around this limitation, Météorage has developed a method based on lightning ground strike point data collected by the French national lightning locating system computing the separation distances of return strokes identified as using the same attachment point on the ground. As a result, statistics on the relative location accuracy over the last 10 years of operation at the national scale are produced. In order to determine whether this data could be a proxy for the absolute location accuracy they are compared against systematic errors estimated in the vicinity of high elevation towers well known to attract or trigger lightning. If the study shows some discrepancies between relative and absolute errors at the beginning of the period, mainly due to technological upgrades in the system, it turns out both parameters fit nicely since 2010. This tending to demonstrate the relative errors estimated based on the ground strike point can be used as a good proxy for the absolute location errors estimate.**

Keywords—Météorage; lightning locating system; absolute and relative location accuracy; ground strike point; lightning data;

I. Introduction

The Location Accuracy (LA) is one of the important parameters characterizing the performance of a Lightning Locating System (LLS). For such systems using Low Frequency (LF) sensors it describes the distance error being made between a computed lightning return stroke position and its real location to the ground. Obviously knowing the unpredictable character of lightning it is extremely difficult to collect reliable ground truth data. However, accurate georeferenced ground truth data can be collected on localized area either with rocket triggered lightning or using instrumented towers [1]. Because such experiments require a high technology and particular skills they are costly to run and cannot be deployed worldwide. In addition, because the area of data collection is confined within a single point the absolute LA measurement based on those data may not be representative of the global performance of the LLS being tested.

In order to increase the ground truth data collection area, an intermediate technique has been developed to determine the relative LA. It is based on time synchronized video records taken with a mobile high speed video camera tracking thunderstorms [2]. For multiple stroke flashes it is possible, when the field of view is clear, to identify return strokes going along the same ionized channel created between the cloud and the ground. For strokes being located by a LLS it is then possible to compute the distance separation between individuals either taken in pair or in respect to a particular stroke in the group. These separation distances are assumed to represent the error committed by the LLS and thus determine the relative LA. Although the relative LA might not describe the effective performance of a LLS like the absolute LA, this parameter is nowadays the only one available to assess LA on large scales.

The results of the work being presented in this document intend to determine in a first step the evolution of the LA for the French National LLS so called Météorage. The analysis focuses on lightning data collected in France over a 10 years period ranging from 2005 to 2014. The relative LA is computed based on an original method using the Ground Strike Point (GSP) lightning data, described later in the next section. Then in a second step, the yearly absolute LA is estimated around elevated objects well known to attract or trigger lightning over the same 10 years period [3]. Finally, both relative and absolute LA are compared on these reduced areas in order to check whether a relationship exists between both parameters and possibly generalize the use of the relative LA based on GSP data to determine the absolute LA.

II. The Ground Strike Point Lightning Data

About half of the downward negative Cloud-to-Ground (CG) multi-stroke flashes exhibit multiple GSP, meaning these flashes may attach to the ground in several places. Statistics in the literature show an average ranging from 1.5 to 1.7 ground contact per negative flash with a mean separation distance in the order of 1.8 km [4][5][6]. Furthermore, the terrain and the local meteorological conditions seem also to influence this parameter [7].

Some years ago, Météorage developed an algorithm capable of identifying and localizing the different GSP in a flash based on lightning flash/stroke data [8]. It implements an adapted clustering method so called 'k-means' aiming to make consistent groups of strokes likely to have used the same channel. As a result a group can be made of a single or multiple strokes. Data collected by the French and the Austrian national LLS served to develop and tune this algorithm out of which the resulting GSP were compared against high speed video records. This comparison was run on data gathered from 2012 to 2014 showing in 95% of the cases the algorithm managed to identify correctly the GSP in flashes with a computed number of strokes per ground contact of 1.84 against 1.87 being observed on video records [9].

According to the fairly good results obtained during the test and validation period, this algorithm was implemented in the Météorage's operational lightning acquisition system to compute GSP and store the resulting flash, GSP and stroke data in a lightning flash database structure. The latter is a hierarchical tree using a SQL relational model. Therefore it is possible to retrieve the information of the corresponding strokes grouped in a GSP, and the same between GSP and flashes. It is interesting to know the location of a GSP is computed as the average of the locations of the strokes assigned to that GSP. To note this computation is weighted according to the semi major axis of the confidence ellipse of each stroke position [10]. Of course, when there is only one stroke in the GSP both locations are identical.

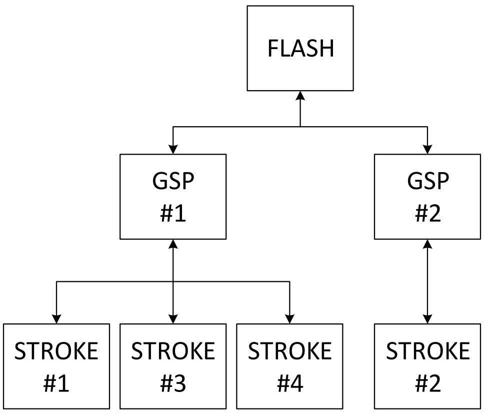

Figure 1- lightning hierarchical model implemented in the Météorage's lightning database

III. RELATIVE LA AT THE NATIONAL SCALE

The first part of this study focusses on the yearly evolution of the relative LA over France during the last 10 years. This parameter is computed as the distance between strokes locations and their respective unique ground attachment location represented by the GSP. As the location of the latter is an average of the locations of its composing strokes it is likely to minimize the individual stroke locations errors and therefore to be a good reference point. The relative LA is determined for all GSP exhibiting at least two return strokes. In order to get a significant dataset the GSP identification algorithm was run to replay lightning data collected by the Météorage's LLS from January 2005 to December 2014 making a 10 years period of GSP data available for this study.

The figure 1 represents the yearly distribution of the median value (orange line) and the standard deviation (blue line) of the relative LA over the France computed as previously described. Relative location errors values can be read in meter on the left hand side axis. The number of strokes used in the computation is also shown in the bar graph related to the axis on the right side of the figure.

Between 2005 and 2010, the median location error is surprisingly quite small and stable over the years, lower than 160 m, despite several major technological upgrades on sensors and lightning analyzers. This tends to demonstrate the upgrade of the sensors in 2009 from IMPACT 141T [10] and LS7001 [11] produced minor effects on LA that is somehow unexpected. In 2011, the median location errors starts decreasing after the onset time corrections are applied [12]. This result is expected while the time of arrival measurement is crucial for the stroke location accuracy. The relative LA continue to improve in 2012 because of a better assessment of the standard deviation on the time of arrival measurement to reach a low in 2013 when the time propagation corrections are used by the system [12]. All those changes have led to reduce the median location errors by 40% during the period 2011 to 2013 period.

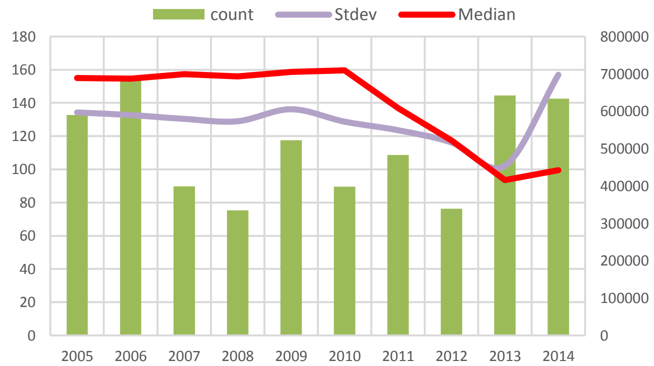

Figure 2-Yearly evolution of the Météorage's median relative LA and standard deviation in France on a 10 years period

On the period, the standard deviation follows the same decreasing trend in a lesser extent. Interesting to note the bigger improvement seems to be linked with the setup of the time propagation correction in 2013. This means the dispersion of location errors is getting smaller traducing an improvement in the repeatability of the measurement. In 2014, the relative LA deteriorates a little because of a configuration issue in the operational lightning analyzer. As this error was corrected beginning of 2015, it is expected the performance of the LLS on relative LA will retrieve the level of 2013 for the next lightning season.

IV. Comparison of relative and absolute LA errors

The second part of this study consists of comparing the relative and absolute LA in some places in France. The idea driving this analysis is to check whether the relative LA previously computed can be an efficient proxy of the absolute LA. To do so particular areas that are well known for attracting or triggering lightning are selected. The choice is the Mont Ventoux (1911 m) in South-East of France, Aiguille du Midi (3842 m) in the French Alps and the Pic du Midi de Bigorre (2786 m) in the French Pyrénées. All these places are mountain peaks on top of which a tall tower (about 100m) is installed. Interesting to note those particular areas are located at several hundred kilometers from each over.

Assuming the tower is the location where strokes are likely to attach, the absolute error distance is computed as the separation distance between strokes and tower locations. To illustrate, the figure 3 shows the geographical distribution of stroke locations around the towers in Aiguille du Midi (left side), Mont Ventoux (center) and Pic du Midi (right side) computed on the 2013-2014 period. Note the red circle is 150 meters in radius and the top of the maps point to the North.

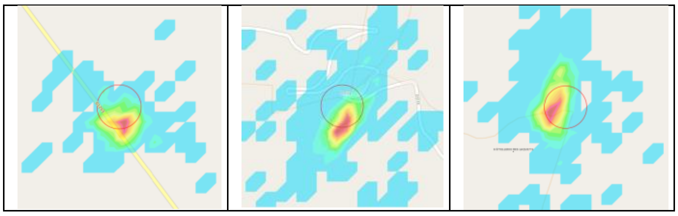

Figure 3 - Systematic error estimations on Aiguille du Midi (left), Mont Ventoux (middle) and Pic du Midi (right) on a 2x2km area

The color scale represents the number of strokes per 0.1x0.1km area. The dark zone is the place where most of the strokes are located by the LLS. One can see the hot spots are shifted in distance and angle in respect to the towers. It gives a rough idea of the magnitude of the systematic errors committed by the LLS.

The qualitative analysis of the median relative and absolute LA is made on a circle of 1 km radius centered on the towers. The period of analysis range from 2005 to 2014. The figures 4 to 6 present the yearly distribution of the median relative and absolute distance errors on the three considered sites. The location errors are represented on the left hand axis, the bar graph representing the comparison ratio of relative LA in respect with absolute LA with values on the right axis.

Several comments can be made from the analysis of the graphs presented here above. Considering the relative LA, one can note all the sites exhibit a median value lesser than 200 m throughout the 10 years period that is consistent with the national results earlier presented.

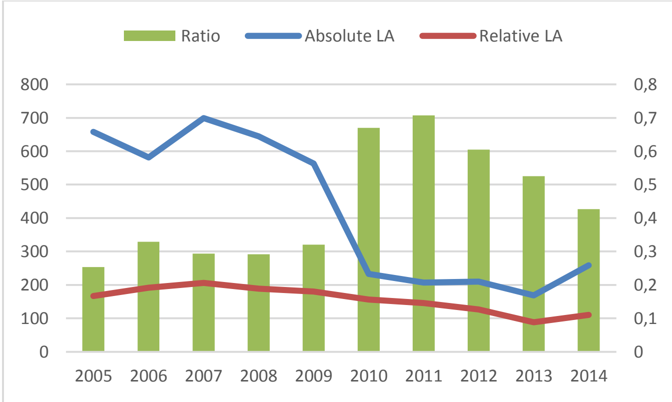

Figure 4 -Yearly evolution of the median LA in Mont Ventoux area

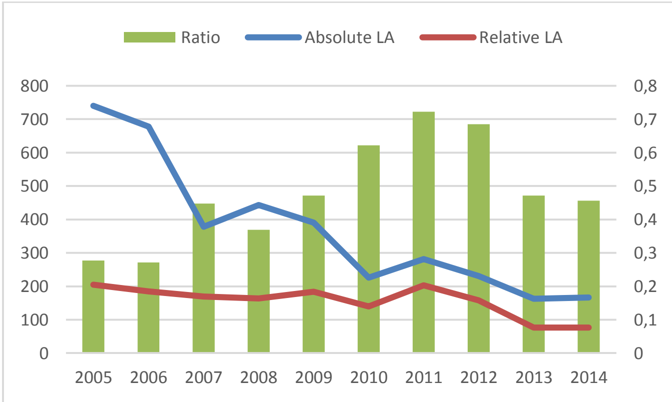

Figure 5 -Yearly evolution of the median LA in Aiguille du Midi area

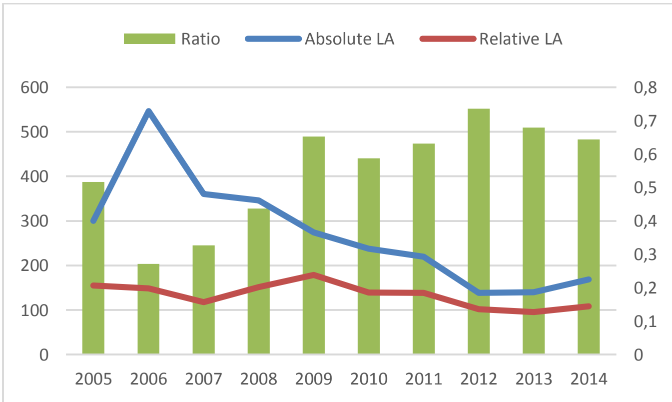

Figure 6 -Yearly evolution of the median LA in Pic du Midi area

One note also a similar improvement trend in the most recent years. Considering the absolute errors distances it seems possible to identify on all sites two different periods. The first ranging from 2005 to 2009 included during which the median values are significantly greater than the relative LA. The second, from 2010 where the absolute LA benefits from a nice improvement getting closer to the relative LA median values. However it is noticeable the evolution of the improvement varies according to the site mainly because the some changes in the LLS concern only local areas. This is mainly the case after a new sensor installation or a nearby sensor upgrade. As a result, the coverage of a given local area may evolve differently than the rest of the network.

V. DISCUSSION

Looking at the difference between relative and absolute LA since 2010 it can be noted both parameters follow the same trend. This is particularly clear on the Mont Ventoux and Aiguille du Midi sites whereas this change seems to occur later in 2012 in Pic du Midi. Indeed this site is located nearby Spain where sensors are still a majority of IMPACT 141 that are not running the onset time correction so preventing the LA to improve. The shift between the two curves might correspond to a systematic error present in the absolute LA possibly due to either the lightning location process or the quality of the dataset itself. Indeed, all the individuals taken into account in the analysis are assumed to be upward discharges but some nearby downward return strokes may be polluting the dataset increasing de facto the median distance between the strokes and the tower.

In addition, the graphs shows in the former years a big discrepancy between the two curves starting in 2005 with a difference about 500 m slowly decreasing from year to year till 2010 when both curves fit. This difference is fairly visible although variable in time and magnitude on all sites. This effect might be related to a side effect of the GSP based relative LA calculation. The GSP identification algorithm groups consistent strokes on an inter-stroke distance criteria whose maximum limit is 500 m. Thus, the absolute locations errors being in the same order as this maximum distance limit, the GSP algorithm might remove the less accurately located strokes from GSP by creating a new ground contact (NGC). Then, the method is considering only the best located individuals leading to underestimating the real location errors.

In order to verify the presence of this effect the evolution of the average GSP per negative CG flash is computed that is shown in figure 7 below. From 2005 to 2008 included the parameter exhibits a value of about 1.16 and does not vary very much. At a first glance this tends to show the poorly located strokes do not artificially create GSP while the mean value is close to one. However, according to the statistics in the literature and the results obtained during the GSP validation process this value seems to be a too low and might rather traduce a stroke detection efficiency issue. The big increase in 2009 related to the upgrade of the network with LS7001 sensors confirms this hypothesis. As a result, one can conclude the computation of LA based on GSP lightning data may introduce a bias principally at the former years when the LLS was producing less accurate locations but it clearly cannot explain the big discrepancy observed between the two curves between 2005 and 2009.

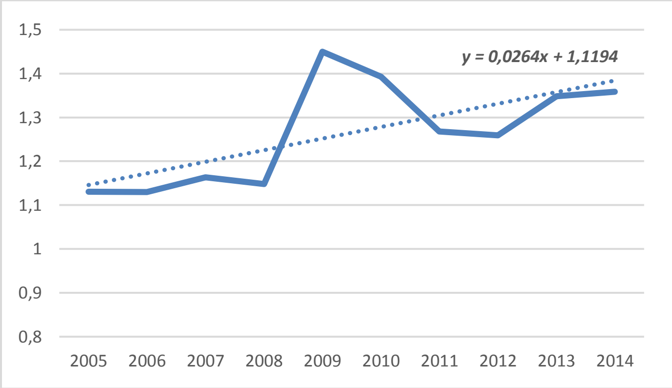

Figure 7-Evolution of the number of GSP per flash in France

Among all the most probable reasons explaining the nice improvement of the absolute LA is the upgrade of IMPACT sensor to LS700X. It was made during the 2008-2009 period in France but started earlier in 2007 in Germany and Austria. These latter sensors contribute to improve the coverage of the Aiguille du Midi region. Associated to the LA improvement is a better assessment of the measurements standard deviation and in particular on timing information in 2010. Finally, this same year, was the upgrade of the central analyzer. It is likely, this latter change in the LS configuration has produced greatest effects in decreasing the location errors. It is interesting to note a similar improvement of the absolute LA was noticed in the area of the Gaisber Tower just after the upgrade of the lightning processor. These results tend to demonstrate the successive technological upgrades have led to a nice improvement in the absolute LA. However, that is still not understood is the reason why the absolute LA has mainly benefited from those changes whereas the relative LA seems to be not affected in the same order of magnitude.

However, the good fitting of both curves that can be observed during the recent years allows to conclude the relative LA computed with the GSP method provides a fairly good proxy to assess the absolute location errors in France.

VI. CONCLUSION

The purpose of this present work is to determine whether the relative LA can be used as a good proxy for the absolute LA assessment on large scales and for LLS using the state of arts lightning detection technology. The first step of the study consists of developing a method based on the use of the GSP data to compute the relative LA on a period ranging from 2005 to 2014. The result shows the median value of this parameter is smaller than 160 m on all the 10 years period. As expected an enhanced improvement can be noted since the onset time and the propagation corrections features are in use leading to a relative errors median value of about 100 m. The second step of the study consists of comparing both relative and absolute LA on three particular reduced areas where the systematic errors can be assessed because elevated objects trigger lightning. Despite some nearby downward cloud-to-ground return strokes polluting the dataset and introducing a bias in the median value of the absolute error it turns out both relative and absolute LA fit nicely in the recent years. The latter result tends to demonstrate the relative LA computed based on the GSP lightning data is a relevant proxy for absolute LA assessment at large scales.

According to this general result, it is possible to state the location errors committed by the Météorage LLS in France are statically smaller than 200 m median value on all the 10 years period decreasing down to 120 m in the recent years.

A future work would consist of filtering out the dataset used for the absolute LA estimation from possible outliers in order to improve the absolute LA assessment. A better method would be to use validated measurements on instrumented towers to ground truth data measurement and perform the comparison with the local relative LA based on GSP lightning data.

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