Analysis of Outliers in the EUCLID Network

W.Schulz[1], D.R. Poelman[2], R.Kaltenböck[3], E. Goudenhoofdt[2] and L. Delobbe[2]

1) OVE-ALDIS, Vienna, Austria
2) Royal Meteorological Institute of Belgium, Brussels, Belgium
3) Austro Control, Innsbruck, Austria

Abstract

In this paper we provide details about a performance parameter of the EUCLID lightning location system (LLS) called the percentage of outliers. The term outlier means an event (CG stroke or IC pulse) located by the LLS on a wrong place. In this study we use data from weather radar networks in two regions of the EUCLID network (Belgium and Austria) to distinguish between outlier and non-outlier. It is shown that the percentage of outliers is sensitive to changes in the network and also changes related to the location algorithm itself. The overall percentage of outliers for both regions is between 0.8% and 1.9% for a distance to the nearest precipitation of 2km.

Keywords: Lightning location systems, performance, outliers.

1. Introduction

During recent years the performance of lighting location systems (LLS) got more and more attention [1]. The network operators of the largest low-frequency (LF) networks in the world namely the NLDN (National Lighting detection network) in the U.S. and EUCLID (**EU**ropean **C**ooperation for **LI**ghtning **D**etection) in Europe performed several campaigns to validate their network performance in terms of Detection Efficiency (DE), Location Accuracy (LA) and peak current estimation (see [2], [3], [4], [5], [6], [7]).

The latest comprehensive performance analysis of the EUCLID network based on ground truth data, showed that the flash DE and the stroke DE for negative cloud-to-ground discharges in large regions of the EUCLID network are greater than 93% and 84% respectively [7]. For positive events flash and stroke DEs are greater than 87% and 84 % respectively. This performance analysis further showed the continuous improvement of the LA from 2005 to 2014 with a median LA of about 100m within the majority of the network in 2014. In [7] ground truth observations are collected in Austria and Belgium, the same regions of the EUCLID network which are under consideration in this paper. Fig. 1 shows the layout of the EUCLID network during August 2015.

Depending on the customer application of the LLS data, different performance features are more, while others are less important, e.g. a power utility normally does not care about the intra-cloud DE of a LLS network.

For the aviation control and MET services which often trigger warning messages based on LLS data, the number of events located on a completely wrong position, which are often called outliers, are an important performance parameter of a LLS.

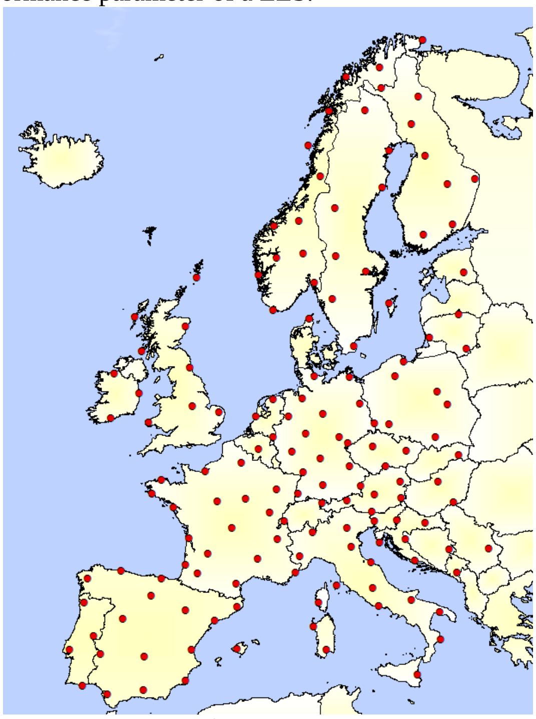

Fig. 1: EUCLID network configuration 2015/08

Recently Poelman et al. [8] presented a paper dealing with the LLS performance analyses regarding outliers in Belgium, mainly based on hourly quantitative precipitation estimation (QPE) derived from weather radar data. They used a rainfall intensity threshold of 0.1 mm/h and a search radius varying between 2 and 10 km to distinguish between outlier and non-outlier events. They found that over a 10 year period between 2006 and 2015 the number of outliers varied significantly and decreased from 2010 on. Further an increase of the percentage of outliers during the winter months and larger average semi major axis of outliers compared to non-outliers was demonstrated.

The goal of this paper is to extend this first outlier analyses for EUCLID in Belgium with data in and around Austria and to use radar observations with a 5-min timestep.

2. Used Data and Methodology

2.1 EUCLID Data

Cloud-to-Ground (CG) and intra-cloud (IC) data from the EUCLID network [9] are used from 2011 till

2015. During this time period significant improvements of the EUCLID network regarding DE and LA were made [7]. Those improvements are related to new sensor technology, new timing error corrections and a new location algorithm. A list of network changes which might modify the amount of outliers are the following:

- Continuous replacement of sensors with old technology (LPATS and IMPACT)
- 12/2011: Relaxing some PostFilter limits
- 12/2012: Significant reduction of the time and angle standard deviation together with the requirement of two angle information for a good location
- 01/2015: New location algorithm

The sensor upgrades in the network also caused some problems in 2014 because some sensors in Italy had to be re-installed and configured. From the day of the setup till the sensors were calibrated those sensors were configured to provide timing information only. Timing only sensors often increase the number of outliers.

2.2 Weather Radar Data

As already mentioned above we use for this paper data from the Austrian and the Belgium weather radar network.

Austro Control is operating C-band EEC polarized Doppler weather radars in Austria and upgraded the radars from DWSR-93C to DWSR-5001C/SDP/CE between 2011 and 2013. The underlying volume scan contains 16 elevations (0.1 up to 67°) up to a range of 224 km. Doppler and statistical clutter filters are applied before creating maximum projection of reflectivity composite every 5 minutes with a spatial resolution of 1 km. For more details see [10], [11], [12].

The Austrian weather radar network consists of four weather radar stations (see Fig. 2). Two of the radar sites are located on the foothills of the Alps close to Vienna and Salzburg (Rauchenwart and Feldkirchen) and the other two radar sites are situated in the west and south of Austria at mountain tops (above 2000 m) close to Innsbruck and Klagenfurt (Patscherkofel and Zirbitzkogel).

The usage of weather radar data for outlier detection is more complicated in mountainous regions. We realized this by using data from a single radar (Rauchenwart – see Fig. 1) only. It was necessary to limit the detection range of this radar to 50 km to avoid influences of radar beam blockage to the result. To mitigate the influence of the mountainous region we used for Austria composite radar data. To have an overall homogenous coverage of weather radar data we further used the data of a 5 min time period only, if all 4 weather radar stations were in operation. Further we have to note that the Austrian weather radar network was upgraded during the time period of the analyses and during this process the individual radar gains were modified/adapted. This adaptation of the gain could easily influence the findings in this paper.

The composite data exhibits 14 reflectivity levels starting from 11.8 dBZ. In the provided data set the smallest reflectivity greater than zero is at a level of 12 dBZ. The used reflectivity in the composite is the maximum reflectivity over altitude which is provided by one of the radars. The limit of composite and also the weather radar coverage is the outer contour of all four radar regions shown in Fig. 2.

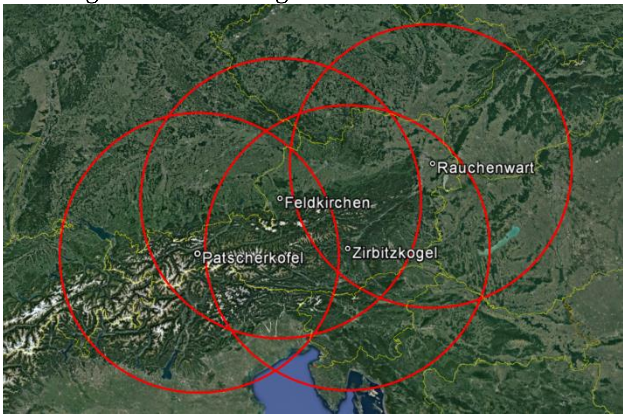

Fig. 2: Positions of the 4 Austrian weather radar stations and their detection range

Three radars are located in Belgium (see Fig. 3), of which two are operated by the Royal Meteorological Institute of Belgium (RMIB). One of these radars, operational since 2001, is positioned in Wideumont (49.9°N, 5.5°E) at 592 m above sea level in the southeast of Belgium, see Fig. 3. This particular radar is a single-polarization C-band Doppler radar and performs a 5-elevation scan every 5 minutes producing reflectivity measurements up to 240 km. The radar thus covers Belgium, Luxembourg as well as parts of France, the Netherlands and Germany. We refer the interested reader to Goudenhoofdt and Delobbe [13] which explains in more detail the treatment of the raw data. In this work the 5-min rain rates are used. The threshold is set at 0.2 mm/h, below which the rain rates are set to zero. This threshold is similar to the 12 dBZ reflectivity threshold used for the Austrian data following the $Z=200*R^{1.6}$ relationship from Marshall and Palmer [14], with Z being the reflectivity and R the rain rate.

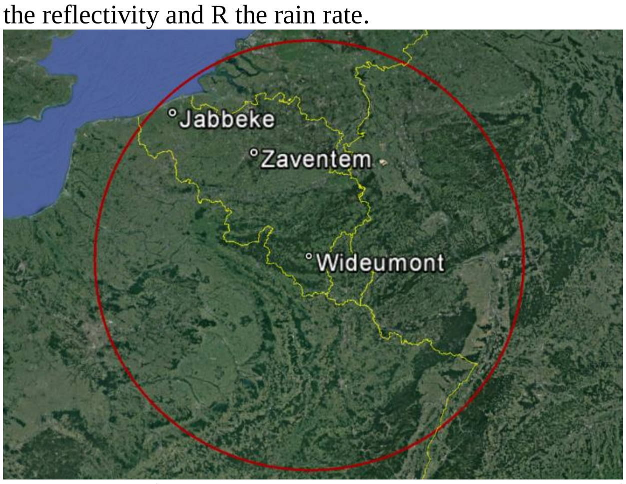

Fig. 3: Position of the 3 radar stations in Belgium and detection range of Wideumont radar station

Both radar networks provided for this analysis radar data with a 5 min time resolution.

2.3 Methodology

All different events located by the LLS (CG strokes and IC pulses) in the corresponding time interval of the radar data are superimposed. An event is categorized as outlier if no radar data within a certain distance exists. The distance (dx) between the lightning event and the nearest precipitation to categorize the event as an outlier/non-outlier is varied over 3 different values (2 km, 5 km and 10 km). This method is supposed to give a lower limit of the percentage of outliers because some of the outliers will, by chance, be placed in a region with radar reflectivity.

3. Results

The overall number of outliers for CG strokes and IC pulses, relative to the total number of events, are given in Fig. 4 for different distances (dx) between the event location and the nearest precipitation. Except for the year 2011 a similar trend during those 5 years for both countries can be seen, with an increase of outliers from 2012 to 2014 and then a decrease in 2015.

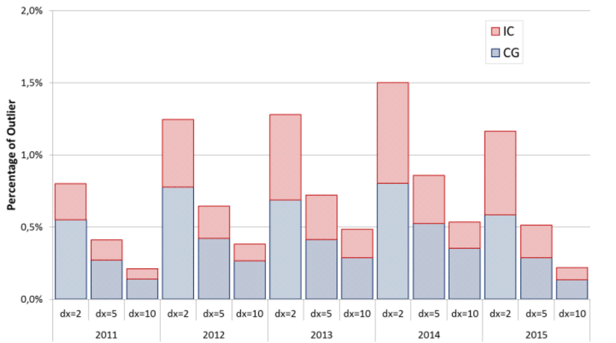

Fig. 4a: Percentage of outliers in Austria (inside the weather radar coverage)

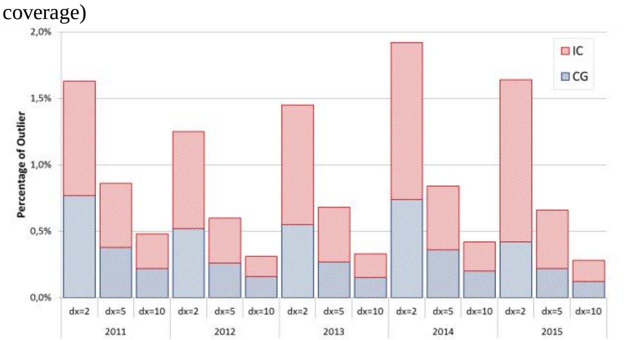

Fig. 4b: Percentage of outliers in Belgium (inside the weather radar coverage)

The overall number of outliers for both regions is between 0.8% and 1.9% for a distance to the nearest precipitation of dx=2km. As expected the number of outliers for each individual year decreases, down to 0.2%, for larger distances to the nearest precipitation. It is further interesting to note that the amount of outliers in Belgium is generally somewhat larger compared to Austria. This could be related to the differences of the used radar data (different absolute gain calibration and maximum reflectivity versus reflectivity of the lowest altitude).

The significant higher number of outliers in Belgium in 2011 can be attributed to a timing only sensor located close to Belgium (Den Haag) and another sensor in the Netherlands which was moved and afterwards operated for a longer time period with deactivated angle information (Roermond). From our experience we know that timing only sensors or sensors providing only time information often cause additional outliers. For the vast majority of the sensors which provide angle and time information those measurements have to be consistent. Measurement consistency is an important method to reduce the number of outliers.

Because the increase of outliers in 2014 compared to 2012 and 2013 appeared in the Austrian and Belgium data we can exclude any local sensor configuration as reason. We think that this increase is related to a change in the location algorithm, relaxing a filter parameter in order to allow more strokes with large peak currents to be detected.

In 2015 a completely new location algorithm was used which improved the grouping of sensor messages to individual events. Although this algorithm exhibited a bug which was corrected after the lightning season the percentage of outliers decreased compared to 2014.

The number of outliers versus month and independent of the categorization of the event (CG or IC) is shown in Fig. 5. The percentage of outliers is related to the total number of events (CG strokes and IC pulses).

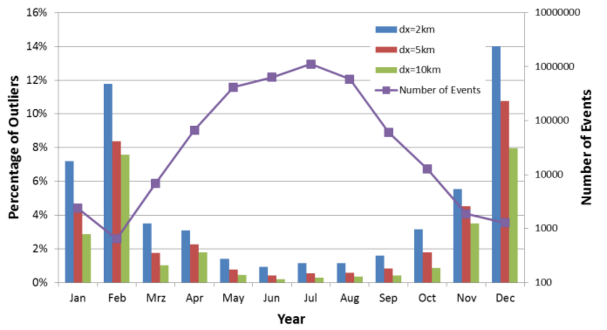

Fig. 5a: Percentage of outliers versus month in Austria

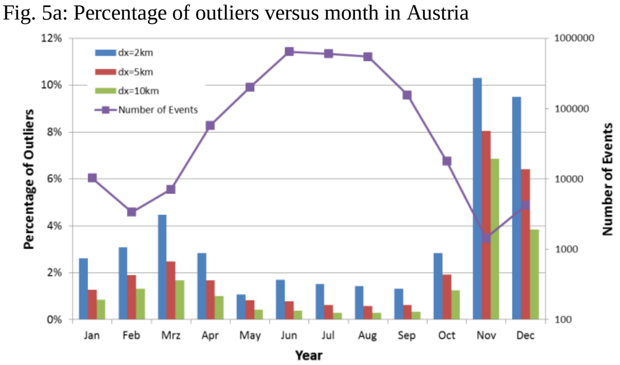

Fig. 5b: Percentage of outliers versus month in Belgium.

Interestingly the number of outliers increases during the winter months in both regions. This feature could be either related to the fact that more sensor upgrades occur during winter or that precipitation of winter thunderstorms is more difficult to detect with the weather radars. Sensor upgrades often result in disabled angle information because systematic angle errors (site errors) are unknown and the correction takes a while because lightning data is necessary. Therefore those upgraded sensors started operation with disabled angle information during winter months.

Nevertheless the number of events during winter is much smaller compared to summer and this increase may not be too important for the majority of applications.

All percentages in Fig. 6 are related to the individual group, e.g. percentage of negative IC is related to the total number of negative IC. Fig. 6 shows that positive CG strokes exhibit the highest percentage of outliers and that this percentage varies significantly over the years and region. This could be related to the fact that positive CG are often accompanied with significant incloud activity ([15], [16]) what causes the electromagnetic field to be complicated. It is therefore harder to detect such strokes and also harder to located them correctly.

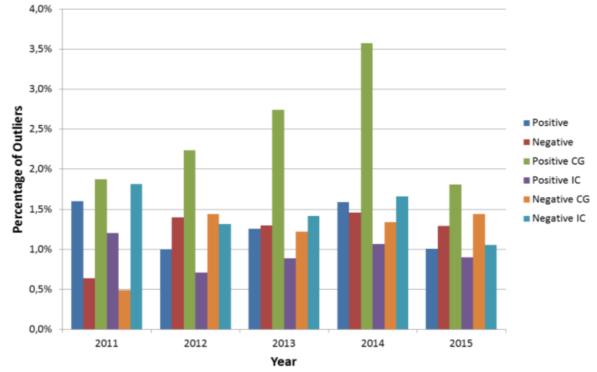

Fig. 6a: Percentage of outlier versus event type in Austria.

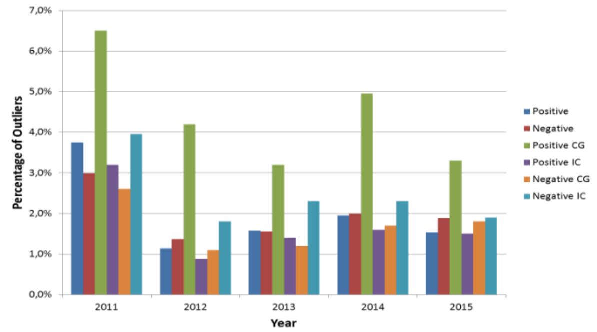

Fig. 6b: Percentage of outlier versus event type in Belgium.

The decrease in 2015 of positive CG strokes could be also an indication of the improved performance of the new location algorithm. It can be further seen in Fig. 6 that the percentage of outliers are more or less unrelated to polarity of the event.

4. Discussion/Summary

Using weather radar data in different regions for outlier detection and comparing them is not a straightforward task. The reason are potential calibration issues in different networks with maybe even different technology, usage of different reflectivities (e.g. maximum over altitude versus lowest altitude reflectivity) and local beam blockage problems especially in mountainous regions. A workaround, at least for the last problem, is to use composite radar data. Independent of those difficulties the overall results in both regions agree quite well. The overall percentage of outliers for both regions is between 0.8% and 1.9% for a distance to the nearest precipitation of dx=2km. This percentage of outliers is quite small having in mind that dx=2km is already a quite a strict criteria.

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