Location Accuracy Improvements of the Austrian Lightning Location System During the Last 10 Years

Wolfgang Schulz

***Abstract*—The Austrian lightning location system ALDIS (Austrian Lightning Detection and Information System) has been in operation for more than 20 years. During this time the system has almost continuously been upgraded and improved. This paper gives an overview of the used methods to evaluate the location accuracy, the main improvements in the network during the last 10 years and their resulting impact on the location accuracy of the network.**

***Keywords*—Lightning location systems (LLS), Location accuracy.**

I. Introduction

Lightning location systems (LLS) are nowadays a standard tool for power utilities, MET services, insurance companies and others. It is obvious that the different users have different needs regarding the performance of the LLS, e.g. power utilities require a mean location accuracy in the order of 100 m whereas for a MET service the location accuracy is not so important (depending on the application).

Beside the detection efficiency and misclassification rate the location accuracy (LA) is one of the most important performance parameters of a LLS.

The main focus in this paper is the validation of the ALDIS network using independently collected ground truth data. Nevertheless it is also possible to assess the LA with spatial analyses of the average length of the 50% confidence ellipses assigned by the LLS to each located stroke, if for all the individual sensors the actual standard deviations of the angle and time measurements are properly configured in the location algorithm. It was shown in [1] that there is a close relation between the average semi-major axis and the actual LA which was determined with data from the Gaisberg Tower (GBT) lightning current measurements. Therefore this type of analysis is preferable for larger networks.

A recent paper [2] describes the advantages and disadvantages of different methods to validate the performance of LLS, namely

- LLS self reference
- Rocket triggered lightning and lightning strikes to tall objects
- Video camera recordings
- Inter comparison among LLSs

The most important advantage of video camera recordings lightning compared to lightning strikes to instrumented towers is the possibility to collect relatively large numbers of ground-truth lightning data in different regions within the coverage area of a LLS. Therefore LA determined from video camera data recorded at different locations in the LLS covered area is valid for a larger region compared to the LA determined from lightning strikes to tall towers which is actually only valid for the region of the tower location.

The Austrian lightning location system ALDIS (Austrian Lightning Detection and Information System) is part of the the **EU**ropean **C**ooperation for **LI**ghtning **D**etection (EUCLID), and therefore in this paper it is always referred to the ALDIS/EUCLID network. The technology used throughout the ALDIS/EUCLID network is provided by Vaisala Inc.

This paper presents the instrumentation used to determine the LLS-LA, describes the recent detection network updates which mainly affected the LA, and presents the results about the improvement of the LA during the 10 year period.

II. ALDIS/EUCLID Network

The Austrian network ALDIS is an integral part of the EUCLID lightning location system which was established in 2001 as a cooperation of six countries (Austria, France, Germany, Italy, Norway and Slovenia) and subsequently other countries as Spain, Portugal, Finland and Sweden also joined this cooperation. As of December 2014 the EUCLID network employs 149 sensors, 7 LPATS, 10 IMPACT, 31 IMPACT ES/ESP and 101 LS700X sensors, listed in order from the oldest to the newest sensor version. EUCLID is one of the LLS worldwide with most validation studies done so far. Validation of the EUCLID network (see Fig. 1) was primarily done with independent ground truth data, e.g. tower measurements and video and E-field data records. Most of the

W. Schulz is with the Austrian Electrotechnical Association - Department ALDIS, Kahlenberger Str. 2A, 1190 Vienna, Austria (w.schulz@ove.at).

validation in terms of location accuracy (LA) and detection efficiency (DE) was done in Austria [3], [4], [5], but validation campaigns took also place in Belgium [6] and in France [7] in 2011 and 2012 respectively.

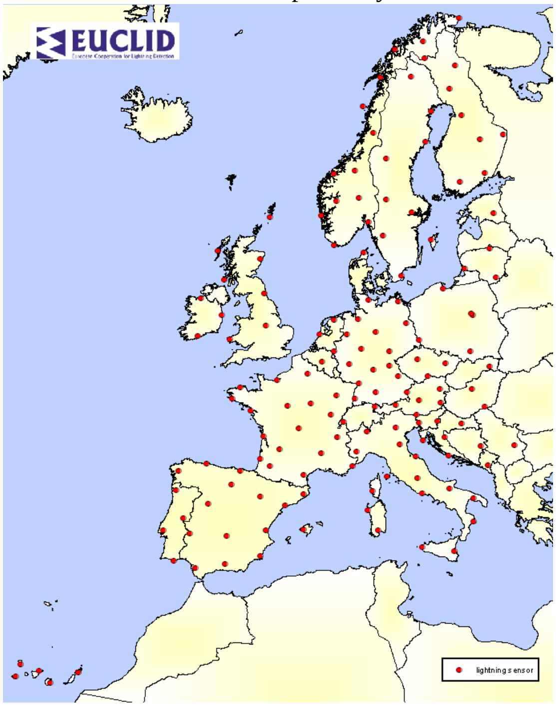

Fig. 1: EUCLID network layout December 2014

The basic EUCLID network layout in terms of sensor sites and number of sensors in and around Austria has not changed during the last years. Only some of the sensors were upgraded to newer technology and some location algorithm updates were implemented (see chapter IV).

III. Instruments to Evaluate the LLS Performance

There are different instruments used to evaluate the performance of a LLS. In Austria we use data from a video and field recording system (VFRS) and data from lightning current measurements on an instrumented tower.

A. Video and field recording system

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, a camera, and a PC based data recorder. The system is described in detail in [8], [9] and [10].

B. Tower measurements

Since 1998 direct lightning strikes to a radio tower have been measured at Gaisberg, a mountain next to the city of Salzburg in Austria [11]. 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 [11].

IV. Important Changes in the ALDIS/EUCLID Network

A. Original network (until2005)

Up to 2005 the ALDIS network consisted of 8 IMPACT sensors. More information about the original network can be found in [12].

B. Update to LS700X technology (2006)

The ALDIS network was the first network in Europe which was upgraded to the LS700X sensor technology in the beginning of 2006. At this time not all the new features of the LS700x technology were used. Therefore the LS700x sensor was basically performing like an IMPACT sensor regarding location accuracy.

C. New location algorithm (2008/07)

At this time an updated location algorithm was installed at the EUCLID/ALDIS central processor. This updated location algorithm does a better job in grouping sensor data to a given stroke and also performs iterations after rejection of sensor messages which exhibit inaccurate time or angle measurements.

D. Sensor based onset time calculation (2011/07)

Up to 2011 the so called onset time was estimated at the central processor. The onset time is the time information which is almost not altered during propagation over different distances and is the time which is used for the location calculation based on the arrival time differences. Therefore it is important to determine the onset time as accurately as possible. In 2011 a new feature at the LS700x sensor was taken into operation, the so called sensor based onset time calculation [13]. This type of onset time calculation is significantly more accurate compared to its estimation at the central processor.

E. Index of refraction (2012/06) and propagation correction (2012/12)

In a country like Austria the correction of timing errors is very important. Those timing errors are the result of a combination of propagation effects due to finite ground conductivity and elongation of the propagation path [14]. Due to the fact that most of the Austrian territory is covered by the Alps those timing errors can be significant.

As an example for the time error correction in Austria the angle and distance dependent time corrections of sensor #2 (Schwaz) are shown in Fig. 2. This sensor #2 is located in a mountain valley that stretches from west to east and is surrounded by high mountains (up to 3000 m). The highest mountains are in the south of the sensor site. Compared to sensors located in a more or less flat region this sensor site shows a really complex structure for timing correction. It shows large time errors in the west and in the south-east of sensor 2. All the regions in blue color are outside the operational range of this sensor and are therefore not corrected for timing errors.

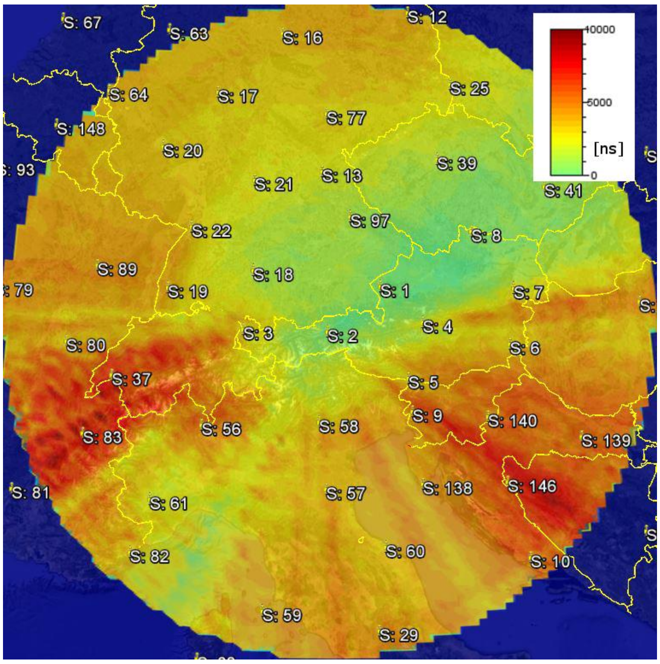

Fig. 2: Example of a propagation correction for Austrian Sensor #2 (Schwaz). The sensor is located in the center of the circular area.

Further to the propagation correction also a more accurate index of refraction was introduced in the location algorithm. The index of refraction is used to adapt the propagation speed (speed of light) of the lightning electromagnetic pulse to the actual propagation speed over ground with finite ground conductivity.

V. Location Accuracy Results

A. Gaisberg Tower (GBT) Measurements

Lightning strikes to the GBT are a perfect reference to evaluate the location accuracy of the ALDIS/EUCLID network, because the tower location (47.805°N / 13.112°E) is known with high accuracy. Almost no positive lightning data is available from the GBT measurements and therefore the results are only valid for negative strokes. Only return stroke pulses are used in the following analyses. Fig. 3A shows a plot of the ALDIS/EUCLID stroke location error for the period 01/2005-06/2008. After 06/2008 the main upgrades of the network related to LA were implemented. The plot origin corresponds to the actual tower location. A median location error of 281 m and a standard deviation of 471 m were determined for all the 278 strokes (see Fig. 3A). Typically location errors exceeding 1 km (only 9.7% of the cases) were observed for strokes located by two or three sensors only or when the location was calculated based on erroneously grouped sensor messages resulting from discharges that occurred almost simultaneously at two separate locations.

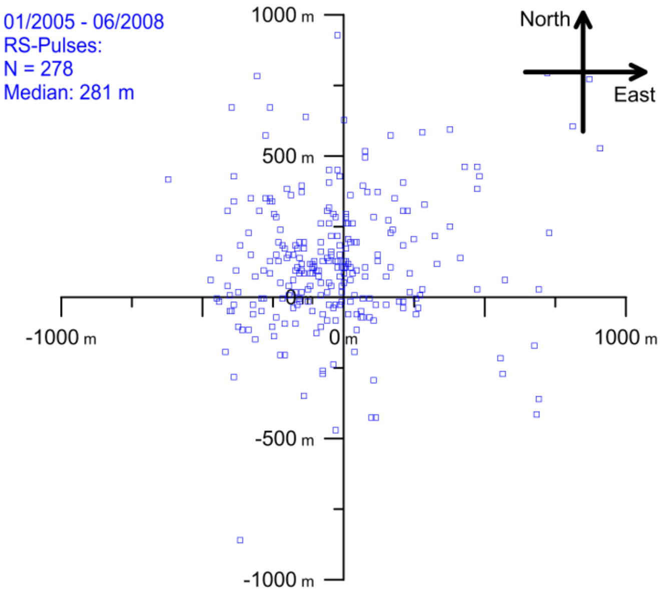

Fig. 3A: LA at the GBT before the main upgrades

After all the upgrades in 07/2012 the location error decreased significantly. The median location error decreased to 65 m with a standard deviation of 139 m. No strokes with a location error greater than 1 km occurred.

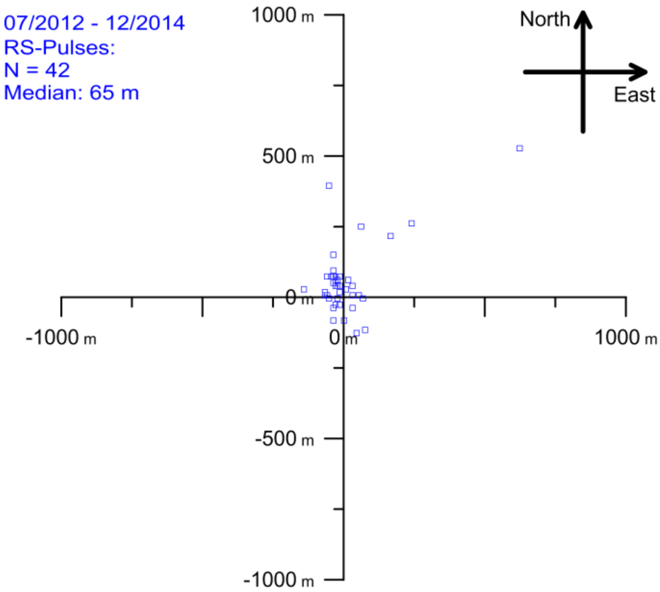

Fig. 3B: LA at the GBT with all the updates applied

The improvement of the LA during the 10 years period can also be seen in Fig.4. This figure shows the moving median of the location error over the last 100 return strokes directly measured at the GBT. The plot starts with 21.1.2005 because on that day the first strike to the GBT during the period of investigation was recorded. The graph starts on the 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 median calculation. The last recorded stroke during the period of interest occurred on 14.5.2014.

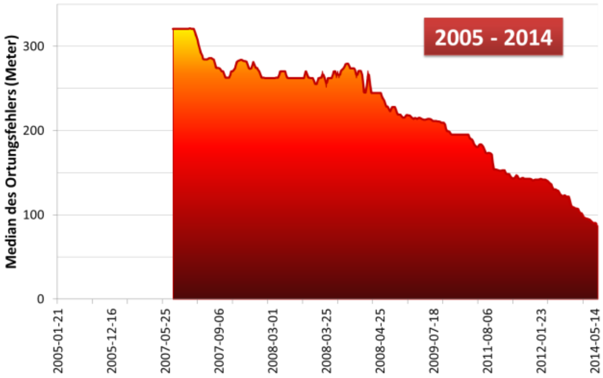

Fig. 4: EUCLID/ALDIS median location accuracy improvement over 10 years.

The LA improvements due to all the changes in the network which are described in chapter IV are clearly visible.

In case of a tower strike the tower itself radiates an electromagnetic field. Compared to a natural lightning strike to ground, when the lightning channel is often tortuous and branched, the tower is completely straight and therefore the resulting electromagnetic field radiated from the tower is more suitable for LLS sensors. As a result, the estimated LA of a LLS using lightning strikes to towers as ground-truth is expected to be somewhat better than that for natural lightning.

B. Video and E-Field data

Location accuracy with video and E-field data is determined from video recorded multi-stroke flashes which exhibit two or more strokes in the same lightning channel to ground. The method to estimate the LLS accuracy is described in more detail in [15],[16]. As positive multi-stroke flashes with two or more strokes in the same channel are rare, only negative flashes are analyzed and the results are therefore only valid for negative flashes.

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 [15].

TABLE 1: MEDIAN LA IN AUSTRIA DETERMINED WITH VIDEO AND E-FIELD DATA 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)

Table 1 shows the significant improvement of LA from 2009-2010 to 2012 [17] related to sensor based onset time calculation, propagation correction and updated propagation speed. No video data are available for the time before 2009.

VI. SUMMARY

In this paper the applied methods to validate the LA of the Austrian LLS have been described and an overview is given on the implemented changes and upgrades in the LLS to improve the LA.

According to the results from tower measurements and video and E-field recordings, the current median value for the LA of the Austrian LLS is in the range of 100 m.

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