2012
22nd International Lightning Detection Conference
2 – 3 April • Broomfield, Colorado, USA
4th International Lightning Meteorology Conference
4 – 5 April • Broomfield, Colorado, USA

LOCATION ACCURACY EVALUTION OF THE AUSTRIAN LIGHTNING LOCATION SYSTEMS ALDIS

W. Schulz[1], C. Vergeiner[2], H. Pichler[1], G. Diendorfer[1], K. Cummins[3]
[1] OVE-ALDIS, Vienna, Austria
[2] Institute of High Voltage Engineering and System Management,
Graz University of Technology, Austria
[3] Dep. Atmospheric Sciences, University of Arizona, USA
E-mail (corresponding author): w.schulz@ove.at

1. INTRODUCTION

Lightning location data have been used by a variety of applications for more than 20 years. Since the first lightning location systems (LLS) were installed the performance of those networks has been steadily improved, e.g. by using newer sensor technology and employing improved location algorithms. Because of these continuous improvements in LLS technology it is important to validate the performance of those systems almost continuously. The most important performance parameters of LLS are the detection efficiency (DE), the location accuracy and the accuracy of the peak current estimate. Often it is tried to determine the performance by cross comparison with other LLS networks. Unfortunately those comparisons do not provide clear results and a number of questions are left unanswered, e.g. [1]. The most straightforward approach to determine the performance is to compare LLS data with ground truth data. Different approaches to collect lightning ground truth data are used:

(1) Lightning to instrumented towers
(2) Triggered Lightning
(3) Combined video and E-Field Studies

All the methods mentioned above have their advantages and disadvantages. As an example it is possible to determine the peak current and absolute location of the subsequent strokes with lightning to instrumented towers and triggered lightning but not with video and E-Field studies. Another difference between these ground-truth methods is the local validity of the results. Performance results determined with (1) or (2) are basically only valid for the site of the measurements, whereas the combined results from (3) recorded at different locations are valid for larger regions. Combined video and E-Field studies (3) have also the advantage of providing DE estimates for first strokes, which is not possible for triggered lightning. It is also difficult to determine first-stroke DE from lightning to instrumented towers, since a majority of flashes triggered by tall objects start with an upward propagating leader which serves to establish an initial continuing current [2].

In Austria we are employing lightning to an instrumented tower and combined video and E-Field measurements to determine the performance of the Austrian LLS ALDIS. Since 1998 direct measurements of lightning currents have been performed at the Gaisberg Tower (GBT) [2]. The location accuracy analysis with GBT data resulted in a median of about 350m [3] and is in agreement with model-based estimates for the location accuracy. But as mentioned before, this value is only valid for the location of the GBT. In order to evaluate the performance in a variety of locations, we developed a portable GPS synchronized video- and field measurement system [4-6]. The data recorded by this system allow us to infer the DE and the location accuracy of the LLS. Further it is possible to use these video and field data to evaluate the type-categorization (cloud-to-ground vs. cloud pulse) assigned by the LLS to located discharges. In this paper we will focus on the location accuracy parameter and compare the results from the GBT measurements with the results from video and E-Field measurements.

2. DATA

Since 2009 GPS synchronized E-field and video measurements were performed in the eastern and southern part of Austria. In 2009 measurements were made during two thunderstorms in the south of Vienna (Bad Vöslau) and in 2010 the measurements were performed in the south of Austria during 15 thunderstorms at 13 different locations shown in Fig.1.

Fig. 1: Measurement locations 2009 and 2010

In the following analysis we have studied 37 multi-stroke flashes out of a total of 154 recorded negative flashes to determine the location accuracy. We have excluded flashes with separate ground strike points only, single stroke flashes and flashes where the lightning channel to ground was not clearly visible on the video. Table 1 shows for each days of data recording a summary of the recorded and useable flashes for the location accuracy analysis in this paper. From the 37 multi-stroke flashes we could estimate 103 location differences (errors) of subsequent strokes, relative to the first stroke in the same channel, to determine the location accuracy of the LLS.

Table 1: Number of measured negative flashes

Date	Location	# negative Flashes	#Flashes used
29.06.2009	Bad Vöslau	31	7
03.08.2009	Bad Vöslau	14	3
27.05.2010	Graz/Platte	1	0
12.06.2010	Liezen	12	0
13.06.2010	Arzberg/Schöckl	7	1
18.06.2010	Puch bei Weiz (Kulm)	9	1
01.07.2010	Maria Saal Magdalensberg	3	0
03.07.2010	Dellach im Gailtal	5	0
12.07.2010	Obervellach im Mölltal	4	2
13.07.2010	Murau	9	3
13.07.2010	Althofen	2	0
15.07.2010	Kalsdorf bei Graz	10	1
17.07.2010	Arzberg/Schöckl	2	0
18.07.2010	Hammersberg Schöckl	35	19
10.08.2010	Assling	10	0
	Total	154	37

The GBT measurement setup and recorded data are comprehensively described in [2]. In this paper we exclusively used subsequent return stroke data for the location error analysis. So called ICC-pulses [2] are not considered.

3. METHODOLOGY TO DETERMINE THE ACCURACY FROM THE VIDEO DATA

The accuracy of the LLS was determined by searching in the video data for strokes which obviously followed the same lightning channel. Fig. 2 shows as an example a flash with a total of nine strokes terminating at four ground strike points. By analyzing the individual video frames it can be seen that stroke 3, 5, 6, 7, 8 and 9 are using the same channel to ground. Assuming that the strokes which are using the same visible channel to ground terminate at the same ground stroke point, the LLS should ideally locate those strokes exactly at the same location. In reality we observe differences in the individual stroke coordinates reflecting the accuracy of the LLS. By calculating the distances of those strokes to the first stroke in the channel it is possible to determine the accuracy of the LLS.

It is stated in [7] that there is still a possibility that the channel geometry and/or the actual ground contact varied slightly from stroke to stroke and were not resolved by the video camera. Therefore the differences determined by this method should be regarded as upper bounds of the actual position differences.

1^{st} stroke 2^{nd} stroke 3^{rd} stroke

4^{th} stroke 5^{th} stroke 6^{th} stroke

7^{th} stroke 8^{th} stroke 9^{th} stroke

Fig.2: Flash #222 (18.07.2010 00:22:55 UTC) with 9 strokes

4. THEORETICAL BACKGROUND ABOUT THE LOCATION ERROR DISTRIBUTIONS

4.1 Absolute error of LLS locations from lightning to a tower or from triggered lightning

The location error distribution follows a Rayleigh distribution because the error of a location is a combination of two Gaussian distributions in latitude and longitude (or x and y). Because the distance d (error) from the tower of the triggering station is calculated by $d=\sqrt{x^2 + y^2}$, the resulting error is a Rayleigh distribution R with $R=\sqrt{N_x^2 + N_y^2}$ where $N_x=N(0,\sigma_x)$ and $N_y=N(0, \sigma_y)$. We assume that the standard deviations are the same for all strokes.

4.2 Location errors determined from video records

Both LLS locations (location of first stroke and subsequent strokes in the same channel) exhibit location errors which are a combination of Gaussian distributions in latitude and longitude (or x and y). The LLS error is determined by calculating the distance between the two LLS provided locations $d = \sqrt{(x_1 - x_2)^2 + (y_1 - y_2)^2}$. Again we assume that each location error is a combination of two Gaussian distributions $N_x(0,\sigma_x)$ and $N_y(0,\sigma_y)$. Therefore the standard deviation of the resulting distributions $N_{\Delta x}$ and $N_{\Delta y}$ (Eq. (1) and Eq. (2)) is increased by a factor of $\sqrt{2}$ because when subtracting two (assumed independent) Gaussian random variables with the same standard deviations, the resulting Gaussian distribution has a standard deviation increased by a factor of $\sqrt{2}$.

$$N_{\Delta x} = N_x(0,\sigma_x) - N_x(0,\sigma_x) = N_{\Delta x}(0, \sigma_x*\sqrt{2}) \qquad (1)$$

$$N_{\Delta y} = N_y(0,\sigma_y) - N_y(0,\sigma_y) = N_{\Delta y}(0, \sigma_y*\sqrt{2}) \qquad (2)$$

Therefore the resulting distribution is again a Rayleigh distribution with $R=\sqrt{N_{\Delta x}^2 + N_{\Delta y}^2}$. It is worth to note that this approach does not show any potential systematic error.

4.3 Comparison of LLS accuracy estimates derived from tower and video measurements

Assuming that the Gaussian distributions of location errors at the instrumented tower and errors derived from the video records at a given location are the same, the resulting median and standard deviation values from the tower measurements and the video records differ by a factor of $\sqrt{2}$. This factor is even correct if σ_x and σ_y are not equal, but the same at the tower site and the site of the video records. In order to make the results from the tower and the video records comparable we have to

- scale the distances between the individual stroke locations following the same channel by $\sqrt{2}$, and
- eliminate the systematic error obtained for the LLS data for lightning to the instrumented tower.

It is important to note that by using data from video measurements it is NOT possible to obtain any potential systematic error in the data (see results from the GBT [3]).

5. RESULTS

Analysis of the 103 first to subsequent stroke distances within 37 flashes result in a median location accuracy of 368m (STD=650m). In this distribution the scaling factor of $\sqrt{2}$, mentioned above, is already considered. The distribution of those 103 distances is shown in Fig. 3. Only 4 distances are greater than 2 km and therefore not shown in Fig.3.

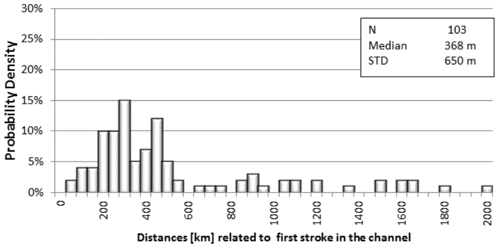


Fig. 3: Location error distribution derived from the video and E-field records 2009-2010

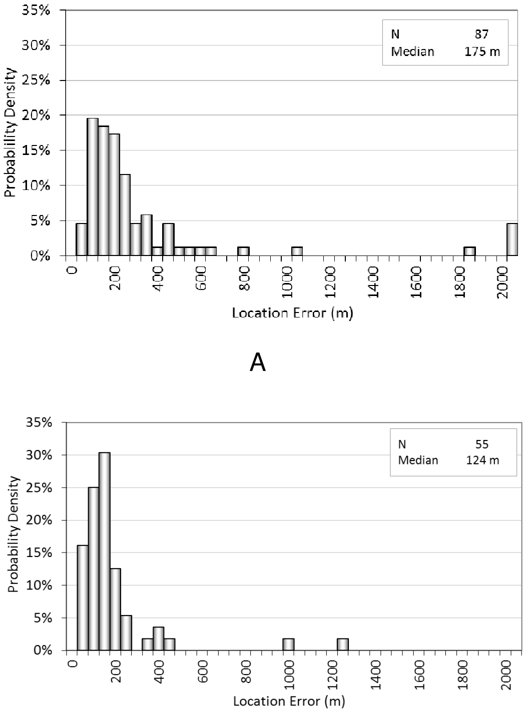
The comparison of the data in Fig. 3 with location accuracy data derived from return strokes to the GBT is done for three different time periods because during those time periods different sensor technology and location algorithms were employed by the ALDIS system.

Before the upgrade of the ALDIS LLS in 2005 the network was operated by using IMPACT 141T sensors. With those sensors and with the original location algorithm a median location error of 368m (STD=768m) was observed at the GBT [3]. Please note that by **chance** the median accuracy at the GBT and the video measurements are identical.

In the following years the sensors were upgraded to the LS7000 technology and also a new location algorithm was employed which does a better job of grouping individual sensors messages to a given stroke. From 7.7.2008 until 30.6.2011 the ALDIS network was operated with the new location algorithm but with LS7000 not using the so called “new onset time” determined by the sensors [8]. Beginning in July 2011 the new onset time calculation at the LS7000 sensors was activated.

Fig. 4 shows the distribution of the location errors for the two post upgrade periods. Compared to the network before the upgrade of the sensors and the location algorithm, the median location accuracy improved from 368 m to 175 m in the 2008-2011 time period (Fig. 4A). It can be further seen from Fig. 4 that the median location error further reduced from 175 m to 124 m by activating the new onset time calculation. The systematic location error decreased during this time from 109 m (pre upgrade period) to 66 m (7.7.2008-30.6.2011) and 44 m (1.7.2011 – 24.1.2012).

To be able to compare the GBT data with data from the video measurements it is necessary to eliminate the systematic location error from the GBT measurements. After eliminating the systematic error the median location error for the period 7.7.2008-30.6.2011 decreased from 175 m to 156 m. From the video records collected in 2009 and 2010 we



A

B

Fig. 4: Location errors for the periods 7.7.2008 - 30.6.2011 (A) and 1.7.2011 - 24.01.2012 (B) determined with data from measurements at the GBT.

obtained a median location error of 368 m. Assuming that the location error at the GBT location and in the south of Austria, where the video records were acquired, are quite similar the result is reasonable having in mind that the location error coming from video observations are upper limits [7].

6. SUMMARY AND DISCUSSION

In this paper we present a detailed accuracy analysis of the Austrian LLS ALDIS with Video and E-field measurements and data from tower measurements at the GBT. We further present the theoretical background to determine and compare the location accuracy of LLS by video measurements. The big advantage of video measurements is that if the measurements are carried out on different places, the result is valid for larger regions. A further advantage is that it is possible to determine a DE including first strokes. The disadvantage is that regionally-specific location bias errors cannot be evaluated.

The location accuracy results from the video measurements are compared to measurements during the same period at the GBT. The location accuracy determined from the video measurements of 368 m is in reasonable agreement with the location accuracy determined from the tower measurements (156 m, after removal of the systematic error).

We also show the influence of the new onset time calculation on the location accuracy. With the new onset time calculation the location error at the GBT decreased from 175 m to 124 m. It is interesting to note that the new onset time calculation significantly reduces the systematical location error, down to 44 m.

REFERENCES:

[1] Drüe, C., Hauf, T., Finke, U., Keyn, S., Kreyer, O., 2007: Comparison of a SAFIR lightning detection network in northern Germany to the operational BLIDS network. Journal of Geophysical Research, Vol. 112, D18114.

[2] Diendorfer, G., H. Pichler and M. Mair (2009), Some Parameters of Negative Upward-Initiated Lightning to the Gaisberg Tower (2000–2007), IEEE Trans. Electromagn. Compat., 51, 3, pp.443-452.

[3] CIGRE WG C4.404A (2009), Cloud-to-Ground Lightning Parameters Derived from Lightning Location Systems - The Effects of System Performance, Brochure No. 376, CIGRE.

[4] Schulz W., Lackenbauer B., Diendorfer G., Pichler H. (2005), LLS data and correlated continuous field measurements, SIPDA, Sao Paulo, Brazil.

[5] Schulz, W. and G. Diendorfer (2006), Flash Multiplicity and Interstroke Intervals in Austria, ICLP, Kanazawa, Japan.

[6] Schulz, W., H. Pichler,, G. Diendorfer (2010), Evaluation of 45 negative flashes based on e-field measurements, video data and lightning location data in Austria, ICLP, Cagliari, Italy.

[7] Biagi, C. J., K. L. Cummins, K. E. Kehoe, and E. P. Krider (2007), National Lightning Detection Network (NLDN) performance in southern Arizona, Texas, and Oklahoma in 2003–2004, J. Geophys. Res., 112, D05208, doi:10.1029/2006JD007341.

[8] Honma N., K.L. Cummins, M.J. Murphy, A.E. Pifer, T. Rogers (2011), Improved Lightning Locations in the Tohoku Region of Japan Using Propagation and Waveform Onset Corrections, 3rd International Symposium on Winter Lightning (ISWL2011).