

On the Performance of the Austrian Lightning Detection and Information System (ALDIS)

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Abstract

In Europe, several Lightning Location Systems (LLS) are operated in order to monitor the lightning activity and to gather information on lightning discharges inside a certain area. For operators of LLS as well as for users of lightning location data, information on the performance of their particular LLS is important. In the past, several studies on the performance of LLS were done with cross comparison of different LLS data sets, but such cross comparisons unfortunately do not provide clear results. Another approach to determine the performance of LLS is a comparison of LLS data with so called "ground truth data". Such ground truth data are for example "natural lightning to instrumented towers" (e.g. Gaisberg tower), "artificial rocket triggered lightning" or "video and E-field measurements of natural lightning discharges". Each of these methods has its advantages and disadvantages. In this paper we describe combined video and E-field measurements, the used Video-Field Recording System (VFRS) and our approach to gather ground truth data with such a VFRS. Based on the comparison of VFRS Data with LLS we show the Detection Efficiency (DE) for flashes and for strokes as well as the Location Accuracy (LA) of the Austrian Lightning Detection and Information System (ALDIS) for the southern and eastern part of Austria.

1 Introduction

Data of LLS provide important information on the behaviour of lightning and thunderstorms. On one hand, LLS (e.g. ALDIS/EUCLID) provide information on individual flashes (e.g. time, location, peak current, number of strokes, etc.), on the other hand properties of individual storms (e.g. frequency of lightning occurrence, storm movement, etc.) can be observed. Lightning location data is an important data for analysing previous thunderstorm events as well as for thunderstorm nowcasting and initiation of thunderstorm warnings. Since ALDIS is operational all year long, estimations on the regional and monthly occurrence of lightning discharges in Austria can be done by using several years of LLS data. As the ALDIS data is important for e.g. power utilities it is worth to investigate the performance of this LLS. Most important performance parameters of LLS are the Detection Efficiency (DE) of cloud to ground (CG) flashes and strokes and the Location Accuracy (LA) of located strokes.

There are different approaches to determine the DE and LA of LLS. Since different LLS often cover the same region, a cross comparisons of different LLS data sets is possible. The significance of such cross comparisons is questionable because a proof on the correctness or existence of detected strokes/flashes cannot be provided by the considered LLS. Another

approach to determine the performance is the comparison of LLS data with so called "ground truth data". Such ground truth data can be acquired via:

- a) Natural lightning to instrumented towers
- b) Artificial rocket triggered lightning
- c) Video and E-field measurements of natural lightning discharges

If a stroke or flash is observed by a ground truth data providing system, a proof on the existence of this individual stroke or flash can be guaranteed. This is a major advantage compared to LLS data cross comparisons. However, systems which provide ground truth data have their particular advantages and disadvantages. Instrumented towers or rocketed trigger systems are locally restricted and mostly experience special types of lightning discharges (e.g. upward lightning) whereas video and E-field measurements can be deployed at various places. Therefore a large region can be investigated and the observation of all thunderstorm related cloud to ground discharges is possible. Different ground truth data providing systems provide different data for comparison. Instrumented towers as well as rocketed trigger systems typically observe the current wave shapes via direct current measurement whereas a VFRS, used for this study, provides electric field and video data. E-field data allows the calculation of peak currents via field-to-current conversion [4] [5]. High-speed videos give a proof

on the existence of flashes and strokes and provide, depended on the properties of the used camera, a lot of additional information (e.g. ground strike points, continuing current durations, leader propagation properties etc.). To determine the LLS DE and LA of large region, the comparison of LLS data with VFRS ground truth data is an appropriate way.

2 Instrumentation

a) Austrian Lightning Detection and Information System (ALDIS)

The Austrian Lightning Detection and Information System, a LLS within the European Cooperation for Lightning Detection (EUCLID) is operational since 1992. The ALDIS system consists of 8 Sensors (Vaisala LS 7000) deployed at different sites all over Austria. Each sensor has an average detection range of ~400 km. As ALDIS is integral part of EUCLID, EUCLID sensors contribute to the detection and location of strokes in Austria. Figure 1 gives an overview on the ALDIS and surrounding EUCLID sensor sites.

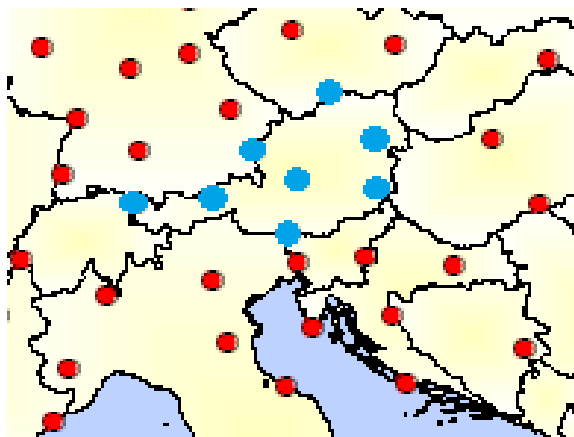


Figure 1: ALDIS and EUCLID Sensors inside and around Austria, March 2013. The blue dots show ALDIS Sensors, the red dots show the surrounding EUCLID sensors.

Detailed information on ALDIS and EUCLID can be found in [12], [13], www.aldis.at and www.euclid.org.

b) Video Field Recording System (VFRS)

The VFRS is a transportable system and independent of any external power supply. It consists of three main parts. First part is the calibrated E-field measurement consisting of a flat plate antenna, an integrator-amplifier, a fibre optic link and a digitizer. The bandwidth of the E-field measurement is in the range from about 350Hz to about 1MHz. A 12 bit digitizer with a sampling rate of 5 MS/s is used for data acquisition. Second part of the system is a "high speed camera" with 200 fps (5 ms/frame), 640 × 480 pixel and 8 Bit greyscale resolution. Third part is a GPS clock to provide an accurate time

stamp for the E-field and the video data. Detailed description of the used VFRS can be found in [2] and [15]. Figure 2 shows the VFRS in the field with all its parts.



Figure 2: VFRS deployed in the field. 1-flat plate antenna, 2-integrator amplifier, 3-fibre optic transmitter, 4-fibre optic cable, 5-high speed camera, 6-GPS antenna, 7-VFRS components inside the car, 8-power supply. Note: The generator is typically 50 m distant from the car and the antenna deployed.

For the observations, described in this paper, the VFRS was operated in the manual trigger mode using an adjustable pre- and post-trigger. We typically recorded 6 seconds of data with 2 seconds of pre-trigger data per observed flash. These 6 seconds of recorded data ensure capturing the entire lightning discharge, with all its strokes and continuing currents.

3 Data

Between 2008 and 2010 we recorded 236 flashes during 18 storms at 15 different sites in southern and eastern Austria. Out of these 236 flashes, 82 flashes lowered positive (+CG) and 154 flashes lowered negative (-CG) charge to ground. Table 1 shows the sites and the number of recorded flashes per storm.

Table 1: Date, observation site and number of recorded flashes between 2008 and 2010.

Date	Observation site	-CG	+CG
01.06.2008	Gießhübl	0	9
29.06.2009	Bad Vöslau	31	0
03.08.2009	Bad Vöslau	14	1
27.05.2010	Graz	1	0
07.06.2010	Graz	0	2
12.06.2010	Liezen	12	1
13.06.2010	Arzberg	7	9
18.06.2010	Puch/Weiz	9	0
01.07.2010	Maria Saal	3	0
03.07.2010	Dellach/Gail	5	0
04.07.2010	Wernberg	0	6
12.07.2010	Obervellach	4	0
13.07.2010	Murau	9	0
13.07.2010	Althofen	2	0
15.07.2010	Kalsdorf	10	34
17.07.2010	Arzberg	2	20
18.07.2010	Hammersberg	35	0
10.08.2010	Assling	10	0
2008-2010	Southern and eastern Austria	154	82
		236	

The sites for VFRS observations were chosen in order to collect data all over southern and eastern Austria. Figure 3 shows the regions where lightning discharges were observed.

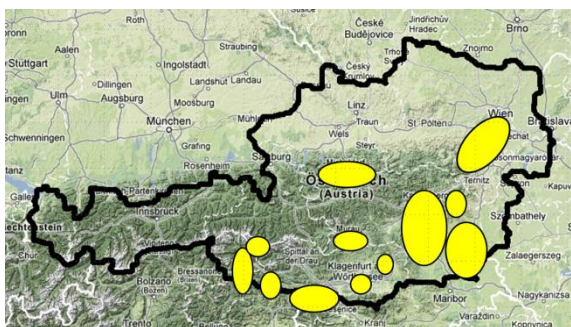


Figure 3: Regions in Austria between 2008 and 2010 where the VFRS was deployed. Inside the yellow marked regions, lightning discharges were observed.

Most of the lightning discharges were observed in the region around Graz, Styria due to the high thunderstorm activity during the observation period. It is worth to mention that during some storms, the majority of observed discharges were of positive polarity (see Table 1). The percentage of observed positive flashes is ~35 % (82/236). This is significantly more than typically observed [1].



Figure 4: Location of 66 observed positive flashes in the north of Graz. The number beside each location describes the flash number in our dataset.

Interestingly, ~80 % (66/82) of all observed positive flashes between 2008 and 2010 as well as the majority of this +CG producing storms were located in the north of Graz (see Figure 4). A good example for such an interesting behaviour is a storm observed between 17.07.2010 and 18.07.2010 (see Table 1). First observation of this storm (Arzberg) in north-western direction of Graz showed ~91 % (20/22) positive flashes whereas the later observation of this storm event (Hammersberg) to the south east of Graz showed 0 % (0/35) positive flashes. This behaviour should be investigated in the future.

4 Analysis

a) Detection Efficiency (DE)

There are two different types of DE concerned in this paper, the flash DE and the stroke DE. The DE describes the percentage of ground truth lightning events, flashes or strokes, detected by the LLS.

$$DE = \frac{\text{Number}_{\text{detected events}}}{\text{Number}_{\text{observed events}}} * 100\%$$

Figure 5 shows the approach to determine whether an individual stroke was detected by ALDIS or not.

b) Location accuracy (LA)

By analysing the VFRS video data, we were searching for strokes, following the same channel to ground. If the lightning channel of such strokes is visible down to ground, it can be assumed that all strokes following this channel have almost the same ground strike point. If at least 2 strokes follow the same channel and if they are detected by the LLS, the difference in location between these stroke locations can be calculated. It is worth to mention that each LLS location exhibits a location error. To be able to compare video determined location errors with location errors determined by e.g. instrumented towers a scaling factor of $\frac{1}{\sqrt{2}}$ has to be used. Detailed information can be found in [3] and [14].

Note: As the ground strike point of an individual stroke is not always visible, the calculated location error distances are upper limits. Further with this approach, we cannot consider any systematic location error.

Figure 6 shows a four stroke flash with 3 strokes following the same channel (4th stroke is not shown).

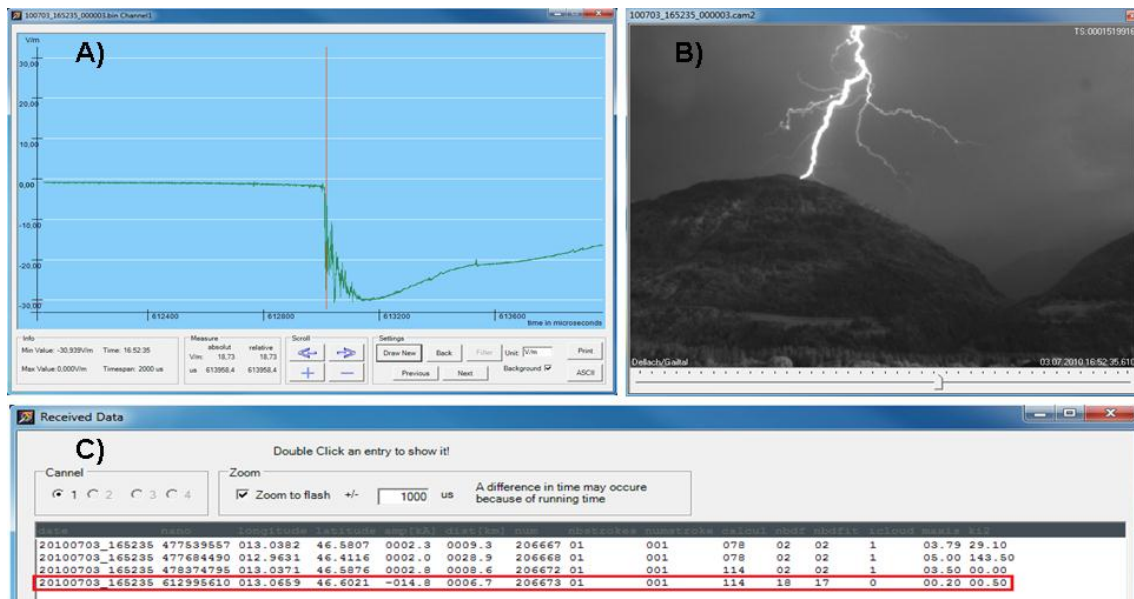


Figure 5: A) and B) show the E-field record and the corresponding video frame for a recorded stroke. The vertical red line in A) shows the detection time, including propagation time from the stroke to the VFRS, of this individual stroke C) shows the corresponding ALDIS data. The red marked line in C) is the ALDIS data set for this stroke.



Figure 6: A), B) and C) show three strokes out of a four stroke flash. All these strokes follow the same channel to ground and were detected by ALDIS. Therefore ALDIS provided location data for each of these flashes and distances between location of A) and B) as well as A) and C) can be calculated. Note: This Figure shows images out of the continuing current sequence because the images of the return stroke sequence are saturated.

By using VFRS data, a LA determination for positive strokes cannot be done due to a) the low multiplicity of positive flashes and b) the reason that positive multiple stroke flashes using the same channel are quite rare. Ishii et al., 1998 reported that all observed positive multiple stroke flashes within their data set created a new channel to ground [8]. During one storm in 2010 we observed two positive flashes with a multiplicity of 2 where first and subsequent stroke followed the same channel to ground. Information on these flashes can be found in [9].

5 Results

a) Detection Efficiency (DE)

The data sets and results for flash and stroke detection efficiency can be seen in Table 2.

Table 2: DE of ALDIS for positive and negative flashes and strokes based on the comparison of VFRS and ALDIS data.

	VFRS	ALDIS	DE
neg. flashes	154	151	98,05
neg. strokes	540	449	83,15
pos. flashes	82	80	97,56
pos. strokes	88	81	92,05

It can be seen that the DE for positive strokes is higher than for negative strokes. As positive strokes typically have higher peak currents (see Figure 10 and Figure 12), they are easier to detect compared to negative strokes. However, due to the poor multiplicity of positive flashes a missed stroke often leads to a missed flash (see Figure 9).

b) Location Accuracy (LA)

To determine the LA, 37 flashes with 103 stroke distances were analysed. The median LA of the ALDIS system during the time period 2008-2010

is 368 m and the standard deviation is 650 m. Figure 7 shows the histogram for the investigated stroke distances.

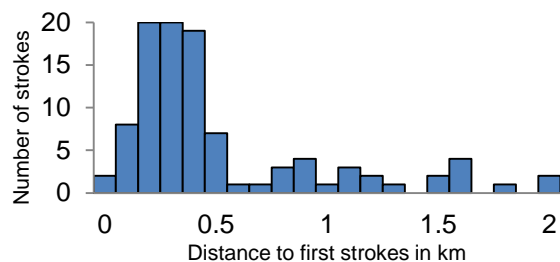


Figure 7: Histogram of location errors. Only four distances were greater than 2 km and are not shown in this figure.

c) Multiplicity

Between 2009 and 2010 154 negative flashes with a total of 540 strokes were observed. Out of these 154 flashes, 27.27 % (42/154) consisted of a single stroke. The mean and median multiplicity for negative flashes is 3.32 and 2 respectively. Figure 8 shows the percentage of negative strokes per flash for ALDIS and VFRS data.

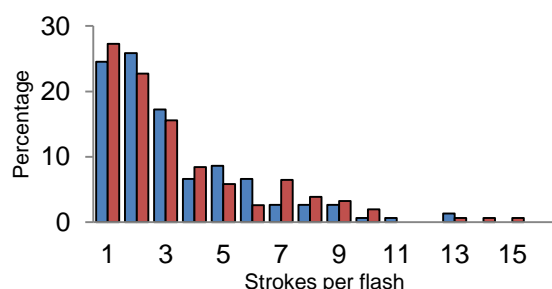


Figure 8: Histogram of negative strokes per flash for ALDIS data (blue bars) and VFRS data (red bars). Differences in the multiplicity are due to not detected or misclassified strokes.

Between 2008 and 2010, 82 positive flashes with a total of 88 strokes were observed. Out of these 82 flashes, 92,68 % (76/82) consisted of a single stroke. The mean and median multiplicity for negative flashes is 1.07 and 1 respectively. Figure 9 shows the histogram of positive strokes per flash for ALDIS and VFRS data.

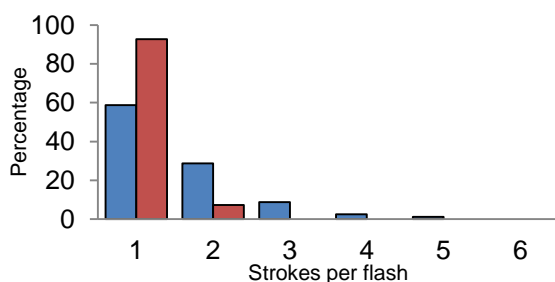


Figure 9: Histogram of positive strokes per flash for ALDIS data (blue bars) and VFRS data (red bars). Differences in the multiplicity are mostly related to the misclassification of cloud discharges (e.g. IB pulses).

It can be seen that ALDIS data for positive strokes deviates significantly from the VFRS data. This behaviour is mostly related to misclassifications of cloud discharges. Further information can be found in [9].

d) Peak current

Between 2009 and 2010, ALDIS data of 448 correct detected negative strokes were analysed regarding peak currents. The minimum peak current was -2.3 kA and the maximum peak current was -171.0 kA. The mean and median value of the analysed peak currents are -14.9 kA and -11.5 kA respectively. Figure 10 shows the peak current distribution for the investigated negative strokes up to -100 kA. Only two strokes had peak current values higher than -100 kA (-136.8 kA and -171.0 kA).

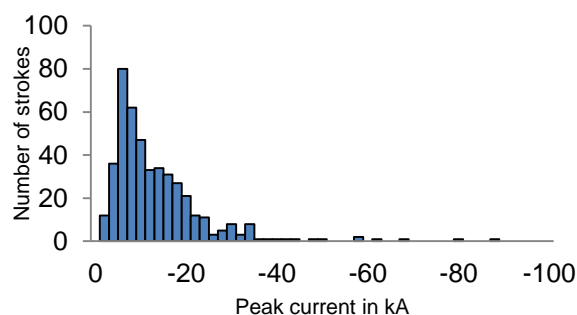


Figure 10: Distribution of peak currents for negative strokes. Only two strokes between 2009 and 2010 had peak currents higher than -100 kA (-136.8 kA and -171.0 kA) and are not shown in this figure.

As the field to current conversion is validated for negative subsequent strokes only, we present the peak current distribution for 149 clearly as subsequent strokes identified negative strokes (see Figure 11). The minimum peak current was -2.5 kA and the maximum peak current was -37.3 kA. The mean and median value of the analysed peak currents are -11.6 kA and -8.8 kA respectively.

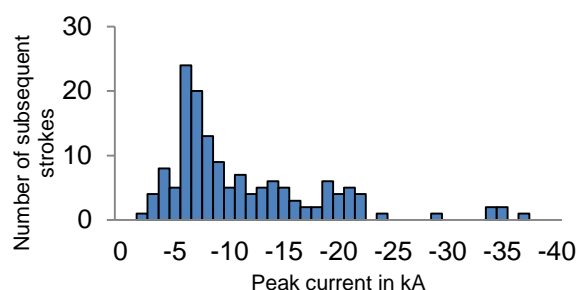


Figure 11: Peak current distribution of 149 negative subsequent strokes.

Also 81 correct detected positive strokes were analysed. The minimum peak current was 9.3 kA and the maximum peak current was 207.6 kA. The mean and median value of the investigated peak currents are 43.7 kA and 33.7 kA

respectively. Figure 12 shows the peak current distribution for the analysed positive strokes.

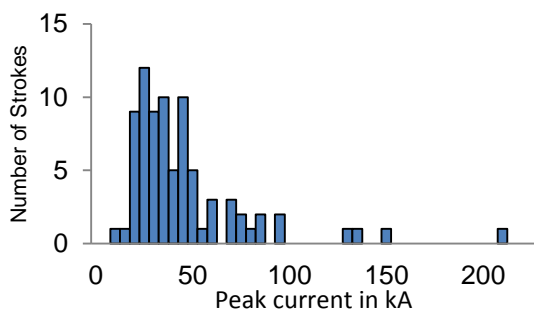


Figure 12: Distribution of peak currents for positive strokes.

Currently no electric field to current calibration of LLS data for positive strokes exists. For these estimated peak currents, the field to current conversion factor for negative strokes is used [1] [10].

6 Summary

This study provides information on the detection efficiency and location accuracy valid for southern and eastern Austria. The results are in good agreement with results from Gaisberg Tower measurements [11].

The mean and median multiplicities of positive and negative flashes are within the expected range. A significant higher percentage of single stroke flashes could be determined in this study (~10 % more than in other studies reported) [1].

For all peak currents, presented in this study, only data of correctly detected strokes were used. Peak currents of ALDIS are continuously compared with current measurements at Gaisberg tower. In average, ALDIS peak currents are 5 % below the measured currents at the Gaisberg tower [6]. As the field to current conversion is valid for negative subsequent strokes only, the presented values and distribution for negative subsequent strokes provide a good overview on peak currents of negative subsequent strokes in Austria.

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