Validation of Detection of Positive Flashes by the Austrian Lightning Location System ALDIS

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Abstract — In this paper we present a detailed evaluation of the performance of the Austrian Lightning location system (LLS) ALDIS regarding detection of positive flashes. Additional to the performance of the LLS some parameters of positive flashes are determined. We also present detailed information about two positive flashes with a subsequent stroke following the same channel to ground as the first stroke.

Keywords-component: Lightning location systems; positive lightning; performance evaluation; E-field measurements, video recording.

I. INTRODUCTION

Naturally occurring positive flashes are not as frequent as negative flashes [1] and therefore available information about the parameters of positive flashes are not as complete as for negative flashes. Recently Saba et al. [2] published the most comprehensive review about those parameters based on high-speed video observations, lightning location data and E-field measurement data. In their dataset they included and examined also nine positive flashes from measurements in Austria which are also part of the dataset used for the study presented in this paper.

Performance evaluation for lightning location systems (LLS) are currently performed all over the world with ground truth data typically from

- triggered lightning [3], [4]
- tower lightning [5], [6] or
- video and field measurement data [7], [8], [9].

To our best knowledge, for triggered and tower lightning no performance evaluation of LLS regarding positive lightning exists today. Only very limited performance analysis based on video and field measurements are available for positive flashes. In [8] the characteristics of cloud to ground lightning in the great plains were analyzed and a detection efficiency (DE) of the NLDN of 89%/88% for positive flashes/strokes is reported. Ballarotti and coworkers included positive flashes in their general DE statistics and found flash DE of 68% [10] for all flashes independent of their polarity for the Brazilian LLS RINDAT.

In this paper we are presenting an extended version of the initial analyses presented in [11] with more data. In addition some detailed information is given about parameters of positive flashes and especially for two positive flashes with subsequent strokes following the same channel as the first stroke.

II. INSTRUMENTATION

A. Lightning location system

The Austrian lightning location system ALDIS was used to determine the distance from the recording location to the stroke, the polarity and the peak current of the stroke. The Austrian LLS is an eight sensor LLS (type LS7000) manufactured by Vaisala Inc. This eight sensor network is incorporated in the European LLS called EUCLID (see Fig. 1). Therefore the performance determined for the ALDIS network is basically identical with the performance of the EUCLID network in the region of Austria. More details about the ALDIS network and about the EUCLID network can be found in [12] and in [9], [13], respectively.

B. Video and Field Recording System (VFRS)

The electric field recording system consisted of a flat plate antenna, an integrator/amplifier, a fiber optic link, a GPS receiver, a PC with two PCI cards (a Meinberg GPS card and a National Instruments data acquisition card NI PCI-6111) and a data acquisition box from National Instruments. It is important to note that for all measurements a fiber optic link was used to connect the integrator with the data acquisition box in order to avoid any erroneously induced voltages due to the electromagnetic lightning fields.

As video camera a Basler Pilot piA640–210gm camera was used. This monochrome camera (8 bit per pixel) produces, at a maximum frame rate of 200 frames per second (fps), data of about 60 Mbytes per second. The camera is time synchronized to the field recording system and therefore also the camera data are GPS synchronized. A red filter type 29 (dark red) was used in front of the camera lens in order to get better image contrast during daytime recordings. We have set the camera to record with 200 fps for all recordings except five flashes of the data collected in 2008 were recorded with 100 fps.

The VFRS is described in more detail in [11], [14].
III. DATA AND METHODOLOGY

During 15 storms in summer periods from 2008 to 2012 we have recorded a total of 109 positive flashes (see Table I).

<table>
<thead>
<tr>
<th>Year</th>
<th># storms</th>
<th># flashes</th>
</tr>
</thead>
<tbody>
<tr>
<td>2008</td>
<td>1</td>
<td>9</td>
</tr>
<tr>
<td>2009</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>2010</td>
<td>6</td>
<td>72</td>
</tr>
<tr>
<td>2012</td>
<td>7</td>
<td>27</td>
</tr>
<tr>
<td>Total</td>
<td>15</td>
<td>109</td>
</tr>
</tbody>
</table>

The E-field and video records were collected at different locations in the east and south of Austria (see Fig. 2). Flashes are considered as positive if all strokes are of positive polarity. Information about stroke location, peak current and polarity of each stroke was obtained from the LLS data. The polarity of the LLS data was also compared to the polarity provided by the VFRS. No discrepancy was found for all the flashes. The mean distance of all strokes to the recording locations was 22 km (ranging from a minimum distance of 3 km to a maximum distance of 39 km). The grouping of strokes to flashes was basically done applying the same criteria as normally used by LLS with a maximum distance between the stroke locations of 10 km and a maximum flash duration of 1s. No maximum interstroke interval criterion was applied. Positive ground flashes are typically a single stroke and only 10 of the 109 (9%) positive flashes had a multiplicity of greater than one. Only in two flashes a subsequent stroke followed the channel of the preceding stroke clearly visible on the video records. All the other observed subsequent strokes created a new channel to ground.

For the majority of the following analyses we used data from all the 109 flashes but in some cases we could use only a subset of the data, e.g. when observation conditions (poor visibility) did not allow determination of the continuing current (CC) duration with sufficient accuracy.

IV. RESULTS

For all the 109 positive flashes in our data set we determined a mean multiplicity of 1.1 and a percentage of single stroke flashes of 91%.

The peak current for the recorded strokes was provided by the Austrian lightning location system. The median peak current of all the positive cloud-to-ground strokes was 34 kA, the smallest peak current was 7 kA and the largest was 208 kA. The median peak current of 34 kA is somewhat lower than reported in [2] for similar observations in the U.S. where a median peak current of 39.4 kA was determined for 116 positive strokes. We have to note that there exists no peak current calibration of the lightning location data for positive strokes [5] and therefore the values given above are rough estimates, nevertheless the same field to peak current conversion used by the LLS was used in [2] and in this study. Fig. 3 shows the histogram of the peak currents separated in first and subsequent strokes.
With the video data it is also possible to determine the duration of the CC. For a total of 78 strokes a CC was clearly visible. Because of the 5 ms time resolution of the video images we analyzed only CC with a duration longer than 40 ms (long CC according to [16], [17]). Out of the 78 strokes 49 (63%) exhibited a CC with a duration exceeding 40 ms. The mean duration of all long CC was 144 ms. A histogram of all long CC durations is given in Fig. 4.

Out of the 109 positive flashes captured by our VFRS, the LLS located and correctly classified 106 flashes (flash detection efficiency 97%), and out of the 119 strokes the system located and correctly classified 110 (stroke detection efficiency 92%). The criteria to determine the DEs are quite strict because not only the location of the stroke has to be provided with certain quality criteria (chisq < 10 and semi major axis of the error ellipse smaller than 7.5 km), but also the CG/IC categorization by the LLS has to be correct.

Out of the 9 “missed” strokes 5 were still detected but misclassified as intracloud (IC) discharges. This means that basically only 4 (3%) strokes were not detected by the LLS. It is interesting to note that all these four strokes exhibited a long CC. On the other hand the LLS misclassifies also ICs as CGs. For each flash the VFRS records a total of 6 seconds of E-field and video data, 2 seconds before and 3 seconds after the trigger and the second where the trigger occurred. Within these 6 seconds of all recorded flashes the LLS located 205 IC discharges (112 negative and 93 positive ICs) within 30km of the recording site (verified as IC with the E-field and video data). 65% (133/205) of those IC discharges were actually misclassified as CG strokes. 69% (92/133) of the misclassified events were of negative and 31% (41/133) of positive polarity. A reason that the network misclassified more negative than positive events is that the LLS is configured to classify positive events with peak current less than 5 kA as IC discharges. It is interesting to note that only 11% (15/135) had amplitudes $I_p > 10kA$. Having in mind that only 5 +CG strokes out of 119 (4%) were misclassified as IC (+CG $\rightarrow$ +IC misclassification) this means that the network misclassifies mainly in the direction +IC $\rightarrow$ +CG.

Subsequent strokes in positive lightning flashes are really rare events. Even less frequent are positive subsequent strokes which follow the same channel to ground as the previous stroke. Therefore in the following section we describe in more detail the only two positive flashes we have recorded up to now with a subsequent stroke in the same channel as the first stroke.

Both flashes were recorded on the same day (15.7.2010) in the same thunderstorm. During this particular thunderstorm the majority of recorded flashes (34 out of 44 or 77%) exhibited positive polarity, indicating that this thunderstorm was an unusual type of storm. We categorized them as flashes with subsequent stroke in the same channel because on the video frames visible geometric features of the stroke channel between 1st and subsequent stroke are identical. Of course we are limited in our analysis by the field of view.

The distance between the LLS provided locations for the two strokes in the same channel of flash #158 (see Fig. 5) is about 500 m and therefore within the range of location uncertainty of the LLS. The interstroke interval between these two strokes was about 19 ms.
For the second positive flash (#164 – see Fig. 6) with a subsequent stroke in the same channel we estimated an interstroke interval of about 90 ms (determined from the E-field data).

The positive flashes with subsequent strokes creating a new channel to ground exhibit a mean interstroke interval of 202 ms (only 7 flashes are included because for one flash only light appears on the video image).

V. SUMMARY AND DISCUSSION

With data from the VFRS the performance of the Austrian LLS ALDIS regarding positive flashes was analyzed. As a result a flash/stroke DE of 97%/92% was determined. The stroke DE of 92% is significantly higher than the 83% stroke DE for negative strokes [18] because the average peak current for positive strokes is greater than for negative strokes. Flash and stroke DE for positive lightning are somewhat higher in Austria compared to the corresponding values for the NLDN (89%/88% [7]) because the mean sensor baseline (average distance between neighboring sensor locations) in Austria is smaller than in the NLDN. We could further show that the LLS mainly misclassifies in the direction of +IC being erroneously classified as +CG (20%). A comparison of the results from this paper to results from the NLDN for positive flashes [8] is classified as +CG (20%). A comparison of the results from this paper to results from the NLDN for positive flashes [8] is classified as +CG (20%).

![Figure 6: Flash #164, striking point ~27 km from the recording site. A) first stroke, B) subsequent stroke following the same channel](image)

The categorization of flashes with strokes in the same channel was done based on identical geometric features visible on the video frames showing the different strokes. The interstroke intervals of both flashes (19 ms for flash #158 and 90 ms for flash #164) are smaller compared to the mean interstroke interval of positive flashes with subsequent strokes creating a new channel (202 ms based on 7 flashes).

Table 2 shows that the NLDN misclassified 58% (113/195) and ALDIS misclassified 27% (41/151) of the detected +CGs. The percentage of misclassified NLDN +CGs is higher because

- In the NLDN data duplicated events are included
- ALDIS classifies positive events with peak current less than 5 kA as ICs

Nevertheless the current result means that positive CG lightning data is significantly contaminated with IC data.

The data recorded with the VFRS are also useful to determine some specific lightning parameters in Austria. For all the 109 positive flashes in our data set we determined a mean multiplicity of 1.1 and a percentage of single stroke flashes of 91%. The median peak current of all the positive cloud-to-ground strokes was 34 kA (based on LLS data), the smallest peak current was 7 kA and the largest was 208 kA. 49 (63%) out of the 78 strokes exhibited a CC with a duration exceeding 40 ms and the mean duration of all long CC was 144 ms.

Because positive flashes with subsequent strokes in the same channel are really rare we documented two cases of them. The categorization of flashes with strokes in the same channel was done based on identical geometric features visible on the video frames showing the different strokes. The interstroke intervals of both flashes (19 ms for flash #158 and 90 ms for flash #164) are smaller compared to the mean interstroke interval of positive flashes with subsequent strokes creating a new channel (202 ms based on 7 flashes).

REFERENCES


