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Evaluation of a LLS based on lightning strikes to an instrumented tower

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Abstract:
In 1998 a radio tower on a mountain near Salzburg was instrumented for direct measurements of lightning currents. When lightning strikes the tower, the entire lighting current pulse is recorded using a shunt and a PC based digitizing system. This experimental setup allows to analyze the performance of the Austrian LLS (ALDIS) in terms of location accuracy, detection efficiency and its ability to provide an estimate for the stroke peak currents.

Since the beginning of the tower measurements we have recorded about 200 events with a total of about 500 current pulses. Almost all of the events are assumed to be upward flashes as typical for elevated objects.
In the paper we will present some initial results for the above mentioned performance parameters of ALDIS.

1. Introduction

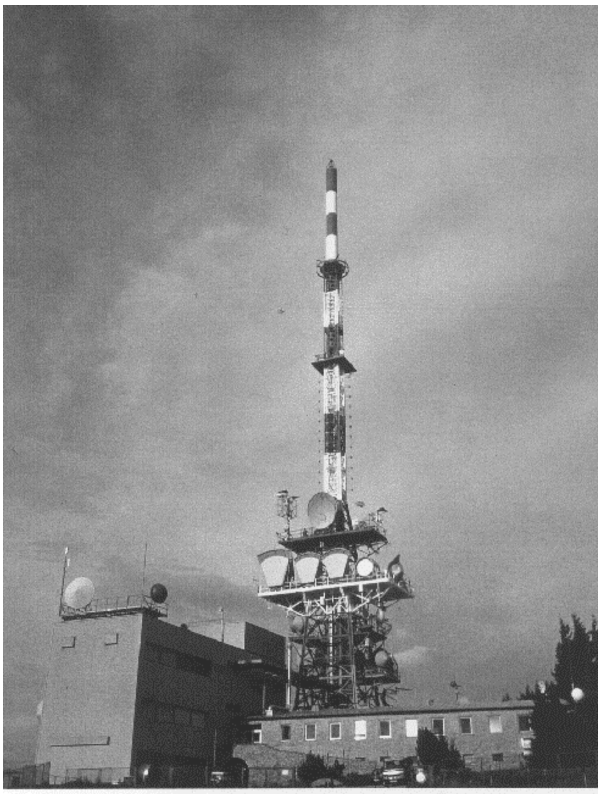


Fig.1: Radio transmission tower at mount Gaisberg

In 1998 we started in Austria to measure currents when lightning strikes a radio tower (Fig.1). This tower was selected because analysis of historical data from the lightning location system showed a flash rate of about 40 – 50 flashes per year to the tower.

The radio tower with a height of about 100 m is located 1287 m above sea level and is situated about 5 km east of the city of Salzburg (Fig.2). The distances to the 8 IMPACT sensors of the ALDIS system are given in Table 1 and they are in the range from 32 km to 261 km.

Table 1:

SENSOR SITE	Distance to the Tower in [km]
DF_1	32
DF_2	116
DF_3	261
DF_4	77
DF_5	142
DF_6	239
DF_7	236
DF_8	204

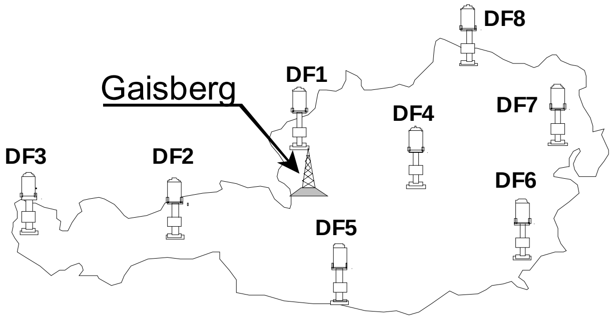
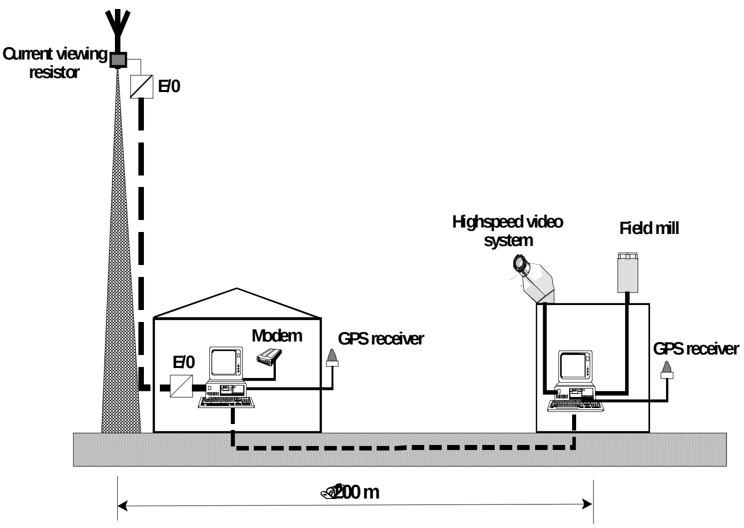


Fig.2: Location of the Gaisberg tower and the sensor sites of the Austrian Lightning Location System (ALDIS)

2. Experimental Setup

In 1998 the experiments started with the registration of lightning currents measured on top of the tower. In summer 1999 additional measurement equipment for recording the static atmospheric electric field and a high-speed video system was installed at a distance of 200 m from the tower. Fig.3 shows an overview on the overall measurement setup.



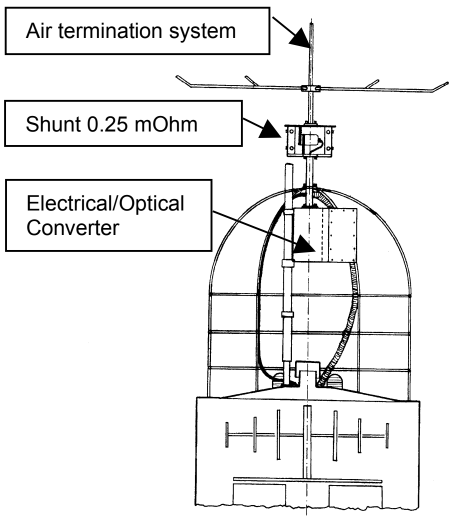


Fig.3: Schematic overview of the experimental setup at Gaisberg tower (E/O: Electrical/ Optical signal converter).

Fig.4: Configuration of the measuring equipment on top of the transmission tower

2.1 Lightning current measurement system

For the current measurement a shunt on top of the tower with a fiber optic link for data transmission and a recording system were installed in a building next to the tower (Fig.3). An appropriate air termination was installed on top of the tower in order to capture most of the lightning discharges to the tower (Fig.4). The lightning current is measured at the base of the air termination by a wide band current viewing resistor (shunt) of 0.25 mΩ with a bandwidth of 0 Hz to 3.2 MHz, manufactured by T&M Research Products Inc.

For reasons of electromagnetic compatibility a fiber optic link (Nicolet Isobe 3000) is used to transmit the shunt output signal to the digitizer. Due to the wide range of expected current peak amplitudes two separate fiber optic channels of different sensitivity are installed:

- Channel 1: 0 - 2.1 kA
- Channel 2: 0 - 40 kA

The shunt output signal is recorded by an 8 bit digitizing board installed in a Personal Computer. The digitizing board (National Instruments PCI-5102) with a bandwidth of 15 MHz and a memory of 16 MB per channel is operated with a sampling rate of 20 MS/s. The trigger of the recording system is set to a corresponding lightning current level of ±200A. All recorded waveforms are time stamped using the time information provided by a GPS clock (Meinberg GPS167PC) in order to be able to time correlate them with the data from the lightning location system. GPS timing is appropriate to identify correspondence of individual strokes recorded at the tower and by ALDIS.

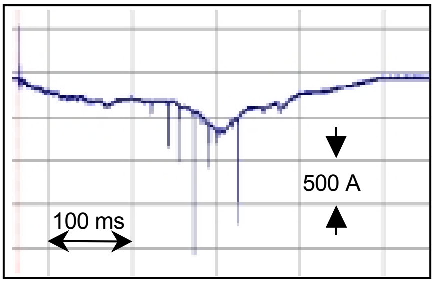
Until the end of September 2000 data of about 200 events have been recorded. In Table 2 we have summarized the number of events where correlated data from the lightning location system are available.

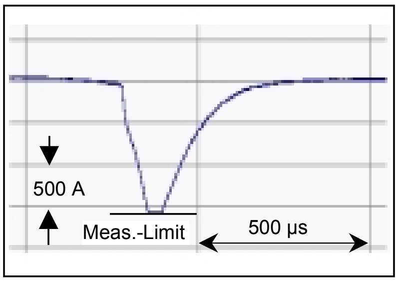
Table 2:

	ALDIS correlated flashes	ALDIS correlated Strokes
1998	2	8
1999	9	20
Up to Sept. 2000	20	116

Obviously for many events there are no correlated data from the LLS available, when lightning current was recorded at the tower.

Up to know almost all the events have been upward initiated discharges showing an initial continuing current (ICC) that is either superimposed or followed by current pulses of different waveshapes. Many of the upward initialed discharges do not contain any current pulses of amplitudes greater than 2 – 3 kA. Often current pulses of even higher amplitude show a slow rising front and therefore do not radiate electromagnetic field pulses of sufficient magnitude to be detected by the LLS-sensors (see Fig.5).





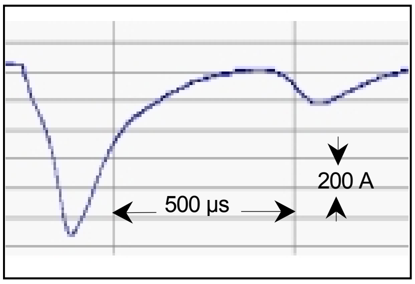


Fig. 5a: ICC-current with 5 ICC pulses (flash #182, Total charge 114 C

Fig. 5b: ICC-pulse # 3 I_{peak}= -3 kA

Fig. 5c: ICC-pulse # 5 I_{peak}= -1,2 kA

3. Peak Current Data

Tower measurements can be used as a reference to test the different steps involved in the process, how a LLS infers peak currents from remotely measured lightning electromagnetic (EM) peak fields.
Following is a brief summary of the main steps and possible errors involved in peak current estimation of a LLS:

Step 1: Accurate Measurement of peak electromagnetic field
→ local noise
→ resolution of digitizer (most effective for small signals)
→ field enhancement (for LPATS III/IV sensors)

Step 2: Range normalization of the measured EM peak fields of the reporting sensors assuming a 1/R distance dependency
→ field attenuation (due to propagation over a surface of finite ground conductivity)
→ contamination of the radiation field component by the induction field component at close ranges

Step 3: Conversion of range normalized EM peak field to peak current by the relation $I_p = K \cdot S_{N,100}$
→ I versus E relation is not strictly linear
→ influence of other lightning current parameters (e.g. di/dt or variation of return stroke velocity)

Comparing peak currents measured at the instrumented tower we have also to take into account any possible error in the direct current measurement as well as the effects of the elevated object due to current reflection at the top and ground level of the tower. Unfortunately all the possible errors and/or effects mentioned above can not be separated easily.

In Fig.6 we have plotted for 26 measured peak currents (I_TOWER) the correlated lightning peak currents reported by ALDIS (I_ALDIS). Those 26 strokes have been selected because the recorded current waveshapes did not have any high frequency structure superimposed and therefore allowed a good determination of the peak current. The regression line I_ALDIS = 0,92 · I_TOWER with a correlation coefficient R = 0,958 indicates an underestimation of peak currents by ALDIS by about 8 %.

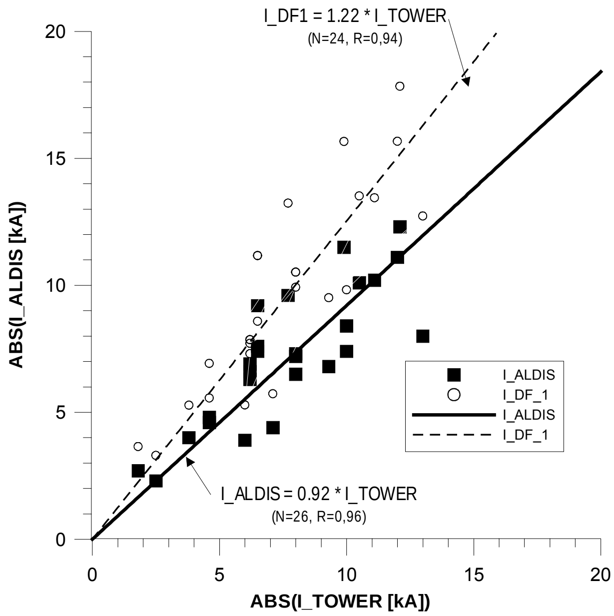


Fig.6: I_ALDIS versus I_TOWER for 26 strokes

A more detailed analysis of the individual sensor reports reveals that this quite satisfying good correlation in Fig.6 is more the result of a compensation of different errors than the output of an appropriate procedure.

In Fig.7 we show the variation of range normalized signals (RNS) for 4 strokes detected by all eight sensors in Austria. All RNS are normalized in addition to the RNS of the closest sensor (DF1) at a distance of 32km. We are assuming that reports from this sensor show minimum effects of signal attenuation due to propagation over ground of finite conductivity. Without any attenuation effects the RNS of all sensors should be around 1,0 in Fig.7. All sensors show a similar ratio among one another whereas there is a significant difference in between the signals of different sensors in the range from 0,35 (DF 2) to 1,0.

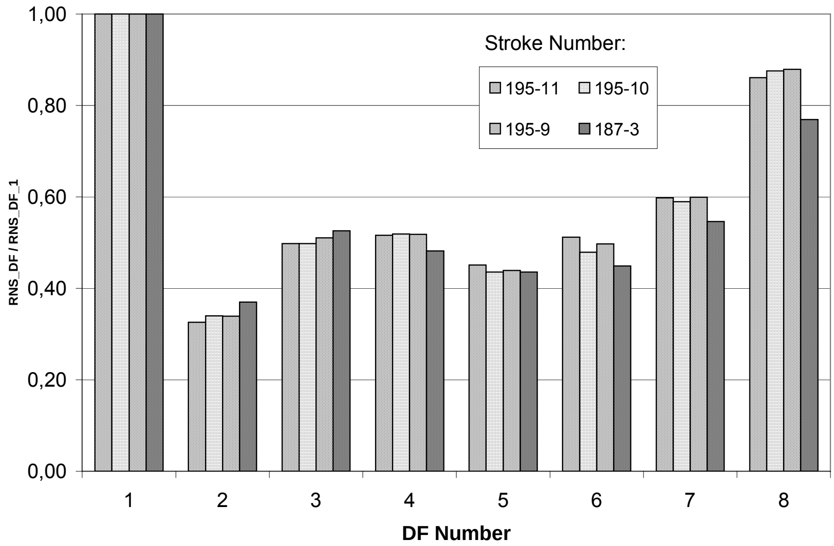


Fig.7: Individual sensor RNS normalized to the RNS of DF1 for four strokes reported by all 8 sensors in Austria.

In Fig.8 we have plotted the distance dependency of the mean of the ratios shown in Fig.7. On average RNS peak fields at the site of sensor # 2 (distance to the tower 116 km) are only about 34 % of the RNS peaks of the closest sensor. On the other hand sensor # 8 (distance 204 km) still reports RNS peak signals of about 85 %. Sensor # 2 is located in the mountainous area of Austria and Fig.7 reflects the very pronounced effects of signal attenuation in this direction. Similar results were obtained in a recent study using lightning data from measurements at a tower in Germany [1].

Fig.8 clearly shows that in this case there is no reasonable mathematical function to describe the peak field attenuation as a function of distance as e.g. determined from triggered lightning data in Florida [2]. To correct attenuation effects in Austria requires a more complex procedure taking into account the high variation in ground conductivity as a function of distance and angle.

When we calculate peak currents based on reports from the closest sensor (DF_1) only, we determine a regression line I_DF1 = 1,22 * I_TOWER (R=0,94), indicating an overestimation of 22% of measured peak currents (see Fig.6).

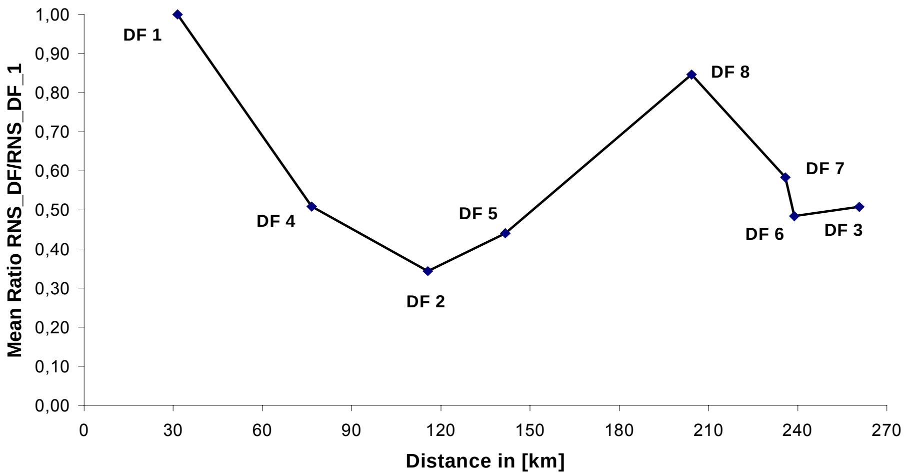


Fig.8: Mean of the normalized RNS_DF/RNS_DF_1 from Fig.7 as a function of distance to the tower

4. Location Accuracy

For N = 138 strokes located by ALDIS we have determined the distance of the calculated stroke positions to the tower location. Fig.9 shows, that most of the ALDIS locations are in a range of 150 m to 1000 m around the tower position with a median of about 500 m.

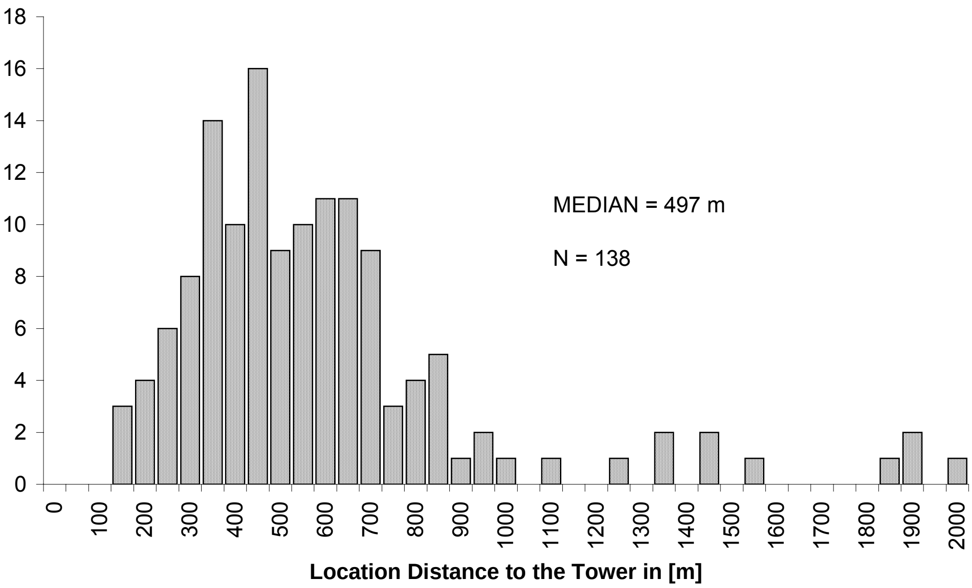


Fig.9: Distribution of distance between ALDIS location and tower position

We have to note that not all the outliers with distances greater than 1000 m are necessarily erroneous ALDIS locations. Some of them are the result of time correlated current pulses on the tower initiated by nearby strokes of high peak currents to ground.

In Fig.10 we have plotted the ALDIS locations when the tower is assumed to be located at the center of the plot. Obviously almost all the locations are shifted to the north-east. We assume that this is an effect of a time error mainly introduced by an elongation of the propagation path over the mountainous area [3].

In case of a successful correction of this systematic location error the remaining location error would be in the range of 200 to 300 m.

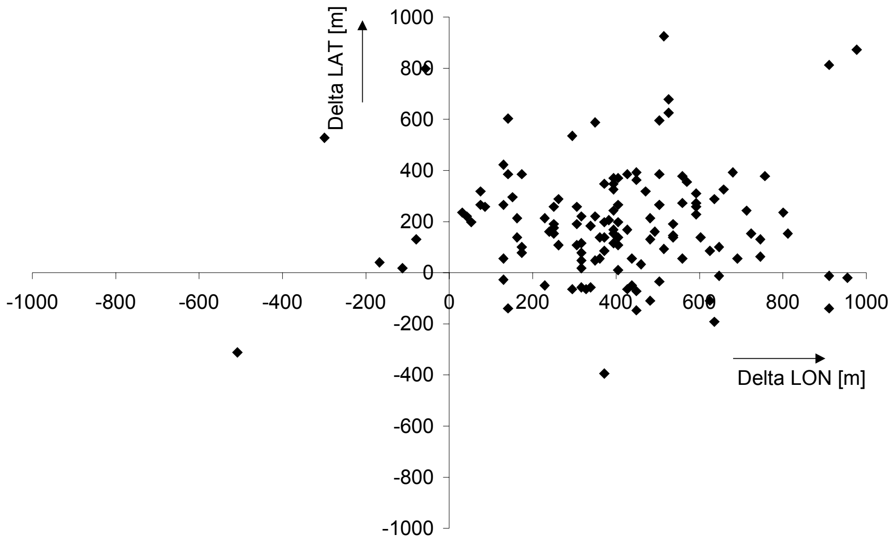


Fig.10. Locations provided by ALDIS (tower is located at the center of the plot)

5. Conclusion

By using the data from direct lightning current measurements we could show that determination of peak currents from remotely measured fields requires a more sophisticated correction of effects of field attenuation than a purely distance dependent function.

Although there is on average a very good agreement between the measured and detected peak currents, for individual strokes the error could be significant, depending on the sensors involved in the calculation.

The location accuracy is in the range of about 500 m and could be improved to about 200 – 300 m, when it is possible to eliminate the still existing systematic time error caused by propagation effects.

REFERENCES

[1] Diendorfer, G., W. Schulz, F. Fuchs: Comparison of Correlated Data from the Austrian Lightning Location System and Measured Lightning Currents at the Peissenberg Tower. Conference on Lightning Protection (ICLP), Sept. 1998, Birmingham, United Kingdom

[2] Idone, V.P., et. al.: A reexamination of the peak current calibration of the National Lightning Detection Network. Journal of Geophysical Research, 98, 18323-18332, 1993.

[3] Schulz, W., Diendorfer G.: Evaluation of a lightning location algorithm using an elevation model. 25th International Conference on Lightning Protection (ICLP), Rhodos, Sept. 2000

Acknowledgements

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