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COMPARISON OF CORRELATED DATA FROM THE AUSTRIAN LIGHTNING LOCATION SYSTEM AND MEASURED LIGHTNING CURRENTS AT THE PEISSENBERG TOWER

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Abstract

In 1997 and spring 1998 at the Peissenberg tower 8 flashes with 44 strokes (12 α and 32 β type impulse currents) having peak currents greater than 4 kA have been measured. For the definition of α and β type impulse currents see Zundl et. al 1996. We have correlated reports from the Austrian Lightning Location System (ALDIS) for 35 of those 44 strokes. Measured peak currents of less than 4 kA were not included in this analysis, because this discharges are unlikely to be located by ALDIS due to the distance of the tower to the location network.

We found correlated lightning locations for 75% (9 out of 12) of the α-type impulse currents and for 81% (26 out of 32) for the β-type impulse currents. This indicates a better detection efficiency of the system for β-components than for α components. β components are assumed to be more similar to subsequent strokes.

The location system infers peak currents from measured peak magnetic fields using a calibration function $I_p = f(B_p)$ assuming a 1/R distance dependency for the propagation of the electromagnetic fields. This is exact only for perfectly conducting ground.

1. Introduction

Lightning peak current is one of the most important lightning parameters for the design of lightning protection equipment and for the calculation of lightning radiated fields and their interaction with power and telecommunication lines.

There are different methods to collect data on lightning peak current as outlined below:

Direct current measurements in natural lightning [e.g., Berger et al., 1975, Zundl, 1996]

Such measurements are typically performed at tall towers or at moderate-high towers on tops of mountains, and the measured parameters may be not representative of lightning to flat ground due to longer upward connecting discharges expected from the towers. Additionally, the current wave injected at the tower top should experience reflections at ground and at any discontinuity of surge impedance along the tower.

Direct current measurements in triggered lightning [e.g., Fisher et al., 1993]

Lightning can be artificially initiated (triggered) by launching small rockets trailing thin wires connected to ground. The leader-return stroke sequences in triggered lightning are believed to be similar to those constituting subsequent strokes of natural lightning. On the other hand, several aspects of triggered lightning suggest potential disparities between various properties of natural and triggered lightning: a) absence of a stepped leader and first return stroke, b) contamination of the lower portion of the lightning channel by the vaporized metallic wire, and c) the fact that triggered lightning occurs under cloud conditions in which the discharge is caused to occur prematurely and may not otherwise have occurred.

Inferences from electric and magnetic field measurements (natural and triggered lightning) [e.g., Rakov et al., 1994]

Typically, only a relatively small sample of lightning data is available. In many cases, the exact stroke location is not known. Lightning peak currents are estimated using a regression equation [e.g., Rakov et al., 1992; Idone et al., 1993] relating the measured lightning peak fields and the lightning peak currents or a relation based on the so-called transmission line return-stroke model [e.g., Willet et al., 1989]. Field measurements are usually performed at a single station.

Lightning locating systems [e.g., Orville et al., 1987]

The output of modern multiple-station lightning locating systems includes, besides lightning coordinates, estimates of lightning peak current and number of strokes per flash (multiplicity). One of the major advantages of lightning locating systems is that the measurements are usually available for entire year or even for several years, so that the sample size is large and different seasons and types of thunderstorms are included in the data base. Current peaks are determined from lightning peak fields measured by the system using the following semi-empirical equation.

$$i_p = 0.23 \, . \, S_n \qquad (1.1)$$

where i_p is the lightning peak current in kA and S_n is the mean of the signal strengths from the Direction Finder‘s (DF) participating in the location in LLP-units range-normalized to 100 km. LLP-units are directly proportional to the local electromagnetic field strength at the DF site. Signal range normalization assuming a 1/R distance dependency is exact only for propagation over ground of infinite conductivity. The coefficient 0.23 in Eq. (1.1) is the standard setting proposed by the manufacturer for a high-gain network . Up to now the most reliable relationship between i_p and S_n was obtained, using Florida triggered-lightning data by Idone et al. [1993]. A plot of measured peak currents versus mean normalized signal strength S_n (in LLP units) for 56 triggered strokes was fitted by a regression equation

$$i_p = 4.2 + 0.17 S_n \qquad (1.2)$$

with a correlation coefficient r=0.88 and a standard deviation σ=4.6 kA. It is important to note that this correlation is not based on any return-stroke model. The only assumption made is sufficient similarity of strokes in triggered lightning and first and subsequent strokes in natural lightning in terms of the relation between peak currents and peak fields. Recently performed current measurements for natural lightning hitting catenary wires at the Kennedy Space Center support this assumption [Cummins, K. 1997, personal communications].

Comparison of Eq. (1.1) and Eq. (1.2) shows, that the standard setting used by ALDIS gives a 25% higher peak current compared to the equation of Idone et al. [1993], when the intercept of 4.2 kA is neglected.

2. Experimental setup

Details of the experimental setup used for peak current measurement at the Peissenberg Tower are described comprehensively in Fuchs [1998]. For this paper we are using the results of peak current measurement from the 200 kHz current transformer. Although the bandwidth is limited these data are available for all the strokes used for this study whereas integrated currents from a high bandwidth di/dt sensor are not available for all strokes. In average integration of the di/dt signals results in about 15% higher peak currents compared to the values measured with the 200 kHz current transformer.

The location of the Peissenberg tower and the sites of the lightning location sensors in Austria are shown in Fig.1.

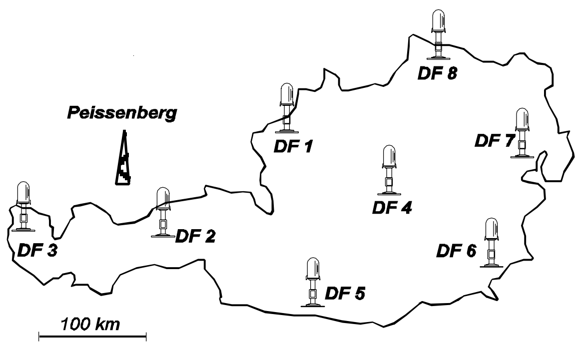

Fig. 1 Sites of IMPACT sensors in Austria and location of the Peissenberg tower

Distances of the sensors to the instrumented tower are in the range from 72 km to 390 km (see Table 1).

Table 1: Distance of the Austrian sensors to the Peissenberg tower

	DF1	DF2	DF3	DF4	DF5	DF6	DF7	DF8
Distance to Tower in [km]	151	72	110	227	239	390	391	340

Most of the strokes to the tower were located by the sensors DF1, DF2 and DF3 respectively. A minimum of two sensors reporting a stroke is required to be able to calculate a stroke location.

3. Data analysis

In this paper we compare peak current measurements from the Peissenberg tower over the time period from January 1997 until March 1998. Over this period a total of 12 flashes with 86 strokes has been recorded by the tower monitoring equipment. All recorded strokes have been of negative polarity. Because many of those strokes had peak currents in the range of 1 - 4 kA and this very small currents are outside of the detection range of the Austrian location system we limit our analysis to measured peak currents greater than 4 kA. This reduces our data set to 44 strokes (12 of type α and 32 of type β) in 8 flashes. In 4 flashes only strokes of I_p < 4 kA have been measured.

Because the number of sensors reporting a stroke is mainly dependent on its signal strength, for each individual stroke a different number of sensor reports is available. In case of a well known distance between striking point and DF as discussed in this paper even from a single DF report we can estimate the lightning peak current based on Eq (1.1), although the LLS will not provide a location for those strokes.

The main features for the correlated data are summarized in Table 2.

Table 2: Available DF reports for the directly measured strokes

Directly measured peak current I_p > 4 kA for 44 strokes to the tower					
12 α-type pulses			32 β-type pulses		
9	1	2	26	4	2
≥2 DF	single DF	no DF	≥ 2 DF	single DF	no DF

In Fig. 2 we plot peak current I_{ALDIS} as reported by the LLS versus directly measured stroke peak current I_{TOWER}. For these data, the linear correlation coefficient, r, is 0.974 and the linear regression equation is specified as

$$I_{ALDIS} = 1.13 * I_{TOWER} \qquad (1.3)$$

when we force the regression line to go through the origin.

A slope of 1.13 of the regression line in Fig.2 indicates that ALDIS overestimates the peak current by about 13% - a somewhat surprising result when we compare the peak current median in Austria with -15 kA with the -30 kA median given by Berger et al [1975]. This difference would be more an indication of an underestimation of peak currents by the ALDIS location system than for a 13 % overestimation.

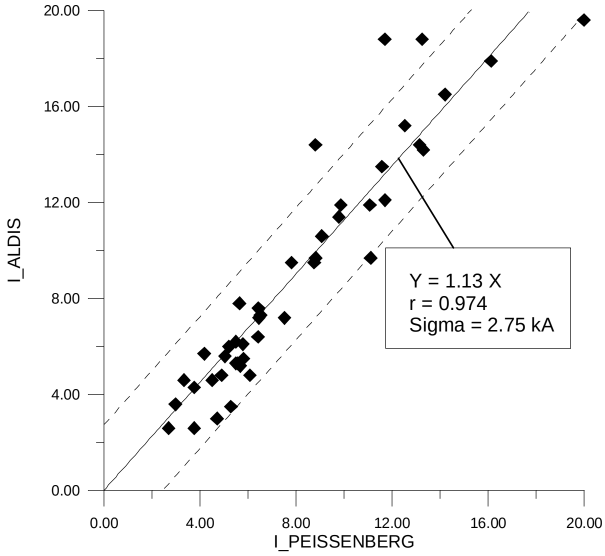

Fig. 2: Scatter plot of measured stroke peak current versus peak current reported by ALDIS (dashed lines represent the plus/minus sigma region)

3.1 Signal attenuation

The different steps of estimation of a the lightning peak current for a given stroke reported by 4 DF‘s are summarized in Table 3. This located stroke is time correlated to the following tower event:

Date: 6.1.1998, Time: 01:16:19.022, I_p =-11.6 kA (measured by the 200 kHz current transformer).

Table 3: DF reports and range normalized signal strength for a given flash

DF - reports					
DF	Time	Angle	S_i [LLP-units]	$S_{i,100} = S_i * R_i / 100$	I_{DF}= 0,23* $S_{i,100}$ [kA]
2	01:16:19. 0218691	313.8	-52.8	-38.0	-8.7
3	01:16:19. 0219949	62.2	-71.2	-78.3	-18.0
1	01:16:19. 0221335	259.7	-43.3	-65.38	-15.1
8	01:16:19. 0227643	255.8	-15.6	-53.04	-12.2

The stroke peak current is calculated by the LLS as the mean of all the available I_{DF} values and therefore

$$I_P = -(18.0 + 8.7 + 15.1 + 12.2)/4 = -13.5 \text{ kA} .$$

Although the directly measured peak current at the Peissenberg tower of -11.6kA and the peak current provided by the LLS are in good agreement, obviously signal attenuation causes significant differences in the peak current estimates based on the individual sensor signal strength reports being in the range from - 8.7 kA for DF 2 to -18.0 kA for DF 3. Theoretically all I_{DF} should be the same and equal to the measured peak current. This example clearly demonstrates the necessity to include signal attenuation effects for peak current estimates especially in regions of poor ground conductivity like some mountainous areas in Austria.

Although DF 2 is the sensor closest to the tower the range normalized signal strength with -38 LLP-units is only 58 % of the range normalized signal strength of DF 1 (65 LLP-units). This result indicates significant attenuation of the lightning field pulses from the tower to DF 2. Propagation path to DF 2 is mainly over a mountainous area of limestone of low conductivity. Mountain tops altitudes are in the range of 2000 m - 2500 m.

Similar ratios of the DF signal strength was observed for all the other strokes. In Fig. 3 we plot the regression lines for the range normalized signal strength for the three closest DF (DF1, DF2 and DF3 in Fig.1).

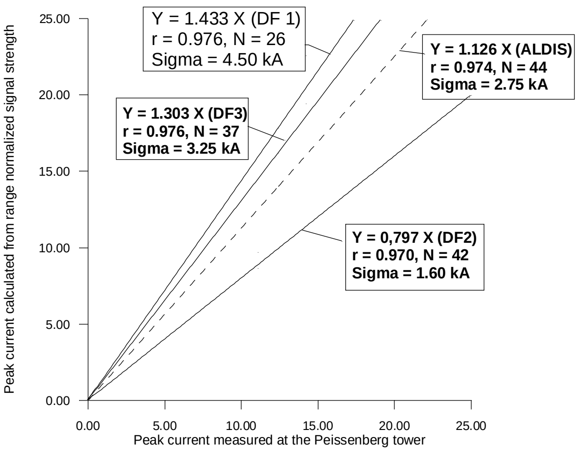

Fig.3.: Regression lines fitted to the range normalized data of the three closest DF to the Peissenberg tower

With a slope of 0.797 the signals at DF2 are about 45 % lower than the normalized signals of DF1. This indicates major differences in the field attenuation to the different sensors. Propagation path is more important than propagation distance. Distance to DF1 is about twice the distance to DF 2 and signals are much less attenuated than at DF2.

These results also show that attenuation models for lightning location systems that are only distance dependant [e.g. Idone et al., 1993]

$$E_{100} = E_D \left| \frac{D}{100} \right| \tag{1.4}$$

(β = -1.09 for Florida) are only applicable in regions of nearly homogenous ground conductivity like in Florida.

In Austria attenuation varies significantly depending on regional conditions and needs to be specified as a function of distance and angle. A first approach to estimate distance and angle dependant field attenuation is shown in Mair et al. [1998] where for a geographical grid of 10 km x 10 km σ values have been calculated.

In Mair et al.[1998] σ is defined as the ratio

$$\sigma = E_{DF} / E_{\infty} \tag{1.5}$$

where E_{DF} is measured field and E_{∞} is the field in case of infinite ground conductivity.

For the 10 km x 10 km grid where the Peissenberg tower is located we have estimated

$$\sigma_{DF1} = 0.70$$
$$\sigma_{DF2} = 0.45$$
$$\sigma_{DF3} = 0.60$$

A value $\sigma_{DF2} = 0.45$ means, that in average signals from the Peissenberg region arrive at the DF2 site with about 45% of their unattenuated signal strength. This causes the low slop for DF2 in Fig.3. It is worth to note that the ratios of this σ values are in the same range as the ratios of slopes for the three sensors given in Fig.3.

Correcting the slopes of the regression lines in Fig. 3 with the σ values given above the slopes increase to 2.04 for DF1, to 1.77 for DF2 and to 2.17 for DF3, respectively. Correcting the individual sensor reports with the σ values results in a regression line slope of 1.98 for the peak currents calculated as the average of the three corrected DF currents (r = 0.988, Sigma = 3.81 kA).

Summary and discussion

Comparison of directly measured peak currents at the Peissenberg tower with peak current provided by the Austrian Lightning Detection System (ALDIS) revealed significant effects of signal attenuation. Because the most closest sensor shows the most pronounced signal damping these effects can not be avoided by a simple distance dependant attenuation model as proposed recently in literature and by the system manufacturer. In regions of inhomogeneous ground conductivity a more sophisticated model - distance and angle dependant is required.

Assuming insignificant attenuation for the field propagation from Peissenberg tower to DF 1 the data reveal an overestimate of peak current by about 40 % in regions of good ground conductivity when the default setup proposed by the manufacturer is used for the calculation of peak currents from the range normalized signal strength.

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