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CRITICAL ANALYSES OF LLS DETECTED VERY LARGE PEAK CURRENT LIGHTNING STROKES

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1. INTRODUCTION

Peak currents of natural lightning are typically assumed as log-normal distributed. Most of the amplitudes of direct current measurements at instrumented towers or from rocket triggered lightning are in the range of a few kA up to 50 kA. Because of their low probability of occurrence very limited data of directly measured currents exceeding 100 kA is available and directly measured current waveforms of either polarity found in the literature do not exhibit peaks exceeding 300 kA or so. Lyons et al. (1998), using U.S.NLDN (U.S. National Lightning Detection Network) data reported that the largest current peaks were -957 kA and +580 kA for negative and positive flashes, respectively. It is important to note that peak currents reported by any Lightning Location System (LLS) are estimated from measured magnetic radiation field peaks using an empirical formula, the validity of which has only been tested for negative subsequent strokes with peak currents not exceeding 60 kA.

Detection of large peak currents in the U.S.NLDN was analyzed by Cummins (2000). LPATS sensors provide one location-related parameter – the arrival time - and IMPACT sensors provide two location parameters - arrival-time and arrival angle for computing a location. Cummins (2000) observed the highest number of location parameters for peak currents in the 75 – 100 kA range and for estimated peak currents greater then 100 kA the average number of location parameters decreases steadily.

In Fig.1 we show a histogram of the average number of the degree-of-freedom as a function of peak current for positive and negative strokes, respectively, for strokes in a circular area of 300 km radius around 47.5° N and 14° E detected by the EUCLID network. If the degrees-of freedom is zero, no additional information was available for optimizing the position. If the degree-of-freedom is greater than zero, additional information was available and the location algorithm optimized the position using all available information. Thus the degree-of-freedom is a similar measure as the number of location parameters analyzed by Cummins (2000).

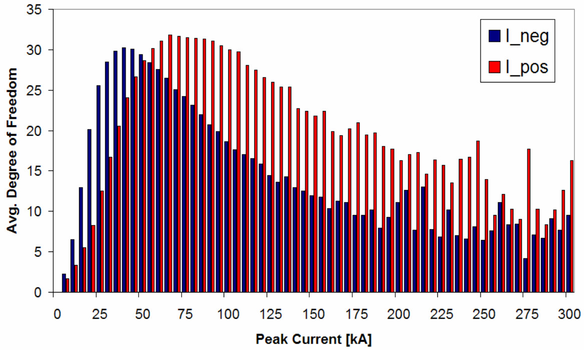

Figure 1: Histogram of average degree-of-freedom grouped by ranges (5 kA steps) of estimated peak current in the EUCLID network

For negative events the maximum value (30) of degree-of-freedom is observed for peak currents in the range of 30 - 40 kA. The maximum for positive strokes is slightly higher than for negative strokes and is observed for peak currents in the range of 70 – 100 kA. A possible reason for the differences between positive and negative strokes in Fig.1 is the presence of stepped leader pulses of sufficient amplitude in case of large negative strokes. When those leader pulses are large enough, they can exceed threshold at some closer sensors and can produce measurements that are inconsistent with the real return stroke pulse seen by the more-distant sensors, and those sensor reports are excluded from the calculation (Cummins, personal communication 2008).

Increasing complexity of waveform for larger peak currents is also expected to affect the consistency of the sensor reports making it more difficult to locate large events with sufficient confidence.

Completely erroneous stroke positions are also a reason for some large current events in LLS data sets. When a stroke is completely misplaced for various reasons the estimated peak current is consequently wrong. The distance between sensor location and estimated stroke position is used to calculate the RNSS (range normalized signal strength) and consequently any error in the stroke location coordinates causes an error in the peak current estimate. In single cases this can result in extraordinary peak currents as shown later in this paper, when a -350 kA LLS stroke report is analyzed in detail.

2. SPATIAL DENSITY OF LARGE PEAK CURRENT FLASHES

To see if there is any spatial effects on the occurrence of large peak current events Fig.2 shows the number of all flashes located in Austria for the eight year period 2000-2007 based on a grid size of 10 km x 10 km.

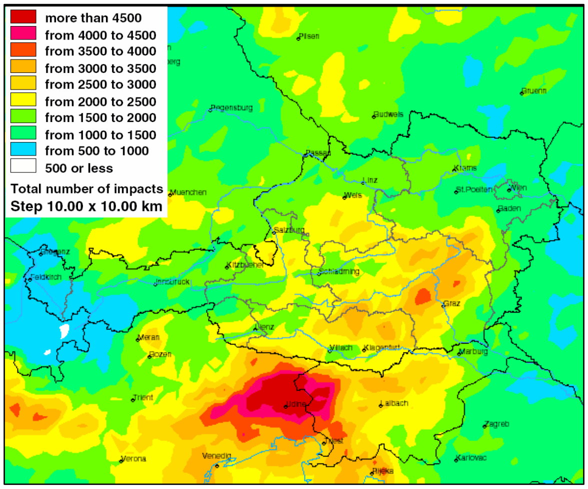

Figure 2: Number of flashes in 10 km x 10 km grid cells in the period 2000 – 2007 including flashes of both polarities and all amplitudes

In Fig.3 we have selected only flashes with absolute values of inferred peak currents exceeding 100 kA. Obviously higher numbers of large peak current events are observed in the region south of Austria along the southern rim of the Alps.

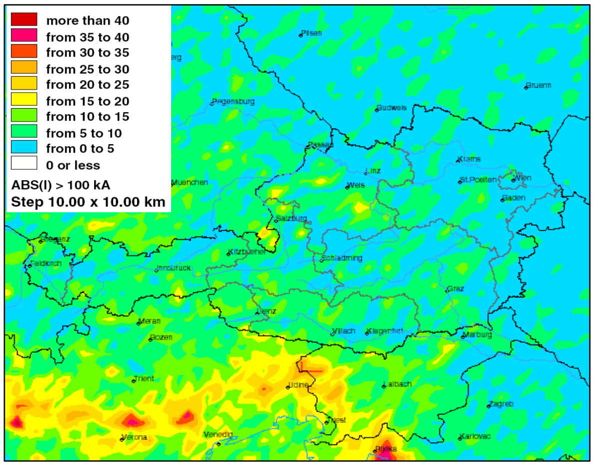

Figure 3: Number of flashes with peak currents exceeding 100 kA in 10 km x 10 km grid cells in the period 2000 – 2007

3. SINGLE CASE ANALYSIS

In this paragraph we are analyzing in detail one particular discharge to demonstrate one possible scenario resulting in a very large peak current stroke detection.

On May, 22nd 2007 at 12:15:01 a 2 stroke flash listed in Table 1 was located by the EUCLID network. This particular flash was selected because it was the flash with the largest inferred peak current (-350 kA) reported during a period of 09:30 to 13:45 UTC, where also continuous field records are available. The electric field was continuously recorded using the field measuring system described by Pichler et al. (2007) and this field records allow confirmation of the located events by an independent source.

TABLE 1: EUCLID data of a located (bipolar) flash with 2 strokes and an inferred peak current of -350 kA for the second stroke

	Time	Lat	Lon	kA
Stroke 1	12:15:01.201966	45.730	11.040	+169.8
Stroke 2	12:15:01.202023	45.669	10.975	- 350.0

The time interval between 1st and 2nd located stroke is 57 µs and significantly shorter then typically observed interstroke intervals. The time interval between successive return strokes in a flash is usually several tens of milliseconds but can also be as small as one millisecond or less (Rakov and Uman, 2003).

Fig. 4 shows the plot of the time correlated lighting radiated electric field measured at a distance of about 350 km from the striking point. Peak field at 350 km distance arrives delayed by the propagation time of $\Delta t = 350\ \text{km}/3.10^8\ \text{m/s} = 1167\ \mu s$ and hence at 12:15:01.203132, indicated by the dashed line in Fig.4. This time corresponds well with the 1st located stroke of positive polarity. Obviously there is no separate negative field pulse after a time of 57 µs that corresponds to the 2nd stroke of negative polarity and a peak current of -350 kA. Thus we conclude that this high negative peak current event is not a real negative discharge and most likely a result of a fake location caused by ionospheric reflections.

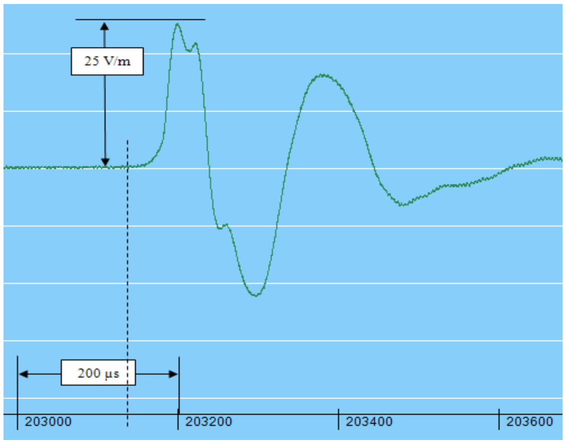

Figure 4: Vertical electric field measured with a flat plate antenna in Wels (distance to striking point of -350 kA stroke) at 12:15:01 UTC. Time scale in milliseconds, vertical scaling 10V/div

The first positive pulse (+25 V/m) in Fig.4 represents the ground wave that typically shows a 1/R distance dependency plus some additional attenuation due to finite ground conductivity. The second negative pulse (peak field -22 V/m) represents the first order sky-wave. The sky wave arrives at the flat-plate antenna site at a distance of 350 km delayed by about 100 µs (see e.g. Volland, 1995). At larger distances the first pos. pulse gets more and more attenuated and the sky-wave becomes dominant.

In a large network as EUCLID with a north-south extension of about 4000 km and east-west extension of about 2000 km there is a chance that several sensors at larger distances from the strike point trigger on the polarity inverted sky-wave. If a sufficient number of sensors detect the sky-wave (see Table 2 and Fig.5) a fake location as the 2nd stroke in the example above is calculated. Peak current is inferred from the range normalized signal strength (RNSS) assuming a 1/R distance dependency and applying an attenuation model. The large field peak of the ionospheric reflection detected at large distances result in the outstanding peak current for a negative stroke of -350 kA.

Table 2 shows a list of the involved sensors locating stroke 2 in Table 1 with their distances to the strike point and the reported signal strength SS_i and corresponding $RNSS_i$.

Several criteria in the location algorithm are used to avoid such fake locations but obviously these criteria are not perfect. This should be considered especially when searching for extreme peak current events.

TABLE 2: Sensors participating in the location of Stroke 2 in TABLE 1

Sensor #	Type	Dist. km	SS [LLP units]	RNSS [LLP units]
S 97	LPATS IV	381	- 55	- 279
S 39	IMPACT ESP	548	- 162	- 1390
S 77	IMPACT ESP	594	- 245	- 2393
S 25	IMPACT ESP	677	- 146	- 1759
S 73	IMPACT ESP	725	- 162	- 2195
S 69	IMPACT ES	743	- 141	- 1996
S 74	IMPACT ESP	872	- 138	- 2619
S 75	IMPACT ESP	988	- 116	- 2802

Fig.5: Location of the -350 kA stroke and the sensors contributing to the location calculation

4. CONCLUSION

When we search for the largest peak current strokes in a data archive of a LLS the results should be interpreted very carefully. A large number of those events are probably the result of fake strokes. Unfortunately there is no simple and effective procedure to isolate the fake from the realistic events case by case and hence this search results are of high uncertainty. In addition peak field-to-current conversion is only validated by tower measurements and triggered lightning for subsequent negative stroke peak currents of less than 60 kA. No data are published for positive and first strokes.

5. REFERENCES

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