The relationship between first and subsequent stroke electric field peak in negative cloud-to-ground lightning

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ABSTRACT:

In this paper we show details about the relationship between first and subsequent stroke electric field peak in negative cloud-to-ground lightning in Brazil. A field measurement campaign during summer 2006 in Brazil collected electric field data with a GPS synchronized fast electric field flat-plate antenna. The data analysis shows that the ratio between first stroke fields and subsequent stroke fields in Brazil and in Austria is smaller than in Florida and that the ratio which is including single strokes, differs significantly even between Austria and Brazil. We further found that 38.2% of the flashes in Brazil had at least one subsequent stroke peak field greater than the first stroke peak field.

1. INTRODUCTION

Electric field measurements of first and subsequent strokes by the Austrian Lightning Detection and Information System (ALDIS) and by electric-field antennas in Florida, United States, show no agreement about the ratio between first-stroke peak field and subsequent stroke peak field in cloud-to-ground lightning [Diendorfer et al., 1998]. While in Florida the results are in agreement with what is usually accepted in the literature, that is, the mean negative first-stroke peak field (or current) is approximately two times larger than subsequent stroke peak field for strokes in the same channel, in Austria the ALDIS network data does not show any difference between the median values of the electric field (or current) for first and subsequent strokes. This study compares the results of previous works to a similar analysis performed in Brazil for two thunderstorm days.

2. EXPERIMENTAL SETUP

The measurement hardware consists of a PC with two PCI-cards (the GPS card Meinberg GPS168PCI and the data acquisition card NI PCI-6110), a data acquisition box (DAQ BOX NI BNC-2110), a flat plate E field antenna, an integrator/amplifier and a GPS antenna. For the measurements the PC was connected to a UPS which was powered by batteries. There was no connection to an AC power supply. Except that in this measurement setup no fiber optic link was used the configuration was identical to the measurement setup which was used to record data in Austria [Schulz and Diendorfer, 2007]. The principal setup of the measurement system including the fiber optic link is given by Schulz and Diendorfer [2007].

The field measurement system (FM-System) is able to record the electric field during lightning activity continuously. The measurement system has two channels and is configured to operate with a sampling rate of 5 MS/s for each channel. Although synchronous recording of two channels is possible with a sampling rate of 5

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MS/s and the existing hard- and software, only one channel was used for the field measurement in this project. The vertical resolution of the digitizer is 12 bits and is therefore providing sufficient dynamic range. The total recording duration is limited only by the size of the data storage media, the hard disc. Every second a file (size of the file is 10 MB) is created containing the digitized field data of the last second. Moreover the recorded data are GPS synchronized in a way that each file starts and ends exactly at the full second and starting time is assigned as filename.

The bandwidth of the FM-System is limited by the bandwidth of the integrator/amplifier. During the measurements in 2007 the FM-System (integrator/amplifier + flat plate antenna) had an overall bandwidth from 350 Hz to about 1.5 MHz. With this bandwidth the local noise level was approximately ±0.75 V/m at the selected measurement site in São José dos Campos.

3. DATA

All the data were recorded during two thunderstorms around São José dos Campos. The first occurred on 15 February 2007 between 19:29 and 20:25 UTC and the second occurred on 11 march 2007 between 19:46 and 20:32 UTC. The data set was limited to flashes occurring within a distance of 200km from the FM-System because more distant strokes may not show all the field signatures required to classify the stroke correctly. Fig. 3.1 shows an overview of the stroke locations relative to the location of the FM-system.

In this paper we analyze negative cloud to ground strokes only. To determine the distance between the FM-system and the stroke location and to determine which stroke belongs to which flash we used data from the Brazilian lightning location system (RINDAT). To classify the individual field peaks as cloud-to-ground lightning stroke, we required only the peak-to-zero time of the field waveform to be less than 10 μs.

A total of 409 negative flashes were detected, 259 were negative multiple-stroke and 150 single-stroke flashes. Fig. 3.2 shows the resulting multiplicity distribution of the 409 flashes. The average multiplicity is 3.2 and the percentage of singles stroke flashes is 37% for those two storms.

Figure 3.1: Geographical overview of the lightning activity around São José dos Campos (located at the center of the circle)

4. RESULTS

There are basically two possibilities to analyze the relationship between first and subsequent stroke electric field peak in negative cloud-to-ground lightning:

Method A1) By the first method, the mean peak values of strokes are calculated for each stroke order. Afterwards the mean values can be compared to each other and a statement can be made on the ratio of the first stroke mean value to the overall mean values of subsequent strokes (single stroke flashes included).

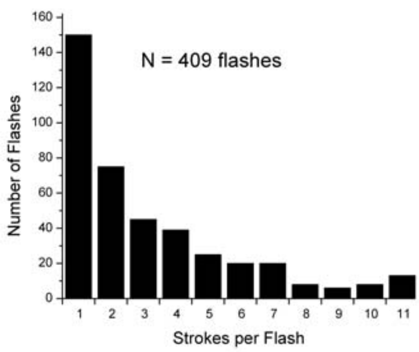

Fig. 3.2: Number of strokes per flash

Method A2) The same as **A1** but excluding single stroke flashes from the sample of first strokes.

Method B) Another method is to calculate the ratio of the first stroke peak fields and the mean value of peak fields of all the subsequent strokes in each individual multiple-stroke flash.

All the data were analyzed in a similar way to the one used in Austria [Schulz et al., 2005; Schulz and Diendorfer, 2007]. Because more flashes were obtained during the measurement campaign in Brazil stroke orders greater than 6 are present. Fig. 4.1 shows the number of strokes detected for each individual stroke order.

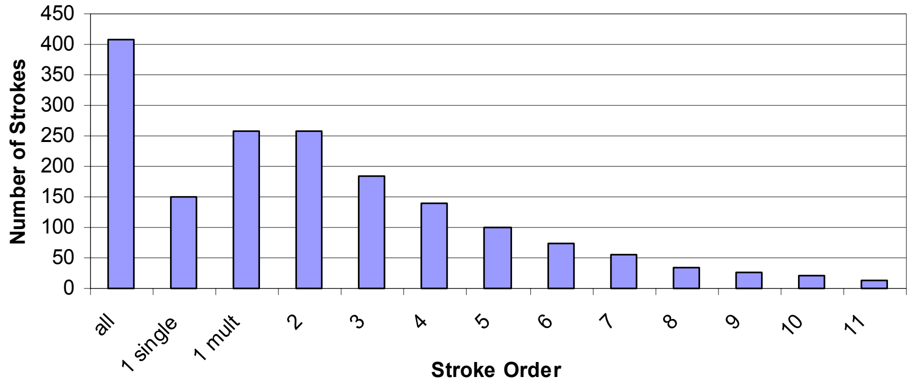

Fig. 4.1: Number of negative CG strokes for each stroke order of the FM data

Fig. 4.2 shows mean peak field values normalized to 100 km for all first strokes (all), first strokes of single-stroke flashes (1 single), first strokes of multiple-stroke flashes (1 mult) and for stroke orders greater than one. It is interesting to note that the mean field peak for single stroke flashes is only slightly smaller compared to the mean field peak of all first strokes. There is a clear distinction between the average values of strokes of order 2 to 5 and strokes with order 6 to 11. The greater values of the former ones are probably due to the fact that new channel formation may occur in strokes with order 2 to 5, which according to Rakov et al. [1994] produce higher field peaks. Subsequent strokes with stroke orders greater than 5 were never observed to create a new channel to ground [Saba et al., 2006].

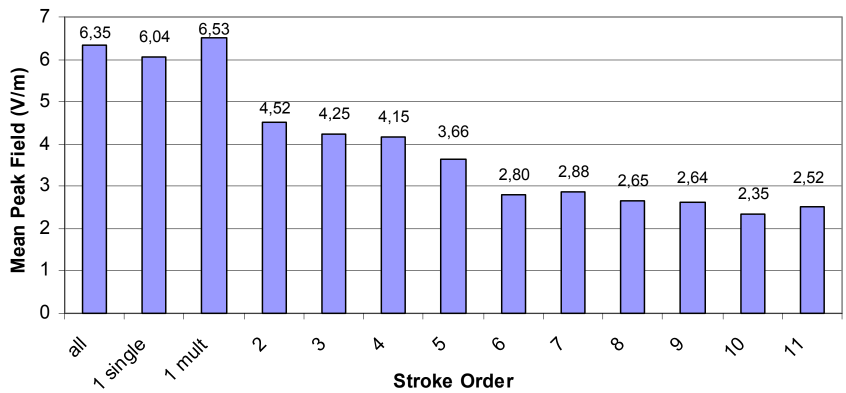

Fig.4.2: Mean peak value normalized to 100 km in V/m versus stroke order of CG strokes of FM data

Table 4.1 shows a comparison of the ratios between first and subsequent stroke peak fields for three different regions, Brazil, Austria and Florida. We present the data depending on what value was used to calculate the ratio, the geometric mean (GM) or the arithmetic mean (Mean). It can be seen that the values for Method A1 (including single stroke flashes) differ significantly between all three studies.

Table 4.1: Ratios between first and subsequent stroke peak fields

	Method A1		Method A2		Method B	
	GM	Mean	GM	Mean	GM	Mean
Brazil this study	1.69	1.64	1.75	1.69	1.53	1.78
Austria [Schulz and Diendorfer, 2007]	-	1.04	-	1.41	-	1.60
Florida, USA [Rakov et al., 1994]	2.03	-	2.14	-	-	-

Another interesting aspect of the data is the number of subsequent strokes with a field peak greater than the first stroke (see Table 4.2). In our data we found that 38.2% of the flashes had at least one subsequent stroke peak field greater than the first stroke peak field. In Florida this percentage was 33% [Rakov et al., 1994]. In our data we found even 1 flash with 7 subsequent stroke peak fields greater than the peak field of the first stroke (7 > 1^{st}).

Table 4.2: Number and percentage of flashes with subsequent greater than the first stroke peak field.

	0 > 1^{st}	1 > 1^{st}	2 > 1^{st}	3 > 1^{st}	4 > 1^{st}	5 > 1^{st}	6 > 1^{st}	7 > 1^{st}
Number	160	66	19	7	3	1	2	1
%	61.8	25.5	7.3	2.7	1.2	0.4	0.8	0.4

5. SUMMARY AND DISCUSSION

In this paper we compare the ratio between first-stroke peak field and subsequent stroke peak field in cloud-to-ground lightning with two similar previous studies. The overall multiplicity for the flashes in this study was 3.2 and the percentage of single stroke flashes was 37%. We could observe that the peak electric field of strokes of order 2 to 5 are greater than the peak field of strokes with higher order. We attribute this difference to the fact that strokes of order 2-5 are capable of initiating new terminations on ground. The ratios between first and subsequent stroke peak fields for Florida are higher than those encountered in Brazil and Austria. Both in Florida and in Brazil, the inclusion of single first strokes in the ratio calculation does not alter the results significantly. In Austria the significant difference between method A1 and A2 maybe due to the fact that the amplitudes from single stroke flashes are small. We found that 38.2% of the flashes had at least one subsequent stroke peak field greater than the first stroke peak field. Finally, 10% of the flashes had 2 or 3 subsequent strokes with peak field greater than the first stroke. These percentages suggests that, contrary to what is normally assumed in most lightning test and protection standards, flashes containing subsequent strokes with field peak (and by inference peak current) higher than the first stroke are not unusual.

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