Electric field waveforms of positive return strokes

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ABSTRACT: Positive flashes are usually composed of a single stroke. A large fraction of the positive cloud-to-ground (+CG) flashes (81%) produces just a single-stroke, and the average multiplicity is only 1.2 strokes per flash. Almost all (~95%) subsequent strokes in multiple-stroke +CG flashes create a new ground termination [Saba et. al. 2010]. In the present work we combine high-speed video recordings (obtained by two different cameras, Red Lake Motion Scope 8000S and Photron Fastcam 512 PCI, operating at frame rates ranging from 1000 or 8000 frames per second) with fast electric field measurements (obtained through the use of flat plate antennas) to investigate the characteristics of the electric field changes produced by leader pulses and return stroke in positive flashes.

1. INTRODUCTION

The initial process in a lightning discharge is a precursor to both ground and cloud flashes. Electric field signatures of the initial process usually present a train of bipolar wave shape pulses [Ushio et al., 1998; Gomes and Cooray, 2004; Nag et al., 2010]. The return stroke process usually presents waveshape characteristics similar to negative strokes, however some parameters defining this waveshape are different. In this study, the duration of breakdown pulses of positive cloud-to-ground lightning will be examined with electric field measurements. Various features will be examined: breakdown waveforms, breakdown pulse duration, return stroke amplitude and zero-to-peak risetime and 10-90% risetime return stroke.

2. DATA AND INSTRUMENTATION

A total of 40 positive cloud-to-ground discharges that were initiated by downward-propagating leaders had their electric-field signatures recorded during several summers in southern Brazil. All 40 positive cloud-to-ground flashes were single stroke flashes. All flashes occurred at ranges of 8 km to 76 km from the electric field sensor site. The observing site used during the data acquisition is located at São José dos Campos (23.212º S; 45.867º W, altitude: 635 m).

2.1 *Electric Field Sensor*

The electric field measuring system consisted of a flat plate antenna with an integrator/amplifier, a GPS receiver, and a PC with two PCI-cards (a GPS card Meinberg GPS170PCI and a data acquisition card NI PCI-6110), and a data acquisition box (DAQ BOX NI BNC-2110). The waveform recording system was configured to operate at a sampling rate of 5 MS/s on each channel and the resolution of the A/D converter is 12 bits. The same type of measuring system has been used previously in lightning experiments in Austria and Sweden and is described in more detail by Schulz et al. [2005].

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2.2 *Lightning Location System*

In order to determine the stroke location, polarity, and an estimate of the peak current, we used data from BrasilDat. More information on the characteristics of this network is given by Pinto et al. [2003]. The matching of strokes between the E-field sensor and the network was done using GPS time-synchronization (to an accuracy better than 1 millisecond).

3 RESULTS

3.1 Breakdown pulses

Usually there are two or three smaller pulses superimposed on the rising portion of the initial breakdown pulse, while the falling portion and the opposite polarity overshoot are smooth [Weidman and Krider, 1979]. In most of cases, bipolar pulses in pulse trains have an initial polarity similar to that of the succeeding return stroke.

Table 1: Statistics of width of breakdown pulses obtained in different studies.

	T_1 (µs)		T_2 (µs)		T_1+T_2 (µs)			
	This work	Gomes and Cooray [2004]	This work	Gomes and Cooray [2004]	This work	Gomes and Cooray [2004]	Qie et al. [2002]	Ushio et al. [1998]
Number of cases	150	57	150	57	150	57	50	132
AM	10.7	13	18.2	13	28.8	27	27	18.8
SD	6.0	4	8.4	4	12.4	6	19	7.9

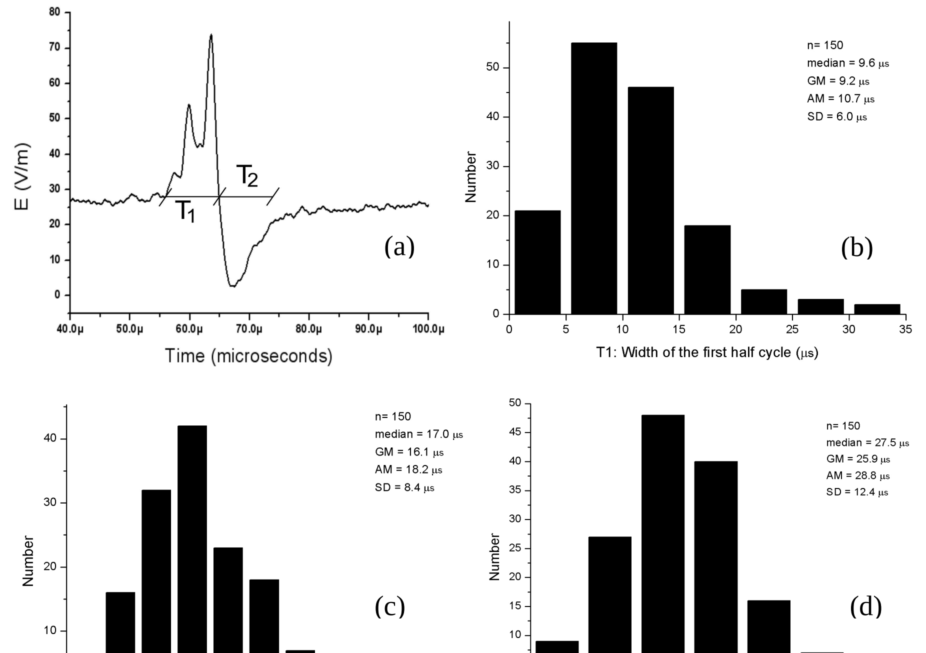

Figure 1 (a) Typical breakdown pulse (b) T_1: width of initial half cycle of pulses (c) T_2: width of second half cycle of pulses (d) T_1+T_2 width of pulses

All 40 positive cloud-to-ground flashes were analyzed. A typical initial breakdown is presented in Figure 1a. In this work, following a previous study of Gomes and Cooray [2004], T1 and T2 are defined as the aproximate duration of the first half cycle and the second half cycle, respectively, of an individual bipolar pulse.

Thus, T1+T2 is aproximately equal to the total pulse width

3.2 ***Return Stroke Characteristics***

The peak amplitudes of the positive return strokes fields, when normalized to 100km using inverse distance dependence are distributed in the range of 3.1 to 39.2V/m with median, geometric mean (GM) and arithmetic mean (AM) equal 10.8 V/m, 11.0 V/m and 12.8 V/m respectively. In comparison with the literature, Nag et al. [2010] reported results to AM and GM equal 21.7 and 18.1 V/m respectively which are higher than the values found in this study.

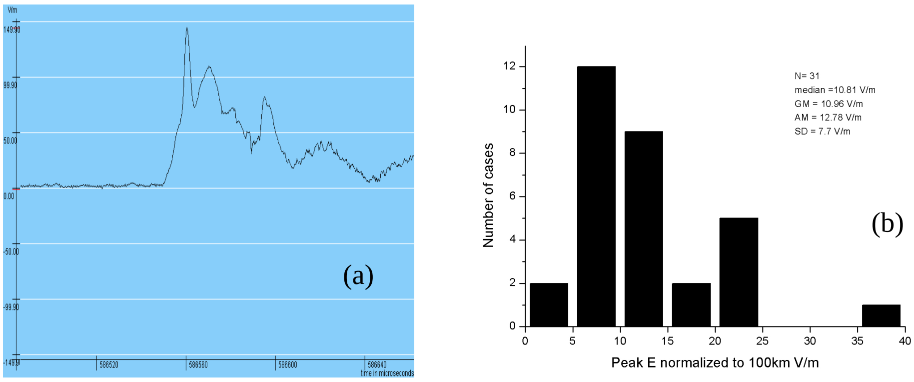

Figure 2 (a): Waveform for example of positive return-stroke electric field.
(b) Distribution of the peak electric field normalized to 100km.

The distribution of zero-to-peak risetime observed is shown in figure 3(a). The data collection is distributed over the range 4.4 to 16.2µs. The AM and GM are 8.9 and 9.28 µs respectively. Nag et al. [2010] found 7.77 and 6.92 µs AM and GM.

Table 2: Statistics of different parameters of positive return stroke fields obtained in different studies

	Number	Median	GM	AM	SD
Zero-to-peak risetime (µs)					
This work	38	8.9	8.9	9.27	2.7
Nag et al. [2010]	62	7.19	6.92	7.77	3.76
Cooray [1986]	20	--	--	8.9	1.7
10-90% risetime (µs)					
This work	38	5.4	5.1	5.33	1.6
Nag et al. [2010]	62	3.71	3.4	4.02	2.12
Cooray [1986]	15	--	--	6.2	1.4
Peak Amplitude Normalized to 100km (V/m)					
This work	31	10.96	10.81	12.78	7.7
Nag et al. [2010]	48	--	18.1	21.7	--
Cooray et al. [2004]	46	--	--	11.5	6.7

Histogram of the 10-90% risetime for 38 return strokes electric field waveforms is shown in figure 3 (b). The AM and GM are, respectively, 5.1 and 5.3, with range from 2.6 to 9.2 µs. The 10-90% risetime values found by Nag et al. [2010] are 4.02 and 3.40µs for the AM and GM respectively.

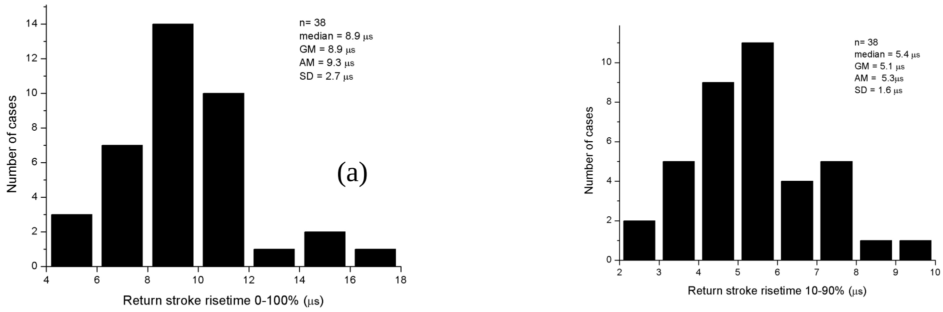

Figure 3: (a) Histogram of the zero-to-peak risetime (b) Histogram of the 10-90% risetime for 38 return strokes.

4. CONCLUSION

For the first time in Brazil, some characteristics of the initial breakdown pulses and of the positive return stroke were examined with electric field measurements. The duration of the breakdown pulses is similar to what was measured in China and Sweden but larger than what was found by Ushio et al. [1998] in Japan. The GM values of stroke peak amplitude normalized to 100km measured in Florida [Nag et al., 2010] are nearly two times higher than the values measured in this work and in Sweden. These higher values correspond to a GM peak current reported by the NLDN of 74.6 kA (also two times higher than the GM reported by Saba et al. [2010], 37.4 kA for 101 positive strokes). It is interesting to note that although the peak amplitude measured by Nag et al. [2010] is nearly 2 times higher than obtained in Sweden and in Brazil, the risetime measured in Florida is slightly shorter than in Sweden and in Brazil.

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