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Characterization of positive return strokes from a thunderstorm day observed in Bogotá, Colombia

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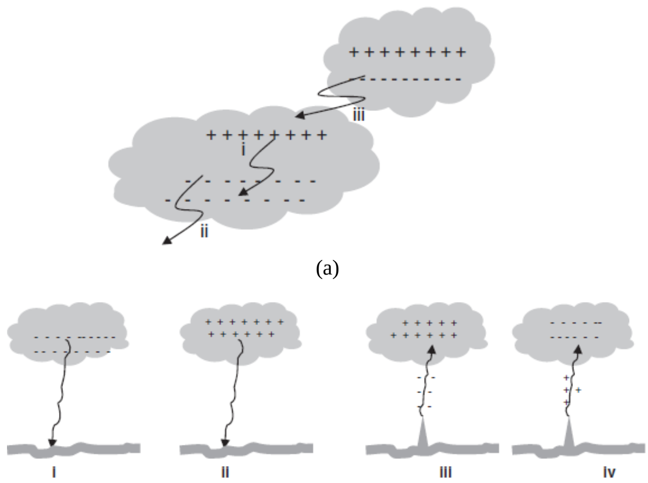
***Abstract*— This paper presents the parameters characterization of the electric field signatures produced by the first (FRS) and subsequent return strokes (SRS) of 12 positive cloud-to-ground flashes observed in Bogotá-Colombia. These signatures were obtained from a single thunderstorm day during the measurement campaign October-November 2018. First, the features of the electric field measuring system and its geographical location are presented. Later, the characterization of the magnitude and temporal parameters was performed. The peak value of the electric field, the slow front amplitude relative-to-peak and the overshoot amplitude relative-to-peak were selected as the magnitude parameters. On the other hand, temporal parameters such as the slow front duration, the fast transition duration, the zero-to-peak rise-time, the 10-to-90% rise-time and the zero-crossing time were analyzed.**

Keywords—Positive cloud to ground lightning, positive return strokes, electric field meassurments.

I. INTRODUCTION

Lightning discharges can be separated into two main categories: ground flashes and cloud flashes. Lightning discharges that contact ground are referred as cloud-to-ground (CG) flashes and the rest are referred as cloud flashes. Cloud flashes can be divided into three types: intracloud flashes, air discharges and intercloud discharges. These different categories of lightning flashes are illustrated in Fig. 1(a). On the other hand, the CG flashes can be divided into four categories that are based on the polarity of the charge that the flash brings to the ground and its point of initiation. These categories, shown in Fig. 1(b), are: downward negative ground flashes, downward positive ground flashes, upward positive ground flashes and upward negative ground flashes. The polarity of the flash, i.e. negative or positive, it is based on the polarity of the charge brought to the ground from the cloud [1].



(b)

Fig. 1. *(a) Types of cloud flashes: (i) intracloud; (ii) air discharges; (iii) intercloud. (b) Types of ground flashes: (i) downward negative ground flashes; (ii) downward positive ground flashes; (iii) upward positive ground flashes; (iv) upward negative ground flashes.*[1]

Once the connection between the cloud and the ground is made through the current channel (heating up to several tens of thousands of degrees) making the channel luminous, an event called the first return stroke (FRS) is occurring. If the FRS channel happens to be in a partially conducting stage with no-current flow during the encounter, it may initiate a dart leader that travels towards the ground.

Sometimes the lower part of the channel decays to such an extent that the dart leader stops before actually reaching the ground. These are termed attempted leaders. In other instances, the dart leader may encounter a channel section whose ionization has decayed to such an extent that it cannot support the continuous propagation of the dart leader. In this case the dart leader may start to propagate towards the ground as a stepped leader. Such a leader is called a dart-stepped leader. If these leaders travel all the way to ground, then another return stroke (RS), called the subsequent return stroke (SRS) is initiated [1].

Several studies have reported that negative CG flashes are more common that their positive counterparts. In fact, the relation of occurrence is of approximately 90% in favor of the negative CG flashes. However, the positive CG flashes have larger currents and major charge transfer, aspects that can make these even more dangerous. In addition, due to the low occurrence and its scarcity, it is difficult to collect a large sample of electric fields generated by positive CG flashes [2]. For this reason, this type of discharges and their return strokes are less studied and less understood compared with the negative CG flashes.

This work presents a preliminary study about the parameters characterization of the electric field waveforms produced by 12 positive CG flashes and their 21 return strokes. These signatures were recorded in Bogotá, Colombia during a single thunderstorm on October the 2th, 2018. This is the first study of this kind performed in Colombia and its results are of interest if it is considered that Bogotá is located in a mountainous region with an altitude about 2550 m. In addition, this study provides information on the occurrence and features of the positive CG flashes in tropical regions.

II. MEASUREMENT SET UP

In general terms, the measuring systems used to capture lightning-generated electric field signatures are composed by four stages: (A) electric field sensor; (C) electronic circuit based on an operational amplifier; (E) recording equipment; and (F) personal computer. Under these conditions, the measuring system used in this work is shown in Fig. 2 [3].

This system consists of a parallel plates circular antenna, an electronic circuit implemented with the buffer-amplifier BUF602 (C) and the recording device is an Agilent DSO6104A digital oscilloscope (E). For the connection of the elements (B) and (D), coaxial cables RG-58/U were used. The cable connected between the circuit and the oscilloscope was properly terminated to avoid reflections. It is important to mention that the BUF602 is a new replacement for the typical amplifier LH0033 [3] because its manufacture was interrupted since 2008. A summary of the features of the measuring system are presented in Table I.

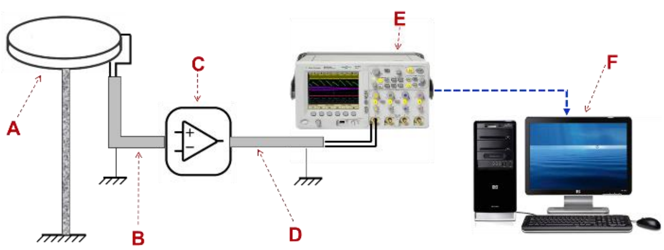


Fig. 2. *Scheme of the electric field measuring system. (A) parallel-plate antenna; (B) short coaxial cable RG58U; (C) electronic circuit; (D) long coaxial cable RG58U; (E) digital oscilloscope.*

TABLE I. SPECIFICATIONS OF ELECTRIC FIELD MEASURING SYSTEM

ID	Elements	Technical characteristics
A	**Electric field antenna**	• Circular parallel plates • Diameter of the plates: 0.45 m • Separation between plates: 0.03 m • Antenna bandwidth: 30 MHz • Metallic support mast: 1.5 m
B	**Short coaxial cable (antenna-electronic circuit)**	• Reference: RG 58 / U • Characteristic impedance: 50 Ω • Length: 50 cm • Simple shielding
C	**Electronic circuit**	• BUF602 buffer amplifier • Bandwidth: 1000 MHz • Growth rate: 8 kV / µs
D	**Long coaxial cable (electronic circuit-oscilloscope)**	• Reference: RG 58 / U • Characteristic impedance: 50 Ω • Length: 12 m • Simple shielding plus metal shell
E	**Oscilloscope**	• Agilent DSO6104A • Bandwidth: 1 GHz • Maximum sampling: 4GSa / s
F	**Desktop computer**	• 4-core processor at 2.3 MHz • 4 GB RAM memory • 320 GB Hard Drive • LAN and WI-FI connection

For the acquisition process, the oscilloscope was set to operate at a sampling rate of 100 ns, using a full observation window of 500 ms. In addition, to capture transient signals with negative polarity (translated as positive downwards charge hence positive cloud-to-ground flashes), a vertical trigger with a magnitude of 10 V/m (or 250 mV) and a pre-trigger time of 75 ms were adjusted.

The parallel-plate antenna and the electronic circuit were located on the roof of block B5 of the Camilo Torres Unit at the Universidad Nacional de Colombia Campus. This place is located at the central region of Colombia at approximately 4.641° N, 74.091° W and 2550 meters above sea level. The approximate height between the ground plane and the roof of building is 15 meters. The recording equipment was located in an office belonging to the EMC-UNC research group (5th floor of the building).

III. METHODOLOGY

The electric field signals analyzed in this paper were recorded on October the 2th, 2018 during a single thunderstorm day. The measurements started at 00:09 hours and ended at 07:38 hours with a total duration of 7,5 hours. The dataset is composed by 12 positive CG flashes and 21 return strokes (RS). From these flashes, five are singles flashes, while seven flashes have between 2 and 4 RS.

For the characterization of the waveforms, the fine structures of the positive CG flashes are analyzed. This method includes the slow front duration, the fast transition duration, the zero-to-peak rise-time, the 10-to-90% rise-time and the zero-crossing time. On the other hand, the peak value of the electric field, the slow front amplitude relative-to-peak and the overshoot amplitude relative-to-peak were considered as magnitude parameters.

These parameters are shown in Fig. 3 using a positive return stroke signature. In this figure, the red line corresponds to the background or reference electric field (pre-discharge level) on which the features of the return stroke signature are not evidenced yet. As can be seen this reference value does not necessarily correspond to zero and it could be attributed to the electrostatic components of the measurement itself, as well as other errors such as electronic noise and the DC output offset of the electronic circuit [3]. Despite the noise components and the background electric field, the measuring system have been successfully tested and validated and the results obtained in this study (waveforms) are similar to the ones reported by other studies. In addition, the number of samples (signatures), the maximum and minimum values and the statistics of these parameters, such as the arithmetic mean (AM) and geometric mean (GM), are calculated.

In order to identify a positive RS, the waveforms and the parameters presented in [4] and [5] are considered. However, as concluded by both works, the temporal parameters concerning to the rise-time of the RS are dependent on the medium of propagation (over land or seawater), as well as the seasonal variation and its polarity. For this reason, positive RS generally present larger rise-times compared to negative ones.

Considering the conclusion mentioned above and adding the fact that Bogotá (and the measuring station itself) is located near a mountain chain, a maximum zero-to-peak rise-time of 140 µs was set in order to classify an electric field signature as a positive RS. This temporal parameter has relation to the results presented by Hazmi *et al.* [6], Johari *et al.* [7] and, especially, the results reported by Wooi *et al.* [8], which present similar latitude conditions (location close to the equator).

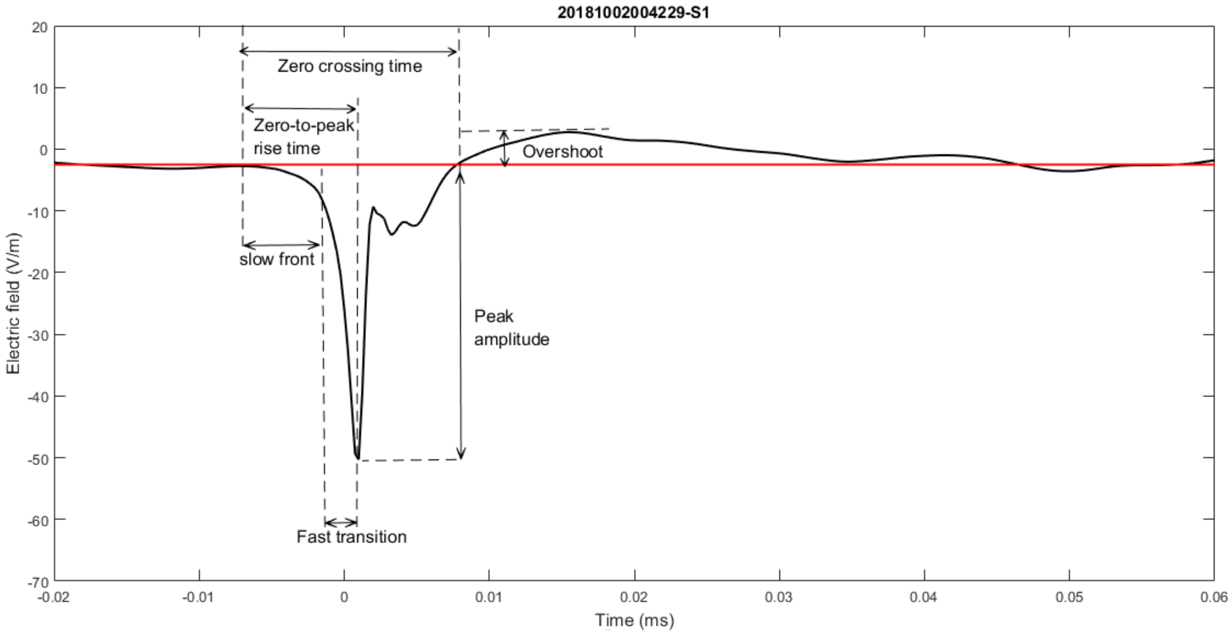


Fig. 3. *Parameters of the electric field signature produced by a positive return stroke: zero-to-peak rise-time, slow front, fast transition, zero-crossing time, peak amplitude and overshoot*

TABLE II. PARAMETERS OF THE ELECTRIC FIELD SIGNATURES PRODUCED BY FRS AND SRS OF POSITIVE CG FLASHES RECORDED IN BOGOTÁ, COLOMBIA

Strokes	Parameter	Slow front duration [µs]	Fast transition duration [µs]	Zero-to-peak risetime [µs]	10-to-90 % risetime [µs]	Zero-crossing time [µs]	Peak electric field [V/m]	Slow front amplitude relative-to-peak	Overshoot amplitude relative-to-peak
All return strokes	**Sample size**	18	18	21	21	18	21	18	17
	Min	1,75	1,50	2	1	8,75	15,08	7%	8%
	Max	48	15	53,75	33	71,25	62,82	40%	78%
	AM	13,93	6,86	18,73	9,51	34,79	30,16	21%	44%
	GM	10,72	5,42	14,26	6,69	29,70	27,90	19%	38%
First return stroke	**Sample size**	11	11	12	12	10	12	11	10
	Min	1,75	1,50	2	1	8,75	20,11	7%	8%
	Max	48	15	53,75	33	71,25	62,82	33%	78%
	AM	15,64	5,89	19,90	8,92	38,93	34,77	19%	46%
	GM	11,22	4,55	13,59	5,60	30,80	32,66	18%	38%
Subsequent return stroke	**Sample size**	7	7	9	9	8	9	7	7
	Min	6	3,25	6,50	3,75	15,25	15,08	7%	14%
	Max	21,50	14	31,75	26,25	42,25	37,71	40%	67%
	AM	11,25	8,39	17,17	10,31	29,63	24,02	25%	42%
	GM	9,97	7,15	15,20	8,48	28,39	22,62	22%	38%

IV. RESULTS AND DISCUSSION

In this section, the statistical results obtained for each parameter of the 21 positive RS are presented. In order to compare these results, the parameters of the first return strokes (FRS) and the subsequent return strokes (SRS) were divided and summarized in Table II.

A. Slow front duration

According to Table II, the slow front of the 18 RS analyzed has a duration ranged from 1,75 to 48 µs. The AM and GM values were 13,93 µs and 10,72 µs, respectively. For 11 FRS, this duration ranged from 1,75 µs to 48 µs, while the AM and GM values were 15,64 µs and 11,22 µs, respectively. For the SRS, the duration ranged from 6 µs to 21,5 µs, while the AM and GM values were 11,25 and 9,97 µs, respectively. Fig. 4 shows the statistical distribution of the slow front duration. In this way, the histogram reveals that 8 FRS (72%) and 7 SRS (100%) present a slow front duration between 1,75 µs and 24 µs.

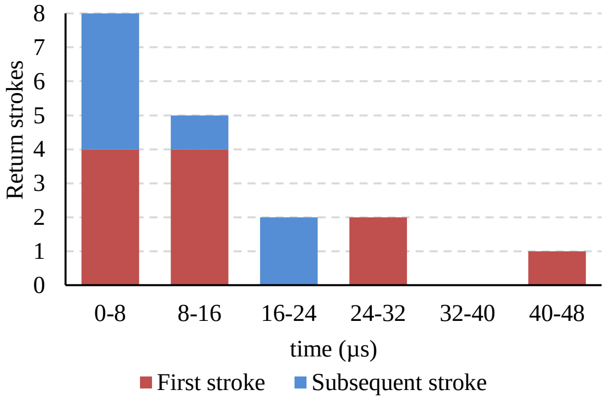


Fig. 4. *Histogram of the slow front duration*

B. Fast transition time

For the 18 RS that exhibited this structure, the maximum and minimum values were 1,5 µs and 15 µs. The AM for the fast transition time was 6,86 µs, while the GM was 5,42 µs. For 11 FRS, the duration ranged from 1,5 µs up to 15 µs, while the AM an GM values were 5,89 and 4,55 µs, respectively. For 7 SRS, the fast time varied between 3,25 µs and 14 µs, while the AM and GM were 8,39 µs and 7,15 µs, respectively. The distribution of this parameter is shown in Fig. 5. In this case, nine FRS (82%) present a fast transition with a duration less than 9 µs, while only four signatures (57%) of the SRS present the same behavior.

C. Zero-to-peak rise-time

The duration of the zero-to-peak rise-time for the 21 RS analyzed is between 2 µs and 53,75 µs. The AM and GM were 18,73 µs and 14,26 µs, respectively. The statistical distribution of this parameter is shown in Fig. 6. It is possible to observe that 75% (9 signatures) of the FRS and 100% (9 signatures) of the SRS have a zero-to-peak rise-time less than 40 µs.

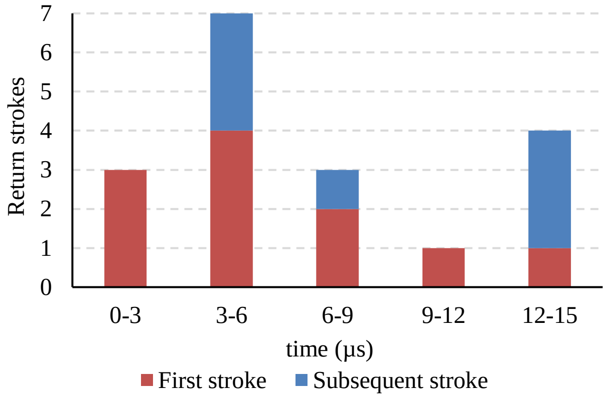


Fig. 5. *Histogram of the fast transition time*

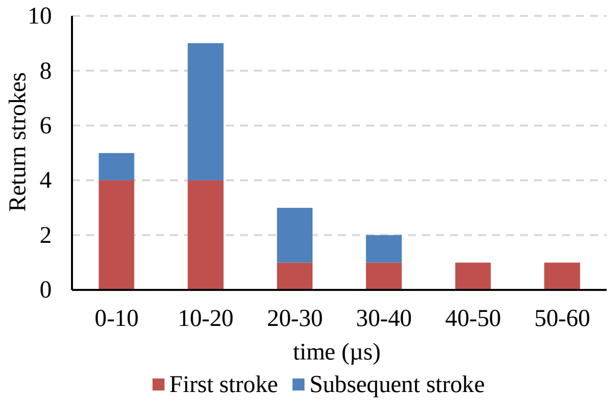


Fig. 6. *Histogram of the zero-to-peak rise-time*

D. 10-to-90 % rise-time

Fig. 7 shows the histogram of the 10-to-90% rise-time. For the 21 return strokes this duration ranged from 1 µs to 33 µs. The AM and GM values were 9,51 and 6,69 µs, respectively. For 12 FRS, this rise-time ranged from 1 µs to 33 µs, while the AM was 8,92 µs and the GM was 5,6 µs. For 9 SRS, the duration varied from 3,75 µs up to 26,25 µs. In addition, the AM and GM values were 10,31 µs and 8,48 µs, respectively. Analyzing these results, 92% of the FRS (11 signatures) and 78% of the SRS (7 signals) present a 10-to-90 % rise-time between 1 µs and 15 µs.

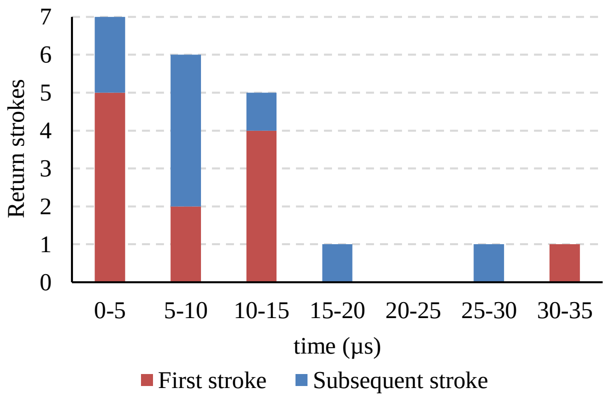


Fig. 7. *Histogram of the 10-to-90 % rise time*

E. *Zero-crossing time*

For the 18 RS that exhibited zero-crossing time (ZC), the values ranged from 8,75 µs to 71,25 µs. The AM and GM values were 31,79 and 29,7 µs, respectively. For the FRS (10 signatures), the duration ranged from 8,75 µs up to 71,25 µs, while the AM an GM values were 38,93 µs and 30,8 µs respectively. For the SRS (8 signatures), the ZC time changed from 15,25 µs up to 42,25 µs, while the AM was 29,63 µs and the GM was 28,39. Fig. 8 shows the distribution of this parameter. In this case, six FRS (60 %) and eight SRS (100 %) present a ZC time between 8,75 µs and 45 µs.

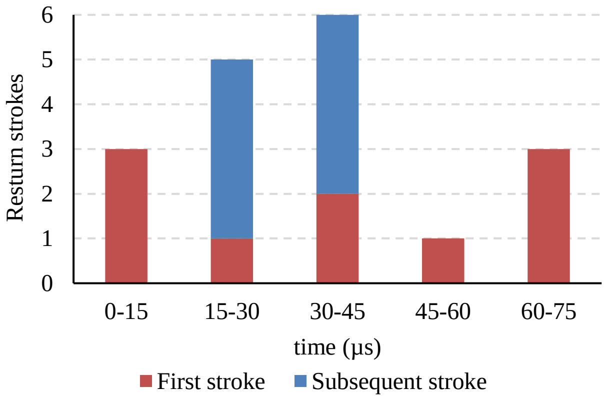


Fig. 8. *Histogram of the zero crossing time*

F. *Slow front amplitude relative-to-peak*

The percentage of the slow front amplitude relative-to-peak for the 18 RS was between 7% and 40%. The AM and GM were 21% and 19%, respectively. For 11 FRS, the percentage ranged from 7% up to 33%, while the AM was 19%. For 7 SRS, the percentage varied between 7% and 40 %, while the AM and GM were 25% and 22%, respectively. The histogram of this parameter is shown in Fig. 9. In addition, all return stroke signatures shown a slow front amplitude relative-to-peak less than 40%.

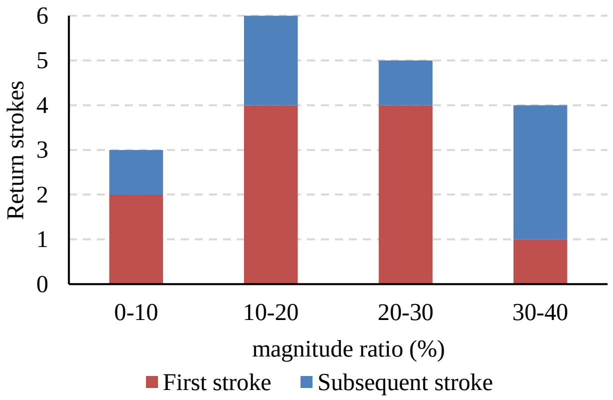


Fig. 9. *Histogram of the slow front amplitude relative-to-peak*

G. *Overshoot amplitude relative-to-peak*

With respect to the overshoot amplitude relative-to-peak for the 17 return strokes varies between 8% and 78%. For the dataset the AM and GM values were 44% and 38%, respectively. For the FRS, the overshoot amplitude fluctuates from 8% up to 78%, while for the SRS this parameter varies between 14% and 67%. With respect to the AM and GM, the values were 46% and 38% for the FRS, while for the SRS these statistics are 42% and 38%, respectively. The histogram of this magnitude ratio is shown in Fig. 10. In this way, the major part of the return strokes analyzed have an overshoot with a magnitude between 30% and 75% of its peak value.

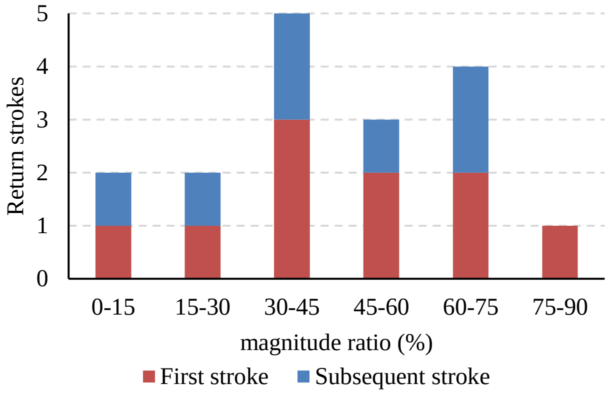


Fig. 10. *Histogram of the overshoot amplitude relative-to-peak*

V. Conclusions

In this paper, the waveform features of 12 positive CG flashes containing 21 return strokes (12 FRS and 9 SRS) recorded in Bogotá, Colombia (mountainous region located at tropic) were analyzed. In addition, a comparison of the characteristics (in time and magnitude) of positive FRS and positive SRS was depicted in Table 2.

The statistical analysis shows that the AM and GM of some parameters such as the slow front duration and the zero-crossing time exhibited higher values for positive FRS than for positive SRS. In the case of the fast transition, the zero-to-peak rise-time and the 10-to-90% rise-time of the SRS have shorter durations than the FRS.

With respect to the magnitude parameters, the FRS present higher peak values (electric field), while the slow front amplitude relative-to-peak is greater in the SRS. In relation to to the overshoot amplitude relative-to-peak, the FRS show a slight difference in comparison to the SRS. Although, these results are a first approximation from the characteristics of positive return strokes in Colombia, it is necessary to carry out further analysis using a more representative dataset (more than 100 or 150 signatures if possible).

The values reported in this preliminary study are comparable to those reported by Wooi *et al.* [8], which were taken in Malaysia, a tropical zone near to the equator. However, the zero-to-peak rise-time and the 10-to-90% rise-time are generally larger than those reported in temperate and subtropical countries. This may be explained by the special geographical conditions of Bogotá such as: the height at which the thunderclouds form in the mountainous area, the altitude and the propagation medium (overland close to a mountain chain) that could produce interferences in the propagation of the electromagnetic waves.

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REFERENCES

[1] V. Cooray, *Lightning Protection*, vol. 127, no. 12. 2010.

[2] Z. A. Baharudin, V. Cooray, M. Rahman, P. Hettiarachchi, and N. A. Ahmad, "On the characteristics of positive lightning ground flashes in Sweden," *J. Atmospheric Sol.-Terr. Phys.*, vol. 138–139, pp. 106–111, 2016.

[3] H. E. Rojas, C. A. Rivera, J. Chaves, C. A. Cortés, F. J. Román, and M. Fernando, "New circuit for the measurement of lightning generated electric fields," *2017 Int. Symp. Light. Prot. XIV SIPDA 2017*, no. October, pp. 188–194, 2017.

[4] V. Cooray, "A novel method to identify the radiation fields produced by positive return strokes and their submicrosecond structure," *JGeophys Res*, vol. 91, no. D7, pp. 7907–7911, 1986.

[5] M. Ishii and J.-I. Hojo, "Statistics on fine structure of cloud-to-ground lightning field waveforms," *J. Geophys. Res.*, vol. 94, no. D11, p. 13267, 1989.

[6] A. Hazmi, P. Emeraldi, M. I. Hamid, N. Takagi, and D. Wang, "Characterization of positive cloud to ground flashes observed in Indonesia," *Atmosphere*, vol. 8, no. 1, 2017.

[7] D. Johari, V. Cooray, M. Rahman, P. Hettiarachchi, and M. M. Ismail, "Features of the first and the subsequent return strokes in positive ground flashes based on electric field measurements," *Electr. Power Syst. Res.*, vol. 150, pp. 55–62, 2017.

[8] C.-L. Wooi, Z. Abdul-Malek, B. Salimi, N. A. Ahmad, K. Mehranzamir, and S. Vahabi-Mashak, "A Comparative Study on the Positive Lightning Return Stroke Electric Fields in Different Meteorological Conditions," *Adv. Meteorol.*, vol. 2015, pp. 1–12, 2015.