Leader characteristics in positive cloud-to-ground lightning flashes

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Abstract: Past results from streak photographs by Berger and Vogelsanger [1] show that there may be no steps on the positive leader propagation. Steps in positive leader propagation have never been observed by high speed cameras with frame rates up to 8000 frames per second [2]. However some other studies found pulses on the electric field during the progression of the leader toward ground that could indicate the presence of steps in the leader propagation. Hojo et al.[3] observed electric field leader pulses in 26-30% of their cases, with mean time interval of about 17µs (ranging from 3µs to 31µs). Proctor [4] observed two out of 175 flashes in South Africa that show pulses on the leader. Cooray and Lundquist [5] reported step pulses within a mean time interval of 26µs for positive lightning in Sweden. This work presents high-speed video camera and electric field measurements of downward leaders in positive cloud-to-ground lightning in Brazil. Several cases were analyzed and the percentage of leaders containing pulses is reported.

Keywords : Positive leader, positive cloud-to-ground

1. INTRODUCTION

Our present knowledge about the physics of positive lightning is not as good as that for negative lightning, and many questions still remain about the genesis of positive discharges. Although positive cloud-to-ground (+CG) lightning flashes are usually not as frequent as negative flashes, their special characteristics of high peak , large impulse , and long continuing make understanding their physical parameters an important issue. The largest directly measured peak currents and charge transfers to ground are produced by +CG flashes [6]. Positive flashes are also a major concern for the designers of lightning locating systems because their electromagnetic waveforms are frequently very large and often have a complex structure [7]. Therefore positive flashes are sometimes hard to detect by lightning location systems. This paper analyses some characteristics of the electric field pulses during the propagation of the leader towards ground in +CG flashes.

2. INSTRUMENTATION

2.1 HIGH-SPEED CAMERAS

Six different high-speed digital video cameras (Photron Fastcam 512 PCI, Red Lake Motion Scope 8000S, Phantom v7.1, v310, v12.1 and Basler Pilot piA640-210gm), with time-resolutions and exposure times ranging from 83 microseconds (11,800 frames per second) to 10 milliseconds (100 frames per second), have been used to record images of cloud-to-ground lightning in southern and southeastern Brazil, southern Arizona (USA), South Dakota (USA) and Vienna (Austria) between February 2003 and September 2009. All video imagery was recorded without any frame-to-frame persistence and was time-stamped to GPS. The minimum recording length of all the cameras was two seconds; previously, Saraiva et al. [8], in a multiple-camera study, reported a maximum flash duration of 1.4 s with approximately 99% of the more than 400 cases lasting less than 1 s for negative CG flashes. We believe that this recording length is sufficient also for positive lightning, as discussed in the following sections. For more details about the accuracy of high-speed camera technology for lightning observations and more details on the measuring systems, see the works by Saba et al. [9], Schulz and Saba [10], and Warner and Orville [11].

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2.2 LIGHTNING LOCATION SYSTEMS

All recordings were obtained in geographical regions that were covered by Vaisala lightning location systems (BrasilDat in Brazil, the NLDN in the USA, and ALDIS in Austria). These systems are nearly identical, and further information about their performance can be found in Schulz et al. [12], Cummins and Murphy [13], and Naccarato and Pinto Jr. [14]. Data from the lightning location systems (LLS) were used to obtain the stroke polarity, an estimate of the peak current (Ip) in each stroke, and the locations of the ground strike points. The polarity identification was also double-checked in approximately 40% of the dataset with the help of electric field measurements; no contradiction was observed in the analyzed dataset.

2.3 ELECTRIC FIELD MEASUREMENT SYSTEM

The electric field measuring system consisted of a flat plate antenna with an integrator/amplifier (bandwidth from 306 Hz to 1.5 MHz), a GPS receiver, and a PC with two PCI-cards (a GPS card Meinberg GPS168PCI 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. [15]. The recordings were performed using two different amplifiers, one 10 times more sensitive than the other.

3. RESULTS AND ANALYSIS

From a dataset of 105 positive cloud-to-ground flashes recorded with high-speed cameras, (described by Saba et al. [16]), this work selected 19 strokes from 17 positive flashes because for those strokes we had also data from the electric field antenna.

The electric field waveforms studied in this paper originated in +CG lightning flashes that occurred between 7 and 44 km from the recording site. All strokes were located by the lightning location networks from which we used the peak current estimates. Visual information from the videos were used during the analysis of the presence of leader pulses in the electric field data. Figure 1 presents a typical sequence of images taken by a high speed camera showing the leader propagation to the ground.

Leader pulses were observed in 14 (74%) of the 19 strokes. Figure 2 presents a train of pulses observed prior to a +CG flash. It was possible to check if the absence of pulses was due to low amplification of the electric field and/or due to attenuation of the electric field (in case of distant lightning) with the help of the two amplifiers/integrators, verifying their sensibility to such pulses for different distances

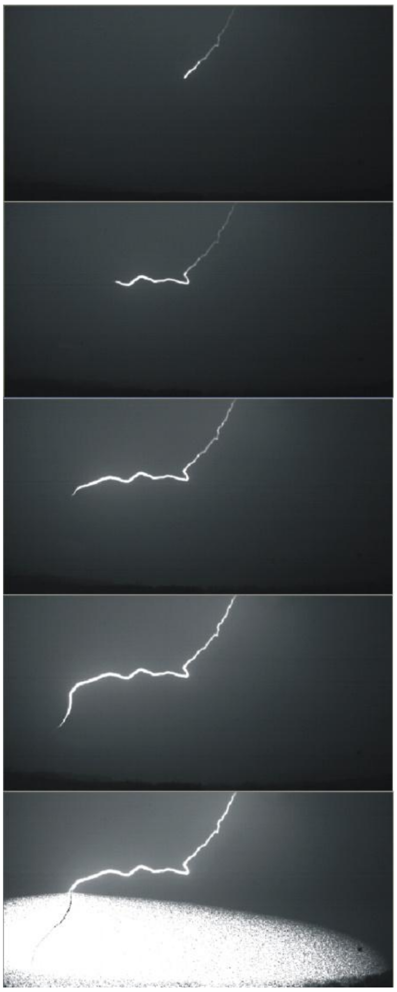

Fig. 1. Sequence of images of a positive leader approaching ground. The last image shows the luminosity of the return stroke moving upward.

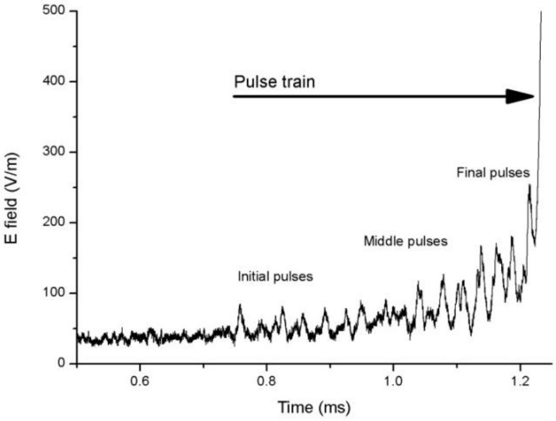

Fig. 2 Typical train of pulses observed prior to a +CG flash.

Figure 3 shows two cases of electric field measurements of positive CG flashes with similar values of estimated peak current (Ip) and distance (d) from the antenna. Note that despite these similarities, no pulses are observed prior to the stroke shown in Figure 3b.

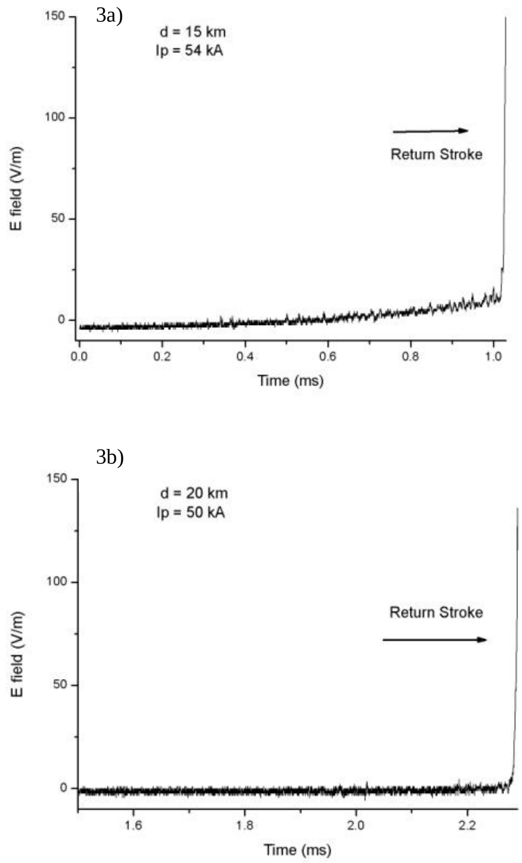

Fig. 3. Two cases of electric field measurements of positive CG flashes with similar values of estimated peak current (Ip) and distance (d) from the antenna.

Statistics of the time interval between the beginning of the pulses and the return stroke is shown in Table 1.

Table 1 – Statistics of the time interval between pulses

Time interval between the first pulse and the return stroke					
Number of strokes	Mean (μs)	Min (μs)	Max (μs)	Geometric Mean (μs)	Average number of pulses
14	452.5	143	1315	372.9	20.4

Table 2 – Time interval between pulses and their relative amplitude

	N	Initial	Middle	Final
Average time interval between pulses (μs)	14	22.5	20.7	20.2
Average relative peak amplitude (pulse/return stroke)	7	2.1%	2.6%	3.6%

As one can see on Table 2, the mean time interval between pulses does not vary significantly along the progression of the leader towards ground. There are no apparent differences in the mean time interval between pulses that occur at different stages (initial, middle or final) of the train of pulses prior to the return stroke.

In order to compare the amplitude of the pulses in relation to the amplitude of the return stroke we have calculated the ratio between them of and obtained the average ratio for different periods of the pulse sequence. As shown in Table 2, the relative amplitude of the pulses increases as the leader approaches ground.

4 - DISCUSSION AND CONCLUSIONS

Leader pulses were observed in 14 (74%) of the 19 strokes. Hojo et al.[3] observed pulses in only 26-30% of the +CG strokes. This major discrepancy with the past studies may be due to capability of our instrumentation in recording pulses that have amplitude usually less than 5% of that of the return stroke.

All the observed leader pulses appeared just 1 ms or less prior to the return stroke.

The time interval between pulses remains constant along the train of pulses prior to the return stroke. In average, it is similar to the values found by Cooray and Lundquist [5] (26 μs) and by Hojo et al. [3] (17.4 μs). Although the sample size is relatively small, the observed relative amplitude of the pulses increases as they approach ground.

It is difficult to say for sure if the pulses are indeed due to the downward leader or not. Given the time scales involved, it could also be produced by the upward negative connecting leader, which would also produce pulses of the same polarity. This question remains open and should be addressed in future works through the comparison between characteristics of pulses observed in positive and negative flashes.

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