Observations of natural cloud-to-ground lightning leaders from simultaneous high-speed video recordings and electric field measurements

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ABSTRACT: The aim of this investigation is to analyze the phenomenology of positive and negative (stepped-, dart- and recoil) leaders observed in natural lightning from simultaneous high-speed video recordings and electric field measurements. For that intent we have used two different high-speed cameras (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) and two different types of electric field sensors (slow and fast) in addition to data from a lightning locating system (BrasilDat). All the instruments were GPS time synchronized in order to avoid ambiguities in the analysis and allow us to estimate the peak current of and the distance to each flash that was detected by BrasilDat. From these data it is possible to calculate the two-dimensional speed of each observed leader, allowing us to obtain its statistical distribution along with its correlation to other characteristics of the associated flash, such as return stroke peak current, interstroke interval and presence and duration of continuing current after the return stroke initiated by the leader. Also, the availability of electric field data makes it possible to correlate it to the optical characteristics of each leader type, providing us new insights on the microphysics of these phenomena. In the analyzed dataset, the speeds of positive leaders and negative dart-leaders follow a lognormal distribution at the 0.05 level (according to the Shapiro-Wilk test), while the negative stepped-leaders have a similar distribution even though according to a relatively weaker test (Kolmogorov-Smirnov). Unfortunately, due to the range of frame rates reached by the used cameras, only the minimum propagation speeds could be estimated in the recoil leaders that were observed.

1. INTRODUCTION

Early studies on lightning leaders were based on either streak camera recordings [e.g., Schonland et al., 1935] or electric-field measurements [e.g., Chapman, 1939] but there have been no investigations that combined both instruments to analyze how lightning channels are formed. With the help of digital high-speed video cameras it has been possible to shed some light on the characteristics and behavior of positive leaders, allowing a comparison with the available data on negative stepped leaders and providing first optical documentation of recoil leaders [Saba et al., 2008]. In this paper we present preliminary results and insights provided by simultaneous high-speed video recordings and electric field measurements of lightning leaders. Despite the limited length available for this paper we expect to be able to expand the presented results and analyses before

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upcoming conference.

2. INSTRUMENTATION

2.1 ***High-speed camera***

The data presented in this work were provided by two different high-speed cameras set to operate with a temporal resolutions between 1000 and 4000 frames per second (250 microseconds to 1 millisecond exposure times) in a field campaign conducted in São José dos Campos, SP, south-eastern Brazil. Both cameras are GPS synchronized and provide time-stamped images with no frame-to-frame brightness persistence.

2.2 ***Slow and fast electric field measuring systems***

In addition to the high-speed video data we have used three flat plate antennas to measure electric-field changes produced by lightning. Two of these antennas were operated as fast electric-field change sensors with the help of an integrator/amplifier (with a bandwidth that ranges from 306 Hz to 1.5 MHz), a GPS receiver for temporal synchronization, and a data acquisition system that operates at a sampling rate of 5 MS/s on each channel and a 12-bit analog/digital (A/D) converter. In order to guarantee enough sensitivity without the risk of losing data due to saturation, both antennas were operated simultaneously using integrator/amplifier circuits with sensitivities that are different by a factor of 10. Finally, the third antenna was used as a slow electric-field change sensor.

2.3 ***Lightning locating system***

The observation site in São José dos Campos, SP, Brazil, is located in an area well covered by the Brazilian Lightning Detection Network (BrasilDat). From the data provided by the lightning locating system it was possible to obtain estimated values of the distance from the instruments to the return stroke strike point, a vital parameter in estimating the two-dimensional (2-D) propagation speeds of the leaders. Also, we were able to compare the flash polarity with the one observed with the help of the electric-field measurements, allowing us to minimize the errors in selecting positive leaders for a detailed analysis.

3. PRELIMINARY RESULTS

Our dataset consisted of 62 negative stepped-leaders, 76 negative dart-leaders, and 29 positive leaders. An example of correlated electric-field measurements and high-speed video recordings of a single negative stepped leader is presented in Figure 1. There is a clear correlation between the beginning of the occurrence of electric field pulses and the observed luminosity inside the cloud.

Similarly to the work by Saba et al. [2008], we assume that “speeds measured along the path of the leader” are termed “partial speeds”, while “the average speed is calculated by dividing the length of the entire 2-D trajectory by the time taken to cover it” [Saba et al., 2008, p. 2]. A statistical analysis of the dataset has showed that the average 2-D speeds of positive leaders and negative dart-leaders follow a lognormal distribution at the 0.05 level, according to the Shapiro-Wilk test [Shapiro and Wilk, 1965]. The negative stepped-leaders have a similar distribution, although according to the Kolmogorov-Smirnov test, usually considered to be not as strong [Stephens, 1974]. Considering that slower cases of each leader type would provide more individual partial speed measurements throughout their propagation, in order to avoid an statistical bias towards lower values, in Figure 2 we present histograms that show only the statistical distributions of average 2-D speeds of each leader type.

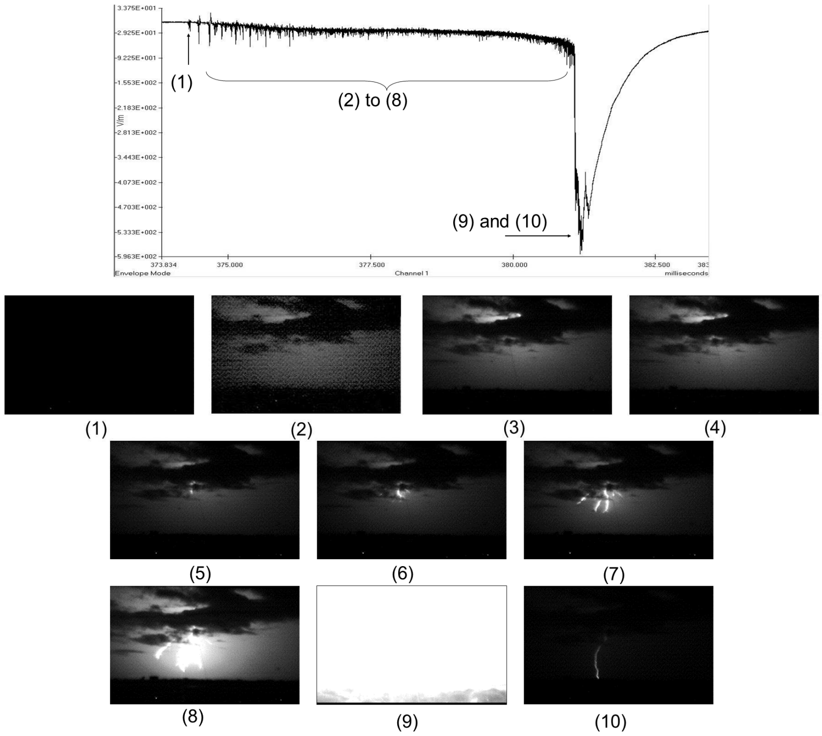

Figure 1. Correlated fast electric field measurements (top) and high-speed camera frames (bottom) of a negative stepped-leader. The time interval between each frame is 1 ms.

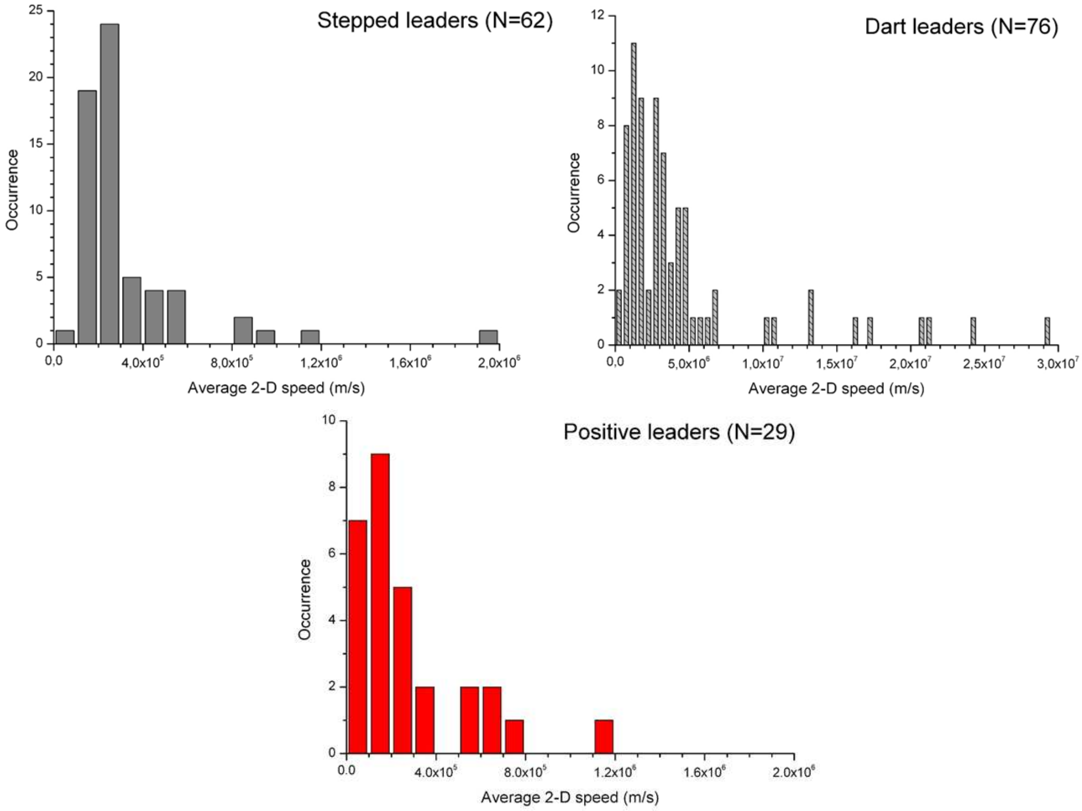

Figure 2. Histograms of average 2-D speeds of 62 negative stepped leaders (top, left hand), 76 negative dart leaders (right, left hand) and positive leaders (bottom).

4. CONCLUDING REMARKS

The present paper accounts for preliminary results derived from an ongoing analysis in which the microphysics of natural lightning leaders is being studied with the help of simultaneous high-speed video recordings and electric field measurements.

Up to now it is still not well established if positive leaders develop towards the ground either in a continuous or a stepped manner. Even though results from laboratory-produced sparks point towards a continuous mode of propagation (e.g., Les Renardières Group [1977], Gallimberti et al. [2002]), some experiments on natural [Qie and Kong, 2007; Wang and Takagi, 2011] and triggered [Biagi et al., 2009] lightning presented evidence that positive leaders might develop through steps, so this question remains open. This matter has been approached in a previous paper by some of the authors and collaborators [Campos et al., 2010] in which a clear tendency of positive leaders to increase their speed as they approach the ground was found, while negative stepped leaders do not show such a remarkably strong acceleration. An effort is being made to increase the dataset of this previous study in order to make it more statistically significant, and we believe that the addition of the electric field data will be of great assistance in this discussion. We expect to be able to expand the presented results and make a deeper discussion during the upcoming conference.

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