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Electric field waveforms of M components in negative and positive ground flashes

A comparative analysis

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***Abstract*—There has been some discussion concerning the nature of luminosity pulses observed during the continuing currents of positive cloud-to-ground flashes. It still undefined whether or not these pulses can be considered M components when compared to similar events observed in negative flashes. In the present paper we expand this discussion by analyzing electric field waveforms associated with channel luminosity enhancements of both negative and positive ground flashes. Typically, negative M components are preceded by high-frequency pulses similar to those that can are associated to recoil leaders that are visible below cloud base. On the other hand, luminous processes in positive flashes (similar to M components) did not present a particularly common electric field signature, and no pulses could be positively correlated to their inception inside the cloud. We believe that this polarity asymmetry favors previous theories on the production of negative M components according to the bidirectional leader model. The distinctive features of the positive M components suggest that they are related to different processes.**

Keywords-M component; recoil leader; K change; electric field; high-speed video

I. INTRODUCTION

After the report of the occurrence of luminosity pulses similar to M components during the continuing current of positive flashes made by Campos et al. [1], Mazur and Ruhnke [2] have questioned whether such pulses could be a completely different phenomenon. Their argument is based on a theory which describes negative M components as being initiated by the occurrence of recoil leaders in the upper, in-cloud region of the bidirectional leader, a concept that was first introduced by Kasemir [3]. As there have been no conclusive reports on the existence of positive recoil leaders [4-6], their proposed model indicates that the luminosity pulses previously observed [1] should have a different nature.

The present paper consists in the preliminary results of a comparative analysis between time-correlated luminosity and electric field data of M components observed in both positive and negative continuing currents. We have attempted to provide observational data that not only allow us to make an initial evaluation of the arguments presented by Mazur and Ruhnke [2] but also work as a complementary research to the results previously presented by Campos et al. [1].

II. INSTRUMENTATION AND DATASET

A number of case studies have been conducted on M components identified in both positive and negative flashes recorded during the 2010/2011 summer season in São José dos Campos, Brazil. The instruments used for that campaign are detailed below.

A. High-Speed Camera

Digital imagery has been provided by a Photron FASTCAM-512 PCI 2k high-speed camera set to operate at either 4000 or 800 frames per second (with either 250 or 125 microseconds between consecutive frames, respectively), depending on the available field of view provided by the cloud base height.

A computational algorithm has been used to identify channel luminosity variations that could be associated to M components. This tool plots luminosity *versus* time curves from the arithmetic mean of the pixel values included in the channel region on each frame recorded by the high-speed camera. This technique has been previously used and detailed by Campos et al. [1,7].

B. Electric Field Sensors

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. The third antenna was used as a slow electric-field change sensor. Even

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though its data has been considered for the case studies conducted for the present paper, no records are presented in the following sections.

C. 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 return stroke peak current and distance from the instruments. Also, we were able to compare the flash polarity with the one observed with the help of the electric-field measurements, allowing us to double-check it when categorizing each individual event.

III. RESULTS AND DISCUSSIONS

In this section we present a few selected case studies of recoil leader activity along with negative and positive M components. Also, we discuss their features and how they might fit together in the context of the bidirectional leader model.

A. *Electric field waveforms associated with recoil leader optical activity*

The first step to evaluate the theory presented by Mazur and Ruhnke [2] concerning the initiation of negative M components by the occurrence of recoil leaders is to analyze if they present a specific electric field signature.

Fig. 1 shows an example of comparison between a fast electric field record and simultaneous high-speed video records. The recoil leaders observed on frames (c) and (e) are very similar to those previously reported in literature from standalone high-speed records [5,6] and seem to be related to the production of microsecond-scale pulses superimposed to a millisecond-scale change observed with the help of the fast electric field sensor. It is worth noting that these pulses are similar to those observed by Rakov et al. [8] during K changes of intracloud and cloud-to-ground flashes.

More than one similar event were observed to follow the same pattern: slowly varying field change on which short duration pulses are superimposed and could be associated with recoil leaders recorded by the high-speed camera.

B. *Negative M components*

From the analysis of a few tens of individual M components we have noticed that the electric field signature of the majority of cases follow a pattern. A typical example is shown in Fig 2. Two main common features have been observed in these events: (i) the luminosity increase of the lightning channel is usually preceded by a slowly varying field change (opposite to the return stroke change) on which one or more microsecond-scale pulses occur; and (ii) the peak luminosity value coincides with the peak electric field value within the limitations of the temporal resolution of the high-speed camera record.

A simple comparison between the recoil leader behavior, illustrated in Fig. 1, and the pulses that precede most M components, as shown in Fig. 2, suggest that the inception mechanism presented by Mazur and Ruhnke [2] is reasonable.

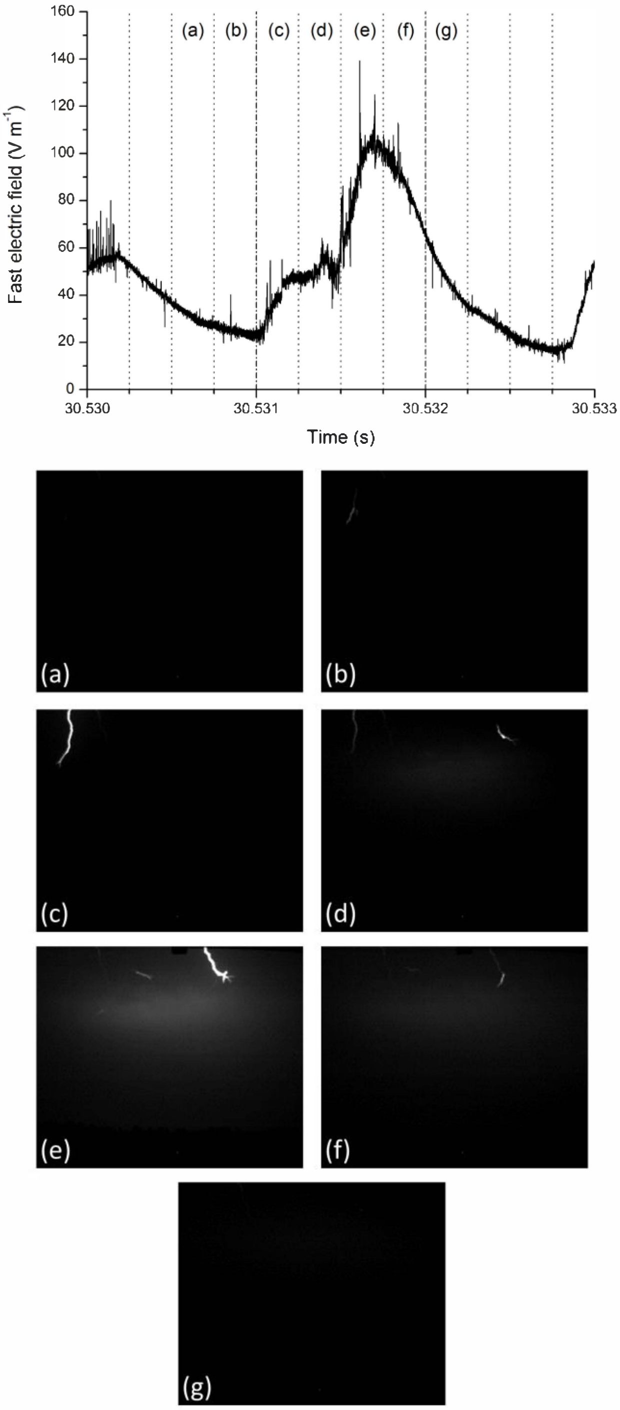
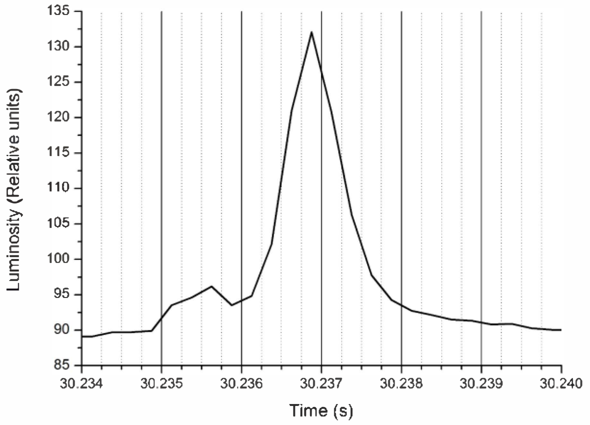
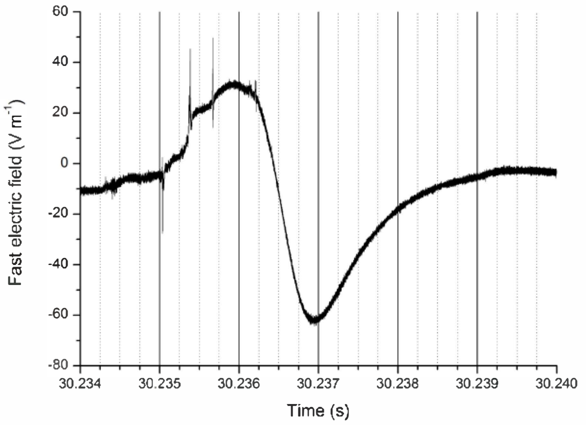


Figure 1. Fast electric field waveforms related to the occurrence of visible recoil leaders (recorded at 4000 frames per second).

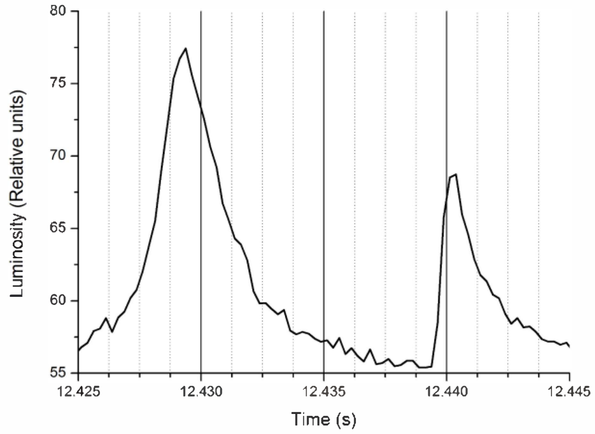


(a)

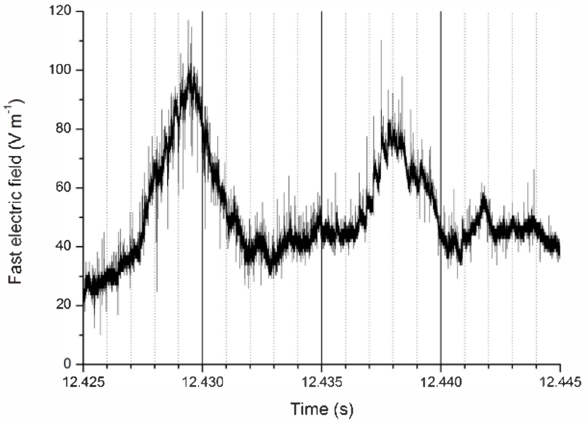


(b)

Figure 2. Temporal relationship between (a) channel luminosity curve for a negative M component and (b) fast electric field waveform (a negative return stroke deflects downwards).



(a)



(b)

Figure 3. Temporal relationship between (a) channel luminosity curve and (b) fast electric field waveform for two successive positive M components.

C. Positive M components

A number of case studies of luminous processes observed in positive flashes, similar to M components, have been conducted. Even though no typical electric field waveform has been found a few common characteristics were noted. Fig. 3 presents a selected case in which two successive luminosity pulses are shown. Similarly to what has been observed in negative M components, the first luminous process presented in Fig. 3 presented a peak value that coincides with the corresponding electric field peak. The second process, though, did not present such temporal matching, unless one considers the lower amplitude pulse. The main feature, however, that has been observed in all analyzed cases, consists in the presence of high-frequency pulses throughout all the phases of the electric field changes. It is not possible to correlate either individual pulses or pulse trains to the inception of the luminous process, as observed in most negative M components.

D. Summary of discussions

We believe that the similar features of the electric field pulses associated with visible recoil leader activity (Fig. 1) when compared to those that seem to be related to the inception of negative M components (Fig. 2) support the mechanism presented by Mazur and Ruhnke [2]. Additionally, we have not observed any clear electric field signatures related to the luminosity pulses observed in continuing current of positive flashes, first reported by Campos et al. [1]. This suggests that the nature of the luminosity pulses present in negative and positive continuing currents is different. If we consider that an M component is defined by its physical process (recoil leader connecting to the in-cloud upper portion of a bidirectional leader) and not one of its observable results (channel current or luminosity pulse) then, as suggested by Mazur and Ruhnke [2], the luminous processes associated with positive continuing currents should not be considered as M components.

IV. Concluding Remarks

We have presented time-correlated high-speed video recordings and electric field data of recoil leaders, negative and positive M components. The analysis of such processes suggest that recoil leaders are responsible for initiating negative M components while their positive counterpart seems to be related to other mechanisms. This result is reasonable with the M component physical model presented by Mazur and Ruhnke [2] and the current status of the bidirectional leader theory of lightning [3, 4].

In a future work more case studies of both polarities will be presented, along with a comparison between the pulses associated with recoil leaders and the signature of narrow bipolar events (NBE), reported by many authors [e.g., 9, 10].

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