Characterization of M components in positive lightning from high-speed video and electric field data

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Abstract: Recent high-speed video experiments have indicated that positive cloud-to-ground lightning (+CG) might present M components during their continuing current period. As only optical data were available, their results consisted mainly on occurrence- and time-related parameters and their statistical distribution. In the present work we address this issue by extending those investigations through the addition of simultaneous slow and fast electric field data (obtained through the use of capacitive antennas) to the high-speed camera 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). Through the use of an algorithm previously developed by the authors we were able to plot luminosity-versus-time curves of each continuing current recorded by the cameras. Once an individual M component is identified in this luminosity data, it is possible to find the electric field change it has produced and that could be measured by the antennas. This type of data is very relevant for both engineering applications (such as EMC studies) and scientific research (especially sprite initiation and the bidirectional leader model for lightning).

Keywords : Positive lightning, M components, sprites

1. INTRODUCTION

Malan and Collens [1] were the first researchers that reported luminosity pulses in the channel of negative cloud-to-ground flashes (–CG) during the continuing current period. Such pulses were termed M components and could also be studied through the electric field changes they produce [2]-[4]. Fisher et al. [5] and Thottappillil et al. [6], from triggered lightning experiments, were able to observe channel current pulses associated with the M component optical signature, while Shao et al. [7] detected these processes in VHF data from natural discharges. More recently, Campos et al. [8] used high-speed video data of natural negative lightning to analyze the optical characteristics of M components along with statistics on occurrence- and time-related parameters of this phenomenon. They have also used the same technique to analyze luminosity pulses in positive cloud-to-ground flashes (+CG) that were also termed M components [9]. These pulses could be compared with the previous literature on both –CG [2]-[4], [7], and triggered flashes [5], [6]. Even though there has been some discussion concerning whether or not these pulses in +CG are, in fact, the same physical processes that are recognized as M components in –CG [10], there is also much speculation concerning their role in the initiation of sprites and other transient luminous events, as noted in the theoretical studies by Yashunin et al. [11] and the computer simulations conducted by Asano et al. [12]. If M components can really occur during the continuing currents of +CG, some concepts of the current status bidirectional model of lightning formation must be reviewed [10], [13]. In addition to the scientific relevance, such investigations are also going to have implications in electromagnetic compatibility studies [14].

In the present paper we present early results of a study that combines the high-speed video observational technique developed by Campos et al. [8], [9], with electric field change measurements to analyze the luminous pulses reported in +CG continuing currents. We are hoping to be able to contribute to future attempts on answering the questions raised in some of the lightning-related fields of research mentioned above [10]-[14].

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2. INSTRUMENTATION

2.1 HIGH-SPEED CAMERA

The data presented in this work were provided by a single high-speed camera (Photron FASTCAM 512 PCI) set to operate with a temporal resolutions of 4000 frames per second (250 microseconds exposure time) in a field campaign conducted in São José dos Campos, SP, southeastern Brazil. The camera is GPS synchronized and provide time-stamped images with no frame-to-frame brightness persistence. A triggering system based on a signal from an external source was used and for the present study this signal came from a button pressed by the camera operator. It is possible to set the pre- and post-trigger time within the total recording time of 2 seconds. The pre- and post-trigger time of 1 second has proven to be long enough to prevent the first strokes to be missed and allow the complete recording of the lightning flash considering its total duration in both –CG and +CG [15], [16]. In-depth discussions on the accuracy of high-speed cameras for the determination of lightning parameters are presented on previous works by Ballarotti et al. [17] and Saba et al. [18].

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. Previous studies using this measuring system were conducted in Austria by Schulz and Saba [19]. The third antenna, initially designed and operated by Ferraz et al. [20], was used as a slow electric-field change sensor but could not be GPS-synchronized for the +CG event we observed and describe in this paper.

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) [21]. 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 and analyze whether any M component event was detected and classified as a return stroke (as observed in –CG by Saba et al. [22]).

3. OBSERVATION AND ANALYSIS

We present a descriptive analysis of five luminosity pulses (analogous to M components) produced throughout the development of the same +CG continuing current event. It has occurred on January 4th, 2010, at 20h20min12s (UT) and was detected by the BrasilDat with an estimated peak current value of +27 kA and a ground contact point that was 6.2 km away from the instruments. A selected frame provided by the high-speed camera is shown in Figure 1, illustrating the channel morphology at approximately 26 milliseconds after the return stroke. Figure 2 presents the luminosity-*versus*-time curve for this flash, obtained from the high-speed video record with the help of the software developed by Campos et al. [8], [9], partially showing the continuing current period (which lasted approximately 340 ms). RS indicates the return stroke (which occurs at 12,390 seconds and saturated the camera CCD sensor) and the symbols M_1 through M_5 indicate the location of the five M components we have selected to present in greater detail. It is worth noticing that all the M components considered occurred with the same positive channel morphology.

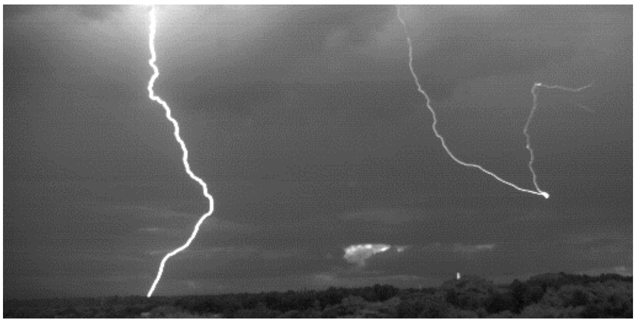

Fig. 1. Selected frame of the high-speed video recording of the +CG event analyzed in this work (approximately 26 ms after the return stroke). Distance from the camera: 6.2 km.

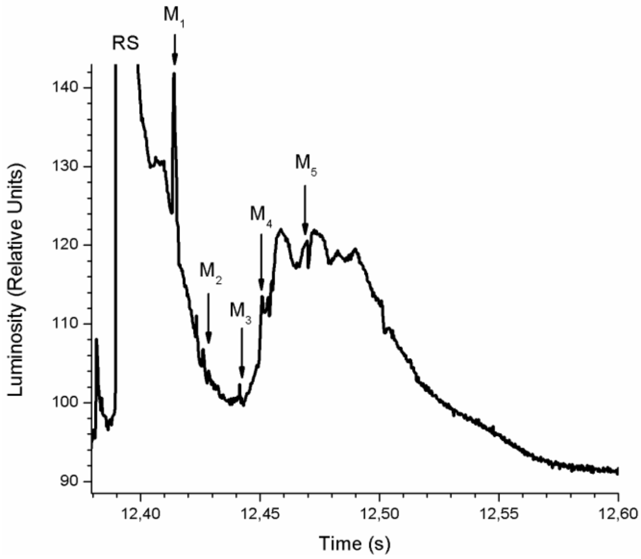

Fig. 2. Luminosity-*versus*-time curve showing the continuing current period of the selected +CG event. RS indicates the return stroke (which saturated) and M_1 through M_5 identifies the M components analyzed. The luminosity peak that occurs prior to the return stroke was produced by the positive leader.

The first M component selected (indicated as M_1 in Figure 2) occurs approximately at 12,414 seconds (24 milliseconds after the return stroke) and is presented in detail in Figure 3, in which we correlate luminosity (black line), fast electric-field change (blue line) and slow electric field change (red line). From the luminosity curve we estimate that the M component lasted approximately 2.75 milliseconds. It is possible to notice that there is a very good correlation between luminosity and fast electric-field change for M_1; although there also seems to be a slow electric-field change associated to it, it is not as clear.

M_2 is presented in detail in Figure 4, in which luminosity (black line), fast electric-field change (blue line) and slow electric field change (red line) are correlated. As it was superimposed to a period of decay in luminosity, it is not as simple to estimate its duration from the luminosity curve as it was for M_1, but we believe it is between 1.00 and 1.75 milliseconds. It is possible to notice a second pulse of luminosity (between 12,426 and 12,427 seconds) which was correlated with the illumination of the section of lightning channel that appears on the right hand region of Figure 1. Considering the optical characteristics of recoil leaders in +CG [23], we believe that this illumination was caused by one.

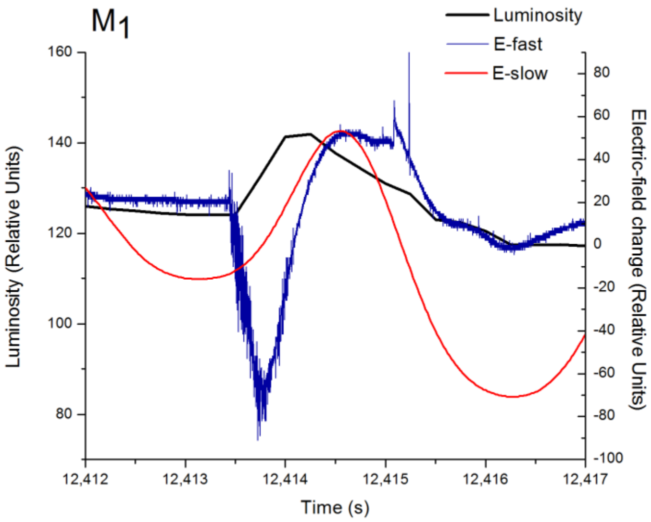

Fig. 3. Correlated luminosity (black line) fast electric-field change (blue line) and slow electric-field change (red line) for M_1.

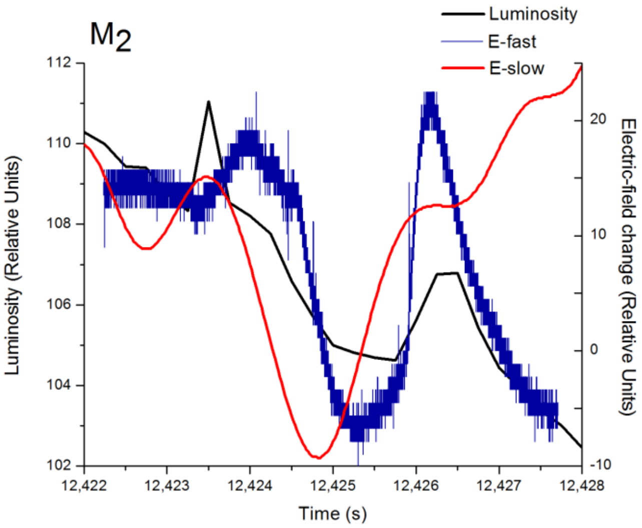

Fig. 4. Correlated luminosity (black line) fast electric-field change (blue line) and slow electric-field change (red line) for M_2.

Figure 5 shows the correlation between luminosity (black line), fast electric-field change (blue line) and slow electric field change (red line) for M_3. The luminosity pulse lasted approximately 1.00 milliseconds and was associated with a clear fast electric-field change. There is some visible and intense cloud activity (which ressembles recoil leaders) during the occurrence of this case, which, similarly to M_2, might explain why the fast electric-field change signature is so distinct from M_1 (Figure 3).

Through the analysis of Figure 6 it is possible to notice that M_4 has a fast electric-field change signature which is very similar to the one observed in M_1 (Figure 3). It is worth noticing, though, that there seems to be a temporal shift between these cases, if one considers the temporal location of the luminosity peak value. M_4 lasted approximately 2.25 milliseconds (as obtained from the luminosity curve).

Finally, M_5 is presented in detail in Figure 7. There is also a clear correlation between luminosity and fast electric-field change, which has a signature that ressembles that of M_3 (Figure 5).

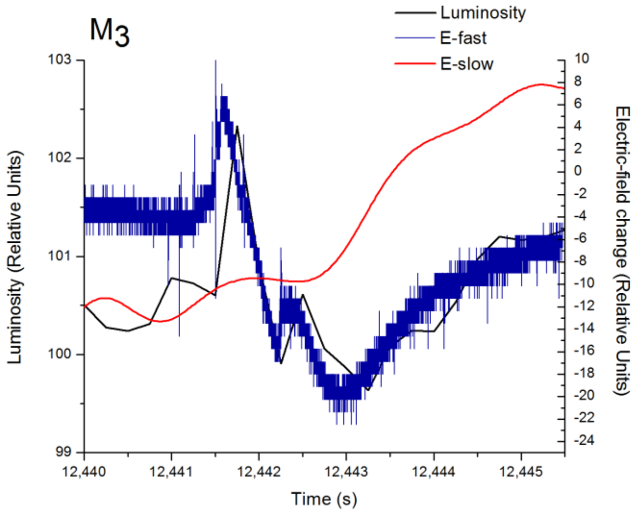

Fig. 5. Correlated luminosity (black line) fast electric-field change (blue line) and slow electric-field change (red line) for M_3.

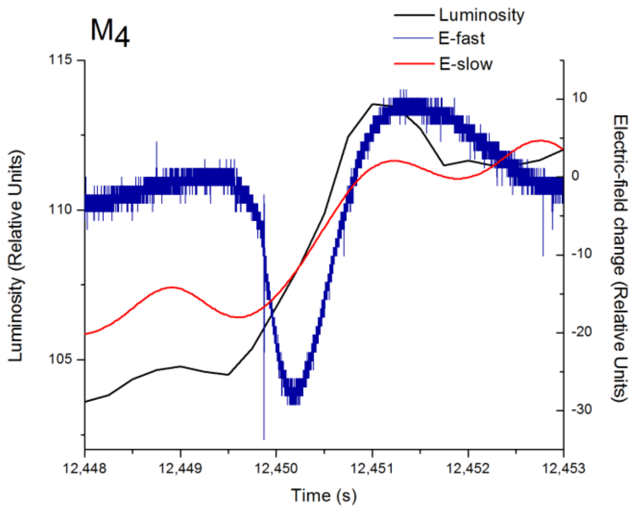

Fig. 6. Correlated luminosity (black line) fast electric-field change (blue line) and slow electric-field change (red line) for M_4.

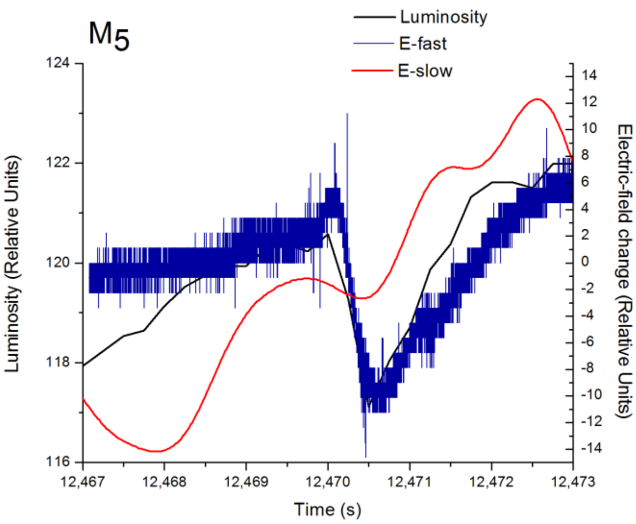

Fig. 7. Correlated luminosity (black line) fast electric-field change (blue line) and slow electric-field change (red line) for M_5.

4. CONCLUDING REMAKS

We have presented a preliminary analysis on M components in positive cloud-to-ground lightning using simultaneous high-speed video recordings and electric-field change measurements. It is still not clear whether or not these luminosity pulses during +CG continuing currents (first identified by Campos et al. [9]) are produced by the same physical process responsible for the M components during the continuing current of –CG flashes. Future works shall address this issue in greater detail, presenting a deeper analyses of electric-field waveforms and comparing with negative M components observed with the help of the same equipments. We expect to be able to use an electrostatic model to estimate the peak current and total charge transfer to ground of each M component observed from the slow electric field data and correlate these intensity-related parameters to occurrence- and time-related parameters such as duration, elapsed time since the return stroke and time interval between successive M components, making it possible to see at which periods of a given continuing current M components can be more or less intense. Once more information on this phenomenon is obtained, we are hoping to be able to have a better understanding on the bidirectional leader model [10], [13] and on how well it describes the physical processes in lightning. Also, given the polarity assymetry observed in the formation of sprites [24] and the frequency of occurrence of the so-called "long delayed sprites" [25], such study will also shed some light on the issue as to whether or not M components can be responsible for the initiation of these (and others) transient luminous events [11], [12].

5. ACKNOWLEDGEMENTS

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