2010 21st International Lightning Detection Conference
19 - 20 April • Orlando, Florida, USA
3rd International Lightning Meteorology Conference
21 - 22 April • Orlando, Florida, USA

M components or cloud-to-ground subsequent strokes?

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ABSTRACT

From the analysis of digital high-speed videos and electric field records of two flashes, some relationships are presented between the channel luminosity preceding the occurrence of the luminosity pulse and the characteristics of the related electric field signature. Some M components may produce E-field signatures very similar to those produced by subsequent return strokes if the preceding luminosity of channel flash is very faint. These M components may be detected by LLS. If the channel luminosity is high, that is, if the continuing current flowing through it is high, then the E-field signature is different from the signature of a subsequent return stroke. The luminosity intensity preceding each M component along with its 10-90% risetime, estimated peak current and peak E-field are presented.

1. INTRODUCTION

Return stroke discharges are accompanied by a strong pulse of light. M components, first described by Malan and Collens [1937] are observed as increases in luminosity of the channel during the occurrence of a continuing current (CC) event. Video observations of a lightning flash may thus differentiate M components from subsequent return strokes (RS) by the luminosity level preceding them. If a luminosity pulse occurs after the cessation of any luminosity in the channel it is an indicative of a subsequent RS, but if the pulse enhances the brightness of an already luminous channel, it is an indicative of an M component mode of charge transfer. In this work the classification of the discharges as being either M components or subsequent RS will be based on this luminosity criterion.

We will present two cases of CG flashes where some misclassification may occur if the luminosity criterion is not used and discuss the thresholds that differentiate a RS from an M component.

2. INSTRUMENTATION

2.1. High-speed cameras

A high-speed digital video camera (Photron Fastcam 512 PCI) with resolution and exposure time of 250 microseconds (4000 frames per second) was used to record images of cloud-to-ground flashes in São Paulo (southeastern Brazil) and southern Arizona (USA), during March 2008 and August 2009, respectively. Images were GPS synchronized, time stamped and recorded without any frame-to-frame image persistence. For more details on the accuracy of high-speed cameras techniques for lightning observations and details about the measurement systems see the works by Saba et al. [2006] and Schulz and Saba [2009].

In order to analyze the luminosity intensity variations during CG flashes, a computational algorithm was developed to open and analyze the pixels of each frame obtained by the high-speed camera. Graphs showing luminosity versus time can be then generated.

As reported by Diendorfer et al. [2003] from tower measurements, the lightning channel luminosity is directly proportional to the current that flows through it, following a linear correlation in the range of 10 to 250 A. As this range is also the typical range observed for CC in natural flashes [e.g. Shindo and Uman, 1989; Ferraz et al., 2009], one could use the luminosity-versus-time graphs to infer how the continuing current intensity varies with time. A more detailed description and validation of this methodology is presented by Campos et al. [2007].

2.2. Lightning Location Systems

The video recordings were obtained in regions that were well covered by lightning location systems (BrasilDat in Brazil, and the NLDN in the USA). More information on the characteristics of these networks is given by Naccarato and Pinto Jr. [2009] and Cummins and Murphy [2009]. Data from the lightning location systems (LLS) were used to obtain the stroke polarity, an estimate of the peak current, and the location of the ground strike point.

2.3. Electric Field Measurement Systems

Two electric field measurement systems were used. The first one consisted of a PC with two PCI-cards (a GPS card Meinberg GPS168PCI and a data acquisition card NI PCI-6110), a flat plate e-field antenna, an integrator/amplifier and a GPS antenna. The measurement system is configured to operate with a sampling rate of 5 MS/s for each channel. The decay time constant is 0.5 milliseconds. A second one is used to monitor field change due to the CC. The decay time constant is approximately 1 sec. From the field derivative it is possible to estimate the intensity of the CC [details are given by Ferraz et al., 2009].

The electric field waveforms were used to check the LLS classification and polarity of strokes and also to estimate the peak current of strokes that were not reported by the LLS. To a first approximation, the peak E-field that is radiated by a return stroke is proportional to its peak current [Uman et al., 1975; Schulz et al., 2005]; therefore, for strokes that occur at a similar distance from an E-field sensor, the peak current of an undetected stroke can be estimated by multiplying the peak E-field of the waveform by the ratio of the estimated peak current of a detected stroke to the peak field of the detected stroke [Fleenor et al., 2009].

3. RESULTS AND DISCUSSION

3.1. Case 1

Figure 1 shows a sequence of frames recorded at 4000 fps (250 microsseconds interval between images) of an M component detected as a CG stroke by the NLDN. The estimated peak current (I_p) for this discharge was –8.7 kA. The M component is initiated at the upper extremity of the channel and progresses toward ground [in agreement with what is described by Rakov et al., 1995]. Note in Figure 2 that there was some luminosity present in the channel during the progression of the M component.

The reason why M components like these can be detected as RS is due to the fact that their E-field radiation pulses can be very similar to those produced by return strokes. As will be presented in the analysis of Case 2, this similarity seems to depend on how intense the current in the preceding CC was.

3.2. Case 2

In Case 2, a single-stroke CG lightning flash was followed by a long CC with M components. Some M components occurred during a period of intense luminosity of the channel (Period 1) and some during a very faint period (Period 2).

The distance of this flash to the camera and other instrumentation was 14 km. By using data from the slow E-field antenna and considering the height of the negative charge center as being approximately 6 km, it was possible to estimate the intensity of the CC during these periods. The intensity of the CC flowing through the channel during Period 1 was approximately 400 ampères, and during Period 2 approximately 100 ampères.

Figure 3a shows the fast antenna recording of the electric field variation during the flash. The first pulse is produced by the initial breakdown (**bd**). The first RS is indicated by the letter **a** and the following M components that happen during the CC (lasting 704ms) by letters **b** to **i**. Figure 3b shows the luminosity variation of the channel during the flash. Note that the luminosity of the channel is high during the first period of the CC (Period 1) and then decreases but remains above zero during Period 2.

Figure 1- Sequence of frames recorded at 4000 fps of an M component.

Figure 2 – Contrast enhancement of the third frame of the previous figure.

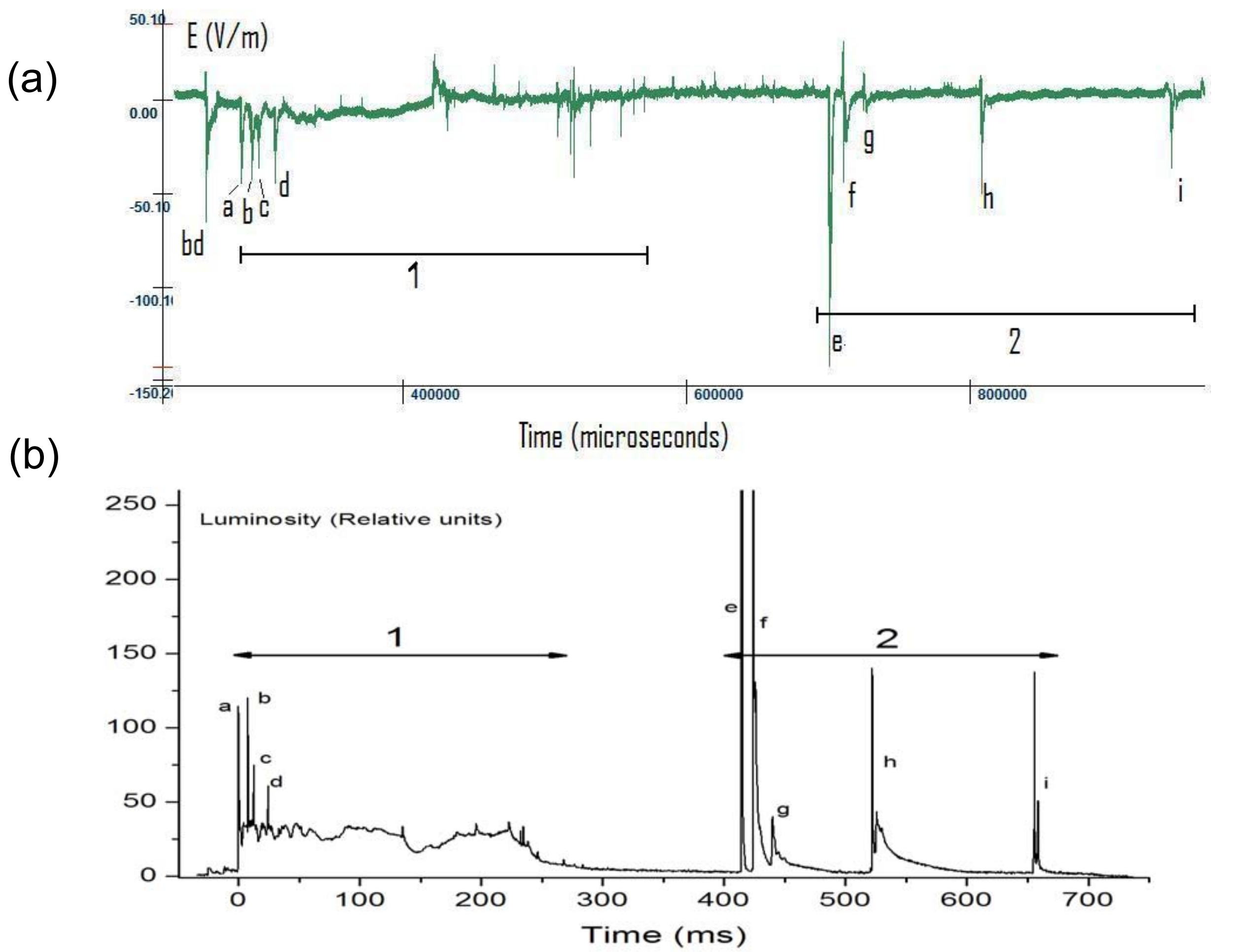

Figure 3 – (a) The electric-field and (b) the luminosity variation of the channel measured 14 km from the lightning attachment point. Note that different time references are used in these plots.

Figure 4 shows the sequence images of the two M components previously named **b** and **f** in Figure 3. It also shows their corresponding electric field signature. Note that for M component **f** the preceding channel luminosity is low and its electric field signature is very similar to that of a RS. This behavior is also true for M components **e**, **g**, **h** and **i,** which have also occurred during a faintly luminous channel (Period 2).

The electric field signature of M component **b** (and also of M components **c** and **d**, not shown) is very different from the characteristic signature of a RS. As also shown in Figure 4, the luminosity of the channel when M component b occurred was considerably high .

Table 1 shows some parameters for discharges (either RS or M component) **a** to **i**. The estimated I_p in bold numbers are taken from the BrasilDAT lightning location system. The I_p values in italic were estimated from the electric field peaks.

Table 1 – Parameters of discharges **a** to **i**.

	1^{st} RS	**Period 1**			**Period 2**				
	a	**b**	**c**	**d**	**e**	**f**	**g**	**h**	**i**
Time from RS (ms)	0	7	12	24	414	423	439	522	655
Peak E-field (V/m)	45.1	32.9	26.6	39.6	129.9	57.3	16	50.0	40.9
Channel luminosity (relative units)	0	34	36	28	3	4	8	3	3
10-90% risetime (μs)	4	15	15	36	1.4	1.4	1.6	0.8	0.6
Estimated I_p (kA)	**-7.5**	*-5.0*	*-3.8*	*-6.4*	**-24.2**	**-10.5**	*-1.8*	*-8.4*	**-6.1**

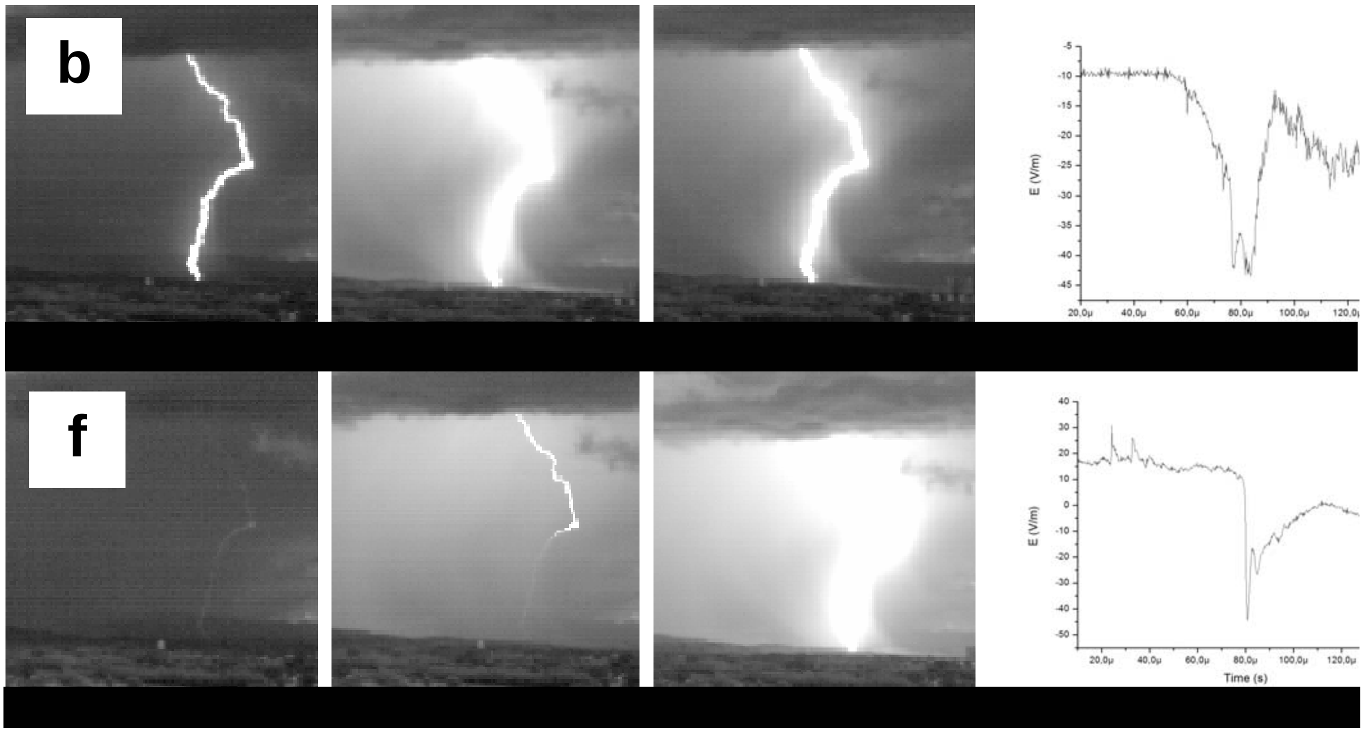

Figure 4 – Sequence of images of two M components (**b** and **f**) and their radiated electric field.

It is interesting to note that in Case 2 the peak currents of the M components **e** and **f** are greater than the peak current of the first stroke. LLS often detect subsequent return strokes that are greater than the first stroke [e.g., Diendorfer et al., 1998]. The fact that the LLS sometimes misclassifies M components as subsequent strokes biases the amount of flashes with subsequent stroke I_p greater than the first stroke I_p.

Note that when the previous channel luminosity is low, the 10-90% risetime is also low. This situation favors the occurrence of pulses more similar to those of subsequent RS occurring in a previously used channel. On the other hand, when the channel luminosity is high, the 10-90% risetime is also high and the signature of the E-field pulses diverges from a typical subsequent RS. This partially explains why discharges **b**, **c** and **d** they were not detected by the LLS. Accordingly, the multiplicity of a flash may be very much influenced by the instrumentation used to monitor it. Particularly, the multiplicity of the CG flash presented as Case 2 in this work would be 4 according to the LLS, more than 6 if monitored only by an electric field recording system and one, that is, a single-stroke flash, if monitored by a high-speed camera.

4. CONCLUDING REMARKS

We have presented two cases of CG flashes whose M components were misclassified as RS by LLS. An analysis of the channel luminosity and E-field peak and risetime indicates that M components tend to be more intense (and with shorter risetimes) when the preceding luminosity if less intense. As mentioned before, the luminosity of a channel is proportional to the current that traverses it [Diendorfer et al., 2003]. This indicates that when the luminosity (and consequently the current) is low, the channel has a very low conductivity which makes its conditions similar to those that precede a subsequent stroke. This in turn may suggest that the differences between some M components and subsequent strokes may be sometimes very subtle if intermediate levels of conductivity are present in the channel (Figure 5).

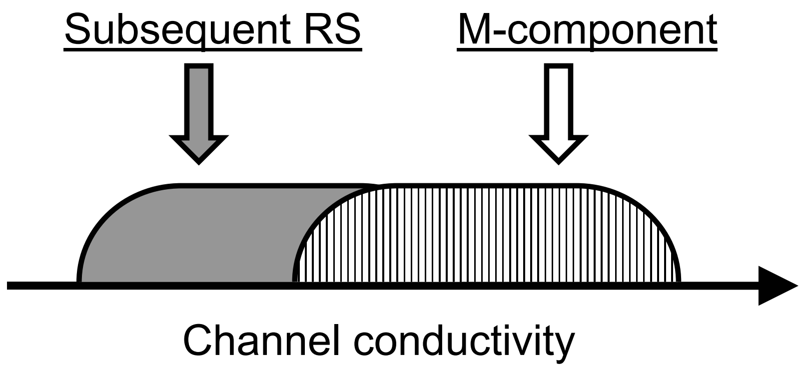

Figure 5 – Occurrence of a subsequent RS or an M component as a function of the channel conductivity.

Finally, the brightness of a return stroke (RS) discharge is usually much more intense than the brightness of an M component, but sometimes this may not be so (as in Case 2 with the M component named **e)**. Strong M components like this one may be visually misclassified as RS events when the presence of CC is not evident to the observer.

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