Electric Field Changes Produced by Upward Lightning Flashes

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ABSTRACT: Tens of upward lightning flashes have been recorded by high-speed cameras and electric field sensors in Sao Paulo, Brazil, since 2012. The simultaneous and combined observations of upward lightning flashes with high-speed video cameras help to understand the physical processes that occur during an upward flash. The understanding of the characteristics of the electric field changes produced by upward flashes will also help to improve the ability of lightning location and detection systems (LLS) to detect and discriminate them from cloud-to-ground flashes. This work describes our observations and the characteristics of the electric field changes produced by upward lightning flashes.

INTRODUCTION

Recorded in January 2012 for the first time in Brazil, upward flashes are lightning discharges that initiate from tall structures such as communication towers, skyscrapers or wind turbine generators. When a thunderstorm approaches a tall structure, the electric field becomes so intense that favors the initiation of upward leaders that propagate towards the cloud base. The leader propagation provides the initiation of an electric current that will flow through the tip of the tower. This current may last several hundred milliseconds and is named initial continuous current (ICC) [Schumann et al., 2014]. The ICC may fluctuate and contain current pulses named ICC pulses. After the cessation of the ICC, downward leaders may arise, which will produce subsequent return strokes which may or may be not followed by a continuing current.

In this study we document all phases of two upward flashes with high-speed video cameras and fast electric-field sensors. The comparison between measurements given by these instrumentations is the main goal of this work. We believe that this comparison will help the identification of the processes of an upward flash even if only one instrument is available.

INSTRUMENTATION

The upward flashes analysed in this study were recorded in Sao Paulo, a city in southeast Brazil at an average elevation of around 800 meters above sea level and a flash density of 15 flashes/km².year. They were initiated from towers that are located on top of Jaragua Peak, a 300m tall hill relative to its surroundings. This peak is located inside the urban area and has two tall TV towers (tower T1 with a height of 136m - 1239 m above sea level - and tower T2 with a height of 70m, 1169m above sea level) and also several other smaller communication towers (Figure 1).

Fig 1 – Jaragua peak in Sao Paulo city and the two main TV towers viewed from where the *Phantom v711* high-speed video camera was placed. The distance between towers T1 and T2 is of 400m.

High-speed video cameras

All processes of the upward flashes were identified using high-speed video recordings. The recordings were done by a *Phantom v711* high-speed video camera located at a distance of 5 km from the towers. The frame rate used was 20,000 images per second. Each image is time stamped with GPS precision.

Electric field measuring system

The electric field measuring system consisted of a flat plate antenna with an integrator/amplifier, 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 Zhou et al. [2012]. Two electric field measuring systems were used. One located very close to tower T1 (distance of 27 m) using a low gain amplifier (Figure 2) and another at a distance of 11.6 km from the tower T1 using two amplifiers (one of the amplifier had a gain 10 times greater than the other). Utilizing the physics sign convention, which is used in this paper, the electric field change due to a positive CG return stroke is positive.

Electric field meter

The electric field meter (EFM) to monitor the ambient electric field change caused by upward flashes was a Campbell Scientific CS110 (Figure 2). The sampling rate used was of 1 sample per second.

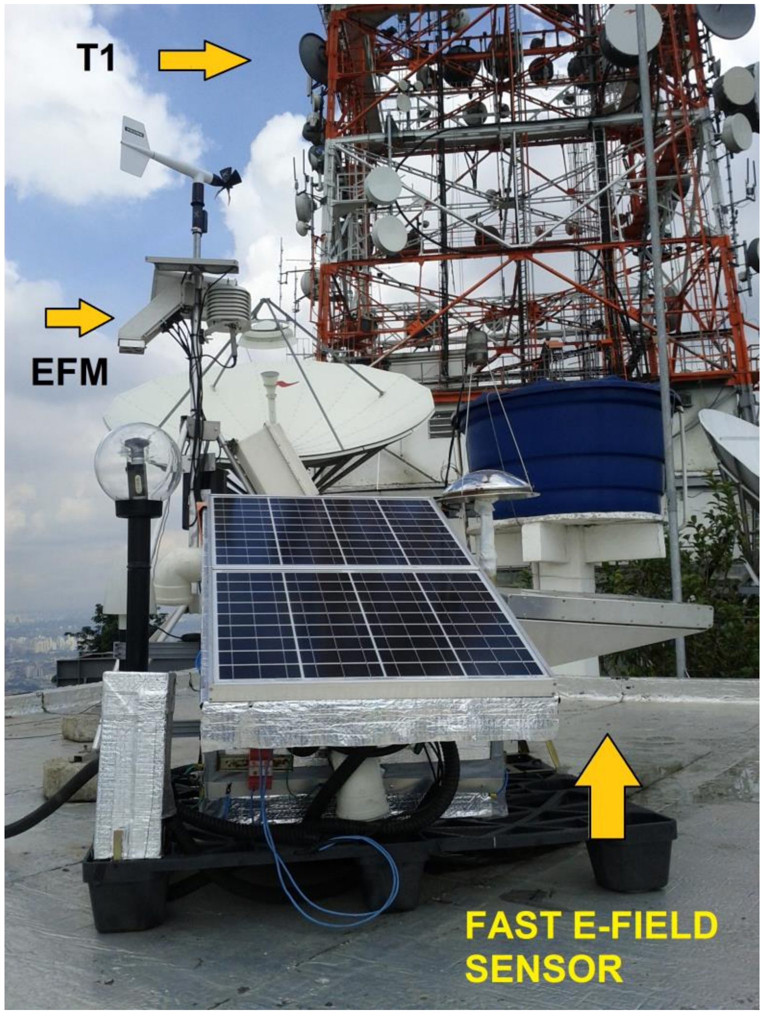

Figure 2 – Electric field meter (EFM) and fast electric-field system close to tower T1.

RESULTS

On January 16, 2014, two upward flashes, UP1 and UP2, initiated from tower T1 at 005912 UT and at 010432 UT respectively (Figure 3). Both were triggered by positive cloud-to-ground flashes (+CG). UP1 was triggered by a +CG that struck ground at a distance of 47 km with an estimated peak current of 70 kA (distance and estimated peak current given by the BrasilDAT, Brazilian lightning location system). UP2 was also triggered by a +CG (estimated peak current of 81kA, distance of 49 km). Both upward flashes initiated with a positive leader propagating upward.

Figure 3 – Nikon D800 digital still images of UP1 (on left) and of UP2 (on right). Camera settings were as follows: ISO, 100; aperture, f/8; focal length, 20 mm; exposure time, 18.2 s.

Analysis of data collected from the electric field meter located at 27 m from tower T1 showed a non- to slowly-varying positive electric field (physics sign convention) prior to both flashes. In each case, the electric field experienced a negative change caused by the development of upward positive leaders (UPLs) from the towers (Figure 4). The high absolute values of the electric field are due to the enhancement of the ambient field by the peak on top of which the EFM is placed.

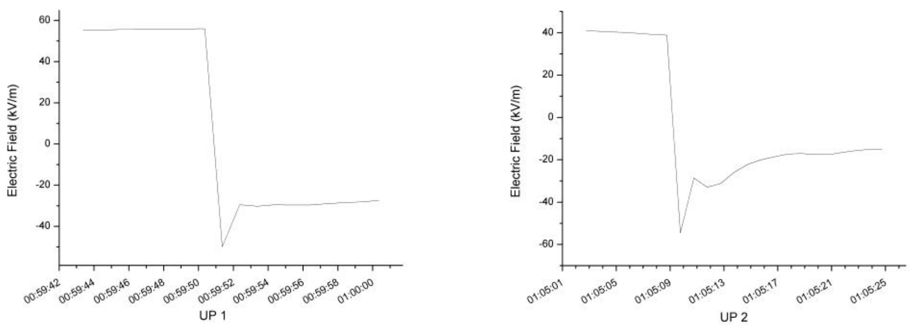

Figure 4 – Electric field meter recordings for UP1 (left) and UP2 (right).

The following subsections will present images from high-speed video recordings and electric-field measurements for different processes of the upward flashes (leader initiation, recoil leaders and M-components). Each of these processes has similar behaviour in both flashes.

Initiation of the positive leader

The initiation of the upward positive leader starts when a clear brightening in the sky above the tower appeared in the high-speed video recording. During 1 or 2 ms before the positive leader starts a steady propagation, luminosity pulses occur at the tip of the tower in almost regular intervals. These luminosity pulses are well correlated in time with the electric field pulses caused by the initiation of the upward leader in both flashes (Figure 5).

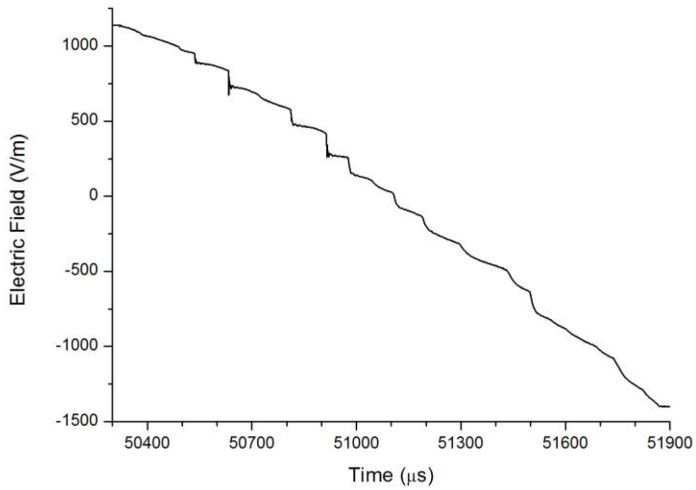

Figure 5 – Electric field changes associated with luminosity pulses that occurred before the steady propagation of the upward leader.

Recoil leaders

Recoil leaders (RLs) are self-propagating, negative leaders that move along previously developed paths of the positively charged portions of bidirectional leaders. Upward flashes initiated by UPL exhibit numerous RLs when the leader is on its way toward the cloud base aloft. RLs start close to the tip of decayed branches of the UPLs. The bipolar/bidirectional leader expands with the negative end propagating toward the branch point along the main channel and the positive end propagating toward the positive leader tip. The negative end travels back to a midway point in a branch, or sometimes to a branching point in the channel. When they travel all the way down to the tower they result in an impulsive discharge that is usually named *M-component* if the RL moves along a luminous channel (i.e., current present) or named *return stroke* if the channel is already dark (after cut-off) [more discussions on this nomenclature can be found in Flache et al., 2008; Mazur and Ruhnke, 2011 and Winn et al, 2012].

Figure 6 and Figure 7 show a sequence of images illustrating a RL that connects to a branch point and a RL that stop before reaching a branch point. The E-field changes for these RLs are shown in Figure 8. RLs produce an unipolar pulse that is more intense if it reaches a branching point.

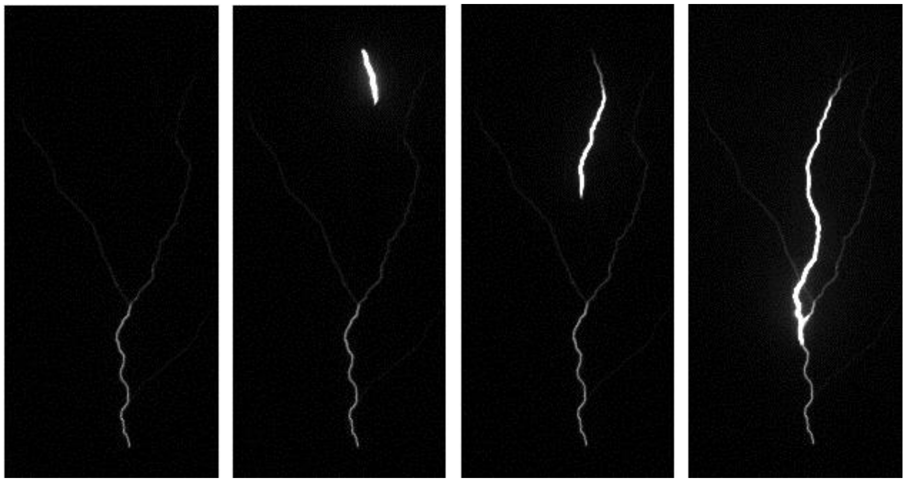

Figure 6 – Sequence of video images showing an example of RL that connects to a branching point.

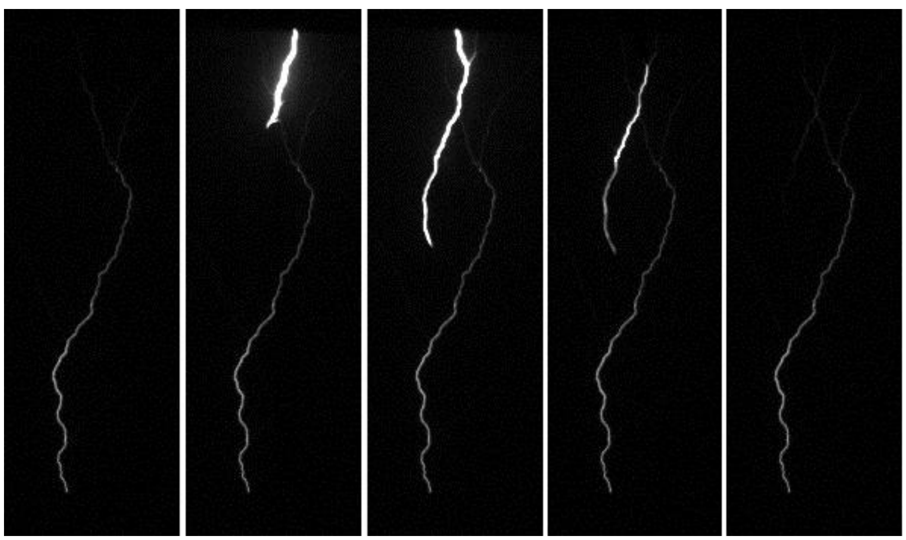

Figure 7 - Sequence of video images showing an example of RL that stops before reaching a branch point.

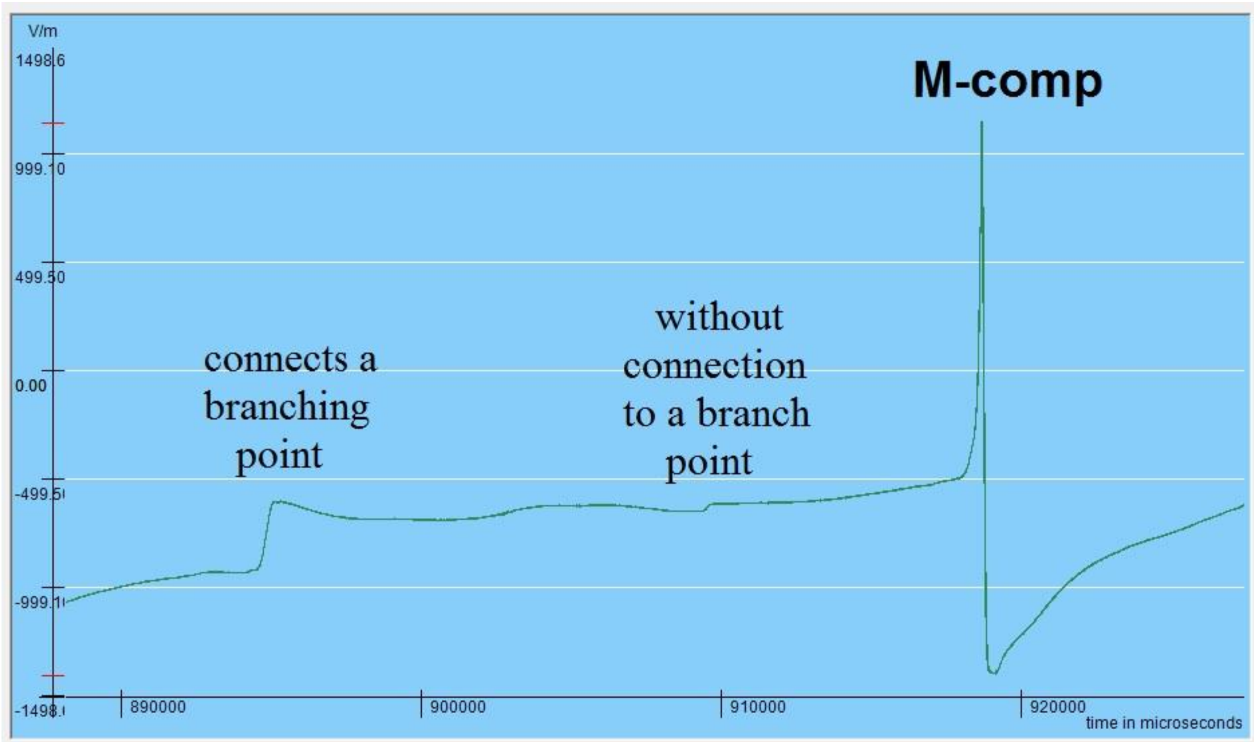

Figure 8 – E-field change for RLs and M-component recorded by the E-field system at distance of 27 m from T1.

M-components

In the two upward flashes analyzed (UP1 and UP2) most of the M-components were caused by RLs that travelled downward toward the tower tip as shown in Figure 9. No return strokes were observed; i.e., all RLs reached the tower while the channel was still luminous (no cut-off/dark channel was observed previous to the RL). The electric field change signature for these M-components was of a bipolar pulse. The unipolar pulse produced by the downward propagation of the leader was followed by an inverted pulse (Figure 8). The inverted pulse is associated with the connection to the tower and the upward luminosity/current wave similar to those seen in return strokes, although less intense.

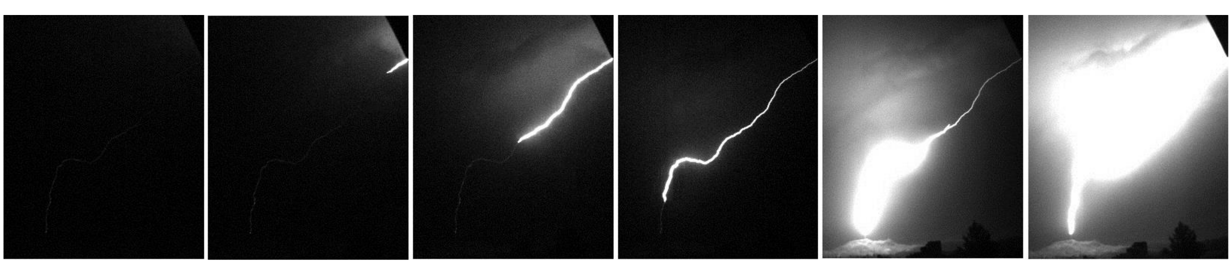

Figure 9 – Sequence of video images showing an example of M-component. The RL connects tower T1.

Curiously, one different type of M-component occurred in UP1. The initiation of a bidirectional RL took place very close to the tip of the tower (approximately 500 m above). The negative end of the RL reached the tip of the tower in less than 300 microseconds producing a very bright discharge similar to a return stroke (Figure 10). The electric field change signature for this M-component did not show the initial positive pulse due to the approaching of a downward RL seen in regular M-components.

Figure 11 show the signatures of two M-components as observed by a fast electric field sensor 11.6 km away. The first one corresponds to the unusual M-component initiated by a bidirectional RL starting close to the tower T1 tip. Both M-components were detected by LLSs as negative CG flashes.

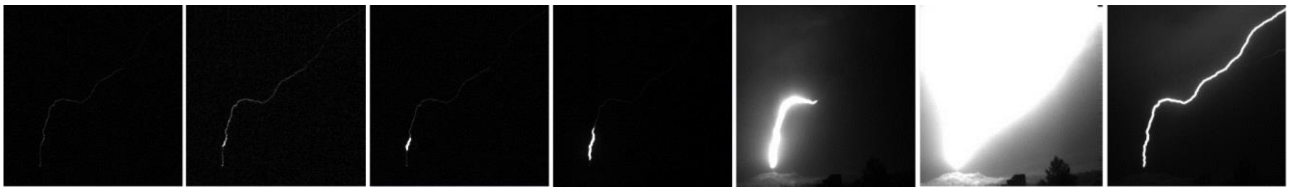

Figure 10 – A different M-component initiated by a bidirectional RL starting close to the tower T1 tip.

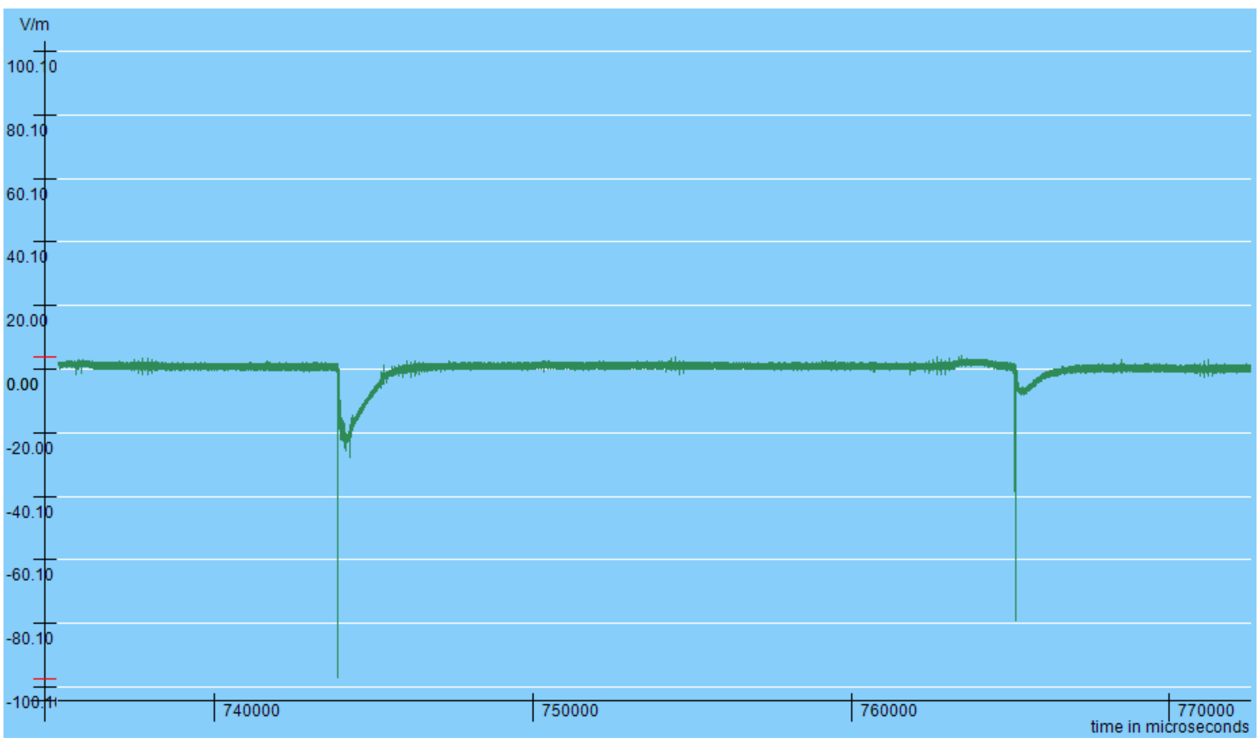

Figure 11 – Two M-components observed by the fast electric field. The first one corresponds to the unusual M-component initiated by a bidirectional RL starting close to the tower T1 tip.

SUMMARY

The present study compared images from high-speed video of two upward flashes with the electric field changes measured at distances of 27 m and 11.6 km. Electric field changes caused by RL that do not reach the tower are unipolar and very small to be observed by the electric field sensor that was located at a distance of 11.6 km. Those that reach a branch point are more intense than those that do not. When RLs reach the tower while the channel is still luminous an M-component occurs and the electric field change is similar to that of a return stroke and can be detected by LLSs as a negative return stroke. An unusual M-component was observed. For this M-component, the initiation of a bidirectional RL took place very close to the tip of the tower (approximately 500 m above) and caused an electric field change that was unipolar.

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