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UPWARD LIGHTNING IN BRAZIL

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1. INTRODUCTION

Observations of upward lightning from tall objects have been reported since 1939. Interest in this subject has grown recently, some of it because of the rapid expansion of wind power generation. Also, with the increasing number of tall buildings and towers, there will be a corresponding increase in the number of upward lightning flashes from these structures. Reports from recent field observations are beginning to address the nature of upward lightning initiation, but much still needs to be learned. Examples are studies of upward lightning from towers in winter thunderstorms in Japan (Wang and Takagi, 2010; and Lu et al., 2009) and summer thunderstorms in Europe (Miki et al., 2005; Flache et al., 2008; and Diendorfer et al., 2009; Zhou et al., 2011) and in North America (Mazur and Ruhnke, 2011; Hussein et al., 2011; Warner, 2011, and Warner et al., 2011).

This paper describes a field campaign to study upward lightning for the first time in Brazil. A combination of high-speed video and standard definition video were used to record upward lightning flashes from multiple towers in Sao Paulo, Brazil, a city located in southeastern Brazil with a population over 10 million people, an average elevation of around 800 meters above sea level, and a flash density of 15 flashes/km^2/year. Observations made with these assets were analyzed along with BrasilDAT Lightning Detection Network and a lightning mapping array (LMA).

2. INSTRUMENTATION AND METHODOLOGY

In order to know if upward lightning occurs in this urban area full of skyscrapers and tall TV towers, a previous analysis using data from BrasilDAT, the lightning detection network covering the area, was conducted. Lighting stroke incidence in square areas of 250m x 250m over the urban area of São Paulo was plot during the period of 1999 to 2011. The plot of lightning incidence included elevated areas of the city that contain several skyscrapers and TV towers. The maximum lightning incidence detected and accumulated in one of the 250x250 m area during the analyzed 13-year period was of 45 strokes (Figure 1). It occurred over Jaragua peak, a 300m tall mountain relative to its surroundings.

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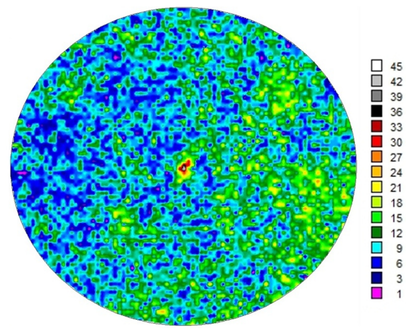

Figure 1 – Lightning stroke incidence from 1999 to 2011 for an area of 10 km radius around Jaragua peak. The numbers shown in the legend correspond to the amount of strokes that occurred in square areas of 250m x 250m during the period.

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 90m) and also several other smaller communication towers (Figure 2). Although the high incidence of lightning flashes in the area is not necessarily due to the presence of upward lightning, we took it as a starting point for this study.

A place nearby Jaragua peak was chosen for the installation of a high-speed camera. A Photron Fastcam 512 PCI, operating at 4000 images per second (ips), was placed at a distance of 5 km from the peak. All video imagery was recorded without any frame-to-frame persistence and was time-stamped to GPS. The minimum recording length used was two seconds. A standard-speed video camera (30 images per second, ips) was also looking at the Jaragua peak from the same position.

Data from a lightning mapping array (LMA) network that was deployed and operational during the summer of 2011/2012 was also available.

Figure 2 – Jaragua peak in Sao Paulo city and the two main TV towers viewed from where the Photron camera

was placed. The distance between towers T1 and T2 is of 400m.

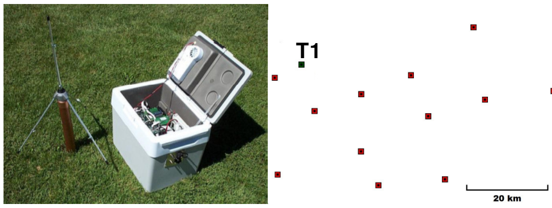

Figure 3 – A portable lightning mapping array station and the network distribution around Tower T1.

3. OBSERVATIONS AND ANALYSIS

Four upward lightning flashes from 2 towers on top of Jaragua peak were observed during a thunderstorm on January 15th, 2012. One of these flashes involved upward leaders from two towers during the same flash. Analyses of acquired data along with comparison with Brazil Lightning Detection Network data show that all upward leaders were associated with a nearby +CG return stroke. They occurred when the trailing stratiform precipitation region associated with a cold front system was over the towers and the triggering flashes were within 50 km.

All upward leaders propagated upward without branching until they were close to the cloud base (height of approximately 1400m above the tower). They then branched into horizontal leaders propagating just below cloud base. Table 1 summarizes some characteristics of the upward flashes and the preceding +CGs.

None of the 2 towers have current sensing instrumentation, so the upward leader (UL) polarity classification was based on optical characteristics of the upward leaders when high-speed video imagery was available. High-speed videos were available at 4,000 ips for 3 of the 4 upward flashes (Flashes 1, 3 and 4). All four flashes were recorded by standard-speed videography (30 ips). Each flash will be described in the following sections.

Table 1. Summary of the characteristics of the upward flashes and the preceding +CGs.

Flash	Upward leader initiation time (UT)	Tower	Video recording frame rate (ips)	Time of occurrence of preceding +CG (UT)	Distance from the tower (km)	Estimated Ip of the preceding +CG (kA)
1	21:34:46.528	1	4,000	21:34:46.421	39.1	40
2	21:38:29	1 and 2	60	21:38:29.633	9.3	68
3	21:40:49.782	1	4,000	21:40:49.779	10.2	46
4	22:58:56.641	1	4,000	22:58:56.638	16.0	72

3.1 *FLASH 1*

A single, non-branched upward leader formed from Tower 1 at 21:34:46.528 UTC, 108 ms after a +CG return stroke occurred 40 km west of the tower. The BrasilDAT Lightning Detection Network (Cummins and Murphy, 2009) recorded an optically correlated +40 kA estimated peak current +CG return stroke at 21:34:46.421 UTC. The UL exhibited extensive recoil leader (RL) activity suggesting it was positive polarity (e.g., Mazur, 2002 and Saba et al., 2008) and lasted 618 ms without any subsequent dart leader/return strokes sequences following current cutoff.

Following the positive return stroke, negative leaders were visible propagating just above the cloud base toward the tower. Figure 4 shows a sequence of images showing the propagation toward the towers and the in-cloud brightening overhead the towers.

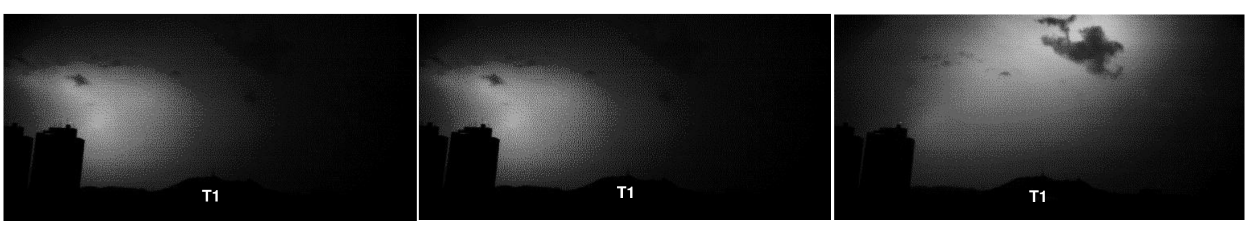

Figure 4 – Sequence of images showing the approach of negative leaders following a +CG return stroke that occurred at 40 km from the Tower T1.

The approach of negative leaders following the +CG return stroke is confirmed by the LMA plot shown in Figure 5. Note that negative leaders after the occurrence of the +CG, represented by greenish dots, move towards the towers. Right after the passing of the negative leader an upward positive leader developed from Tower 1.

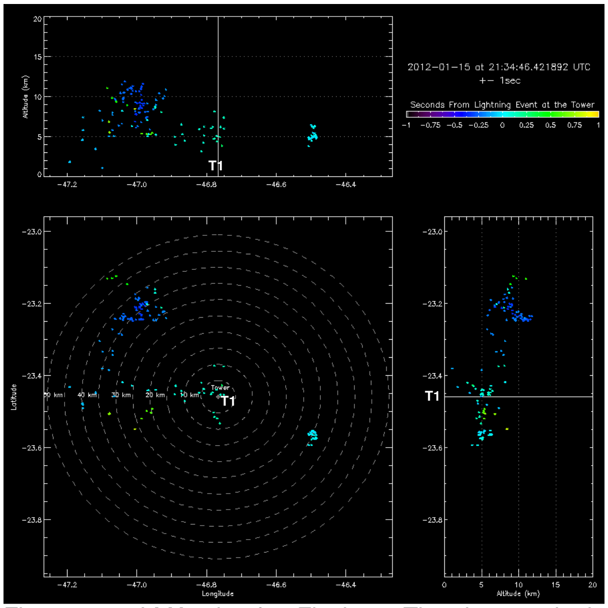

Figure 5 – LMA plot for Flash 1. The time scale is centered at the moment of the occurrence of the +CG preceding the upward flash. T1 is located at the center of the image.

The upward leader grew vertically without branching and then branched once with the two subsequent leader segments transitioning to horizontal propagation just below cloud base. Both segments branched further as it propagated with the additional branches remaining below cloud base. Some of the outermost UL branches developed RLs. There were 6 intense RL connections with the main luminous positive channel prior to UL current cutoff. A sequence of images of one RL retracing the path of the previously-existing branch and connecting with the stem of the upward leader at the branching point is shown in Figure 6. Note the luminosity intensification of the main channel that connects to the tower.

3.2 *FLASH 2*

The second upward flash was also associated with the occurrence of a +CG flash. In this case, however, ULs developed from two towers instead of one. As high-speed video imagery was not available, it is not possible to know the precise time difference between the occurrence of the +CG and the initiation of the UL (certainly less than 2 frames duration, i.e., 60ms). The durations of the upward leaders were approximately 150ms and 240ms for the leaders from towers T1 and T2 respectively.

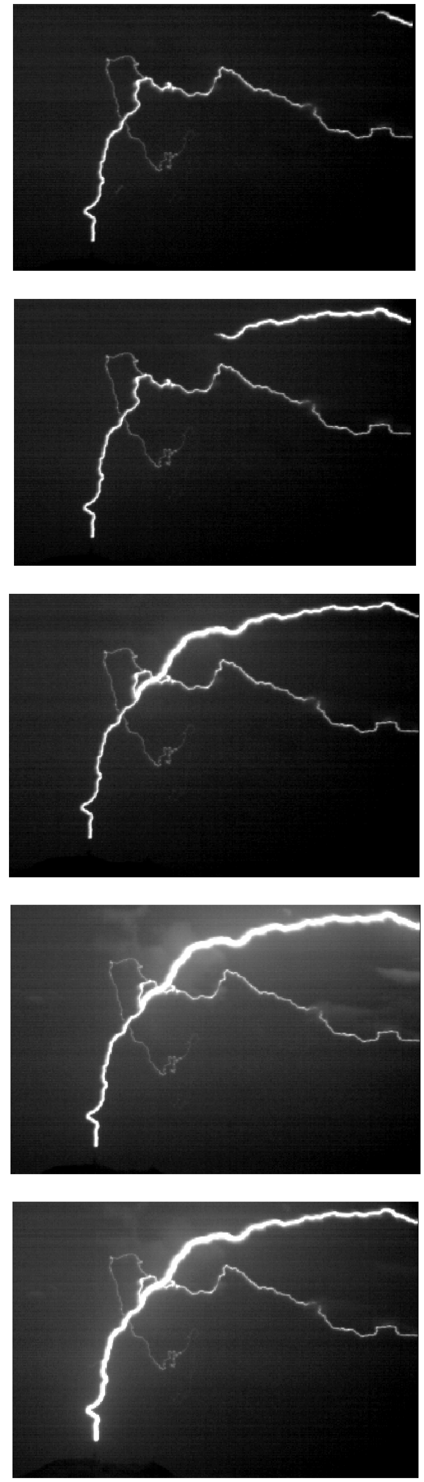
Figure 6 - A sequence of images of one RL connection to the main UL. The time between images is 250 µs.

The time integrated image of the flash time is shown in Figure 7.

Figure 7 - Time-integrated video segment from the high-speed camera (4.000 ips, 250 µs exposure) showing the development of bright RLs on the weakly luminous branches. Many of the RLs faded prior to connecting to a main channel.

3.3 *FLASH 3 AND FLASH 4*

These two flashes were similar to Flash 1. The main difference is their short duration (Flash 3, 111 ms and Flash 4, 102 ms) and the absence of intense RL retracing the path of the previously-existing branch and connecting with the stem of the upward leader at branching points.

4. SUMMARY

We present images from high-speed video data of the first observed upward lightning in Brazil. As far as we know this is the first time an upward flash is registered simultaneously by a high-speed video and a lightning mapping array.

All four upward flashes were associated with the occurrence of +CG flashes. One of these flashes involved upward leaders from two towers during the same flash.

For sure, three of them (those observed by the high-speed camera) were triggered by the approach of horizontally propagating negative leaders near the towers. All 3 upward flashes observed by the high-speed video exhibited extensive recoil leader (RL) activity suggesting they were positive polarity. The preliminary LMA analysis of one upward flash confirmed noticeably that the propagation of negative leaders close to the cloud base was the triggering mechanism.

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