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HIGH-SPEED OBSERVATION OF UPWARD LIGHTNING FLASHES IN BRAZIL

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Abstract— **Studies of upward flashes from tall structures around the world have been reported since 1939. The characteristics of the triggering mechanism and of the upward flashes are of increasing interest to wind power turbines, telecommunication toware and power distribution companies. Observations of upward flashes in Brazil are recent. Since 2012, upward events were observed in all different seasons of year. They initiate on several towers 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. Some of the towers are located on top of buildings or hills. In this study, we will present some characteristics of these upward flashes, based on high speed video observation: flash duration, presence of subsequence of return stroke, previous lightning events, initial continuous current pulses and the presence recoil leader.**

Keywords—upward flashes; lightning; tall structures

I. INTRODUCTION

Since the seminal study of McEachron in 1939, many other studies of upward flashes have been done around the world [Miki et al. 2005; Takagi et al., 2006; Wang et al., 2008; Flache et al., 2008; Lu et al., 2009; Diendorfer et al., 2009; Mazur and Runkhe, 2011; Zhou et al., 2012]. Altough less common, upward flashes pose a serious threat to wind turbines, communication towers and skyscrapers.

Measurements at the tower tip show that an upward flash current starts slowly and lasts hundred milliseconds. This low amplitude current (tens of amperes to a few thousands of amperes) is named initial continuous current (ICC). During this ICC phase some pulses may occur and are named ICC pulses. They are similar to M-components in downward flashes [Rakov and Uman, 2003]. After the ICC phase it is not uncommon to find a subsequent return stroke after a no current period.

The present study is based on optical observations of 55 upward flashes. Some important characteristics will presented in the following sections.

II. INSTRUMENTATION

All upward flashes 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. The majority of them were initiated from towers that are located on top of a hill, a few initiated from towers over buildings. Two towers (heights of 130 m and 90 m) are located on top of Jaragua Peak. 17 towers on top of buildings located at Paulista Avenue in Sao Paulo downtown have heights ranging from 60-220 m.

All analysis were based on high-speed video recordings. 3 types of high-speed cameras were used: a Phantom v310, a Phantom Miro4 and a Photron Fastcam 512 PCI. The frame rate of the cameras ranged from 4,000 to 20,000 images per second. Each image is time stamped with GPS precision. The cameras were located at a distance of 5 km from the towers.

III. RESULTS

A. General Characteristics

Data base of this analysis was 55 upward flashes occurred in Sao Paulo city during 23 thunderstorm days. All cases were recorded with high-speed cameras.

Only 9% (5 out of 55) of the upward lightning flashes involved simultaneous upward leaders from two and only 24% of them (13 out of 55) contained subsequent return strokes (SRS). The 13 flashes containing SRS occurred during only 5 of the 23 thunderstorms that produced upward flashes. The total number of SRS recorded was 29. The number of SRS in each of the 13 upward flashes is shown in Figure 1.

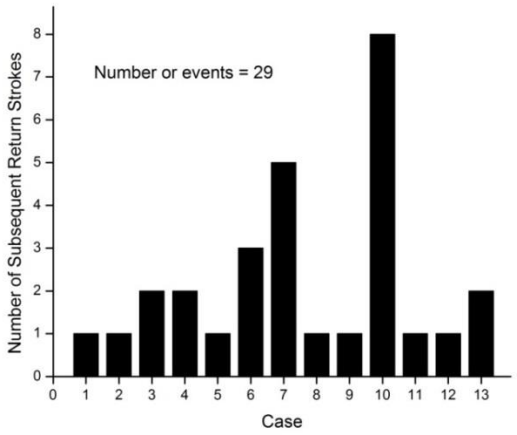

Fig. 1 Number of SRS in each of the 13 upward flashes that contained SRS.

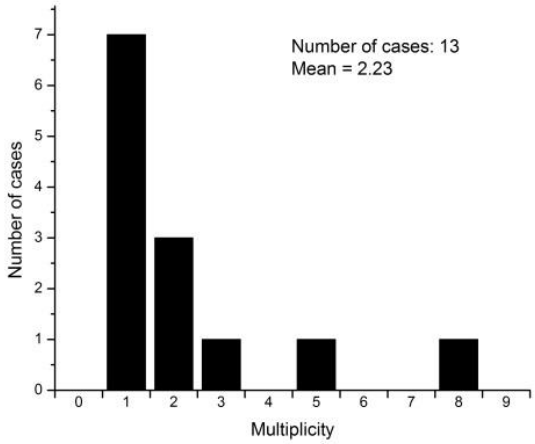

Fig. 2 Multiplicity of flashes: Flashes with SRS

The average multiplicity of SRS in 13 flashes is 2.23 strokes per flash (Figure 2). If all 55 cases are considered, then the multiplicity drops to 0.53 strokes per flash (Figure 3).

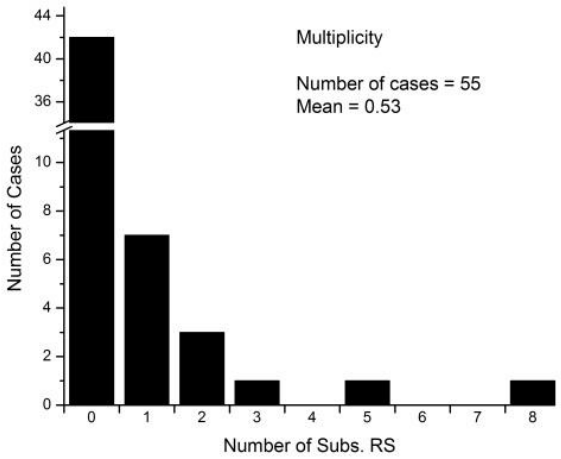

Fig. 3 Total of Multiplicity: Included cases with only ICC

The upward flashes were either triggered by intracloud (IC) lightning or cloud-to-ground (CG) flashes. The discrimination of the previous triggering event (IC or CG flash) was based solely on video information. This information was available for 30 upward flashes. Only 5 cases were triggered by IC flashes. The distribution of the time interval between the previous event and the initiation of the upward flahse is presented in Figure 4. The average, minimum and maximum values were 48 ms, 3ms and 140 ms respectively.

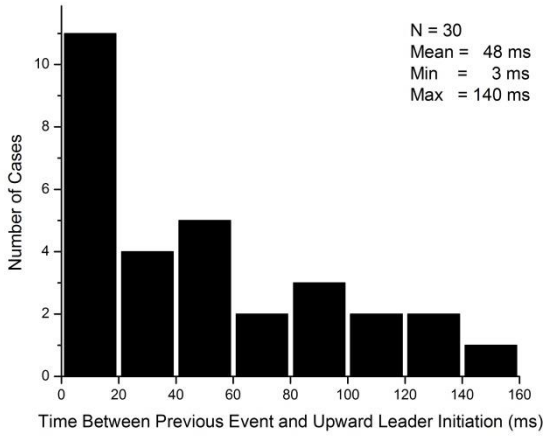

Fig. 4 Time between previous event and upward leader initiation

B. Leader Characteristics

Mazur [2002] and Saba et al. [2008] reported that the presence of recoil leaders, i.e. negative leader retracing branching channels that became cutoff, is an indication of positive polarity leader development. In 51 of the 55 cases (93%) the presence of recoil leaders was observed, suggesting a positive polarity upward leader.

28 out of 55 cases (51%) presented branching before reaching cloud base. Only one leader branched at the tower tip. The leader usually propagates towards the cloud base and then when reaching a maximum height H starts moving horizontally. The average time duration required to reach the maximum height H is 21 ms (minimum and maximum are 5.6ms, 61ms respectively).

Fig. 5 Estimation of horizontal channel propagation height H.

To observe height H of the horizontal propagation we used the size of the tower (130m) as a reference as shown in Figure 5. Based on video observation the height of the horizontal propagation is in average 1920 m. (Maximum and minimum H are 3380 and 1232 meters respectively).

C. ICC Characteristics

Mean time duration for Initial Continuous Current was 354 ms. The minimum and maximum duration were 86 ms and 1143 ms respectively (Figure 6).

ICC Pulses are seen in video observations as an intensification of brightness in the main channel. 29 out of 55 ICC contained ICC Pulses. All ICC Pulses had their brightness intensified along the whole channel. Sometimes this brightness enhancement was produced by a leader that reached the tip of the tower in a sequence of a few frames of the video (up to 3 frames). 40 out of 130 ICC Pulses had their brightness as intense (image saturation) as usually noticed in a return stroke event.

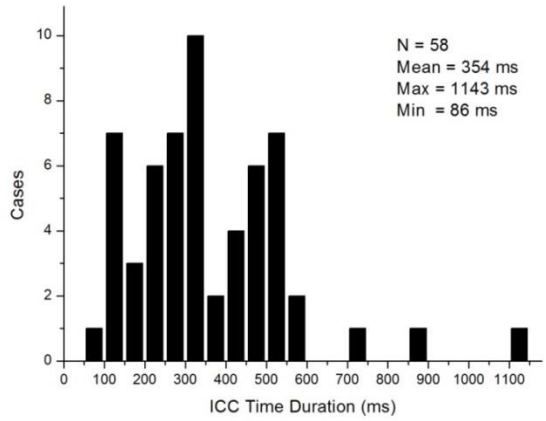

Fig. 6 Distribution of the ICC duration.

IV. SUMMARY

In this paper, we analized high speed video of upward lightning flashes in Sao Paulo, Brazil. Only 9% (5 out of 55) of the upward lightning flashes involved simultaneous upward leaders from two and only 24% of them (13 out of 55) contained subsequent return strokes (SRS). The average multiplicity of SRS in 13 flashes is 2.23 strokes per flash. If all 55 cases are considered, then the multiplicity drops to 0.53 strokes per flash. Only 5 cases were triggered by IC flashes. The average, minimum and maximum values of the time interval between the previous event and the initiation of the upward flahse were 48 ms, 3ms and 140 ms respectively. In 51 of the 55 cases (93%) the presence of recoil leaders was observed, suggesting a positive polarity upward leader. 28 out of 55 cases (51%) presented branching before reaching cloud base. Only one leader branched at the tower tip. Based on video observation the height of the horizontal propagation of the leaders is in average 1920 m. Mean time duration for Initial Continuous Current was 354 ms. 29 out of 55 ICC contained ICC Pulses.

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