Upward flashes triggering mechanisms

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Abstract—**Upward flashes can be self-initiated or triggered-initiated. Locations where the tall structures are installed may present only triggering initiated upward flashes, only self-initiated or even both types of upward flashes. Upward flashes that were observed in Sao Paulo and Rapid City were all triggered-initiated by previous activity. This paper will present three triggering components of the triggering flash that provide the conditions necessary for the upward leader initiates based in optical and LMA observations.**

Keywords—Upward flashes, Triggering mechanisms

I. INTRODUCTION

The upward flash steps are well known and described in the literature. Upward flash steps were registered with current measurement (e.g. [1]) and optical observations (e.g. [2]). Figure 1 shows the upward flash steps presented by the literature. It is still uncertain what are the reasons the leaders start from the tower. Wang et al [3] classified two types of upward flashes: self-initiated and triggered-initiated. Triggered-initiated upward flashes require some previous activity nearby the tower such as a cloud to ground flash or even in-cloud activity.

Wang et al. [3] presented 14 cases recorded in Japan where the authors identified 4 self-initiated upward flashes and 10 triggered-initiated upward flashes from wind turbines. Wang and Takagi [4] presented 53 upward flashes recorded during winter and 53% of the cases were triggered-initiated. Zhou et al. [5] showed that only 14% upward flashes (205 cases) were related to previous activity. Jiang et al.[6] presented 4 cases that were triggered initiated. Heidler et al.[7] presented one case of a triggered upward flash in Peissenberg tower and later in Heidler et al. [8] presented 3 triggered- initiated upward flashes. Saba et al. [2] presented 100 flashes that were all triggered-initiated upward flashes.

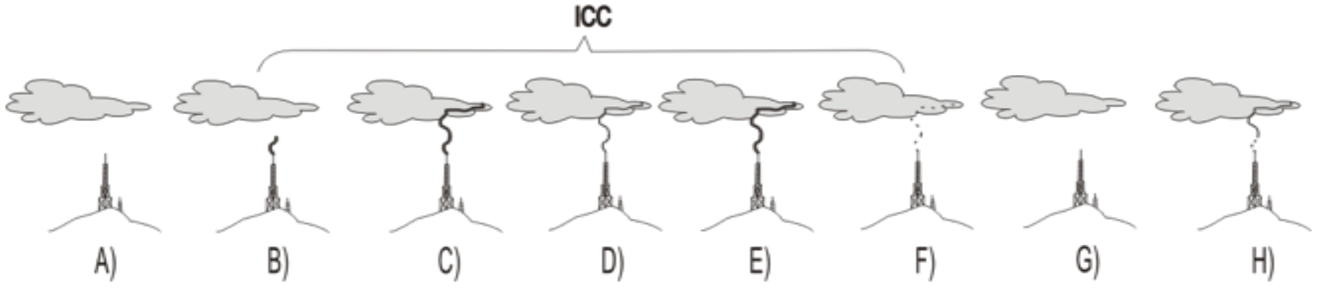

Figure 1: Upward flash steps of development: Initial Continuing current, Pulses, no- current interval, subsequent return strokes.

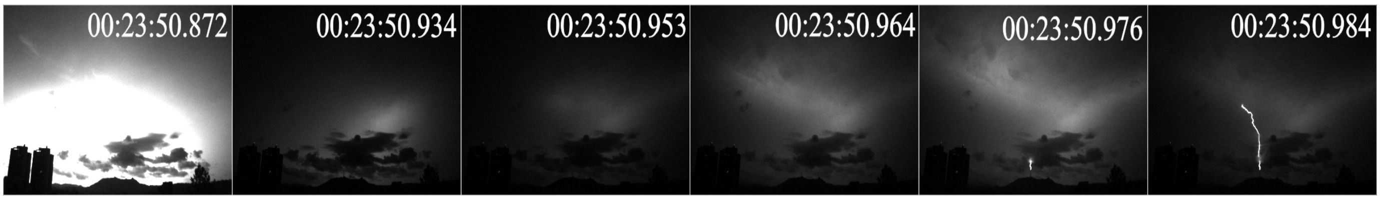

Figure 2: Video: leaders inside cloud approaching tower location

II. DATA AND EQUIPMENT

The activity prior to the upward leader initiation in 72 upward flashes were observed in Rapid City (23) and in Sao Paulo (49). All cases were triggered upward flashes.

5 high-speed cameras were used to record the upward flashes. The camera models used were Phantom: v711, v12, v7.1, v310, Miro4. The frame rate ranged from 1,000 to 100,000 fps. GPS time-stamp in the images allowed correlation to lightning location system and LMA data.

All upward flashes were recorded with high-speed cameras but only 22 were recorded with LMA. LMA sensors were installed during two different campaigns: CHUVA Campaign in 2012 when it was recorded 10 upward flashes in Sao Paulo; and during the UPLIGHTS in 2014 when it was recorded 12 upward flashes in Rapid City - USA.

The Lightning Location System was used to classify the triggering flashes. More details from the two LLS networks can be found in [9; 10].

III. DATA ANALYSIS

During the video analysis it was possible to observe that all flashes had leaders approaching the towers. The three situations that made possible the triggering of the upward flashes are described as follows.

A. First situation - Return stroke:

It was possible to observe the approach of the leader over the tower, but no upward leader from the towers started. Then, a cloud-to-ground return stroke happens and all the charge is distributed along the channel re-illuminating the leader over the towers (intensifying them). When this happened, the upward leader was observed initiating from the tower. In this situation , the time interval between the upward leader initiation and the return stroke (triggering flash) is short. 13 out of 72 cases were associated with this first situation. Figure 3 shows a schematic of the situation.

B. Second situation - Leader due to CC:

In the majority of the cases, it was observed that, when the triggering flash starts, there are no leaders in the proximity of the towers (Figure 4a). The field change produced by the return stroke of the triggering flash (Figure 4b) is not strong enough to initiate upward leaders from the tower. However, the associated leader inside the cloud propagates during the continuing current phase approaching the tower and providing the condition required to start an upward leader from the towers (Figure 4c). 54 out of 72 cases were associated with this situation

C. Third situation - Leader:

In this situation the approach of the leader inside the cloud to the towers was enough to trigger upward leaders (Figure 5). These leaders inside the cloud can develop a downward CG flash afterwards or stay in-cloud. The triggering mechanism in this situation is the in-cloud leader associated with an IC or CG flash. 5 out of 72 upward flashes were associated with this triggering mechanism.

LLS

The lightning location system classification of each event is presented at table 1.Some of the cases were identified as in-cloud flashes by the lightning location system even though the analysis of the electric field sensors or/and the images confirmed them as cloud-to-ground flashes.

TABLE 1: LIGHTNING LOCATION SYSTEM CLASSIFICATION OF EACH EVENT

	Sao Paulo		***Rapid City***	
	CG	***IC***	***CG***	***IC***
First situation - Return stroke	7	3	3	0
Second situation - Leader due to CC	26	10	10	8
Third situation - Leader	1	2	2	0

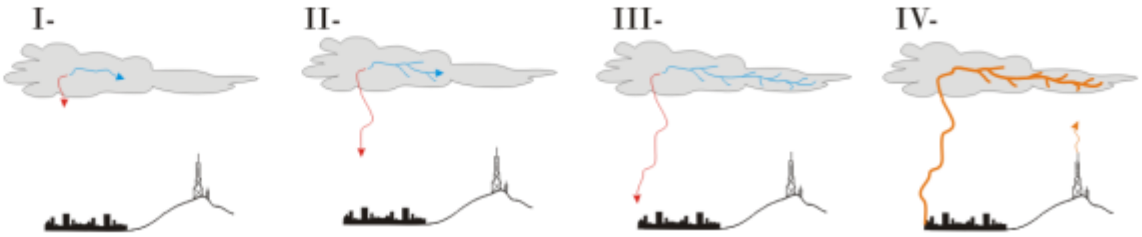

Figure 3: First situation is due the intensification of the leader due to the return stroke , also called as instantaneous triggering.

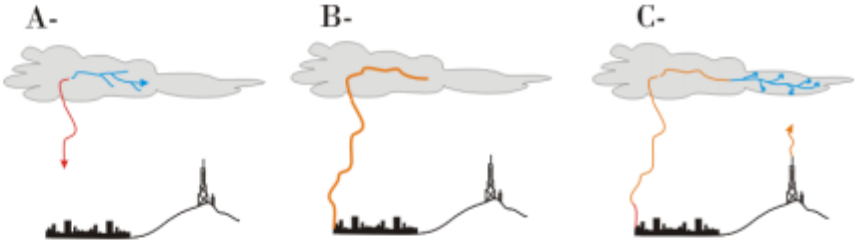

Figure 4: The leader extension from continuing current phase of the triggering flash.

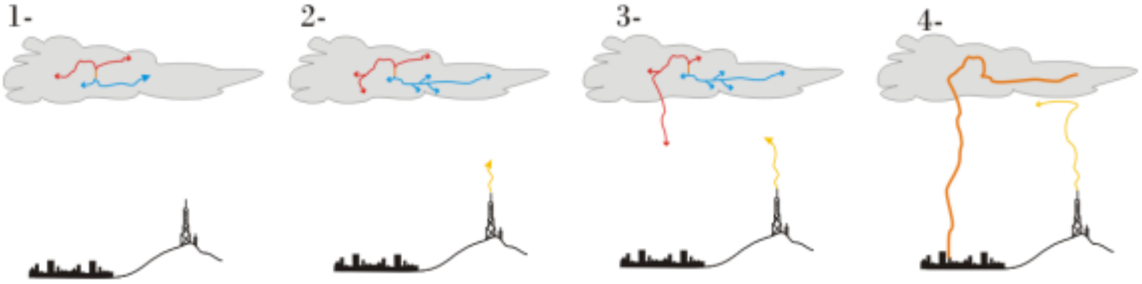

Figure 5: Leader over the tower was enough to trigger upward leader (IC or CG)

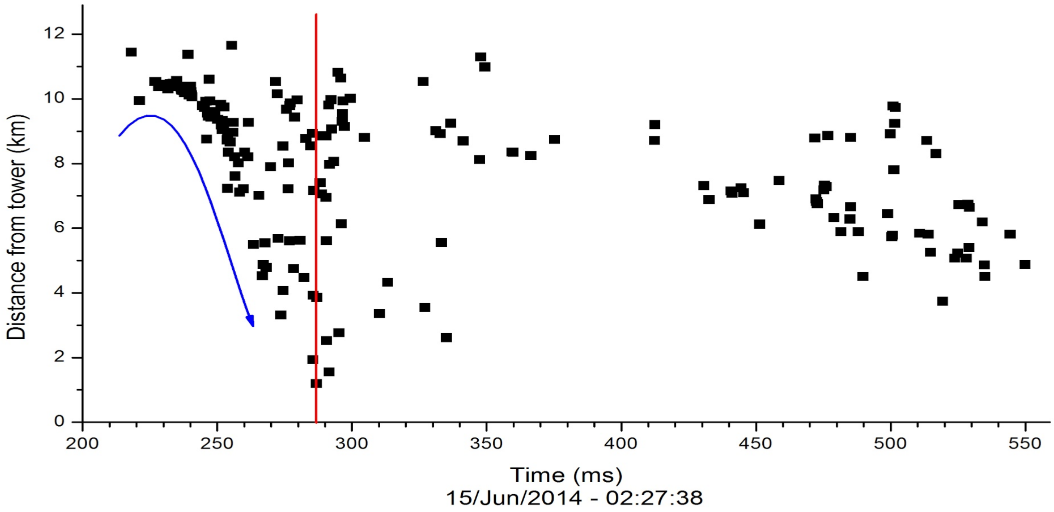

Figure 6: LMA and approximation of the sources: red line indicates when the upward leader started.
The blue arrow indicates the approximation of the source inside the cloud.

22 upward flashes (10 in Sao Paulo and 12 in USA) were registered by the LMA. The distances from the sources to the tower where the upward leader initiated, were analyzed. The horizontal distance from the source (prior to upward leader initiation) to the towers ranged between 1.1 to 4.2km (average of 2.1 km). As Figure 6 shows, it is possible to notice the approach of the sources to the tower. The red line shows time when upward leader started. And the blue arrow indicate the approach of the leader (radio source) inside the cloud.

IV. SUMMARY

All triggered-initiated upward flashes (72 cases) recorded in Sao Paulo and in Rapid City were analyzed and the triggering components could be identified.

In the first situation identified, leaders approach the tower and right after the return stroke which almost always saturates the image an upward leader starts from the towers. On the second situation, the brightness of the return stroke happens, leaders are seen propagating inside the cloud and approaching to the tower. And the third situation is when the leader inside the cloud is close to the tower and an upward leader initiates. Leaders over the towers are the common reason why the upward leader initiates but there are 3 different processes which these leaders are associated in the triggering flash that differentiate the situations.

Three different components from the triggering flashes are responsible to the modification of the ambient electric field on the tower surroundings. The leaders inside the cloud play an important role in the triggering mechanisms that trigger upward leaders from these towers.

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