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Characteristics of positive cloud-to-ground flashes triggering upward flashes in Rapid City-SD

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***Abstract*— Upward Lightning from tall towers and tall buildings has been reported around the world. [Warner et al., 2011; Wang et al., 2010; Hussein et al., 2011; Lu et al., 2009, Diendorfer et al., 2009; Miki et al., 2005; Flache et al., 2008]. Understanding upward lightning initiation will help to improve lightning detection and protection systems for tall structures. Upward lightning can be self-initiated or can be triggered by preceding nearby cloud-to-ground or intracloud flashes [Wang et al., 2010, Zhou et al., 2012 and Warner et al., 2012]. Rapid changes in the ambient electric field due to the preceding flashes are likely responsible for the triggering of upward leaders. During the summer of 2014, a combination of high- and standard-speed video, electric field sensors and lightning mapping array (LMA) were used to record upward lightning flashes from multiple towers in Rapid City, South Dakota USA. Based on analysis of lightning location systems, field Mill and LMA data, this study will present characteristics of positive cloud-to-ground flashes that did and did not trigger upward lightning from the towers.**

Keywords—Upward flashes; LMA; Field Mill

I. INTRODUCTION

Lightning flashes propagating towards and from tall towers have been of interest since the number of these man-made structures increased (e.g. TV towers, windmills)

Diendorfer et al. [2009] reported that only 6 out of 242 flashes on Gaisberg tower were downward flashes. Heidler, [2002] reported that only one flash was downward cloud-to ground flash in 116 flashes recorded at the Peissenberg tower.

Understanding upward flashes, their causes and characteristics is very important to protect tall structures.

Wang et al. [2008] classified two types of upward flashes: triggered- or self-initiated flashes. When a previous flash occurs (intracloud or cloud to ground flashes) a variation of ambient electric field occurs and it may produce an upward flash [Warner, 2012; Mazur and Runkhe, 2011; Zhou et al., 2011]. In self-initiated upward flashes there is no apparent triggering event prior to upward leader initiation.

Previous works in USA showed by that all flashes recorded were triggered-initiated upward flashes (confirmed by analysis of the electric field sensors and cameras)

In this work, data from LMA and LLS was analyzed for thunderstorms that produced at least one upward flash on towers in Rapid City.

II. LOCATION

Rapid City is the second biggest city of the South Dakota, North of USA. There are 10 telecommunication towers in a hill of the city, that can be seen om many places of the city.

These towers range from 91-190 meter tall. All upward flashes have been recorded during the summer. That includes multiple tower upward flashes from two or more towers.

III. DATA AND METHODOLOGY

During the summer of 2014 in Rapid City - SD, 13 upward flashes were observed. 35 positive upward leaders from different towers were filmed.

From one up to six upward leaders were triggered simultaneously from the towers by only one downward flash.

All upward flashes occurred in 5 thunderstorms. Figure 1 shows the LMA of an upward flash recorded.

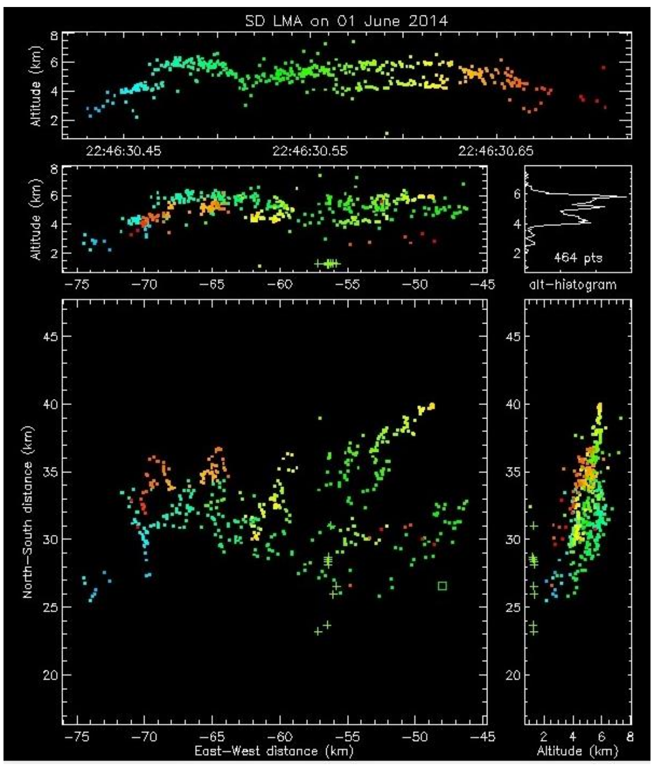

Figure 1: Upward Flash in Rapid City. Propagation towards the towers and upward flash occurs

In order to study the electric field during the same phase of the thunderstorm, we observed the electric field changes by flashes that occurred within one hour prior to the first upward flash and one hour after the last upward flash.

All flashes that produced sources within 40 km radius on LMA were plotted and their trajectory was analyzed.

IV. RESULTS

687 flashes had sources within 50km x 50km centered in the towers, during all 5 thunderstorms that produced upward flashes.

262 out 1590 strokes (64 out of 687 flashes) had their trajectories of propagation passing over the towers. From these strokes 17 were +CG, 48 were –CG and 207 were classified as IC flashes (table 1).

TABLE 1 : CLASSIFICATION OF THE FLASHES

	Strokes w/ activity over the tower	Upward flashes registered
+CG	17	4 cases
-CG	48	0 cases
IC	207	9 cases

From the total of flashes that passed over of the towers, only IC and +CG were effective in triggering upward flashes. The distribution of the distance and peak current of the strokes that triggered upward flashes from the towers is shown in the figure 2.

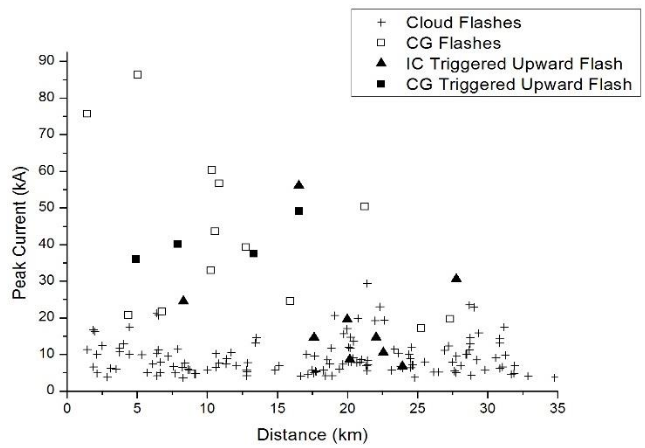

Figure 2 - Distance versus peak current: + and white squares are flashes that not triggered upward flashes; Black triangle are cloud flashes and black squares are CG that triggered upward flashes

Figure 2 suggests no correlation between intense peak current and triggering of upward flashes. Flashes in Brazil also do not show correlation between intensity of peak current and distance [Schumann et al 2014].

Flashes that had leaders passing over the tower and did not produce upward flashes do not presented an expressive different propagation height from the flashes that produced upward flashes.

It is thought that an intense previous ambient electric field together with leaders passing over the towers would be necessary for the occurrence of upward flashes [Schumann et al 2015].

The observed thunderstorm produces upward flash during a time interval, of the thunderstorm that could be associated with a charge center localized on top of the towers. During this time interval a propitious charge intensity together with other characteristics (e.g. size or charged) would provide favorable conditions to trigger an upward flash during the occurrence of a +CG or a IC flash .

In thunderstorms that produced upward flashes, the time window that produced upward flashes lasted tens of minutes as shown in table 2. Also, table 2 shows the number of flashes passed over the towers while the ambient electric field was in the same amplitude and the number of flashes that produced upward flash. This confirms that it is necessary an ambient electric field and leader over the tower with certain characteristics.

When the interval when the ambient electric field is in the same level was analyzed, it was found that several flashes having leaders passing over the towers did not produce upward flashes.

Ambient electric field recorded during a thunderstorm with occurrence of upward flash is shown in Figure 3. Figure 4 is an enlarged image of the time when upward flash occurred. It is possible to see an inversion of the field just prior to the flashes that triggered upward flashes.

These inversions were only observed when upward flashes occurred in the period of the thunderstorm when the ambient electric field was positive. In thunderstorms where upward flashes occur during the negative polarity of the ambient electric field, these inversions were not observed.

TABLE 2: FLASHES IN THE WINDOW OF THE THUNDERSTORM WITH UPWARD FLASHES

#	Interval with upward flashes (in minutes)	Number of flashes over the towers	Number of upward flashes	Number of null cases
1	2	17	2	15
2	21	12	5	7
3	28	10	3	7
4	4	3	2	1
5	-	12	1	11

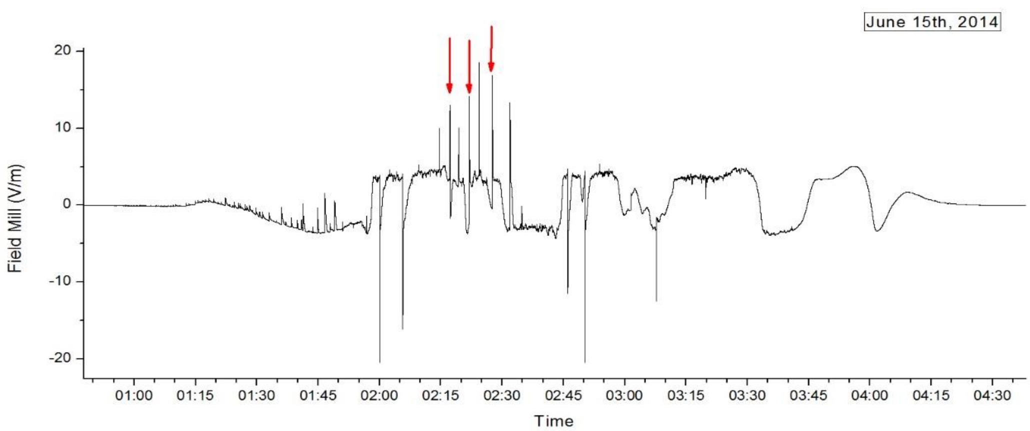

Figure 3– Thunderstorm on June 15th, 2014: Upward flashes (red arrows) grouped in one section of the thunderstorm.

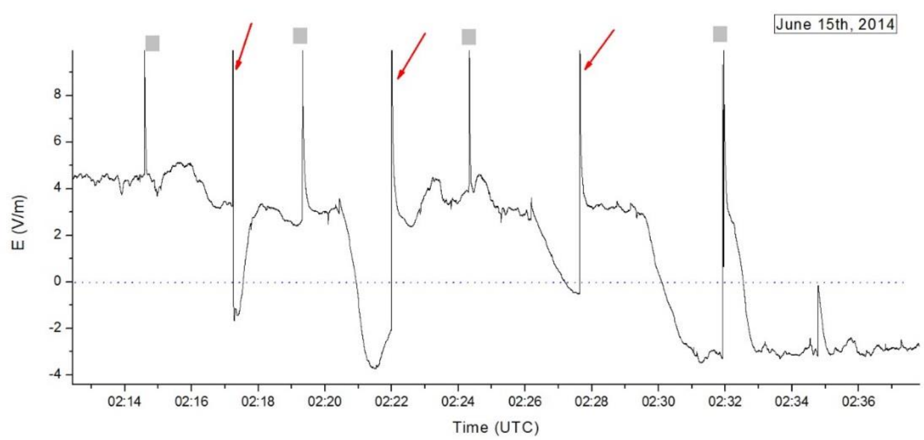

Figure 4 –Section of the thunderstorm with upward flashes. Red arrow indicates upward flashes and grey squares indicates positive flashes that had leader over the towers but did not produce upward flashes. These inversions on the field just prior to the flash may have several seconds (even more than one minute of slope).

V. SUMMARY

This work shows that leader over the tower is not the only condition to trigger upward flashes. Ambient electric field and leaders passing over the towers were not the only required conditions to initiate an upward flash in Rapid City.

The peak current distribution of the flashes does not show any tendency (of intensity or distance) that explains the triggering of an upward flash.

An inversion of the ambient electric field was observed during some seconds, in some cases during more than a minute just prior of the upward flashes, when the electric field of the thunderstorm was positive. This was not observed when the ambient electric field was negative.

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