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On the Classification of Self-Triggered versus Other-Triggered Lightning Flashes

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***Abstract*— We present in this paper lightning current measurements and LMA (Lightning Mapping Array) data associated with upward flashes observed at the Säntis Tower during Summer 2017. The LMA network consists of six stations located in the vicinity of the tower at distances ranging from 100 m to 11 km from it. 20 flashes simultaneously recorded by the current measurement system and the LMA are analyzed. Based on the lightning activity derived from the European Lightning Detection Network (EUCLID) in an area within 30 km from the tower and in a 5-second time window before the start of the flash, all the 20 flashes were classified as 'self-triggered' (ST). However, the investigations based on the LMA data reveal that 3 of the flashes were preceded by nearby activity and should be therefore classified as 'other-triggered' (OT) flashes. The results suggest that the number of OT flashes inferred from LLS data can be underestimated.**

Keywords-lightning, upward lightning, self-triggered, other-triggered, lightning mapping array, lightning location systems

I. Introduction

Characteristics of upward lightning discharges are widely reported by tall structure measurements (e.g., Gaisberg, Peissenberg, Säntis). However, their initiation mechanisms are still under investigation and not well understood. Wang et al. [1] proposed the classification of upward flashes into two categories: self-triggered (ST) and other-triggered (OT), based on the absence or the presence of other lightning activity in the geographical and temporal vicinity of the tower-initiated flash. The number of ST and OT flashes has been shown to vary depending on the geographical area (e.g., [2]). It is also shown that the rate of ST versus OT flashes is correlated, to some extent, to atmospheric conditions [2-4]. Different observation methods have been used to classify flashes into the ST and OT categories, namely based on data from lightning location systems (LLS) [2], electric fields [5], and video observations [6].

OT flashes can be preceded (or triggered) by both cloud-to-cloud (CC) and cloud-to-ground (CG) flashes. CC flashes can occur on both large scales (few tens of km) and small scales (a few hundreds of meters), while CG channels extend to a few kilometers. Those small-scale CC flashes have therefore a higher frequency spectrum component [1]. Schumann et al. [8], using video observations, proposed different mechanisms conducing to the initiation of upward flashes, all of them associated with horizontally propagating leaders in the clouds over the towers.

A Lightning Mapping Array (LMA) is a 3D discharge location system pioneered by D. E. Proctor [9-11]. The detection is accomplished by measuring the VHF radiation from the discharges, while the location is determined using the measured arrival times of the common signal at each station to calculate the spatial position and emission time of the radiation source. Proctor used 5 stations to study small-scale breakdowns of lightning. Clustering algorithms [12-14] can be used to automatically identify lightning flashes from LMA data.

In June 2017, a 3D LMA network [15,16], consisting of 6 stations belonging to the Lightning Research Group of the Polytechnic University of Catalonia (UPC) was installed around the Säntis Tower in Northeastern Switzerland. The covered range is typically about 60 km in diameter. The Säntis Tower is equipped with a direct current measuring system since May 2010. The LMA was operational during two months (July 2017 - August 2017).

In this paper, we report on two sets of simultaneous measurements of current and LMA sources associated with upward flashes from the Säntis Tower obtained during the 2017 campaign. The paper is organized as follows. Section II presents the experimental setup. Section III presents the obtained results and discussions. Conclusions are given in Section IV.

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II. MEASUREMENT SETUP

A. Current Measurements at Säntis Tower

The 124-m tall Säntis Tower located at 47°14'57''N and 9°20'32''E is by far the most frequently struck structure in Switzerland [17], [18]. The tower has been instrumented since May 2010 using advanced equipment including remote monitoring and control capabilities for accurate measurement of lightning current parameters enabling a high-resolution sampling of lightning currents over long observation windows [17], [19]. Lightning currents are measured using two sets of Rogowski coils and multigap B-dot sensors located at two different heights along the tower. The analog outputs of the sensors installed are relayed to a digitizing system by means of optical fiber links. The system is equipped with GPS and allows over-the-Internet remote maintenance, monitoring, and control. More details on the instrumentation can be found in [17], [19-22]. The lightning current is recorded over a 2.4 s interval with a pre-trigger delay of 960 ms.

B. Lightning Mapping Array (LMA)

An LMA network was installed in the Säntis Tower region in June 2017 [23]. The system consists of six stations measuring VHF radiation in 60-66 MHz. The locations of the LMA stations were chosen considering several factors, namely:

1) the magnitude of the local noise within the frequency band,
2) the availability of reliable AC power and communication means,
3) the distance to the source (Säntis Tower), and,
4) a good combination of accessibility and security.

The selected locations correspond to mobile base stations belonging to Swisscom and Swisscom Broadcast and they are shown in Fig. 1. The measurement stations were deployed in the vicinity of the Säntis Tower, at distances ranging from 100 m to 11 km from it. The area of interest is located in eastern Switzerland and it covers parts of the cantons of Appenzell Inner-Rhodes, Appenzell Outer-Rhodes, and St. Gall. The LMA takes the maximum power of VHF radiation within a time window of 80 microseconds and measures the time of arrival with 50 ns accuracy using a PC-based digitizer card coupled to a GPS receiver.

The LMA data were synchronized with the lightning current data using GPS time stamps. Results from the LMA network were transformed from global coordinates to the local coordinate system of the tower taking into account the curvature of earth.

III. DATA AND RESULTS

A. Overall Data

During the campaign, lightning currents and LMA data were simultaneously obtained. In this paper, we present results for 20 analyzed flashes in the period from 29.06.2017 to 18.07.2017. Using the data from the EUCLID network [24,25], the flashes were classified as OT and ST, considering whether or not lightning activity was reported in an area within 30 km from tower and within a 5-s time window before the start of the flash (ICC). Using these criteria, all 20 flashes (18 negative, 1 positive and 1 bipolar) were classified as ST.

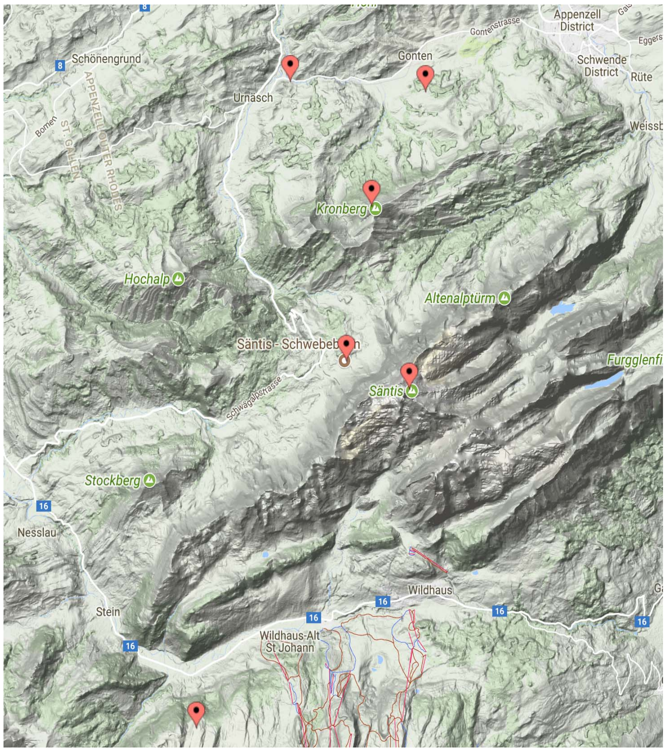

Fig. 1. Lightning mapping array stations around the Säntis Tower indicated by red pins. 12 x 12 km area.

B. Data Presentation

The coordinates of the base of the Säntis Tower are x=0, y=0 and z=2502 m. In figs. 2, 3 and 4, the LMA data are presented with circle markers, with temporal color coding. The size of the markers depends on power of the radiation source. The top panel in figs. 2 through 5 presents a top view of the VHF radiation sources over an area of 15 km x 15 km centered around the tower. The bottom left panel presents an expanded view of the top panel over an area of 300 m x 300 m centered around the tower. Finally, the bottom right panel presents the channel-base current, superimposed with the VHF radiation altitude. EUCLID detected pulses are also presented on the same plot with crosses. The time reference in the presented data corresponds to the start of the plotted current.

In what follows, we will present data associated with two upward flashes, one negative and one positive.

C. *Negative flash*

Fig. 2 presents the obtained data for an upward negative flash. The start of the initial continuous current (ICC) is at about 100 ms, as can be seen in the expanded view presented in Fig. 3.

Interestingly, the flash was preceded by discharge activity as can be seen from the LMA data. This activity initiated at different altitudes (from about 2 to 10 km) in the west of the tower, propagating in different directions, south, north and east towards the tower (dark blue to light blue in Fig. 3), and presumably causing an electric field intensification at the tower tip, resulting in the initiation of an upward flash. As a result, this flash should be classified not as an ST but as an OT flash.

In the bottom right panel of Fig. 2, EUCLID detected pulses are represented using crosses. All six return strokes of the upward flash were detected by EUCLID. The locations of the crosses in the plot correspond to the EUCLID peak estimates, which were divided by 1.8 to account for the field enhancement due to the tower and the mountainous terrain (see [26,27] for further information).

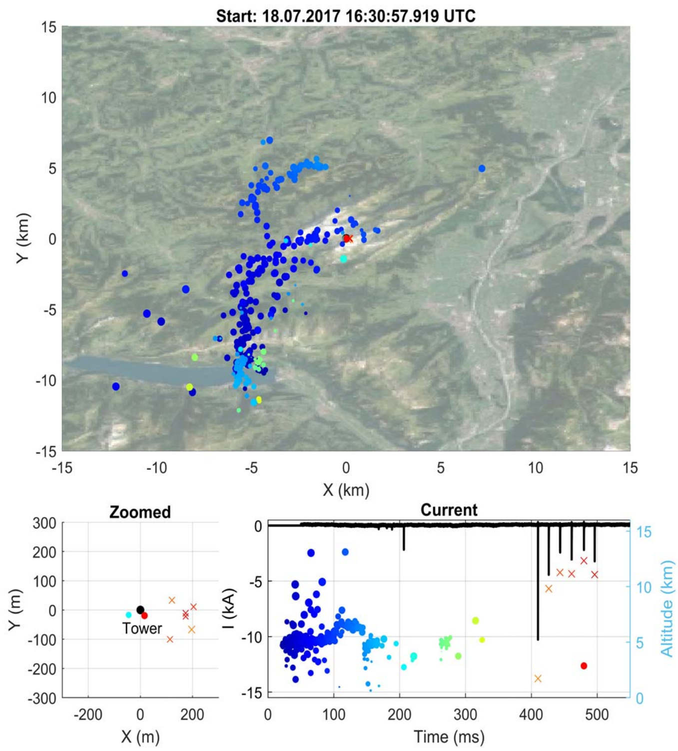

Fig. 2. Upward negative flash recorded at 18.07.2017 16:30:57 UTC. Top panel: top view of VHF radiation sources over an area of 15 km x15 km centered around the tower. Bottom left panel: expanded view of the top panel over an area of 300 m x 300 m centered around the tower. Bottom right panel: lightning current and VHF radiation altitude as a function of time. EUCLID detected pulses are presented in this same plot with crosses. The locations of the crosses correspond to the EUCLID peak estimates divided by 1.8.

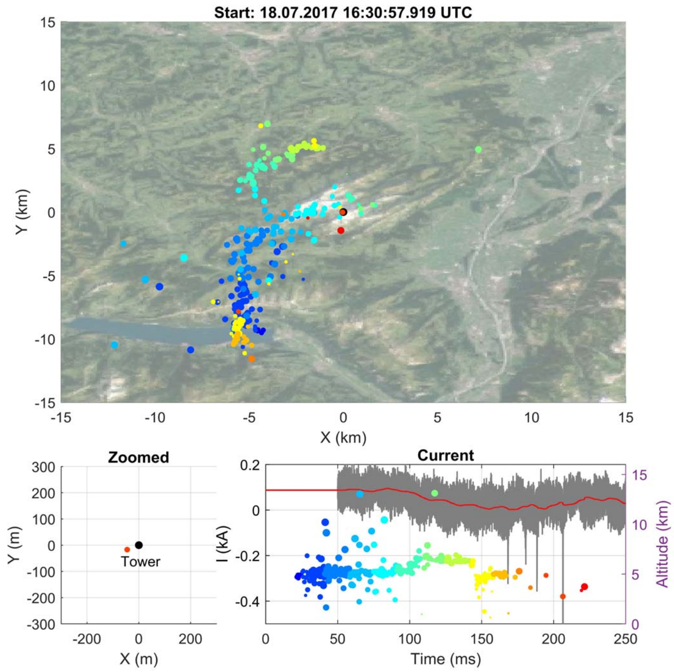

Fig. 3. Expanded view of the ICC phase of the upward negative flash of Fig. 2. The grey curve represents the measured current, and the red one represents the filtered waveform. Top panel: top view of VHF radiation sources over an area of 15 km x 15 km centered around the tower. Bottom left panel: expanded view of the top panel over an area of 300 m, x 300 m centered around the tower. Bottom right panel: lightning current and VHF radiation altitude as a function of time.

D. *Positive Flash*

Fig 4. presents the data associated with an upward positive flash, with a particularly small peak value of about 1 kA. Again, for this case, the LMA data reveal cloud activity starting from about a second prior to the initiation of the upward positive flash. The activity is originated at about 7 km north of the tower and moves towards the east. The in-cloud leader propagation from 5 to 3 km height in the immediate vicinity of the tower can be distinguished by observing the time evolution of VHF sources. Again, this flash should have be classified as an OT flash.

IV. Conclusion

We presented in this paper lightning current measurements and LMA data associated with upward flashes observed at the Säntis Tower during Summer 2017. The LMA network consisted of six stations located in the vicinity of the tower at distances ranging from 100 m to 11 km from it. We analyzed a total of 20 flashes that were simultaneously recorded by the current measurement system and the LMA in the period from 29.06.2017 to 18.07.2017.

Based on the EUCLID lightning activity in an area within 30 km from the tower and in a 5 s time window before the start of the flash, all the 20 flashes were classified as ST. However, the investigations based on the LMA data reveal that 3 of the flashes were preceded by nearby activity and should be therefore classified as OT flashes. The results suggest that the number of OT flashes inferred from LLS data can be underestimated.

We intend to expand the presented study and include in the analysis the available electrostatic field data which are obtained in the vicinity of the tower.

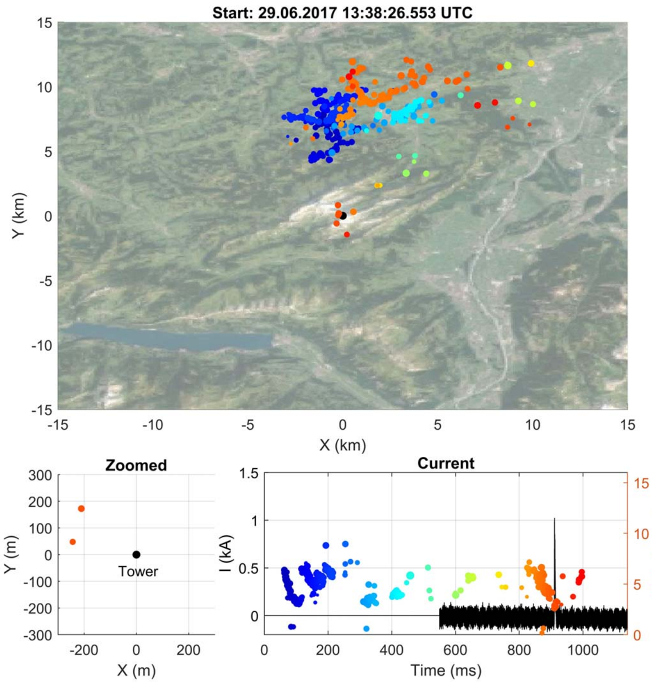

Fig. 4. Positive upward flash recorded at 29.06.2017 13:38:27 UTC. Top panel: top view of VHF radiation sources over an area of 15 km x 15 km centered around the tower. Bottom left panel: expanded view of the top panel over an area of 300 m x 300 m centered around the tower. Bottom right panel: lightning current and VHF radiation altitude as a function of time.

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