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# LMA Observation of Upward Flashes at Säntis Tower: Preliminary Results

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***Abstract*—Lightning striking tall towers is mainly of the upward lightning type, which is characterized by the absence of a first return stroke and the presence of an initial continuous current (ICC) with or without superimposed pulses. The Säntis Tower is 124 m tall and it is located on the top of the Säntis Mountain (2502 m ASL) in the eastern Swiss Alps. The Tower location exhibited the highest lightning flash density in Switzerland during the period from 1999 to 2006. The Tower was instrumented in May 2010 for the measurement of lightning current parameters. In order to complement these data, a Lightning Mapping Array (LMA) was deployed around the Tower during the Summer 2017. The LMA system locates the sources of radio emissions in the very high frequency range (VHF, 60–66 MHz) in three dimensions by a time-of-arrival analysis. The LMA system allows detailed analysis of individual flashes, through the mapping of the lightning channels in the cloud with sufficient time resolution and spatial precision to locate the origin and propagation of each flash. With the help of the LMA, we intend to further investigate the initiation and propagation characteristics of upward lightning emerging from the Tower. From June 29 to August 15 , 2017, 33 upward flashes initiated from the Säntis tower were registered by the LMA network. These records are the first set of VHF total lightning mapping obtained in Switzerland. Preliminary results of the campaign are presented in this paper.**

***Keywords—Lightning mapping array system; VHF lightning mapping; Lightning current measurement.***

## I. Introduction

The use of time of arrival (TOA) measurements to map the progression of discharges in lightning studies was pioneered by D. E. Proctor in South Africa e.g. [1]–[3]. Proctor utilized a network of five stations arrayed along two nearly perpendicular baselines to study the detailed breakdown of individual lightning discharges. VHF Lightning Mapping Arrays (LMAs) [4] that use the same principle of operation of Proctor's original system have become widespread in the last decade. These systems achieve geolocation of impulsive VHF source radiation emitted as the lightning channel develops to produce a map of the discharge path, including channels within the cloud. Each lightning flash produces a cluster of individual VHF signals. A source-to-flash clustering algorithm [5]–[7] can be used to automatically identify flashes as sensed with the LMA.

The LMA measures the arrival times of radiation events at a network of ground-based measurement stations spread over an area typically 60 km in diameter. The signals are received in an unused very high frequency (VHF) television band, usually channel 3 (60–66 MHz). The accuracy of the locations depends on the uncertainty of the arrival time measurements, the background noise level in the operating frequency bandwidth, and the number and positions of the stations used to obtain each solution. The arrival times are measured independently at each station using an accurate time base provided by a GPS receiver [8]. In June 2017, a three-dimensional Lightning Mapping Array network consisting of 6 stations belonging to the Lightning Research Group of the Catalan Polytechnic University (UPC) was installed around the Säntis Tower in northeastern Switzerland. This paper presents the first set of data obtained from that system.

The paper is organized as follows. Section II briefly reviews the instrumentation installed at the Säntis Tower and its vicinity. A brief description of the installed Lightning Mapping Array network around the Tower is given in Section III. The obtained data and preliminary analysis and discussion are given in Section IV. Finally, conclusions are presented in Section V.

## II. Lightning Activity at Säntis Tower

The 124-m tall Säntis Tower sits on the top of the 2502 m Mount Säntis, located in the Appenzell region in northeastern Switzerland. This structure serves mainly as a telecommunications tower and a climate station. The selection of the Säntis Tower site followed an analysis of several candidate sites located in various regions in Switzerland. The study revealed that the Säntis Tower is by far the most frequently struck structure in Switzerland [9], [10].

The 124-m tall Säntis 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 [9], [11]. The analog outputs of Rogowski and multigap B-dot sensors installed at two different heights along the tower are relayed to a digitizing system by means of optical fiber links. The system allows over-the-Internet remote maintenance, monitoring, and control. A PXI platform with a current sampling rate of 50 MS/s is used to digitize and record measured waveforms. The lightning current is recorded over a 2.4-s time with a pre-trigger delay of 960 ms. In 2013–2014, a certain number of updates were made to the overall measuring system. More details on the measurement sensors and instrumentation system can be found in [9], [11]–[14].

An EFM-100 field mill has been installed at about 85 m from the tower since 15 July 2016 to measure the electrostatic field. The EFM-100 can detect lightning activity up to distances of about 40 km from the tower [15].

An electric field measuring system comprising a flat plate antenna and an analog integrator with an overall frequency bandwidth of 30 Hz to 2 MHz is located 14.7 km away from the Säntis Tower [16].

## III. Säntis Lightning Mapping Array

In June 2017, a Lightning Mapping Array (LMA) network was installed in the Säntis tower region. The installed LMA system was operational from June, 29 to August, 15, 2017. The system detects VHF radio emissions sources from lightning discharges. In our case, the power and arrival times of radio noise produced by lightning leaders in the 60 to 66 MHz band were detected at six ground based sensors. Each individual flash is represented by several lightning sources and it can be reconstructed through lightning maps of three-dimensional locations. To install the LMA sensors, six locations around the Säntis tower were identified. 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
3) 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 . 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 arrival times of the 60-66 MHz impulsive VHF radiation sources are measured with 50 ns accuracy using a special PC-based digitizer card coupled to a GPS receiver. If the time of arrival of the radiation from an impulsive event is measured at a minimum of four locations, the 3-dimensional position of the source region can be determined. By measuring the time of arrival of the radiation at four stations, the four unknown parameters including the three position coordinates of the discharge, ($x$, $y$, $z$), and the exact time when the discharge occurred, $t$, can be determined. To provide for redundancy, improve the location accuracy, and to reduce the probability that noise spikes from other source types are not misidentified as lightning, the system uses six receivers. The data from all six stations are used to determine the location (and error in location) of the radiation source.

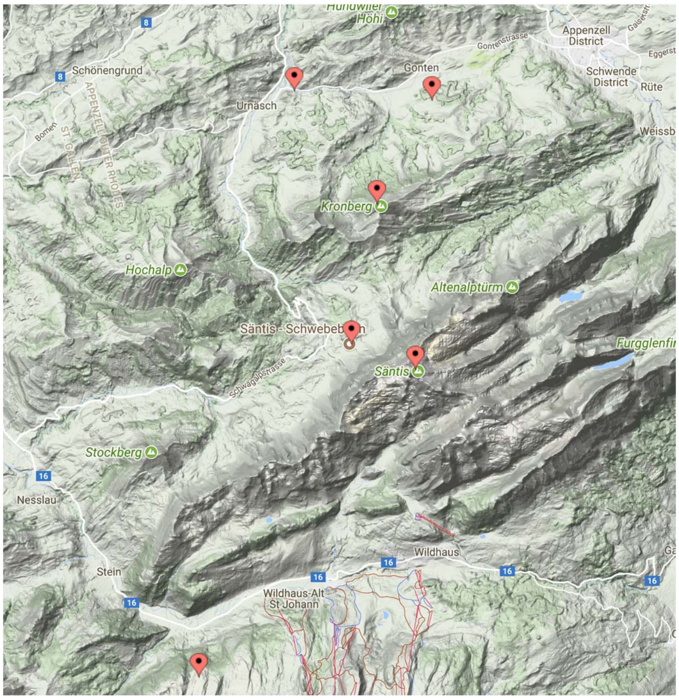

Fig. 1. Lightning mapping array stations around the Säntis Tower.

Timing is accomplished with the use of GPS receivers. GPS receivers provide a timing pulse once per second. Each LMA station digitizes the RF signal and time tags the peaks with a time derived from that timing signal. This time is initially stored at each individual station and transmitted over wireless modems to a central site for real time analysis and display. In addition, the data are made available for post-processing analysis.

## IV. Obtained data and Analysis

Between June 29 to August 15, 2017, 33 upward flashes initiated from the Säntis tower were registered by the LMA network. These records are the first set of VHF total lightning mapping obtained in Switzerland. At the same time, experimental records from current measurements were obtained at the Säntis Tower. The whole area is also covered by the European Cooperation for Lightning Detection (EUCLID) lightning location network [17].

We present here the data associated with an upward negative lightning flash recorded on July 18, 2017 at 16:28:01 (UTC), which include the LMA data, and the lightning current

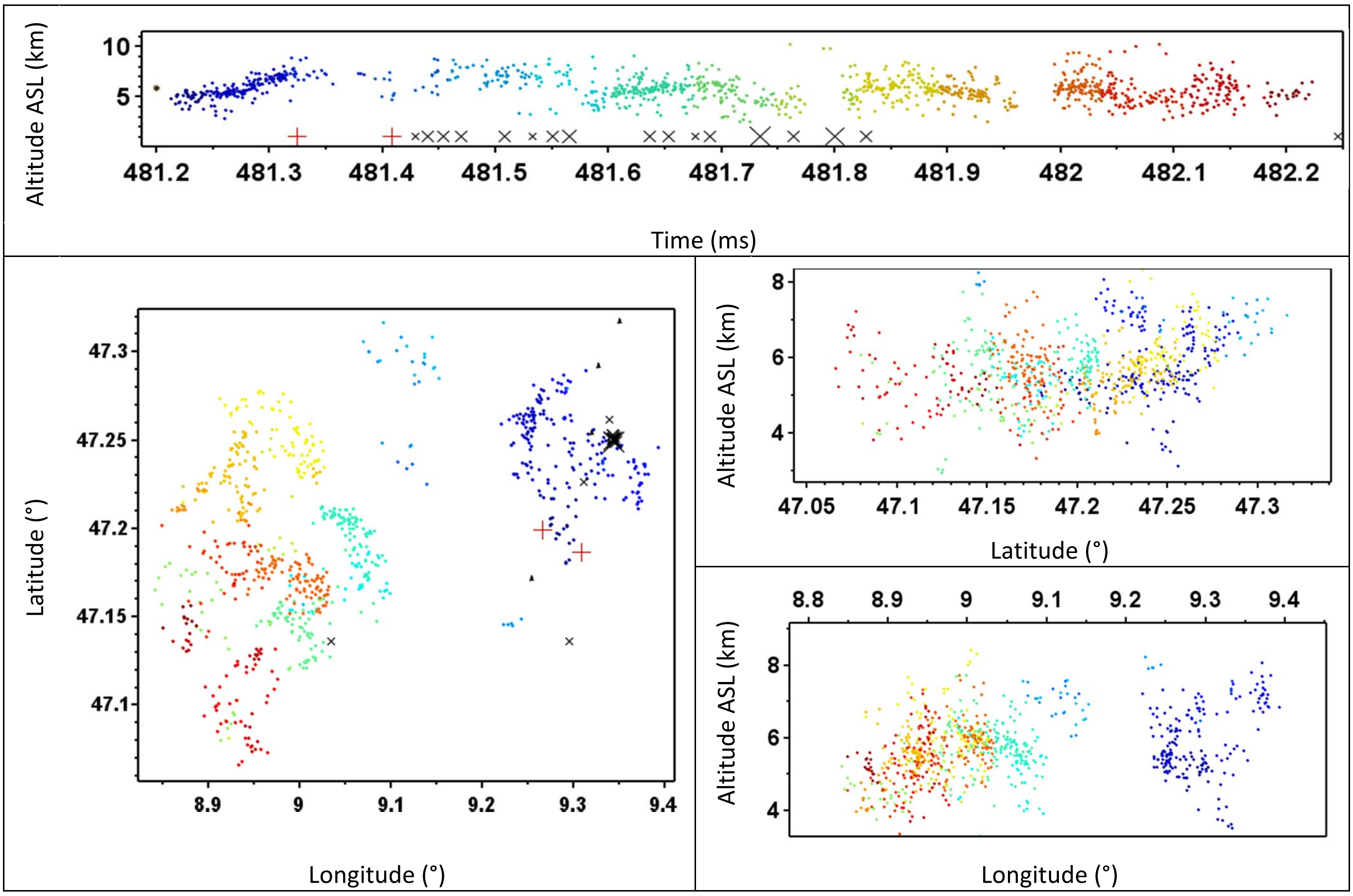


Fig. 2. VHF sources of an upward negative flash from the Säntis Tower occurred on 18 July 2017, 16:28:01 UTC. Sources are colored by time from blue (earlier) to red (later). The time reference is attributed to the first recorded current data at the Tower. The flashes which were recorded by EUCLID are also shown in a way that the shape of the marker corresponds to the polarity of the flash. "x" is used for negative strokes and "+" is attributed to positive strokes.

waveform. The EUCLID data are also added to the LMA data to verify the accuracy of the measurement.

A three-dimensional view of the mapped VHF sources from the triggered flash is presented in

Fig. 2. Sources are colored by time from blue (earlier) to red (later). The flash lasted 1105 ms, reaching up to a 9 km altitude and extending over a horizontal area of 25x30 km$^2$. The time reference is attributed to the starting part of the recorded ICC at the Tower. The flashes that were recorded by EUCLID are also shown in

Fig. 2, the shape of the marker corresponding to the polarity of the flash: "x" for flashes with negative polarity and "+" for positive flashes.

Fig. 3 shows the overall current waveform containing an Initial Continuous Current (ICC) of negative polarity that lasted for about 150 ms and included 5 superimposed pulses with peak values of about 0.5 to 1.9 kA. After the initial continuous current, the flash exhibits more than 20 negative return strokes, of which 10 (identified in the figure by red labels) were detected by EUCLID. The position in time of these return strokes, along with VHF sources recorded by the LMA system for this flash are shown in Fig. 4. Sources marked by an "x" are the recorded data received from EUCLID. The return strokes that were detected by EUCLID and whose current records are available are shown in red. There is also a source marked by "+" which is a recorded data with positive polarity detected by EUCLID, which occurred 8.4 km away from the Tower.

## V. CONCLUSION

This paper presents the first set of data of the three-dimensional VHF lightning measurements in Switzerland obtained from an LMA network installed around the Säntis Tower.

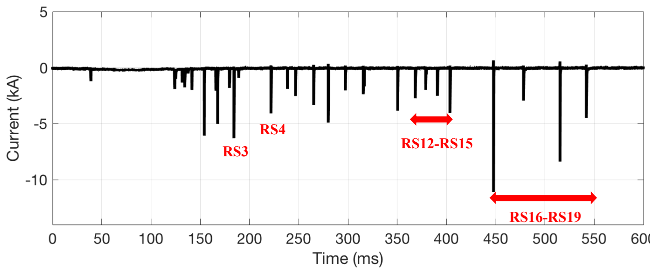


Fig. 3. Current waveform associated with the upward negative flash that occurred on 18 July 2017, 16:28:01 UTC. Return strokes shown in red are also detected by EUCLID.

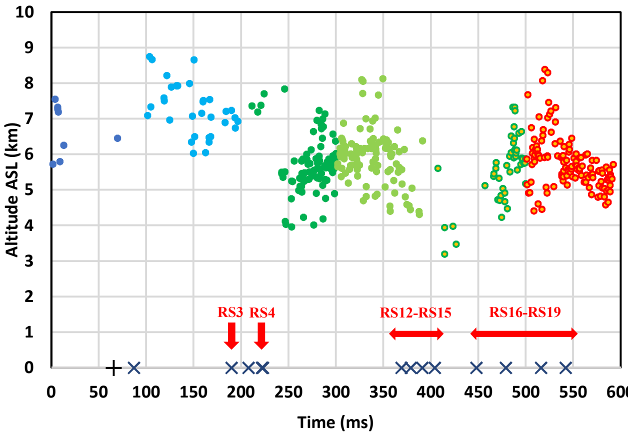

Fig. 4. Altitude vs. time plot of VHF sources of the upward negative flash from the Säntis Tower occurred on 18 July 2017, 16:28:01 UTC. Sources are colored by time from blue (earlier) to red (later). Sources marked by "x" on the time baseline are the recorded data with negative polarity received from EUCLID. Data marked in red are return strokes that are also recorded by EUCLID. The source marked by "+" is a recorded stroke with positive polarity recorded by ECLID, which occurred 8.4 km away from the Tower.

The arrival times and signal power of the 60-66 MHz impulsive VHF radiation sources to 6 LMA stations were measured to locate the three position coordinates of the discharge and the exact time when the discharge occurred.

33 upward flashes initiated from the Säntis tower were registered by the LMA network between June 29 to August 15, 2017. A three-dimensional view of the mapped VHF sources of an upward negative flash from the Säntis Tower that occurred on 18 July 2017, at 16:28:01 UTC, recorded by that system along with its current waveform measured at the Tower was presented in this paper as a preliminary result of the campaign. The final paper will include a more thorough discussion on the obtained results.

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