A Large Bipolar Event Recorded at the Säntis Tower

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Abstract: We present a 4-stroke negative lightning flash recorded at the Säntis Tower for which the current waveform associated with the first return stroke was unusual and resembled a Gaussian pulse. Such current pulses could be the sources of similarly-shaped electric field waveforms that are attributed to LBEs. Correlated data from the EUCLID lightning detection network show that this flash was preceded by a positive flash located 0.8 km from the tower and 1 ms prior to its first stroke. We also present simulation results of the radiated electric fields considering two different models for the LBE and we show that the simulated waveforms agree well with the experimentally observed characteristics of the radiated fields associated with LBEs.

Keywords: Large bipolar event, winter lightning, downward negative flash, tall tower, return stroke, M-component

1. Introduction

High-current lightning discharges are reported as one of the main threats of winter lightning activity in Japan [1]. They constitute one of the major causes for transmission line outages [2]. An extensive study on the electric field signatures associated with high current lightning discharges, referred to as Large Bipolar Events (LBEs), was presented in [3]. The electric field signature of LBEs is characterized by a bipolar, symmetrical pulse whose initial polarity is the same as that of negative return strokes. Using numerical simulations based on the bouncing wave model, it was suggested in [4] that the injected current waveform should be a symmetrical Gaussian pulse in order to reproduce the observed field signature of LBEs.

Wu et al. [3] state that LBEs are probably associated with high grounded objects and they hypothesize that LBEs occur when the negative charge layer in thunderclouds is close to the top of the tall, grounded object since this would explain why LBEs were observed essentially during winter time. An overview of LBEs and other similar events is given by Zhu et al [5]. The reviewed data were obtained both in winter and in summer, but in all cases a tall strike object was involved.

In this paper, we present data for a 4-stroke negative lightning flash recorded at the Säntis Tower that occurred on July 15, 2012. The current waveform associated with the first return stroke of this flash resembles a Gaussian pulse and, therefore, could be indicative of a process of LBE-type. We also present numerical simulations of the radiated electric field associated with this event and we compare its characteristics with observations.

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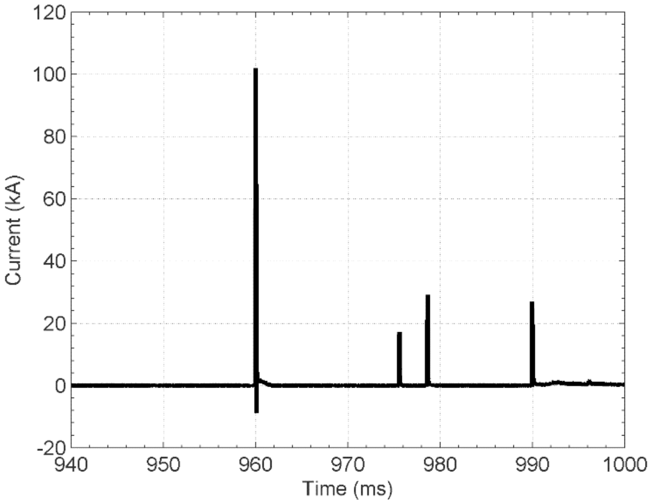
2. Säntis Tower Instrumentation

The 124-m tall Säntis Tower located on the top of Mount Säntis (2502 m ASL) was instrumented with modern equipment for lightning current measurements in May 2010 [6]. Rogowski coils and multigap B-dot sensors are installed at heights of 24-m and 82-m to measure the current and its time derivative. More details on the Säntis Tower instrumentation and data acquisition unit can be found in [6] and [7].

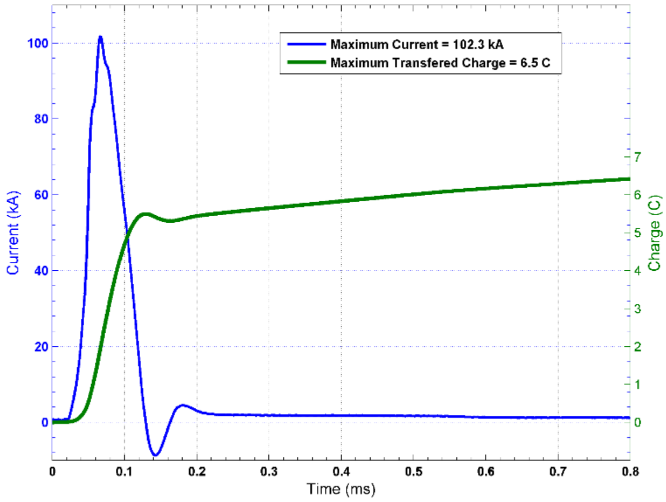
3. Description of the Observed Event

3.1 Overall Current Waveform Characteristics

Figure 1a shows the overall current waveform of the negative lightning flash recorded on 15 July 2012 at 16:56:36 (UTC) at the Säntis Tower. The current waveform does not contain any initial continuous current and it is therefore associated with a negative downward flash. Figure 1b presents the current waveform and the associated transferred charge for the first return stroke of this flash. The peak current is about 102.3 kA, the highest negative peak current measured so far at the Säntis Tower. The total transferred charge to ground is 6.5 C, which is not far from the 4.5 C median impulse charge reported by Berger et al. [8] for first strokes in negative lightning. The waveform appears as a quasi-symmetrical Gaussian-like pulse, which could be associated with an LBE [4]. The waveform is also characterized by an undershoot about 75 µs after the return-stroke peak. The peak of the negative undershoot is -8.5 kA. The first stroke of this flash was followed by three subsequent return strokes with peak current values of 17.2, 29.0 and 26.8 kA. The subsequent return stroke current waveforms were similar to the first return stroke waveform but, unlike the first stroke, they started with a faster rising portion with superimposed oscillations and did not exhibit a negative undershoot. In this paper, we will concentrate on the analysis of the first return stroke.



a)



b)

Fig. 1. Flash that occurred on 15 July 2012 at 16:56:36. a) Overall current waveform of the flash. b) Measured current (blue) and calculated transferred charge associated with the first return stroke of the flash.

3.2 Correlation with Lightning Location System Data

The flash observed at the Säntis Tower was also detected by the European Cooperation for Lightning Detection (EUCLID) network [9, 10]. Out of the four strokes, 3 were detected by EUCLID and one was missed. Table I presents a comparison between the directly-measured peak currents at the Säntis Tower and the peak current estimates provided by EUCLID.

The correlation with EUCLID data revealed that this flash was preceded by a single-stroke positive flash which occurred 1 ms prior to the first stroke to the Säntis Tower, 0.8 km from the tower. No current in the tower was recorded at the time of the positive flash, which suggests a ground connection other than the tower. The peak current of the positive flash reported by EUCLID was 30 kA. The close occurrence of the positive flash in time (1 ms) and in space (0.8 km) with the first stroke of the observed negative Säntis Tower flash suggests that the positive flash might have been involved in the formation process of this later flash. It is worth noting that about 15% of the lightning discharges terminated on the Säntis Tower are preceded by lightning activity in the surrounding area [13].

Table I – EUCLID peak current estimates versus peak currents directly measured at the Säntis Tower for the return strokes of the flash occurred on July 15, 2012 at 16:56:36.

Stroke Order	Directly measured peak current (kA)	Peak current estimated by EUCLID (kA)
1	102.3	126.7
2	17.2	22.9
3	29.0	Not detected
4	26.8	42.3

It can be seen from the table that the EUCLID network overestimated the peak currents. This overestimation can be attributed to the enhancement of the radiated fields due to the presence of the tower and the mountainous terrain [11,12].

4. Radiated Far Field Simulation

In this section, we present simulation results for the radiated vertical electric field associated with the first return stroke of this flash. We use two available models describing the charge transfer to ground, namely (1) a return-stroke-like process and (2) an M-component-like process to obtain current distribution along the stroke channel.

In order to simplify the process of numerical simulations, the measured current was represented using the sum of two Heidler's functions. Figure 2 shows the measured current and its analytical representation by Heidler's functions.

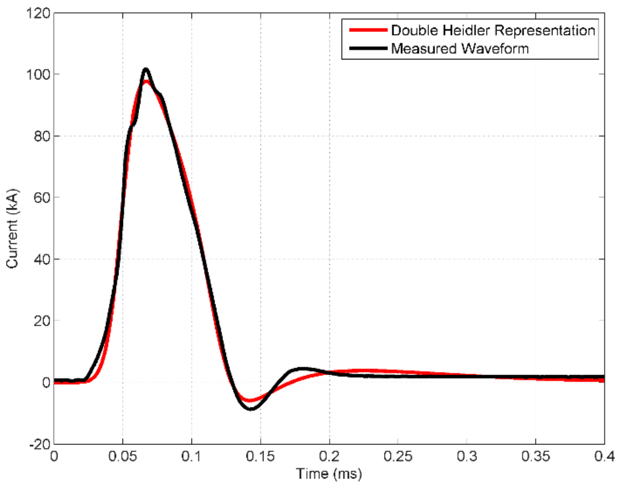


Fig. 2. Measured current waveform associated with the first return stroke of the flash that occurred on 15 July 2012 at 16:56:36 (black line) and its analytical representation using Heidler's functions (red line).

4.1 Return Stroke Mode of Charge Transfer

Assuming a return stroke mode of charge transfer and adopting the MTLE return stroke model [14,15], we calculated the radiated electric field associated with the first return stroke of the considered flash. In this preliminary analysis, the presence of the tower was disregarded and the ground was assumed to be flat and perfectly conducting. Note that a more sophisticated return stroke model including wave bouncing between the channel top and tower base was used in [4].

Figure 3 shows the calculated vertical electric field at 100 km from the channel. The height of the channel was assumed to be 4 km, the attenuation constant of the MTLE model was set to 1 km, and the return stroke speed was assumed to be 1.5×10^8 m/s.

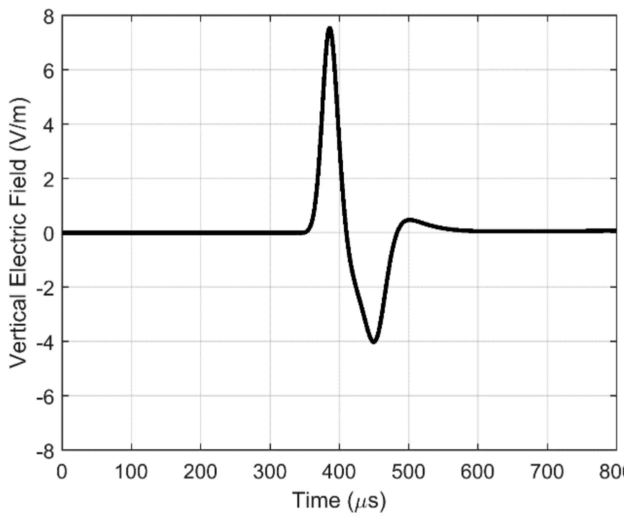


Fig. 3 Vertical electric field at 100 km from the lightning channel associated with the first stroke current of the considered flash (Fig. 1), computed using the MTLE return-stroke model. The height of the channel was assumed to be 4 km, the attenuation constant of the MTLE model was set to 1 km, and the return stroke speed was assumed to be 1.5×10^8 m/s.

4.2 M-component Mode of Charge Transfer

It has been suggested that LBEs can be initiated by a long upward connecting leader which attaches to a downward leader at a high altitude [1]. Following the attachment, the resulting current flows downward towards the ground, experiencing total reflection at the ground interface. This process is similar to the M-component mode of charge transfer [16].

We used the M-component model of Rakov et al. [17] to describe the current distribution along the channel. As with the Return Stroke Mode of Charge Transfer simulations presented in the previous section, the presence of the tower was neglected in the calculations. Figure 4 presents the vertical electric field waveform calculated at a distance of 100 km from the channel, assuming an initiation height for the M-component of 2 km above ground level and a current wave propagation speed of 1x10^8 m/s.

4.3 Discussion and Comparison with Observation of Wu et al. [3]

As seen in Figures 3 and 4, the field waveforms calculated using the two models are quite similar. They exhibit the bipolar signature typical of LBEs reported in winter storms in Japan [2]. Table II presents a summary of the salient parameters of the field waveforms, compared with experimental data of Wu et al [3]. It can be seen that, except for the positive half-cycle width, for which the computed values are larger than the maximum value, all the parameters are within the corresponding ranges of observed values.

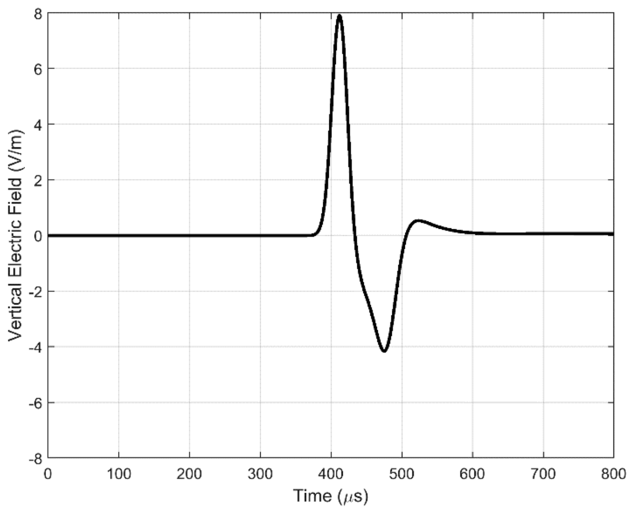


Fig. 4 Vertical electric field at 100 km from the lightning channel associated with the first stroke current of the considered flash (Fig. 1), computed using the guided-wave M-component model of Rakov et al. [17]. The source was fixed at 2 km and the current wave propagation speed was fixed at 1x10^8 m/s.

Table II – Comparison of simulation results with observations of Wu et al [3] (For the definition of the parameters, refer to Fig. 4 of [3]).

Parameter	RS Model	M-component Model	Observations of Wu et al [3]		
			Min	Max	Median
Positive half-cycle width (μs)	47.2	49.1	4	32	15
Ratio of rise time to fall time	0.9	1.3	0.4	4.8	1.4
Ratio of positive to negative half-cycle widths	0.7	0.66	0.4	2	1.1
Ratio of positive to negative half-cycle peaks	1.9	1.9	0.4	2.4	1.1

5. Conclusions

We presented a 4-stroke negative lightning flash recorded at the Säntis Tower that occurred on July 15, 2012. The current waveform associated with the first return stroke of this flash resembles a Gaussian pulse which according to [4] could be indicative of the process of LBE-type.

Correlated data from the EUCLID lightning detection network showed that this flash was preceded by a positive single-stroke flash located 0.8 km from the tower and 1 ms prior to its first stroke.

We also presented simulation results for the radiated electric fields considering two different models for the LBE and found that the resulting simulated waveforms agreed well with the experimentally observed characteristics of radiated fields associated with LBEs, except for the initial positive half-cycle width of the radiated field, which was larger than the maximum experimentally observed value.

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