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The first electric field pulse of cloud and cloud-to-ground lightning discharges

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ABSTRACT

In this study, the first electric field pulse of cloud and cloud-to-ground discharges were analyzed and compared with other pulses of cloud discharges. Thirty eight cloud discharges and 101 cloud-to-ground discharges have been studied in this analysis. Pulses in cloud discharges were classified as 'small', 'medium' and 'large', depending upon the value of their relative amplitude with respect to that of the average amplitude of the five largest pulses in the flash. We found that parameters, such as pulse duration, rise time, zero crossing time and full-width at half-maximum (FWHMs) of the first pulse of cloud and cloud-to-ground discharges are similar to small pulses that appear in the later stage of cloud discharges. Hence, we suggest that the mechanism of the first pulse of cloud and cloud-to-ground discharges and the mechanism of pulses at the later stage of cloud discharges could be the same.

1. Introduction

The breakdown process in cloud discharges has been studied since the early 1930s in order to understand the lightning initiation mechanism. Since the visual observation of cloud discharges is difficult, remote sensing of electric fields provides some valuable information on the initiation process of cloud discharges. A few analyses have been reported by numerous authors (e.g Weidman and Krider, 1979; Le Vine, 1980; Cooray and Lundquist, 1982, 1985; Bils et al., 1988; Villanueva et al.,1994) on lightning cloud discharges. From their analysis, it was found that large microsecond scale pulses were typically present at the beginning of cloud discharges that could be related to the initiation of breakdown process. Detailed analysis of microsecond scale pulses in the first 10 ms of cloud discharges were performed by Sharma et al. (2005) and Bodhika et al. (2006). However, the first electric field pulse was not included in their analysis. Based on the work done by Sharma et al. (2005) and Bodhika et al. (2006) on pulse duration, zero crossing time, FWHMs and the rise time, we additionally analyzed the above parameters of first electric field pulse of cloud discharges. The total duration of cloud discharge records in this study is 160 ms with 40 ms pre-trigger duration, while the duration of previous two studies is limited to 10 ms.

The preliminary breakdown pulses typically found a few ms before return stroke were attributed to the initiation of the breakdown process in cloud-to-ground discharges. Thorough analysis on microsecond and submicrosecond scale pulse durations of cloud-to-ground discharges has been carried out by Nag et al. (2009) using data acquired during summer 2006 in Gainesville, Florida. They found that 78% of the discharges have pulse duration less than 4 μs, with 87% of them being bipolar. Another 22% have pulse durations less than 1 μs. Beasly et al. (1982) showed a significant VHF radiation at the preliminary variations of electric field records of ground discharges. However, in both the above studies no detailed analysis of the initial electric field pulse of cloud-to-ground discharges was included. Since the process involved in lightning initiation is not yet fully understood we were motivated to examine the first pulse of preliminary breakdown pulses in cloud-to-ground discharges and see whether they are similar or differ from the first pulse of cloud discharges.

2. Data

The measurement was performed during summer (August) 2008 in Vero Beach on the eastern coast of Florida (27°N, 80°W). The measuring base station is located at Vero Beach Marine

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Laboratory, owned by Florida Institute of Technology (FIT) and is situated about 200 m from the sea. Vertical electric field (both slow and fast fields), 3 MHz, 10 MHz and *dE*/*dt* of lightning generated electric fields were measured using four parallel flat plate antennas. The oscillators tuned to 3 and 10 MHz were operating at −3 dB bandwidth of 264 and 2020 kHz, respectively. All antennas were placed side by side, separated by 1 m, and about 20 m from the control room where the recording systems were kept. Signals from flat plate antennas were fed into two 4 channel digital transient recorders (12-bit Yokogawa DL1640L and 8-bit LeCroy 9314 DSO) using 25 m long RG 58 coaxial cable and properly terminated to avoid reflections. The DSO operated at a sampling rate of 100 MS/s has been set to work in a 40 ms pre-trigger mode so that signals before and after trigger pulse could be obtained. A 60 cm long coaxial cable (RG 58) was used to connect the antenna and electronic buffer circuit. The rise time of the fast antenna system for step input pulses was less than 30 ns while the decaying time constant is 13 ms to avoid over-loading due to large static field changes produced by close lightning flash. The decay time of the slow antenna system is about 1 s. Details of fast and slow electric field antenna's measuring system is similar to the one explained by Cooray and Lundquist (1982). Further, the triggering window has been set to window triggering mode, so that flashes with both polarities will be captured.

3. Results and discussions

From 140 cloud discharges and 900 cloud-to-ground discharges recorded, 38 and 101 of them were selected, respectively. Only flashes with detectable first pulse in cloud discharges (Fig.1) or with detectable preliminary pulses in cloud-to-ground discharges were selected for analysis. Since a high resolution (12-bit) recorder was used in this analysis, the noise level was low and this minimized the chances of misinterpreting noise as the first pulse. Also the presence of 3 MHz was used to confirm the selected pulse. Since 90% of cloud-to-ground discharges are downward negative lightning and typical cloud discharges are of negative polarity (Rakov and Uman, 2003), our discussion will be restricted only to those types of discharges.

Fig. 2 illustrates an example of the first pulse of a cloud discharge recorded on 12th August 2008. All pulses in individual discharges were grouped into large, medium and small according to their relative pulse amplitude. For that, we calculated the average amplitude of the five largest pulses in each cloud discharge. Then, all pulses with amplitude greater than or equal to 50% of the average amplitude were labeled as 'large pulses', pulses with amplitudes between 25% (including 25%) and 50% of the average amplitude were labeled as 'medium pulses' and pulses with amplitudes between 12.5% (including 12.5%) and 25% of the average amplitude were labeled as 'small pulses'. It is to be noted that most of the large pulses are found to be within the first 20 ms, while most of the medium and small pulses are observed to appear later (after 20 ms). In this study pulse width is defined as the measurement from the initial rising point of the pulse to where the pulse is coming back to the zero line, including the overshoot if any. Further, rise time was taken as 10–90% of the peak value while zero crossing time was measured from the initial rising point of the pulse to where the pulse is first crossing the zero or reference line.

3.1. The first pulse of cloud discharges

In this section, we discussed the characteristics of the first pulses and compare them with other pulses of the same polarity found in each discharge. The atmospheric electrical sign convention is used where the negative electric field change is due to negative charge being transferred to ground. The statistics of the first pulse and other pulses is summarized in Table 1. The mean value of pulse width for the first pulse is 2.08 ± 1.6 μs, smaller than that of 13.41 ± 21.6 μs measured for large pulses. However they are comparable to the value 2.53 ± 1.60 μs measured for

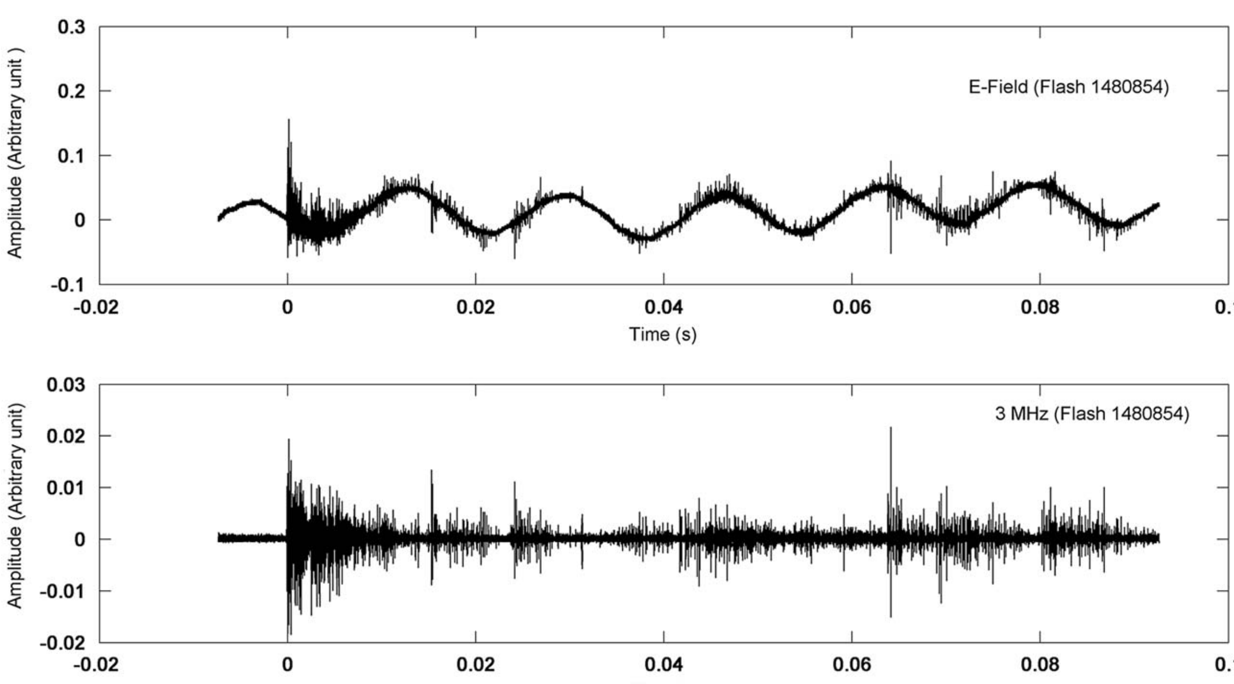

Fig. 1. Electric field of cloud discharges measured simultaneously with 3 MHz radiation where the first pulse was detectable. This figure has been recorded from flash 1480854.