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Characteristics and correlation of return stroke, M component and continuing current for triggered lightning

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ABSTRACT

Based on the channel-base current acquired from Guangdong Comprehensive Observation Experiment on Lightning Discharge (GCOELD), the characteristics and correlation of return stroke (RS), M component and continuing current (CC) were analyzed. As for RS, the geometric average values of peak current (PI), half-peak-width (HPW), rise time ($t_{10-90\%}$) and charge transfer within 1 ms after the beginning of the RS (Q1 ms) are 16.41 kA, 17.03 μs, 0.43 μs and 1.62 C, respectively. As for M component, the geometric average values of PI, duration, $t_{10-90\%}$, HPW and charge transfer from the beginning to the end (Q) are 185.75 A, 1.68 ms, 0.42 ms, 0.70 ms and 0.11 C, respectively. As for CC, the duration, average current and charge transfer are 19.01 ms, 202.58 A and 3.85 C. 66% RSs in triggered lightning are followed by CC processes. And the percentages of long CC (duration ≥40 ms), short CC (10 ms< duration < 40 ms) and "questionable" CC (duration ≤ 10 ms) are 34%, 27%, 39%, respectively. Also, the effects of RS and M component on CC duration have been investigated. An interesting phenomenon of "restricted zone" which indicates that M components with small mean amplitude (<0.5 kA) is a necessary factor for the existence of long CC, has been found. It is possible that there are two types of M components which can exert different effect on CC duration. In addtion, we also found three "restricted zone" phenomena which exist in the correlation between peak current, charge transfer, action integral of RS and CC duration. The phenomena indicate that the peak current, transferred charge in 1 ms and action integral of RS are inherently correlative to CC duration. Especially for action integral of RS, it plays a more key role in the duration of CC. If the value of action integral is larger than 6300 A^2 s, the long CC is highly unlikely to occur.

1. Introduction

A typical cloud-to-ground lightning often includes some discharge processes, such as initial breakdown [1,20], leader [18], return stroke [2], M component [3] and continuing current [4]. The fast charge transfer in the discharge processes often produces strong electromagnetic radiation and large current, which is a main reason to lead to severe damage. Among the discharge processes, return stroke (RS), continuing current (CC) and M-component are three typical cases accompanied by large charge transfer.

As we have known, RS with peak current of some tens kA is the most intense process of charge transfer. Following RS discharge process, CC process with average current of some hundreds amperes can also give a considerable charge transfer through the previous RS channel due to a long duration (some milliseconds to some hundreds milliseconds). According to the difference in CC duration, CC can be classified as three types. "Long" CC is characterized with a steady electric field change with a duration in excess of 40 ms [5,6]. "Short" CC is characterized with a similar field change with a duration between 10 ms and 40 ms [4], and "questionable" CC lasts for 1 ms to 10 ms [7]. M component is pulse superimposed on continuing current [8,9]. These M current pulses have amplitude of typically some hundreds amperes and rise time of some hundreds microseconds.

The currents of RS, CC and M components share the same channel (RS channel), therefore, it is possible that the three discharge processes influence each other. Although a few researchers have found some correlations between RS, CC and M component, the data used in those researches are often video and electric field change,

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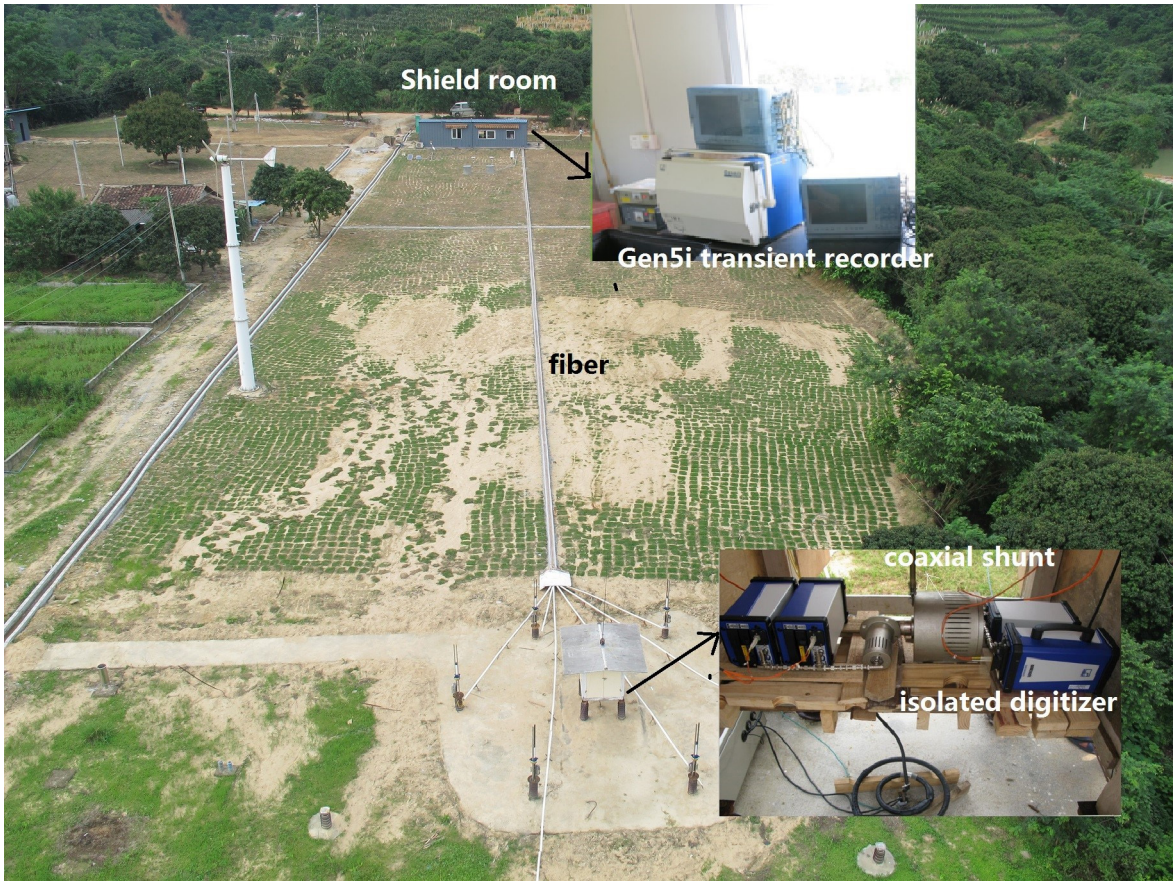

Fig. 1. Experiment field and current measurement system for triggered lightning.

which is difficult to get the accurate charge transfer. Some results of previous researches are as follows. Saba et al. [10] found that negative strokes combining both peak current greater than 20 kA and CC duration greater than 40 ms are highly unlikely to occur during the investigation of the magnitude of the return stroke peak current preceding continuing current (CC) in ground flashes. They believed that the long CC is preceded by the return stroke with low peak current. Brook et al. [6] showed that the RS which is followed by CC often transfers less charge. Campos et al. [11] found that nearly 25% of M-components occur in the first 10% of the duration of the CC, and more than 75% occur in the first half of the CC.

Although the research on the inherent correlation among RS, M component and CC has been conducted for some years, so far it remains need of research into the characteristics and correlation among them due the difficulty in acquiring directly measuring data of lightning current. Artificial triggered lightning, as an important method of simulating natural lightning, can provide the accurate data of direct-measurement current.

In this paper, we will further analyze the characteristics of RS, CC and M component based on the channel-base current data acquired from triggered lightning. In order to get further understanding, the correlation among RS, M component and CC duration is also investigated in detail.

2. Experiment and data

The channel-base current data analyzed in the paper were observed during Guangdong Comprehensive Observation Experiment on Lightning Discharge (GCOELD) from 2008 to 2013. The experiment has been jointly conducted by the Chinese Academy of Meteorological Sciences (CAMS) and the Guangdong Meteorological Bureau at the "Guangzhou Field Experiment Site for Lightning Research and Testing" in Conghua, Guangdong province since 2006. The detailed introduction about the experiment can be found from the research of Zhang et al. [19]. The currents were measured by a coaxial shunt with a resistance of 1 mΩ and transferred to digital signal by an isolated digitizer, and then transmitted to a remote record system through optical fiber. In order to get a completed record of the large and small currents of triggered lightning, two different measurement ranges for isolated digitizer have been set. The detailed information about current measurement system can be found in the research of Zheng et al. [12]. After 2011, we further upgraded old current measurement system. As shown in Fig. 1, the isolated digitizer (6600) and GEN5i transient recorder have been used instead of the isobe 5600 digitizer (or called transmitter) and isobe 5600 transient recorder. New measurement system supports precise acquisition of the current waveforms in different magnitudes with the largest sample rate of 100 MS/s. In the paper, 62 RSs, 236 M components and 41 CCs involved in 17 multi-stroke triggered lightnings are analyzed. The typical waveforms of RS, M component and CC have been shown in Fig. 2.

3. Results

3.1. Current characteristics of return stroke, M component and CC

The parameters of RSs analyzed in this study include peak current (PI), duration, rise time ($t_{10-90\%}$), half-peak width (HPW), charge transfer within 1 ms after the beginning of the RS (Q1ms), and the action integral within 1 ms after the beginning of the