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Simultaneous optical and electrical observations of "chaotic" leaders preceding subsequent return strokes

Yang Zhang [a,b,c,*], YiJun Zhang [a,b,c], Chan Li [a,b,d], WeiTao Lu [a,b,c], Dong Zheng [a,b,c]

[a] State Key Laboratory of Severe Weather, Chinese Academy of Meteorological Sciences, Beijing 100081, China
[b] Laboratory of Lightning Physics and Protection Engineering, Chinese Academy of meteorological Sciences, Beijing 100081, China
[c] Guangzhou Field Experiment Site for Lightning Research and Testing, Conghua, Guangzhou 510925, China
[d] Meteorological Information Center in Hebei Province, Shijiazhuang 050021, China

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ABSTRACT

Based on the synchronous optical-electrical data of natural cloud-to-ground flashes observed from Guangdong Comprehensive Observation Experiment on Lightning Discharge (GCOELD), "chaotic" leaders have been investigated. 44% of subsequent return strokes are preceded by "chaotic" leaders which are characterized by chaotic pulses during the subsequent leader process. Almost all of "chaotic" leaders are accompanied by chaotic E-change and obvious optical radiation. Two types of "chaotic" leaders (type I and type II) with the percentages of 65% and 35% have been identified. Type I exhibits continuously chaotic fast E-change pulses prior to subsequent return stroke, however, type II begins with large chaotic pulses in the fast E-change waveform and then some weak pulses occur in the following waveform preceding subsequent return stroke. The preceding inter-stroke intervals for type I and type II are 54.13 ms and 72.51 ms, respectively. The amplitude ratios of chaotic pulses to the following return stroke for the fast E-change signals of type I and type II are 0.17 and 0.41, and the corresponding ratios for the optical signals of type I and type II are 0.25 and 0.38, respectively. The durations of chaotic pulses for types I and II are 559.9 μs and 414.2 μs. Compared to type I, type II owns the characteristics with larger amplitude ratios of chaotic pulses to the following return stroke, which indicates that type II is associated with a stronger discharge process. It is possible that the characteristics of "chaotic" leaders are partly related to preceding inter-stroke intervals. Two cases with synchronous high-speed video images further depict the two "chaotic" leaders. The leader of type I propagates along one channel branch of previous return stroke to reach ground and the propagation channel is branched. As a comparison, the leader of type II propagates along one prior channel branch at first and then the channel dims accompanied by strong luminosity.

1. Introduction

Leader process, as an important discharge process of lightning, has drawn continuous attention (Campos et al., 2014; Jiang et al., 2013; Warner, 2012; Kong et al., 2008; Qie and Kong, 2007; Aleksandrov et al., 2005; Qie et al., 2002; Chen et al., 1999; Krider et al., 1977). The conventional leaders include stepped leader preceding first return stroke (RS), dart leader and dart-stepped leader preceding subsequent return stroke (Yoshida et al., 2012; Jordan et al., 1992; Orville and Idone, 1982). Dart leader is not usually branched but travels as continuously moving streamers to ground along the main channel formed by the first RS (Schonland, 1956). In addition to those conventional leaders, there is a somewhat controversial class of events usually known as "chaotic" leader (CL) (as shown in Fig. 1) which had been presented firstly by Weidman (1982). He found the irregular pulse trains before subsequent RSs, and termed these return strokes as "chaotic subsequent strokes" or subsequent strokes preceded by "chaotic" leaders. In general, "chaotic" leader has been used to refer to a relatively continuous sequence of irregular electric field pulses occurring within about 2 ms preceding a subsequent return stroke in natural lightning (Lan et al., 2011) or triggered lightning (Hill et al., 2012), but so far no consistent definition has been given.

The previous research on "chaotic" leaders was often focused on the waveform characteristics of electric field change (Bailey et al., 1988; Willett et al., 1990; Rakov and Uman, 1990a,b; Gomes et al., 2004). Although some characteristics of the chaotic pulses and "chaotic" leaders have been given, there is no clear revelation of intrinsic mechanism which causes chaotic pulses due to a lack of multi-parameter observation. For example, Bailey et al. (1988) reported on four events termed "chaotic subsequent strokes" with rapidly varying irregular pulses immediately prior to the onset of subsequent return stroke in the E-change waveforms. They found that "chaotic subsequent strokes" produced larger positive and negative peaks than those preceded by normal dart leaders or dart-stepped leaders. Rakov and Uman (1990b)

* Corresponding author at: Chinese Academy of Meteorological Sciences, No 46, ZhongGuanCun South Street, Haidian District, Beijing 100081, China.
E-mail address: zhangyang@cams.cma.gov.cn (Y. Zhang).

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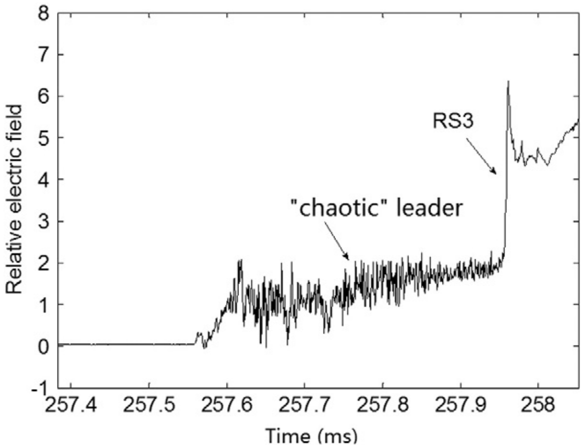

Fig. 1. Fast E-change waveform of "chaotic" leader (Zhou et al., 2014).

proposed that the chaotic pulses might be related to the electromagnetic interaction between the simultaneously propagating downward-moving, negatively charged leader channel and the upward-moving, positively charged connecting leader channel. Gomes et al. (2004) defined chaotic pulse trains (CPTs) as the pulses prior to subsequent return strokes, lasting for a few hundred microseconds, with pulse characteristic of erratic nature in the signal of electric field change. Furthermore, the significant difference between HF signatures of "chaotic" and "non-chaotic" leaders has been observed by Makela et al. (2007). They believed that "chaotic" leaders are genuine physical phenomena and the normal leaders in many cases do not emit HF radiation above the noise threshold. In addition, Davis (1999) found that "chaotic" leaders tend to occur after relatively short inter-stroke intervals and to be associated with relatively high average propagation speeds. The average speeds of two "chaotic" leader events calculated from TOA location results are 3.2×10^7 m/s and 5.0×10^7 m/s, respectively. Lan et al. (2011) also showed a VHF location result of a leader accompanied by chaotic pulses and interpreted chaotic pulse trains (CPTs) as a kind of pulse activity produced by the dart phase of subsequent leader. But it is difficult to show a very detailed structure of leader channel by VHF location results. Advances in high-speed video have allowed a better view of "chaotic" leaders. Hill et al. (2012) investigated the "chaotic" leader in triggered lightning and regarded it as another form of continuous dart leader. But the chaotic E-change signatures in the analyzed leaders only occurred in the final 10 to 12 μs prior to subsequent return stroke. Stolzenburg et al. (2014) studied some branched dart leaders (BDL) by analyzing the synchronous data of E-change and high-speed video. They found that the E-change waveforms for all the BDL cases exhibit an erratic characteristic for at least part of the leader duration. Up to now, although there is some research on chaotic pulses and "chaotic" leaders, the research is still not adequately detailed and the physical mechanism of chaotic behavior remains a controversial topic.

In the work, the classification, occurrence regularity and waveform characteristics of "chaotic" leaders have been analyzed in detail by the simultaneous data of optical and electrical signals which have been recorded during the comprehensive observation experiment on lightning discharge in Guangdong province. Two cases with synchronous high-speed video images further depict the "chaotic" leaders.

2. Experiment and data

The optical-electrical data analyzed in the paper was 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 (latitude 23.34 N and longitude 113.36 E) since

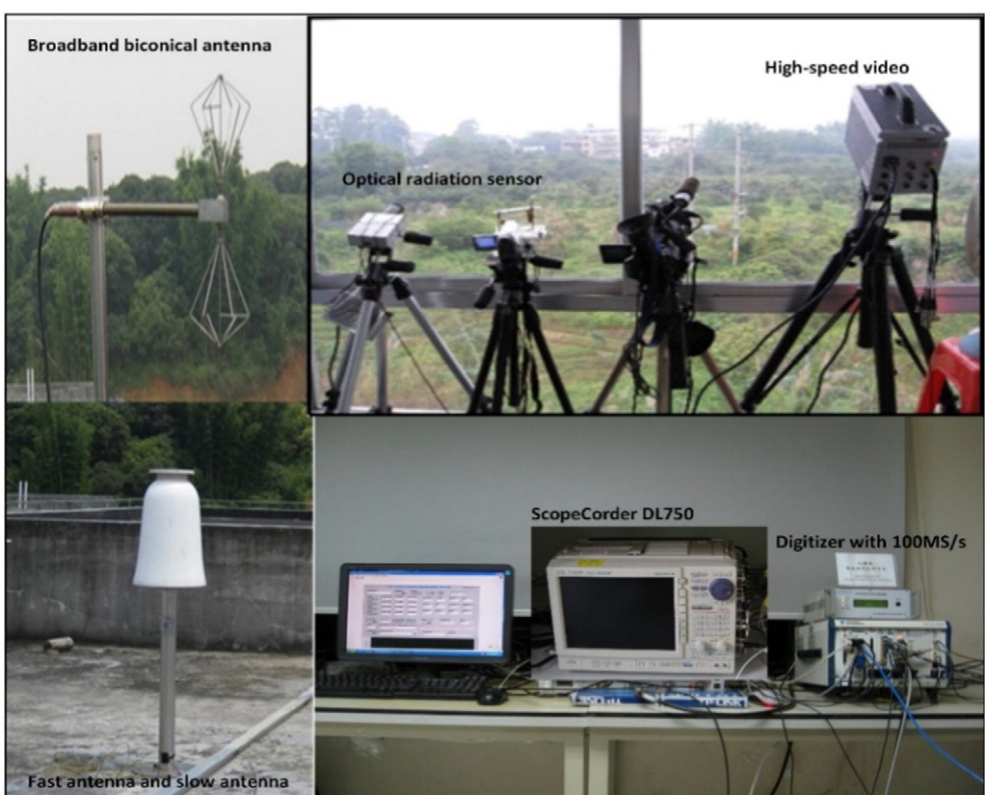

Fig. 2. Comprehensive observation platform during Guangdong Comprehensive Observation Experiment on Lightning Discharge (GCOELD).