Study on occurrence regularity of CPT Discharge Event in Negative Cloud-to-Ground Lightning

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ABSTRACT: The occurrence regularity of Chaotic pulse trains (CPT) in negative cloud to ground (CG) flashes has been analyzed in detail by using the data of electric field change in six thunderstorms observed during the comprehensive observation experiment on lightning discharge in Guangdong in 2012. The results show that CPT event is a prevalent phenomenon throughout negative CG lightning discharge process. As a statistical result, 243 times of CPT appear out of 323 negative CG flashes. It may occur after the last return stroke (defined as CPT-a), before the first return stroke of a negative CG (defined as CPT-b), as well as between the return strokes (including CPT-c and CPT-i). CPT-c is followed by the subsequent strokes, and CPT-i occurs between return strokes in a certain interval. 66.7% of the total subsequent strokes are accompanied by CPT-i and CPT-c. 11.5% of lightning flashes involved CPT-a and most of CPT-a occur in the lightning with 1-3 return strokes. CPT-b events are extremely rare in the whole discharge process of negative CG flash, and only 2 cases are found. In addition, it can be found that the most of CPT-i and CPT-a superimpose on the K change with a percentage of 69.7%, which confirm the speculation about the occurrence of CPT in K change. Further, based on the electrical field waveforms and the located results of the VHF radiation sources, case study of CPT-i and CPT-c show that the propagation speeds of CPT-c and CPT-i are similar to that of the speed of dart leaders. The occurrence of the CPT-c and CPT-i in the two cases is associated with the development of dart leaders.

INTRODUCTION

In recent years, Chaotic pulse trains (CPT) with pulse characteristics of erratic nature in initial polarity, pulse width, pulse separation and pulse amplitude, are observed in lightning flashes, especially prior to subsequent strokes [Davis, 1999], as shown in Figure 1.

Some researches on occurrence regularity of CPT have done. Bailey et al.[1988] and Rakov et al.[1990] have found that CPT is accompanied by larger peak electric field of stroke more than dart leader or dart-stepped leader. Gomes et al. [2004] found that 26% of the total subsequent strokes recorded were preceded by CPT, but Makela et al. [2007] and Lan et al. [2011] found higher proportion, whose percentage is 31%and 46.5% respectively. Lan et al.[2011] also found that with the increase of the order of subsequent strokes, occurrence probability of CPT prior to subsequent strokes also will increase. In

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addition, some researchers [Rakov et al, 1992] have observed CPT accompanied by K changes, but there is no further in-depth research.

The previous research about CPT has mainly focused on that prior to subsequent strokes which often is called 'chaotic leader'. However, we have found that CPT can also appear at other locations in a discharge process of lightning, such as before the first return stroke and after the last return stroke. Up to now, the research on occurrence regularity of CPT is still not adequately detailed. In view of this, this article mainly analyses the occurrence regularity of CPT events in negative cloud-to-ground lightning discharge process.

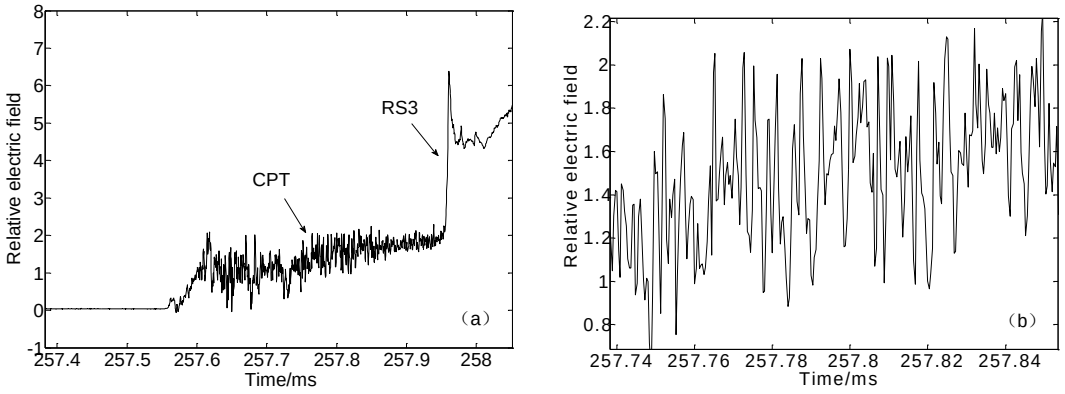

Figure1 A CPT and the succeeding subsequent stroke (a) and A part of CPT in an expanded scale (b)

DATA

The lightning discharges were observed in Guangzhou, in the periods of May to August, 2012. The measuring station is situated at Conghua of Guangdong province (latitude 23.34N and longitude 113.36E). The electric field waveforms were measured by fast antenna and slow antenna in 6 storms. The measuring system is composed of circular plate antenna, integrating circuit, data collector and GPS module. The time constants of fast antenna and slow antenna are 2 ms and 6 s, respectively. As a result, the frequency bandwidth of fast antenna is about 80 Hz to 2 MHz, which is enough for reproduction of microsecond-scale pulses. The frequency bandwidth of slow antenna is about 0.02 Hz to 2 MHz. The transient recorder consisted of a 16-bit data acquisition card with 32-Megabyte memory and an industrial personal computer. The sampling rate was 2.5MHz and the transient recorder was operated in a pre-trigger mode. The pre-trigger delay time was set 209 ms. The electric field waveforms of lightning flashes were continuously recorded for 800 ms. Table 1 gives the detail information of the lightning in 6 thunderstorms. In order to get the propagation information of CPT, the data of broadband interferometer with a bandwidth of 30-300MHz has been used. The detail configuration of broadband interferometer observation can be show in the work of Qiu et al.[2009].

ANALYSIS AND RESULTS

Occurrence location of CPT in the waveform of electric field change

The statistical results in figure 2 show that 75.2% of negative CG lightning is accompanied by CPT discharge events, and CPTs can occur before the first return stroke, between strokes and after the last

return stroke. According to the relative position of CPT events, CPTs could be divided into 4 types, as shown in Figure 2, CPT before the first return strokes (abbreviation as CPT-b), CPT followed by subsequent strokes (abbreviation as CPT-c), CPT occurring between return strokes in a certain interval (abbreviation as CPT-i), CPT after the last return strokes (abbreviation as CPT-a). CPT-b events are extremely rare in the whole discharge process of negative CG flash, and only 2 cases are found, 66.7% of the total subsequent strokes are accompanied by CPT-i and CPT-c, and most of CPT-a occur in the lightning with 1-3 return strokes and the probability of total occurrence is 11.5% of the total last return strokes.

Table 1 information of NCG with CPT in 6 different thunderstorms

Time	No. of NCG	No. of NCG with CPT	Percentage/%
20120613	39	23	59.0
20120623-1	81	68	84.0
20120623-2	75	59	78.7
20120706	26	21	80.8
20120812	91	63	69.2
20120904	11	9	81.8
Total	323	243	75.2

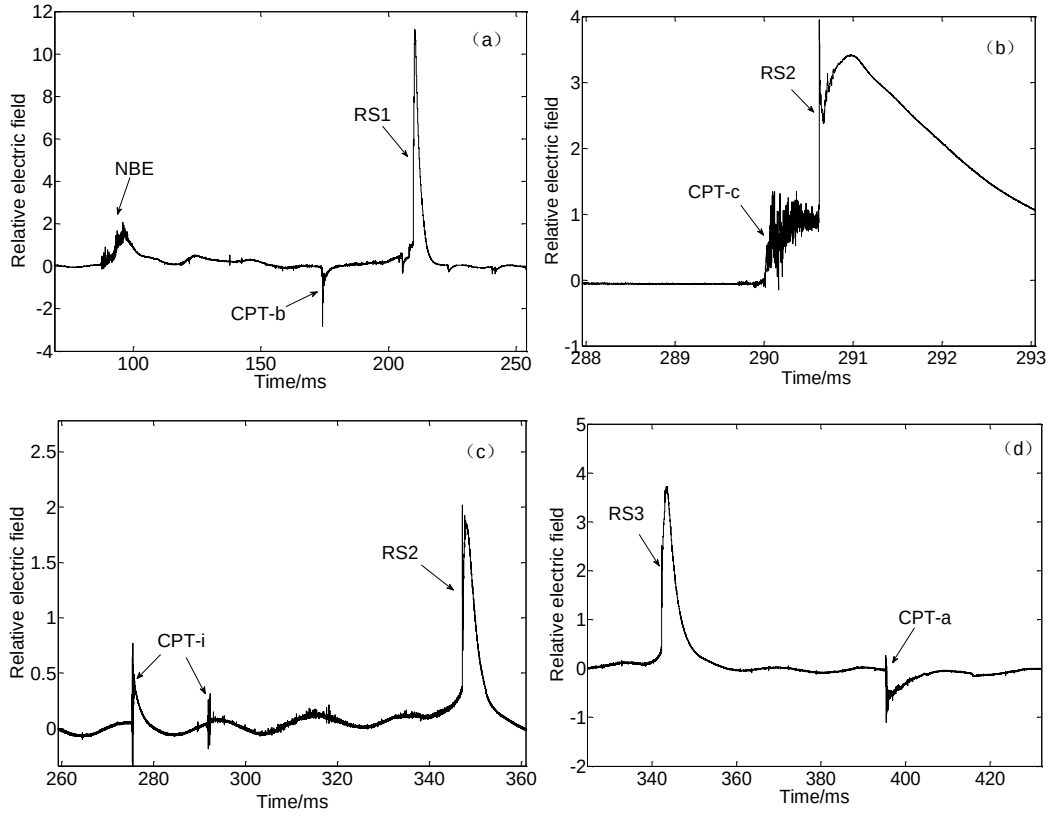

Figure 2. Four types of CPTs in negative CG lightning, CPT-b(a), CPT-c (b), CPT-I (c), CPT-a (d)

Relationship between CPT and K Change

K change with the same polarity of RS electric field changes is defined as negative K pulse, and opposite K change is defined as positive K pulse in this paper. According to our statistics, 69.3% of CPT-i and CPT-a is accompanied by K change. . The most of CPT-i and CPT-a superimpose on the rising stage of negative or positive polarity K change with a duration of a few milliseconds. Moreover, a few of CPT-a superimpose on the dipolar K change. These CPT events also occur on K changes of discharge events in cloud flash. Figure 3 shows the CPTs superimposing on K change. Our results confirm the speculation of Lan et al.[2011]. One cannot rule out the probability that CPTs may occur in the similar discharge process (such as the initiation process of K change and M components) in intense cloud flashes or in ground flashes without any association with return strokes.

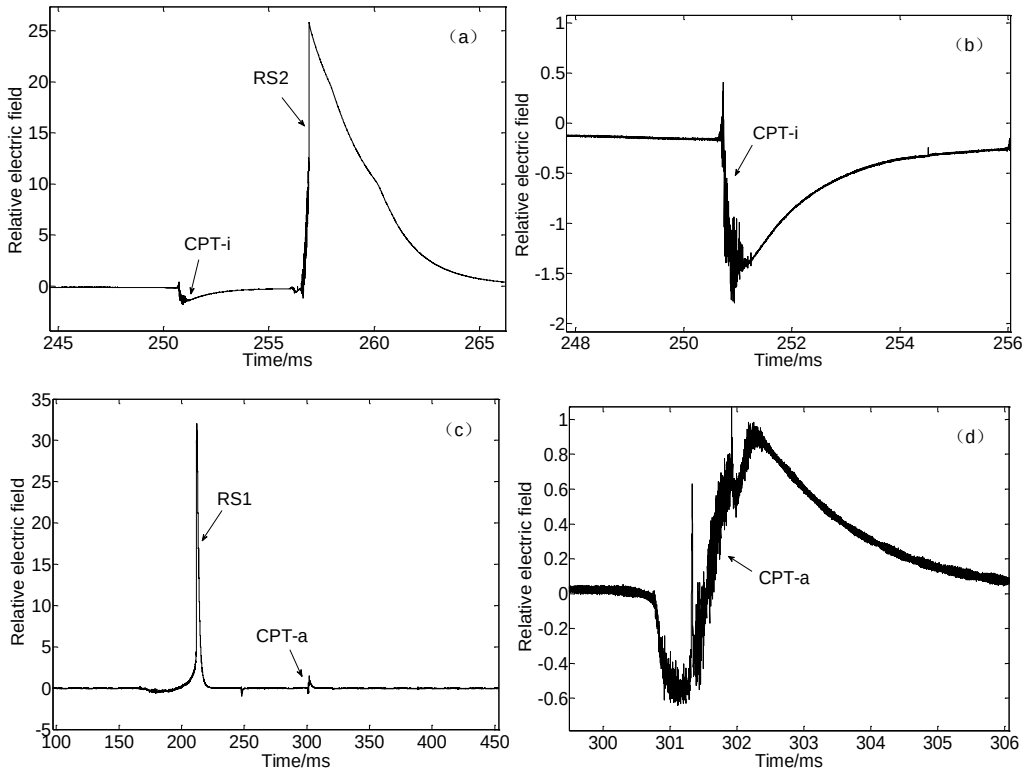

Figure 3. A CPT-i superimpose on rising edge of positive K change (a) and the corresponding change in an expanded scale(b); A CPT-a superimpose on dipolar K change (c) and the corrsponding change in an expanded scale(d)

Propagation Process of CPT

Based on the electrical field waveforms and the location results of the radiation sources, the propagation process of CPT are shown in Figure 4. From Figure 4(a), it can be seen that a CPT-i, lasting for approximately 380 μs, occurs before the first subsequent return stroke with an interval of 3.12 ms to RS2. VHF signals also have been detected by the broadband interferometer and the radiation location can be gotten. The propagating speed of downward channel from 6.1 to 3.2 km is about 2.4×10^7 m/s, which means the leader (associated with CPT) should have followed the pre-existing channel. For some unknown reasons, the leader in Figure 4(a) ceases at 3.2 km before reaching the ground and the return

stroke occurs after 3 ms. One possible explanation is that the subsequent RS would be preceded by a attempted dart-stepped leader with the CPT being associated with the dart phase, and the stepped part which develop downward to ground being the final 3 ms interval. However, since fast E field waveform depicts a smooth profile before the RS, we should leave it open whether the CPT is simply an attempted leader that died out because of some unknown reasons before reaching the ground [Rhodes et al, 1994] or the dart phase of a dart-stepped leader before return stroke.

Figure 4(b) shows a representative CPT-c, which lasts for 420 μs and immediately precedes the second subsequent stroke pulse (RS3). The speed of the downward leader channel is 2.0×10^7 m/s from 4.15 to 1.73 km height, which is the same order as that of the CPT in Figure 4(a). Thus, the CPT immediately preceding RS3 has followed a well-established channel to the ground. We assume the dart phase of the leader of RS3 has followed a pre-existing channel.

In the two cases, the propagation speeds of the leaders associated with the CPTs are similar to that of dart leaders. Thus, the occurrence of the CPTs is associated with the development of dart phase leaders whether it is immediately preceding the return stroke or not.

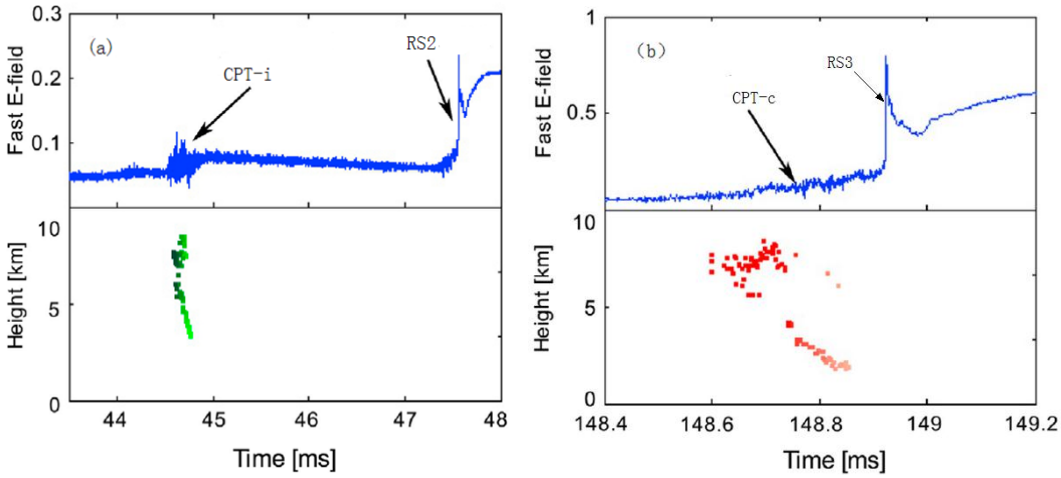

Figure 4. Fast antenna waveform and height-time plots for the leaders and strokes

(a) the second return stroke , (b) the third return stroke

CONCLUSIONS

The occurrence regularity of CPT in negative cloud to ground (CG) flashes has been analyzed in detail using the data of electric field change in six thunderstorms which has been observed during the comprehensive observation experiment on lightning discharge in Guangdong in 2012. The results show that:

(1) CPT event is a prevalent phenomenon throughout negative CG lightning discharge process. As a statistical result, 243 of CPT appear out of 323 negative CG flashes. It may occur after the last return stroke (CPT-a), before the first return stroke of a negative CG (CPT-b), as well as between the return strokes (including CPT-c and CPT-i). Thereinto, CPT-c is followed by subsequent strokes, and CPT-i occurs between return strokes in a certain interval. 66.7% of the total subsequent strokes are accompanied by CPT-i and CPT-c. 11.5% lightning discharges involved

CPT-a and most of them occur in the lightning with 1-3 return strokes. CPT-b events are extremely rare in the whole discharge process of negative CG flash, and only 2 cases are found.

(2) We aslo confirm the speculation of Lan et al.[2011] about the occurrence of CPT in K change.The most of CPT-i, CPT-a superimpose on the rising stage of negative or positive polarity K change, and the percentage is 69.3%. Duration of K change is about a few milliseconds. Moreover, a few of CPT-as superimpose on dipolar K change.

(3) Based on the electrical field waveforms and the located results of the radiation sources, case study of CPT-i and CPT-c show that the propagation speeds are similar to that of the dart leaders. The occurrence of the CPT-c and CPT-i in the two cases is associated with the development of dart phase of a leader preceding subsequent return stroke.

ACKNOWLEDGMENTS

Financial assistance is given by National Natural Science Foundation of China (Grant No. 41205002, 41030960), Basic Research Fund of Chinese Academy of Meteorlogical Science (Grant No.2012Y006) and Development Special Fund for Research Institutes of the Ministry of Science and Technology (2011EG137226) .

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