Atmospheric Research 161–162 (2015) 52–56

Contents lists available at ScienceDirect

Atmospheric Research

journal homepage: www.elsevier.com/locate/atmos

Preliminary breakdown, following lightning discharge processes and lower positive charge region

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ARTICLE INFO

Article history:
Received 29 August 2014
Received in revised form 23 March 2015
Accepted 26 March 2015
Available online 2 April 2015

Keywords:
Lightning discharge
Preliminary breakdown
Detectable
Type
Lower positive charge region

ABSTRACT

Bipolar pulse trains in wideband electric field records are often attributed to preliminary breakdown (PB) processes (Nag and Rakov, 2009). Using electric field waveforms of lightning discharges observed in Beijing and Guangzhou, the detectable PB pulses and the following discharges are analyzed, and the role of lower positive charge region (LPCR) is investigated. Furthermore, a conceptual discharge model is tested. The detailed results are as follows. (1) The percentages of detectable PB pulses are just as a function of latitude in large range of latitude to a certain extent. But the percentages are similar in a small range of latitude. (2) Four discharge types have been identified. Type I, type II, and type III exhibit PB pulses followed by inverted intracloud (IC) discharge, hybrid flash (an IC discharge followed by a negative return stroke (RS)), and leader-RS, respectively. Type IV only exhibits a leader-RS waveform without detectable PB pulses. It is believed that the charge structures of four discharges are characterized with large LPCR, modest LPCR, small LPCR and little LPCR, respectively. (3) The discharges of type IV are about 65.4% and 63.3% in Beijing and Guangzhou. And the percentages of other discharge types are obviously different. There are higher percentages for type I and type II in Beijing, which may be attributed to larger scale of LPCR. (4) The values of pulse interval (T_{pi}) rank in increasing order for type I, type II and type III. Compared with type III, type II exhibits longer pulse-return stroke interval ($T_{p\text{-}ri}$). As for type II, obvious larger amplitude ratio between the maximum peak of PB pulse train and the peak of the first RS ($R_{p\text{-}rr}$) is found in Beijing. It is speculated that the parameters of different discharge types are related to the scale of LPCR. The analysis results are interpreted by a conceptual discharge model and the rationality of the model is also verified by the results to a certain extent.

1. Introduction

Preliminary breakdown in a lightning discharge is a precursor of both IC and CG flashes. Bipolar pulse trains typically occurring a few tens of milliseconds (sometimes considerably less) prior to the first return-stroke pulse and having overall duration of a few milliseconds can be found in wideband electric field records of the initial process due to the discharge that takes place inside the cloud between oppositely charged regions (Rakov and Uman, 2003). Bipolar pulse as important signals of preliminary breakdown process, were usually used in many research (Zhang et al., 2013). In order to simplify the depiction, we term these bipolar pulses preliminary breakdown (PB) pulses.

PB pulses has been observed and researched by many researchers (Zhang et al., 2013; Gomes et al., 1998; Clarence and Malan, 1957; Nag and Rakov, 2008; Schulz and Diendorfer, 2006; Ogawa, 1993; Makela et al., 2008). The detectability depends on the intensity of PB pulses to a certain extent. Some researchers showed that the intensity of PB pulses can be affected by latitude. For example, the ratios of the amplitude of PB pulses and the corresponding first RS in Sweden and in Sri Lanka were analyzed and compared (Gomes et al., 1998; Cooray and Jayaratne, 2000). They suggested that the reason for this different ratio is the weaker positive charge pocket in tropical thunderclouds compared to those observed in higher latitudes. But, the intensity of PB pulses can also be affected by other factors such as storm type (Baharudin et al., 2012; Clarence and Malan, 1957), storm stage and the geometry of channels (Rakov and Uman, 2003). More data are needed to get further conclusions.

As reviewed in Williams (1989), thunderstorms commonly have a tripole charge structure consisting of a dominant negative charge region, upper positive charge region, and an LPCR. LPCR with large magnitude and extensive dimension in the lower part of thunderstorms in Gansu province (about 2 km above sea level), China, has also been found by Shao and Liu (1987) and Liu et al. (1989). It can be affected by the latitude of lightning discharge (Nag and Rakov, 2009) and the altitude of the observation region (Qie et al., 2009). LPCR is essential for the initiation of cloud-to-ground (CG) lightning (Clarence and Malan,

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http://dx.doi.org/10.1016/j.atmosres.2015.03.017

1957). The presence of LPCR beneath the main negative charge is thought to locally enhance the electric field, which provides the impetus for the negative discharge to ground (Jacobson and Krider, 1976). The model simulations by Mansell et al. (2002) also support this hypothesis that negative CG flashes occur only when LPCR exists below main negative charge region.

LPCR plays a key role in the formation of PB pulses and the following discharges (Liu et al., 1987; Cui et al., 2009). It can enhance the electric field at the bottom of the negative charge region and thereby facilitate the launching of a negatively-charged leader toward ground. When a negatively-charged channel extends downward from the main negative charge region and encounters LPCR (Nag and Rakov, 2009), PB pulses can be generated. LPCR with different scale may result in different discharge types. For example, Qie et al. (2005a) observed that negative CG flashes could be triggered frequently by a weak LPCR in the late stage of the Qinghai–Tibet Plateau storm. But, the excessive LPCR may prevent the occurrence of negative cloud-to-ground discharges and facilitate intracloud discharges between the main negative and lower positive charge regions (Qie et al., 2005a,b, 2009).

The earliest and simplest description of the preliminary breakdown processes is the so-called BIL model defined by Clarence and Malan for South African lightning (Clarence and Malan, 1957). In the BIL model, lightning is initiated by the preliminary breakdown process, followed by a quiet intermediate stage with little associated radiation preceding return stroke. However, due to the difference in LPCR scale, the discharge processes from preliminary breakdown to return stroke are not always the simple BIL model. Up to now, although some research has been done, it is not enough to understand the discharge process completely.

In order to further understand the discharge process from the preliminary breakdown to return stroke and test a conceptual discharge model, we will research PB pulses and the following discharges by analyzing the waveforms of electric field from summer thunderstorms in Beijing and Guangzhou. Furthermore, the role of LPCR is also investigated. Considering that the polarities for most of PB pulses are the same as that of negative RS in negative CG flashes, the paper mainly aims to the discharges accompanied by the same polarity PB pulse, the following discharge and negative RS.

2. Experiment

The data used in the analysis are the waveforms of electric field change recorded during summer season. The total records are 269 and 441 in Beijing and Guangzhou, respectively. The measurements were conducted in two sites with different latitudes. One measuring station is situated. One measurement was conducted during several thunderstorms from May to August, 2005 at the Chinese Academy of Meteorological Sciences (latitude 39.94 N and longitude 116.32 E) in Beijing. Another measurement was conducted from May to August, 2009 at Conghua of Guangzhou province (latitude 23.34 N and longitude 113.36 E). The discharges, located in the range of 0–50 km by the lightning location system (LLS) of Guangdong power grid, are used in the paper in order to minimize the effect of detection efficiency. The detailed description about LLS can be seen in the paper (Chen et al., 2012).

The electric field change signals were detected simultaneously by two measuring systems which were often called “fast antenna” and “slow antenna”. The measuring range is ± 10 V for “fast antenna” and “slow antenna”, and the average noise level is about ± 3 mV. Therefore, we can observe both PB pulse and return stroke. Because the same measuring system was used in Beijing and Guangzhou, the detectability in Beijing is the same as that in Guangzhou. Therefore, the comparison results are affected insignificantly by the detectability.

The antennas were installed on the roof of a fourteen-story building at the Chinese Academy of Meteorological Sciences in 2005 and on the roof of a three-story building at the Weather Bureau of Conghua in 2009. Fast antenna was used to measure fast electric field change signal. Slow antenna was used to measure slow electric field change signal. The recording system consists of a 16-bit data acquisition card with a 32-megabyte memory and an industrial personal computer. 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 bipolar pulses. The frequency bandwidth of slow antenna is about 0.02 Hz to 2 MHz. The sampling period was 400 ns and the transient recorder was operated in the pre-trigger mode. The pre-trigger delay time was set 209 ms in order to view the onset of the preliminary breakdown pulses. The discharge waveforms, including PB pulses, intracloud (IC) discharge, cloud-to-ground (CG) discharge, leader and return stroke (RS), were continuously recorded for 800 ms from a double trigger. The detailed description of PB pulses can be seen from the research of Zhang et al. (2013).

3. Results

3.1. Detectability of PB pulses

According to the statistical results in Table 1, 78 flashes including PB pulses (the term “PB flashes” used in the following description) are found out of 254 negative CG flashes in Beijing. The percentage of PB flashes is about 30.7%. The corresponding percentage in Guangzhou is about 34.8%. Other results (Gomes et al., 1998; Clarence and Malan, 1957; Nag and Rakov, 2008; Schulz and Diendorfer, 2006; Ogawa, 1993; Makela et al., 2008) are also listed in Table 1.

It can be seen that the percentages of detectable PB pulses are just as a function of latitude in large range of latitude to a certain extent. PB pulses in the majority of cloud-to-ground lightning can be detected in Sweden, Finland, and Austria where the latitudes are >48°. However, the percentages in the areas with less than 40° latitude, are about 20% in Florida and Sri Lanka, 16 to 37% in South Africa, 36% in Japan and 30.7% to 34.8% in China. The difference can be interpreted as being due to the more frequent presence of a significant LPCR (caused by the more intense corona, Chauzy and Soula, 1999) at higher latitudes than at relatively low ones (Nag and Rakov, 2009).

Although some researchers believe that PB pulses may be weaker in the area with lower latitude, the results in Beijing, Guangzhou, South Africa (Clarence and Malan, 1957) and Kyoto (Ogawa, 1993) show that there is similar detectability in the small range of latitude. In view of the fact with different thunderstorm characteristics in Beijing and Guangzhou (Zhang et al., 1997), we believe that other factors also play a certain role in detectability of PB pulses, which is similar with the viewpoint of Baharudin et al. (2012).

3.2. Discharge types from PB pulses to return stroke

Considering the differences in discharge processes after PB pulses which own the same polarity as negative RS, four types of lightning discharges have been identified from the electric field change waveforms in Beijing and Guangzhou, which is similar to the results of Nag and

Table 1
Percentages of PB flashes.

Latitude	Percentage	Flash number	PB flashes	Site
7	19%			Sri Lanka (Gomes et al., 1998)
23	34.8%	427	149	Guangzhou
26	16–37%	407		South Africa (Clarence and Malan, 1957)
30	18%			Florida (Nag and Rakov, 2008)
35	36%	89	32	Kyoto (Ogawa, 1993)
39	30.7%	254	78	Beijing
48	80%	186		Austria (Schulz and Diendorfer, 2006)
60	100%	41		Sweden (Gomes et al., 1998)
61	90%			Finland (Makela et al., 2008)