The lower positive charge center and its effect on lightning discharges on the Tibetan Plateau

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[1] Electrical characteristics of thunderstorms on the central Tibetan Plateau at an altitude of 4508 m have been studied. The evolution of surface electric (E) field and the E field changes produced by lightning flashes under a representative thunderstorm revealed a tripole charge structure with a larger-than-usual lower positive charge center (LPCC). The storms appear to begin with the lower dipole of a normal tripole structure, rather than with the upper dipole followed by the development of a weaker lower positive charge. The flash rate is quite low and the average value is usually 1 fl/min. The IC flashes were usually polarity-inverted and occurred in the lower dipole. The large LPCC did not cause positive CG flashes to occur during the whole storm lifetime, and only negative CG flashes were observed in the late stage of the storm.
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1. Introduction

[2] Many measurements over 60 years since *Simpson and Scrase*'s [1937] investigation have shown that the tripole structure of thunderstorm is a more accurate representation than the traditional positive dipole [e.g., *Marshall and Winn*, 1982; *Marshall and Stolzenburg*, 1998; *Bateman et al.*, 1999; *Mo et al.*, 2002]. *Clarence and Malan* [1957] suggested that the lower positive charge center (LPCC) is essential for the initiation of cloud-to-ground (CG) lightning. *Williams* [1989] discussed the inaccuracy which might have resulted in some earlier studies if the participation of LPCC is not considered in the analysis of lightning charge transfer. He further suggested to associate intracloud (IC) lightning with convection and the upper positive dipole and CG lightning with sedimentation and the lower negative dipole. *Wang et al.* [1987] and *Liu et al.* [1989] found that a large lower positive charge region usually exists at the bottom of the storms, and nearly all IC discharges appear to occur in the lower portion of the cloud in Chinese Inland Plateau at an average altitude of about 1600 m asl. *Pawar and Kamra* [2004] found that the LPCC plays a dominant role in initiating IC or CG lightning discharges in a tropical thundercloud from the surface measurements of electric (E) field and Maxwell current. The recent observation with Lightning Mapping Array (LMA) unveiled the polarity-inverted charge structure in the storm accompanied by inverted IC discharges [e.g., *Krehbiel et al.*, 2003; *Rust and MacGorman*, 2002].

[3] The goal of the present paper is, first, to present some specific electrical features of thunderstorm observed on Tibetan plateau at an altitude of about 4508 m, then to discuss the relationship between flash activity and the LPCC.

2. Observation Site and Instruments

[4] The observation area is located in the central Tibetan Plateau (31°28′47″N, 92°03′39.8″E) at an altitude of 4508 m asl. During the observation, surface E field of thunderstorm and E field changes caused by the lightning discharges were measured by using field mill, slow antenna with a time constant of 6 s and fast antenna with a time constant of 2 ms, respectively. Both signals from slow and fast antenna were digitized at a sampling rate of 2.5 MHz.

[5] A short-baseline lightning VHF pulse location system with time of arrival (TOA) technique was employed. The band-pass of the system is larger than 100 MHz with a central frequency of 280 MHz, and the radiation signals from lightning discharges can be detected in a wide band. Four dipole antennae were installed at each corner of a square, and the base line between each pair of the four antennas was 10 m. The signals from each antenna were digitized by a LeCroy374L oscilloscope working at a segment pattern. The sampling rate for each channel was 2 GS/s. The development tendency of nearby lightning discharges was estimated in two dimensions based on the time difference between each pair of the antenna. The error, estimated by using an artificial radiation source, was 0.5° in azimuth around the bisector of each pair of antenna and larger than 3° in elevation [*Zhang et al.*, 2003].

3. Evolution of Surface E Field Under Thunderstorm

[6] Thunderstorms are common events in the region during the plateau monsoon season (Mid-June to Mid-September). Up to 5 thunderstorm processes in a thunderstorm day was once observed during the observation. Hail fall or graupel is usually observed on the Tibetan Plateau with a period of shorter than 10 min and the diameter of hailstone on the ground is less than 1 cm. The cloud base height (CBH) is generally about 1 km above ground, and the convective available potential energy (CAPE) is usually less than 500 J/kg. The flash rate is quite low, and the average value is usually about 1 fl/min.

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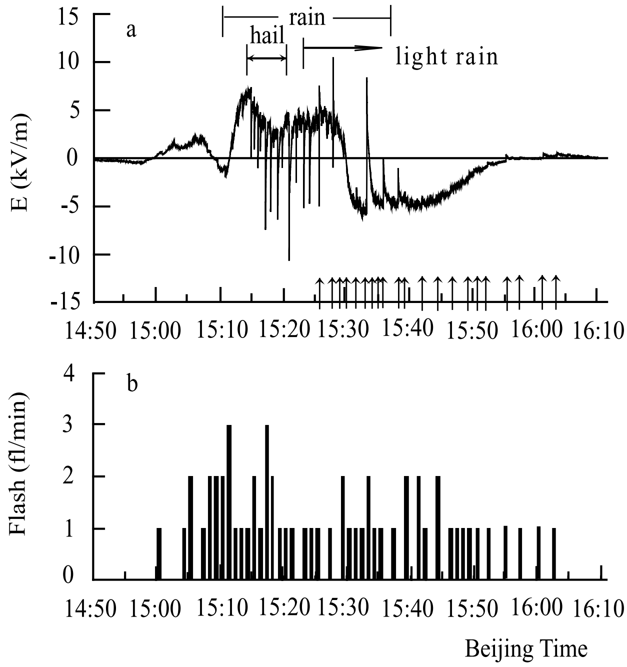

Figure 1. Evolution of (a) surface E field and (b) flash rate for a representative thunderstorm on Tibetan plateau. Positive E field corresponds to a positive charge overhead.

[7] An isolated convective storm developed southwest from the observatory in the afternoon of July 3, 2003. During this day, the CAPE was about 114 J/kg. The CBH was 1182 m. The pea-size hailstones or graupels were observed on the ground for about 6 min. These features are not much different from those of a typical thunderstorm in the region. Figure 1 shows the variation of E field and flash rate during the storm's lifetime. The downward-directed E field is defined as positive according to the "atmospheric electricity" convention, i.e., positive field corresponds to a positive charge overhead.

[8] At about 14:50 Beijing Time (BT), the surface E field shifted obviously to negative from positive of the fine weather, and then changed its polarity three times at 14:59, 15:09 and 15:11 during the initial stage. In the initial 21 min from 14:50 to 15:11, a few IC flashes (e.g., at 15:00:44, 15:04:19, 15:05:57, 15:07:01, etc.) caused very small E field changes. The distance of these lightning flashes from the observatory, as estimated from the time-to-thunder technique, were 3–4 km. Except for a brief negative excursion, E field at the ground was positive, strongly so after 15:15. The long duration of positive E field corresponds to a dominant positive charge overhead and vice versa. Pea-size hail-fall was observed at the observatory from 15:14 to 15:20, and the rain started to decrease obviously at about 15:23, as indicated in the figure. The lightning-produced E field changes before the first negative CG flash at 15:25:32 were all presumably caused by IC flashes. The fact that their E field changes were negative indicates that they discharged a lower dipole consisting of the LPCC and negative charge above it. The only exceptions are the flashes at 15:17:24 and 15:21:14, which caused small positive E change and should occur in the upper dipole. The first negative CG flash did not occur until just before E field started to go negative, indicating that the LPCC was weakening.

[9] The strong LPCC dominated the E field on the ground for about 14 min, and then the field traversed zero and shifted to negative at about 15:31. Negative CG flash dominated afterwards. A total of 21 negative CG flashes were detected, as marked by upward arrows in Figure 1, and only 6 weak IC flashes, possibly between the upper dipole, were detected in the meantime. The E field returned to positive again at about 15:56, and kept a weak positive value for about 15 min. Three CG flashes occurred during this later positive polarity stage, and their distance was estimated to be larger than 10 km.

[10] From the evolution of E field and the occurrence of both IC and CG flashes, it is deduced that the thunderstorm is in tripole charge structure, but the LPCC seems to be much larger than it is in the usual tripole storms. The lower dipole of the tripole is the main source of lightning flashes, and it seems to be more active than the upper dipole. The development of the upper dipole may have been delayed. The precipitation particles, including rain particles and

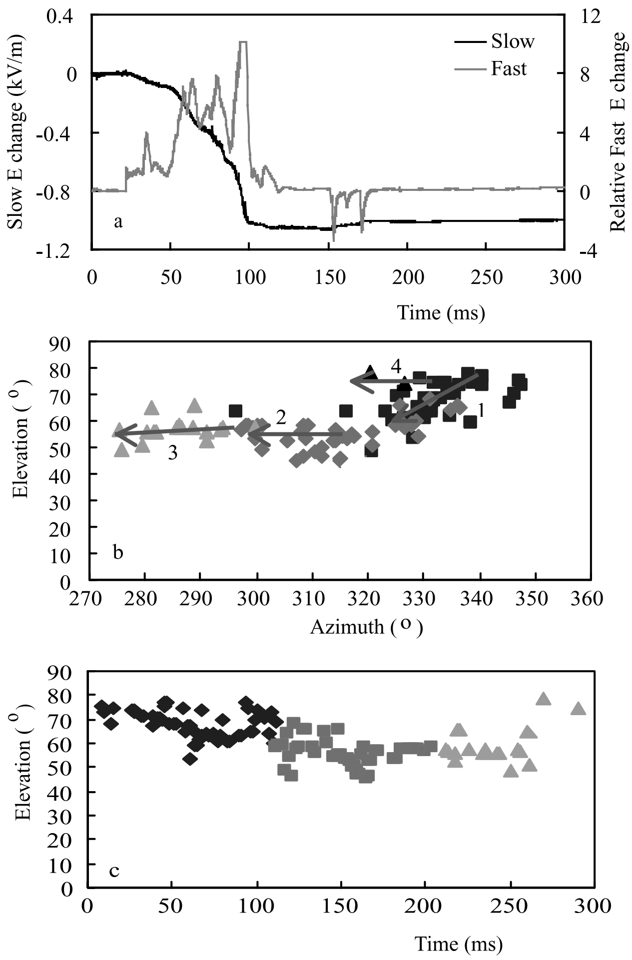

Figure 2. E field change and the VHF pulse locations by using TOA method for a typical IC flash. (a) Fast and slow E field changes. (b) Two-dimensional development of the discharge in azimuth and elevation. (c) Elevation evolution of the discharge with time.

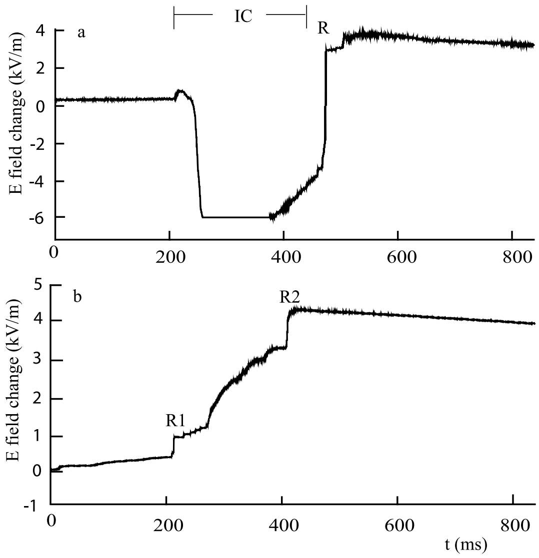

Figure 3. E field change produced by two negative CG flashes on the surface. (a) Negative CG flash during the end of mature stage of thunderstorm. (b) Negative CG flash during the late stage of thunderstorm.

graupels or hails, play a critical role in the development and maintenance of the LPCC. It is interesting to note that the much larger-than-usual LPCC did not cause positive CG flashes to occur, and in contrary no positive CG flash occurred during the whole storm lifetime, and only negative CG flashes were observed in the late stage of the storm.

4. Case Study on Lightning Flashes

4.1. Typical IC Flash

[11] Figure 2a shows the E field changes caused by a typical IC flash, which occurred in the mature stage of thunderstorm while the large LPCC dominated the surface E field. The total discharge lasted about 300 ms, and the distance from the observatory was estimated to be 1–2 km. Figures 2b and 2c show the VHF radiation pulse location in two kinds of display manner with Figure 2b depicting the 2-dimensional development in azimuth and elevation and Figure 2c elevation evolution with time. According to the VHF radiation pulse location results, the IC discharge initiated in an elevation of about 75°, and then developed to an elevation of about 45°. By referring the sign of the electric field changes, it is deduced that the initial decrease of elevation corresponds to a downward development of the discharge. It developed in several branches at the lower level, and only two radiation events were observed at higher level in the final stage of the discharge. The initiation region probably corresponds to the main negative charge region, and the lower region to the LPCC. Such inverted polarity IC discharge between LPCC and main negative charge region, in low flash rate thunderstorms, also have been reported by *Pawar and Kamra* [2002, 2004].

4.2. Two Negative CG Flashes

[12] The negative CG flashes started to occur in the end of the mature stage and dominated afterwards. Figures 3a and 3b show the slow antenna record of the first CG flash at 15:25:32 and another CG flash at 15:35:39, respectively. Both of the flashes are of negative polarity with the first having single return stroke and the second having 2 discrete return strokes and a continuing current in between. The horizontal distance of first CG flash from the observatory was 1–2 km. The discharge lasted about 500 ms. A long-duration IC discharge process just before the stepped leader-return stroke process caused saturation of slow antenna system. The IC discharge lasted about 265 ms. The stroke occurred at the end of the IC discharge. The negative polarity of the IC phase suggests that the IC process destroyed the lower dipole.

[13] The negative CG flash at 15:35:39 occurred in the late stage of the storm when the LPCC decreased greatly. Its distance from the observatory was about 4 km. The field changes just before the leader-return stroke process lasted about 196 ms. The long duration of the IC part of the CG flashes is supportive of the flash dissipating lower positive charge. The positive changes before the first return stroke indicates that the thunderstorm had moved beyond the reversal distance of the E field changes.

[14] Figure 4 shows the durations of IC discharges just before leader/return stroke process of their following negative CG flash. The first 2 CG flashes occurred in the late mature stage of the thunderstorm when surface E field was still positive, and the third and the fourth occurred nearby the zero E field. The flashes from 5 to 19 occurred in the negative E field stage, and the last 3 occurred in the late positive stage with a distance of greater than 10 km. The latter negative CG flashes had a short duration of IC phase, but still longer than the usual preliminary breakdown processes in the usual tripole storms. This probably indicates that the LPCC still existed and participated in the CG flashes.

5. Discussion and Conclusion

[15] One case of representative thunderstorms is studied in the paper. The evolution of surface E field and the lightning flashes revealed a tripole charge structure on the central Tibetan plateau, and the LPCC seems to be much larger than it is in the usual tripole storms. The storms appear to begin with the lower dipole of a normal tripole structure, rather than with the upper dipole followed by the development of a weaker lower positive charge, as in the most normal tripole storms. The lower graupel or hail seems to play a critical role in the development and maintenance of

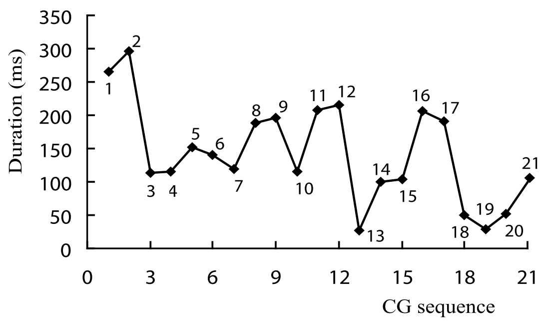

Figure 4. Duration of IC phase just before the return stroke for a sequence of 21 negative CG flashes in the thunderstorm.

the larger LPCC. According to the non-induction charging mechanism [*Takahashi*, 1978; *Jayaratne et al.*, 1983], the hail or graupel is positively charged in the region with a temperature higher than $-10°$ centigrade under the condition of liquid water content being about 1 g/m^3. Such dominant LPCC in the thunderstorms with low flash rate and low cloud base height have been observed very rarely. The thunderstorms observed during STEPS observations show the inverted-polarity charge structure with dominant LPCC [e.g., *Krehbiel et al.*, 2003; *Rust and MacGorman*, 2002]. However, considering the large difference in observed lightning activity, one can expect that the electrical charge structure and charging processes might be quite different in these two types of thunderstorms.

[16] The lower dipole was the main source of lightning flashes on the Tibetan plateau. Polarity-inverted IC flashes between the lower dipole dominated in the mature stage of the storm. It is interesting to note that the much larger-than-usual LPCC did not cause positive CG flashes to occur, and in contrary no positive CG flash occurred during the whole storm lifetime, and only negative CG flashes were observed, but in the late stage of the storm. This is probably caused by the large field strength between the large LPCC and the negative charge center above (both seem close to each other), and the discharge will happen mostly between them, and the initial streamer starts mostly from edge of the negative charge center [*Shao and Krehbiel*, 1996] will do further contribution too.

[17] The first negative CG flash occurred in the late mature stage of the storm when LPCC decreased, and it occurred at the end of an IC phase of the discharge, indicating the LPCC participated in the negative CG discharge. Earlier results [e.g., *Clarence and Malan*, 1957] indicated that the LPCC is conducive to the negative CG flash in the normal tripole storms because the local intense E field makes negative streamer going down. Our analysis shows that large LPCC prevents negative CG flashes from occurrence because abundant lower positive charges make an IC discharge with negative charge region possible. However, in the late stage of the storm, when the LPCC decreased greatly with the fall down of the most positive charge carriers (rain particles and graupels or hails) to the ground, negative CG flashes could be triggered frequently by the LPCC. This probably suggests that the weak LPCC is conducive to the occurrence of negative CG flash, while the larger LPCC conducive to the polarity-inverted IC flashes.

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