Characteristics of Upward Bipolar Lightning Derived from Simultaneous Recording of Electric Current and Electric Field Change

***Daohong Wang* and Nobuyuki Takagi**

Faculty of Engineering, Gifu University of Japan, Yanagido 1-1, Gifu 501-1193, Japan, wang@gifu-u.ac.jp, takagi-n@gifu-u.ac.jp

Abstract

This paper reports the characteristics of upward bipolar lightning derived from simultaneous recordings of electric current and electric field change of three upward bipolar lightning. These characteristics include (1) although the charge lowered to ground by the positive discharge contained in a bipolar lightning is comparable to that lowered by the negative discharge, the electric field change caused by the former is about one order in magnitude smaller than that of the latter; (2) both negative and positive discharges in three bipolar lightning discharges exhibited an electric-current-rise time of around 1 ms; (3) a series of regular pulses in electric field changes are observed about 1 ms before the later part reversal polarity discharge current begins to rise. Based on these observed characteristics, a possible scenario of bipolar lightning is proposed to understand how a bipolar lightning occurs.

1. Introduction

Cloud-to-ground (CG) lightning flashes are usually classified into four types according to the progression direction of their initial leaders and the polarity of the charges transferred to the ground [1]. Actually, this is not exactly correct since the four types of CG lightning do not include bipolar CG lightning which have been observed from the old days of lightning research [2]. A good review of bipolar lightning has been given by Rakov and Uman [3]. It is known that almost all bipolar lightning documented so far are upward lightning either initiated from high grounded structures or triggered by rocket wire techniques. Only recently, Krider et al. have reported two bipolar lightning which are downward lightning [4]. For these reasons, we think that CG lightning should be classified into six types: downward negative lightning, downward positive lightning, upward negative lightning, upward positive lightning, downward bipolar lightning and upward bipolar lightning. This paper reports simultaneous recordings of the electrical current and electric field change of three upward bipolar lightning. Based on the observed characteristics, this paper also offers a possible scenario of bipolar lightning. .

2. Observation

During the winters of 2005, 2006 and 2007, we have recorded the electric current, electric field change and video image of lightning which hit on a windmill or/and its lightning protection tower. This windmill and its lightning protection tower are located at Uchinada-chou, Ishikawa prefecture of Japan, with their heights being 100 m and 105 m, respectively. The windmill and the tower are separated at a distance of about 45 m, and are built on a small hill just adjoining the sea, the height of the hill being 40 m above sea level. The electric current is measured with Rogowski coils installed at the bottom of the windmill and the tower. The Rogowski coils used have a sensitivity of as less as a few amperes. The electric field changes are measured with so called slow antenna and fast antenna at several sites some hundred meters to a few kilometers away from the windmill [5]. The Electric current and electric change recordings are synchronized with GPS at a time accuracy of 2 microseconds.

3. Results

During winters of 2005, 2006 and 2007, we have obtained simultaneous recordings of electric current, electric field change for 11 lightning. For some of them, we also obtained their video images and high-speed images. All these lightning are upward lightning, although they can be sub-classified into two types according to whether these upward lightning are triggered by other nearby discharges or not. Three of the 11 lightning are of bipolar types. The simultaneous recording of the electric current, the electric field changes and the video images are shown in Figures 1a,

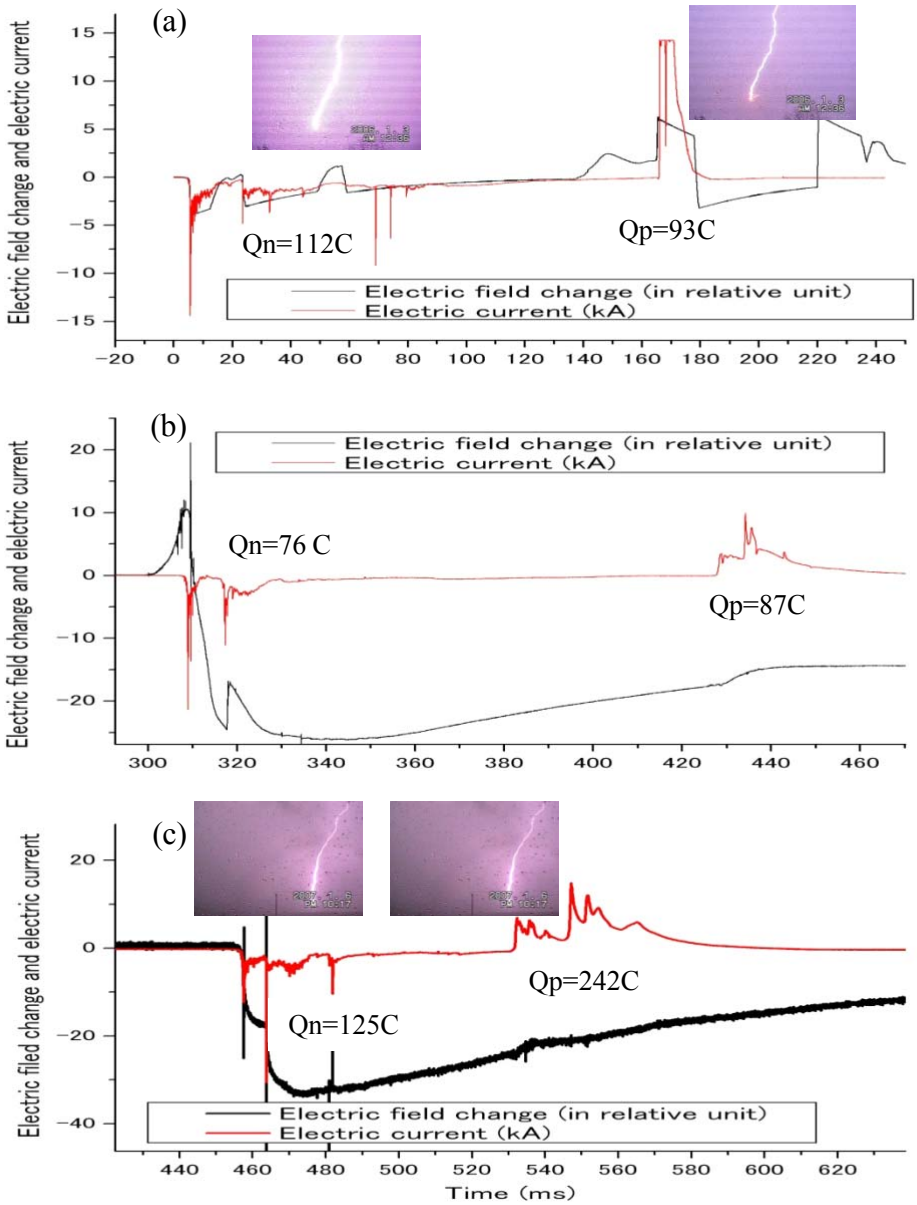

Figure 1 E-field change and electric current of three bipolar lightning which occurred at (a) 2006/01/03 0:36, (b) 2006/12/17 10:47, (c) 2007/01/06 22:17. In (a), E-change is obtained through fast antenna, (b) and (c) through slow antenna.

1b and 1c, respectively. As seen in these figures, the electric current waveforms of all three lightning consist of two parts which have opposite polarities. All three lightning start with a discharge lowering negative charge to ground (BNCG) and then this discharge is followed by a discharge transferring positive charge to ground (BPCG). By integrating the current waveforms, the values of the charge transferred to ground by BNCG and BPCG, respectively, are estimated, and they are also included in Fig. 1. Compared to the single polarity lightning recorded in this study, bipolar discharges tend to lower not only more negative charge but also more positive charge. From the video images shown in Fig.1a, 1c, both BNCG and BPCG follow exactly the same channel with a length at least several hundred meters. For the lightning shown in Fig.1a and 1c, their electric current and electric field change begin to change almost simultaneously, while for lightning shown in Fig.1b, its electric field change exhibits an opposite change prior to the electric current. The lightning shown in Fig.1b is the type of upward lightning which is triggered by another discharge which produces the electric field change prior to the electric current [5]. The lightning shown in Fig.1a and Fig.1c started without any such apparent triggering sources. The initial upward leaders of all three lightning are positive.

Three interesting features, as described in the following, have been obtained from these three lightning.

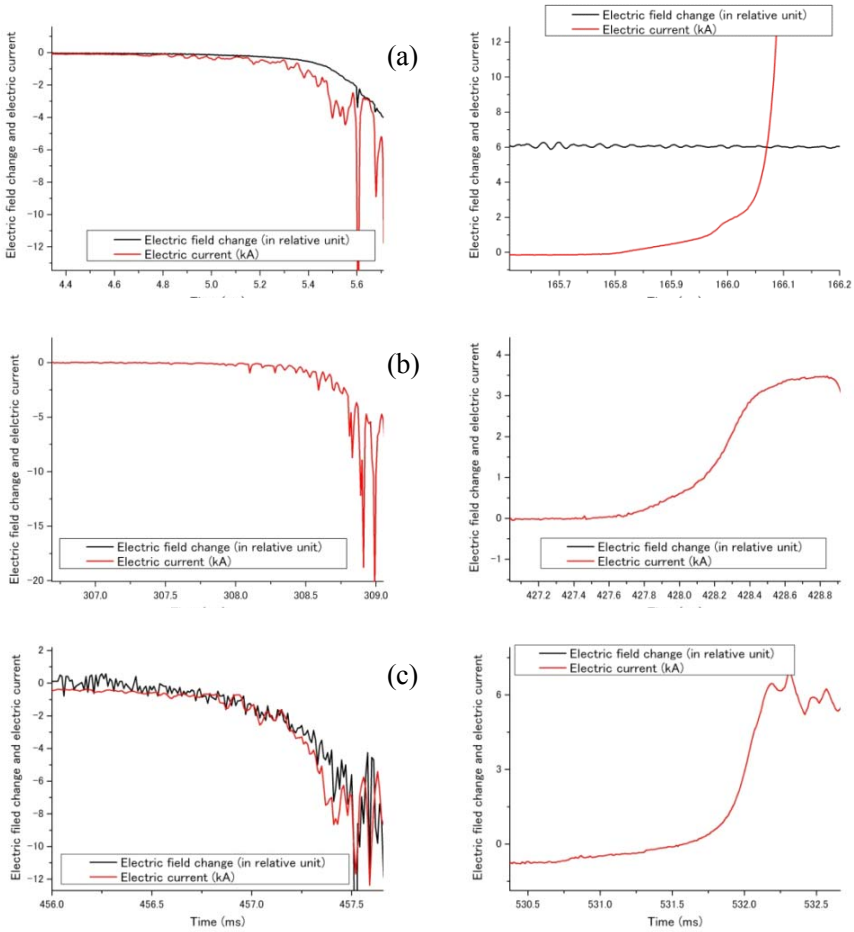

Figure 2 A comparison of the initial current rise of the negative discharge and the positive discharge contained in bipolar lightning discharges.

Feature 1: As seen in Fig.1b and Fig.1c, for each of these two lightning discharges, although the charge lowered to ground by BPCG is comparable to the charge lowered by BNCG, the electric field changes caused by BPCG is about one order in magnitude smaller than that of BNCG. For the lightning shown in Fig.1a, the slow electric field change is saturated during BPCG and is not shown here.

Feature 2: Fig.2 shows a comparison between the electric current rising parts of BNCG and BPCG for all three lightning. BPCG current waveforms rise smoothly than BNCG. All the rise times are similar, a little more than 1 ms.

Feature 3: Fig.3 is an expanded waveform of Fig.1 presenting the initial part of the positive discharges. As seen in this figure, a series of regular electric field change pulses begin to appear from about 1 ms prior to the rapid rise of the electric current. These pulses indicate the progression of a negative stepped leader.

With considering these observed features, a schematic model, as shown in Fig.4 is proposed to understand how a bipolar lightning occurs. **Feature 3** indicates that BPCG is apparently initiated inside cloud, rather than from the tower. To start a discharge inside cloud at a specific time, a channel with some conductivity and length is needed to produce local strong electric field through electrostatic induction at that time. To start a discharge in opposite polarity to its previous discharge, the electric field surrounding the channel must reverse in direction. One possible way to realize these two requirements is through a branch **B1** at the right side as shown in Fig.4. At some instant when the branch discharge **B1** has transferred as much as possible negative charge to ground, its progression stops and its conductivity begins to decay. At this time t=t1, the electric field along **B1** is still in the direction as before, shown with the green arrow in Fig.4a. With further development of branch **B2**, more negative charge is transferred to position "**O**" and then to ground. This could make the

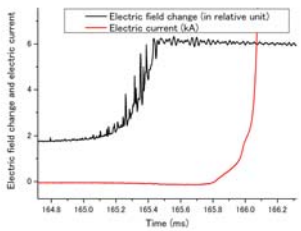

Figure 3 Electric field change and electric current at the initial stage of BPCG shown in Fig.1a.

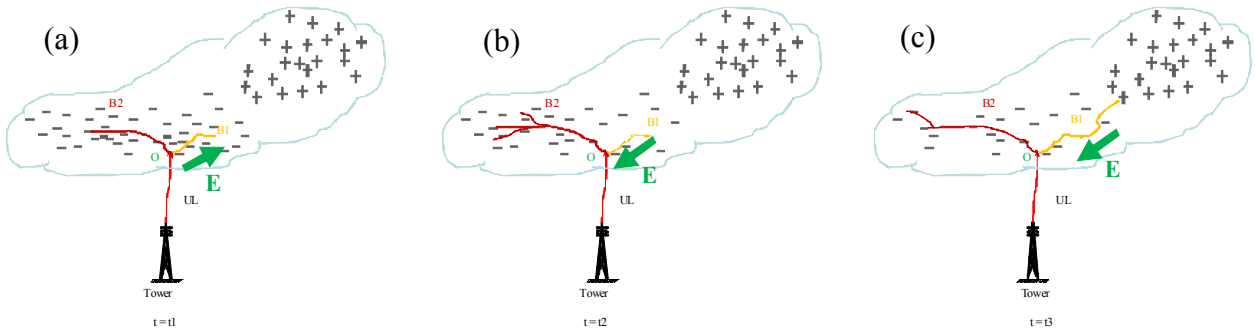

Figure 4 A schematic illustration of a possible scenario of bipolar lightning discharges. Time is from left to right.

electric field surrounding **B1** to reverse in direction as shown in Fig.4b. The charge in **B1**, which remains some conductivity, will redistribute and this may eventually trigger a positive leader downward to the ground and then a simultaneous negative leader propagating toward to the positive charge region as shown in Fig.4c. When the downward positive leader is propagating downward to ground, the previous discharge channel connecting to the tower is still somewhat conductive. The downward positive leader propagates along this conductive channel. Meanwhile, the negative leader, which is propagating toward to the positive charge region, could send a series of electric current waves to the downward positive leader. A composite effect of these waves, including reflection waves from tower, forms the electric current with a rise time of about 1 ms [6]. Compared to BNCG, BPCG charge source is relatively far away from the tower. Moreover, when the positive discharge occurs, an intra cloud discharge between the positive charge and the negative charge may accompany. These two factors combined may explain why the electric field change produced by BPCG is much smaller than that by BNCG. It appears to us that there should have some cloud charge structures, like the one shown in Fig.4, which are conductive to upward bipolar lightning discharges.

4. Concluding Remarks

This paper reports the characteristics of upward bipolar lightning derived from simultaneous recordings of electric current and electric field of three upward bipolar lightning. Based on these observed characteristics, a possible scenario of bipolar lightning is proposed to understand how a bipolar lightning occurs.

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6. References

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