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THREE UNUSUAL UPWARD POSITIVE LIGHTNING TRIGGERED BY OTHER NEARBY LIGHTNING DISCHARGE ACTIVITY

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ABSTRACT: We have reported the electric current and the electric field changes of three upward positive lightning triggered by nearby lightning discharge activities. All these three upward lightning contained only initial continuous current (ICC) stage. During the ICC stage three types of interesting electric current pulses have been identified and studied. Initial upward negative stepped leader pulses exhibited either unipolar positive pulse waveform or bipolar pulse with initial positive peak waveform. In contrast, a type of regular pulse burst identified in each of the three upward lightning all exhibited 4 types of pulses: positive unipolar type, negative unipolar type, bipolar with initial positive polarity type and bipolar with initial negative polarity type. We assumed that the regular electric current pulses observed in this study are caused by a dart-stepped leader propagating along a defunct upward branch at a time when other branches are still carrying continuous currents. An electric current pulse with an amplitude of several tens of Amperes along a high structure has been observed to occur in response to a rapid electric change generated by either a nearby return stroke or K-change. This pulse tends to be immediately followed by even bigger (a few kA) and longer (a few ms) pulses in the cases when the lightning channel connecting to the tower is still conductive.

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1. INTRODUCTION

Upward lightning can be classified as upward positive lightning, upward negative lightning and upward bipolar lightning according to the polarity of the electric charge transferred to the ground by them. In Japanese winter thunderstorms, the upward positive lightning are the rarest ones (Wang and Takagi, 2011) and thereafter the most difficult to be documented. In the winter of 2010, we have documented the simultaneous electric current and electric field changes of three upward positive lightning that are very interesting not only because they struck a tower within a time period of only 5 minutes, but also because they generated some interesting electric current pulses. This paper is to present the three upward lightning as well as the electric current pulses contained in them.

2. OBSERVATION

Our observation sites are located in Uchinada town, Ishikawa, Japan (Wang et al., 2008a; 2008b; Lu et al., 2009). The observation has being aimed at understanding those lightning discharges which strike on a 100 m tall windmill and its 105 m tall lightning protection tower with a separation distance of 45 m. Both the windmill and the tower sit on the top of 40 m high hill adjacent to the sea. For the three upward positive lightning, one occurring simultaneously on the windmill and the tower and two only on the tower, we have recorded their videos, electric currents and electric field changes at three sites, Main, Suimon and Horibokujyo, roughly at a distance of 0.39 km, 0.42 km and 2.68 km from the windmill. In addition, we have recorded the thunderstorm electric field with a field mill at a site called Chitoridai, about 3.68 km from the windmill.

3. GENERAL FEATURES OF THE THREE UNUSUAL UPWARD LIGHTNING

The three unusual upward lightning occurred during a thunderstorm on December 31st, 2010 which lasted more than 2 hours and produced a large number of lightning discharges as seen in the electric field waveforms measured at a site about 3.68 km away from the windmill. The three red arrows in Figure 1 indicate the three unusual

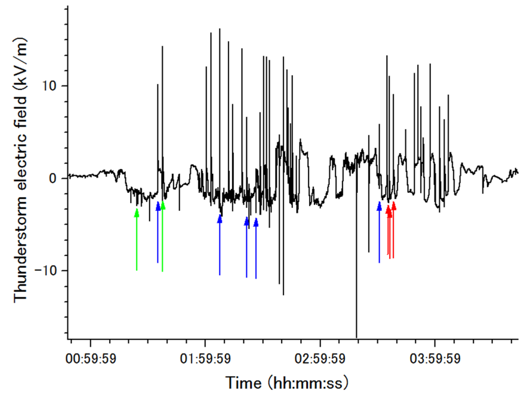

Figure 1. The thunderstorm electric field on December 31st, 2010 at Chtoridai.

lightning discharges which occurred within 5 minutes (3:34, 3:36 and 3:38) at the electric fields of -0.9 kV/m, -2.0 kV/m and 0.1 kV/m, respectively. In the following parts these three lightning are named lightning A, B and C.

3.1 The lightning A that occurred at 3:34

From the video recordings, this lightning struck both the tower and the windmill. Figure 2 shows its electric current flowing along the tower and the associated electric field changes at Main and Horibokujyo sites defined according to the physics sign convention. The electric current began to flow about 27 ms after the electric field change starting point. The electric field change prior to the electric current is apparently caused by a nearby lightning discharge. This nearby lightning triggered the upward lightning at the instant when the electric field change at Main site is about -96 kV/m. From then both the nearby lightning and the upward lightning made

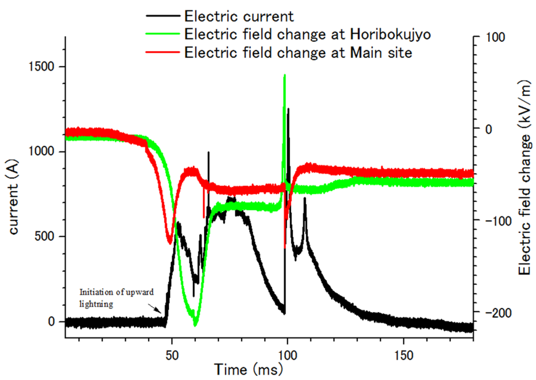

Figure 2. The electric current and the electric field changes of lightning A (3:34).

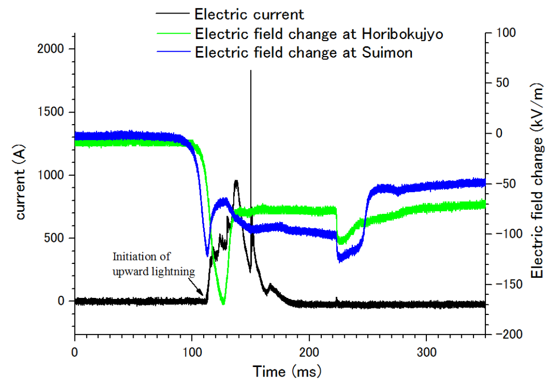

Figure 3. The electric current and the electric field changes of lightning B (3:36).

contribution to the electric changes. The reversing electric field changes 2 ms later at Main site and 13 ms later at Horibokujyo site are apparently caused by the upward lightning. The upward lightning had only initial continuous current stage and lasted about 130 ms. The resultant charge transfer by this lightning to the ground is about 37 C.

3.2 The lightning B that occurred at 3:36

From the video recordings, this lightning hit only the tower. Figure 3 shows its electric current and the associated electric field changes at Suimon and Horibokujyo sites. The electric current began to flow about 22 ms after the electric field change. Similarly, the electric field change before the electric current is caused by a nearby lightning discharge and this nearby lightning triggered the upward lightning. The electric field change at the instant of the upward lightning initiation at Suimon site is about -106 kV/m. The electric changes at the Suimon and Horibokujyo sites began to reverse 1 ms and 15 ms, respectively, after the upward lightning initiation. The upward lightning also contained only initial continuous current stage and lasted about 75 ms with a resultant charge transfer of about 26 C.

3.3 The lightning C that occurred at 3:38

From the video recordings, this lightning hit only the tower. Figure 4 shows its electric current and the associated electric field changes at Main, Suimon and Horibokujyo sites. The electric current began to flow about 16 ms after the electric field change. Similarly, this upward lightning was also triggered by a nearby lightning discharge. The electric field changes at the instant of the upward lightning initiation at Main and Suimon sites are about -100 kV/m and -111 kV/m, respectively. The electric changes at Main, Suimon and Horibokujyo sites began to reverse 4 ms, 7ms and 19 ms,

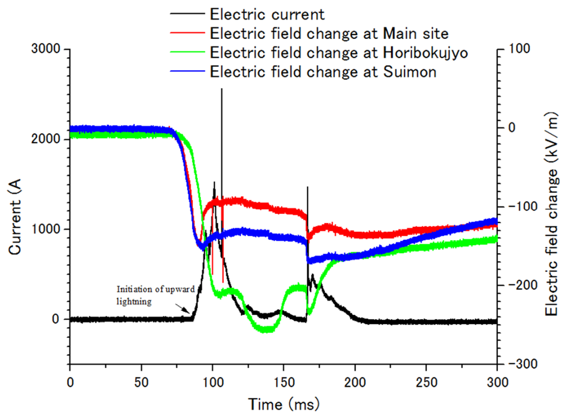

Figure 4. The electric current and the electric field changes of lightning C (3:38).

respectively, after the upward lightning initiation. Similar to lightning A and B, lightning C also had only initial continuous current stage. This lightning lasted about 125 ms and transferred 33 C of charge to the ground.

4. SOME INTERESTING PULSES IN THE ELECTRIC CURRENT WAVEFORMS OF THE THREE UPWARD LIGHTNING

4.1 Negative stepped leader pulses versus a type of regular pulse bursts

As seen in Figure 5, all the three lightning started with a series of current pulses generated by upward negative stepped leaders. The pulses can be generally characterized as positive unipolar type and bipolar with initial positive polarity type. Some of those pulses exhibited several small peaks. By ignoring the small peaks (or small pulses), we have measured the pulse intervals and pulse peak currents and two example results are shown in Figures 6, respectively.

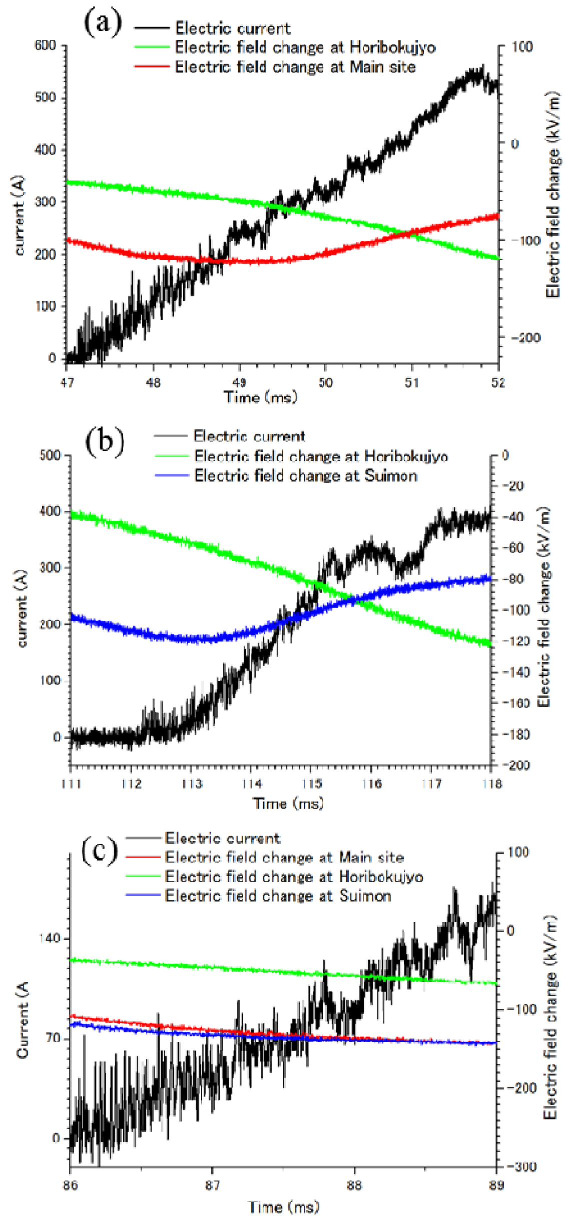

Figure 5. Electric current pulses of initial upward negative stepped leaders of lightning A (a), B (b) and C (c).

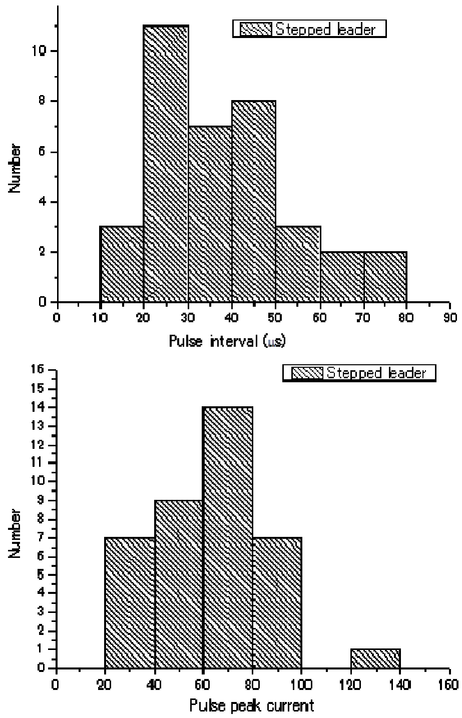

Figure 6. Histogram of pulse intervals and pulse peaks for the initial stepped leader in Figure 5a.

Besides those stepped leader pulses, interestingly we have identified a type of pulse bursts as shown in Figure 6 in all the three upward lightning discharges. After examining their waveforms, we found that those pulses can be classified into positive unipolar type, negative unipolar type, bipolar with initial positive polarity type and bipolar with initial negative polarity type. Surprisingly, majority of the pulses in Figure 6 exhibited initial negative polarity which is clearly opposite to those pulses shown in Figure 5. As a comparison, Figure 8 shows the histogram of

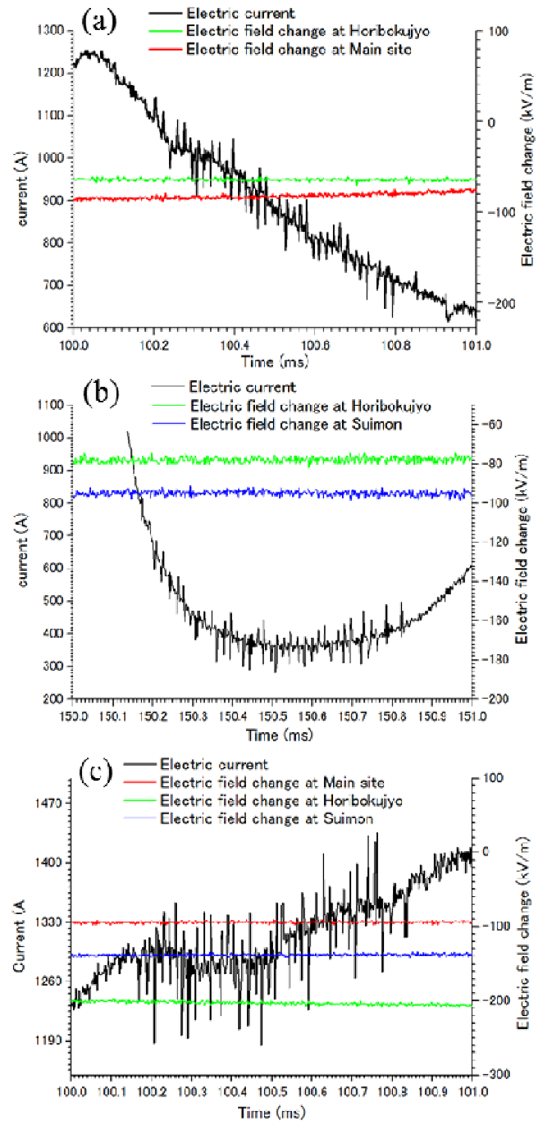

Figure 7. Regular current pulse bursts identified in lightning A (a), B (b) and C (c).

pulse interval and pulse peak current for an example pulse train. Negative pulse peak value indicates that the corresponding pulse is either a negative unipolar pulse or a bipolar pulse with an

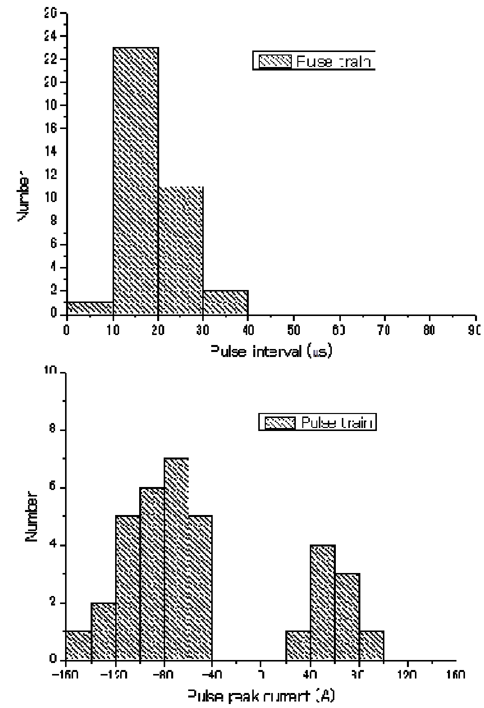

Figure 8. Histogram of pulse intervals and pulse peaks of regular pulses in Figure 7a.

initial negative peak. For bipolar pulses, the peak values are measured between two polar peak values. A comparison between Figures 6 and 8 clearly indicates that the pulses in Figure 8 are more regular than those in Figure 6. Generally, the regular pulses exhibited a pulse interval of around 20 µs and a pulse peak of 100 A or so.

As far as authors know, such regular electric current pulse bursts have never been reported before. What discharge processes in upward lightning generated these regular pulses is apparently an interesting question to be answered. Electromagnetic radiation regular pulses have been reported in either cloud discharges or downward could to ground lightning discharges and have been inferred to be caused by dart-stepped leaders (Krider et al., 1975; Rakov et al., 1996. We assume that the regular electric current pulses observed in this study are caused by a dart-stepped leader propagating along a defunct upward branch at a time when other branches are still carrying continuous currents. As described above, majority of the regular pulses showed opposite polarity to those generated by the initial negative stepped leaders. Right now we are not able to determine the polarity of the dart stepped leader as well as how the four types of pulses are generated.

4.2 Current pulses in response to rapid electric field changes caused by nearby lightning discharges

In the three upward lightning, we have identified three electric current pulses which are apparently induced by rapid electric field changes generated by either nearby return strokes or K-changes as shown in Figure 9. All the three pulses show an initial rapid rise at a time scale less than 20 µs. Followed this initial rise, the pulses in Figure 9a and 9c exhibited further impulsive increase while the pulse in Figure 9b immediately began to decrease with a same time scale as the decay of the electric field change. The pulse in Figure 9a occurred at a background current of 67 A and the pulse in Figure 9c occurred 2 ms after the corresponding upward lightning current has dropped to be zero. In

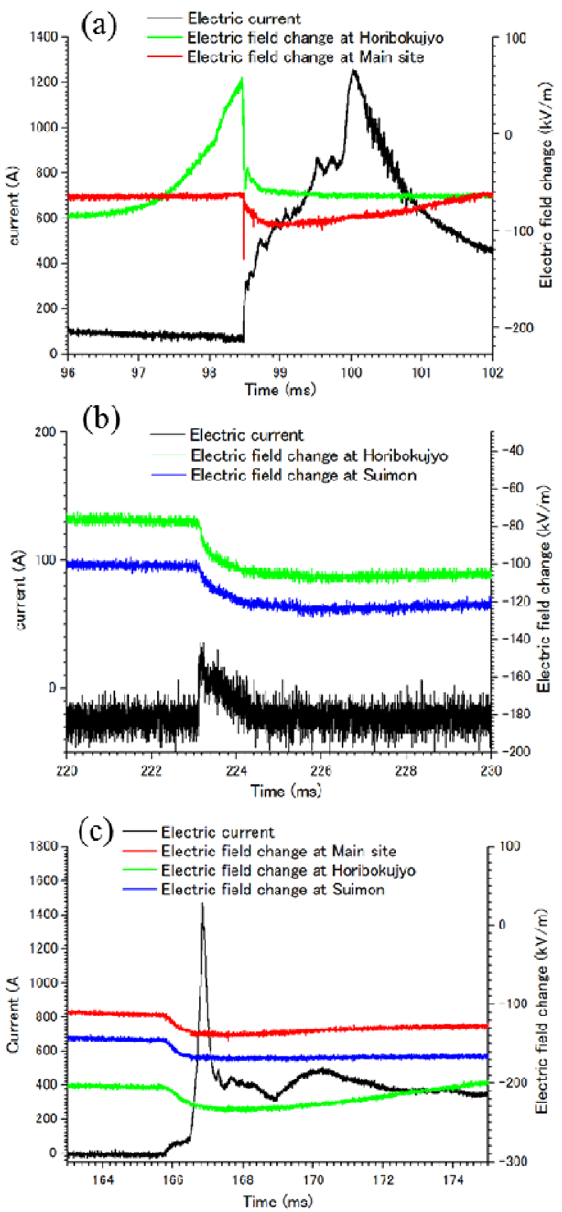

Figure 9. Electric current pulses in Lightning A (a), B (b) and C (c) in response to rapid electric field changes of nearby return.strokes and K-changes

contrast, the pulse in Figure 9b occurred about 30 ms after the upward lightning current has dropped to be zero. It appears that a conducting tower and a conducting lightning channel together could generate more dynamic discharge phenomenon through charge redistribution along both the tower and the conducting lightning channel in response to a rapid electric field change caused by a nearby lightning discharge.

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References

Krider, E. P., G. J. Radda, and R. C. Noggle, Regular radiation field pulses produced by intracloud lightning discharges, J. Geophys. Res. 80: 3801-3804, 1975.

Lu, W., D.Wang, Y. Zhang and N. Takagi, Two associated upward lightning flashes that produced opposite polarity electric field changes, Res. Lett., Vol.36, L05801, doi:10.1029/2008GL036598,2009.

Wang, D., N. Takagi, T. Watanabe, H. Sakurano, and M. Hashimoto, Observed characteristics of upward leaders that are initiated from a windmill and its lightning protection tower, Geophys. Res.

Lett., 35, L02803, doi:10.1029/2007GL032136, 2008a.

Rakov, V. A., M. A. Uman, G. R. Hoffman, M. W. Masters and M. Brook, Bursts of pulses in lightning electromagnetic radiation: Observations and implications for lightning test standards, IEEE Trans. Electromagn. Compat. 38, 156-164, 1996.

Wang, D., N.Takagi, T.Watanebe, M. Hashimoto, Observed characteristics of the lightning striking on a windmill and its lightning-protection tower, Proceedings of 29th International Conference on Lightning Protection, 9c-1, 1-7, 2008b.

Wang, D., N.Takagi, Typical characteristics of upward lightning observed in Japanese winter thunderstorms and their physical implications, Proceedings of 14th International Conference on Atmospheric Electricity, Rio de Janeiro, 2011.