

INITIATION AND PROPAGATION CHARACTERISTICS OF UPWARD POSITIVE LEADERS

D. Wang, N. Takagi, T. Watanabe
Gifu University, Japan
E-mail: wang@cc.gifu-u.ac.jp

Abstract: We have measured the correlated sub-microsecond E-fields and high-speed images of three upward positive leaders from a high tower. We found that all three leaders are initiated without any in-cloud discharge activity as their direct triggers. Pulse discharge processes are observed for all three leaders. Analysis of those pulse discharges allows us to propose a common mechanism for the propagation of all types of pulse discharges including leader pulses, return strokes and M-components.

Keywords: Lightning, leader, pulse discharge

1. Introduction

Judging from propagation direction, leaders are classified as downward leaders and upward leaders. Downward leaders usually initiate in cloud, while upward leaders from high ground objects. By using an automatic lightning progressing feature observation system (ALPS), we have measured the correlated sub-microsecond E-fields and high-speed images of three upward positive leaders that are initiated from a high tower at Hokuriku area, a famous place for winter lightning. The data allow us not only to perform a detailed comparison between the E-field and optical signals in leader initiation stages, but also to have a study on the propagation mechanism of pulse discharges such as leader pulses, return strokes and M-components. This paper is to report the results.

2. Observation

The observation was performed with a new version of ALPS that has been

described in detail in [1]. For the present study, the E-field information from a wide band (0.2Hz- 5MHz) slow antenna was simultaneously recorded with the ALPS system. We chose the top of a 60 m high tower at Hokuriku mountain area of Japan, a place famous for winter lightning, as the view target of ALPS. The distance between the ALPS location and the tower is about 1 km, and the resultant resolution is around 25 m. The time resolution was set at 0.1 μ s.

3. Data and analysis

The correlated E-fields and high-speed images were recorded for three leaders on 13 December 2001. Figure 1a, 1b, 1c show, respectively, the relative light intensity waveforms as a function of time at various heights from S1 (tower tip) through S12 (260 m) as well as the correlated E fields for the three leaders. All the signals are in relative units. As seen in Figure 1, leader light signals were clearly identified. Leaders at the lower heights occur earlier in time, hence these leaders propagate in upward direction. The average speeds estimated over the entire 260 m channel bottom for the three leaders are, respectively, 1.1×10^6 m/s, 1.0×10^6 m/s and 6.5×10^5 m/s. From the E-field features, all three leaders are inferred to be of positive types.

A detailed comparison between the E-fields and the high-speed images in Figure 1 show that the upward leaders started without any apparent precursory E-field changes. This implies that all three leaders are initiated without in-cloud discharge activity as their direct triggers.

Pulse discharge processes are observed for all three leaders as seen in Figure 1. Those pulse discharges can be apparently

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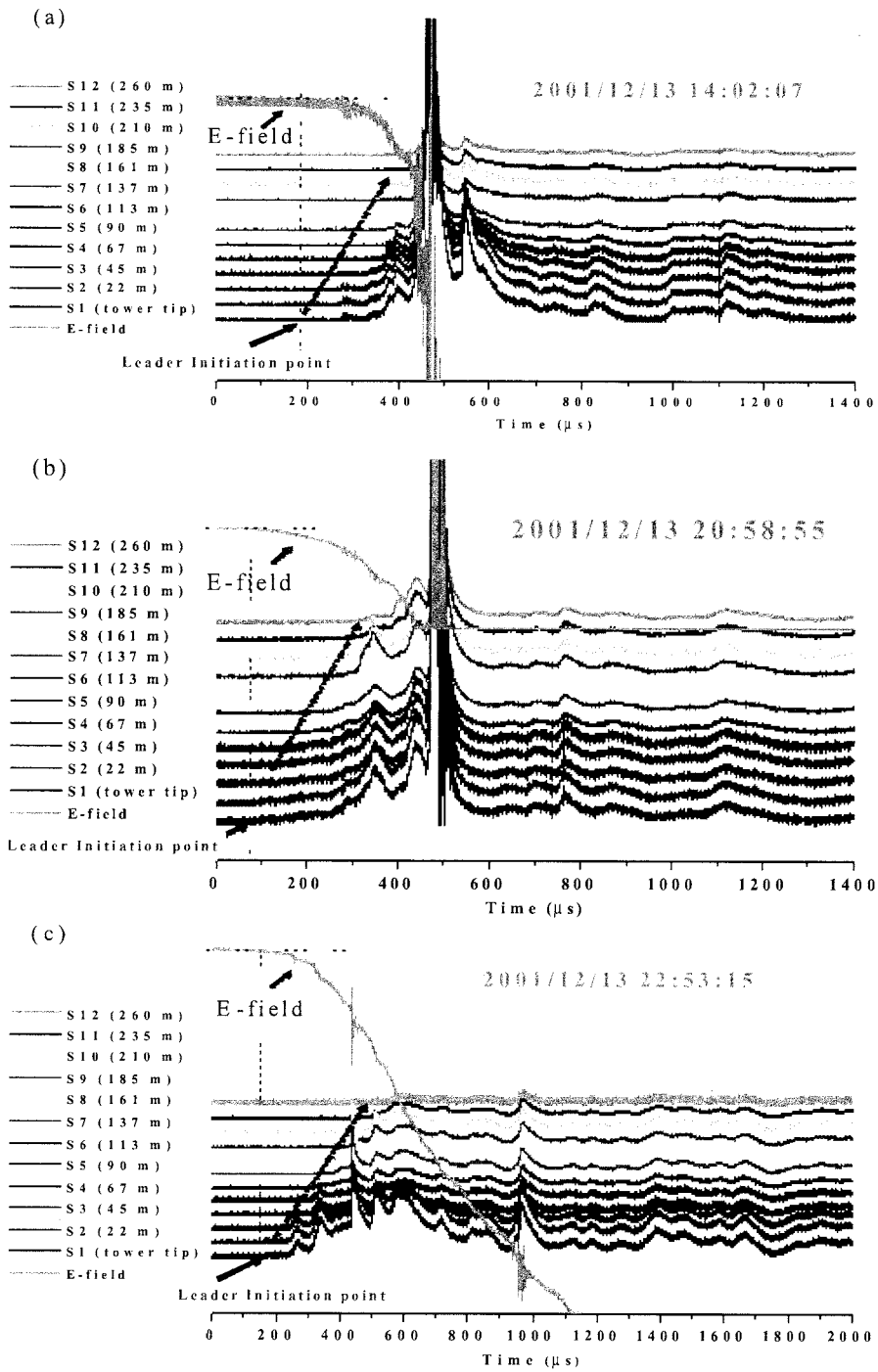


Figure 1 The relative light intensity waveforms as a function of time at various heights from S1 (tower tip) through S12 (260 m) as well as the correlated E fields for leaders a, b, and c.

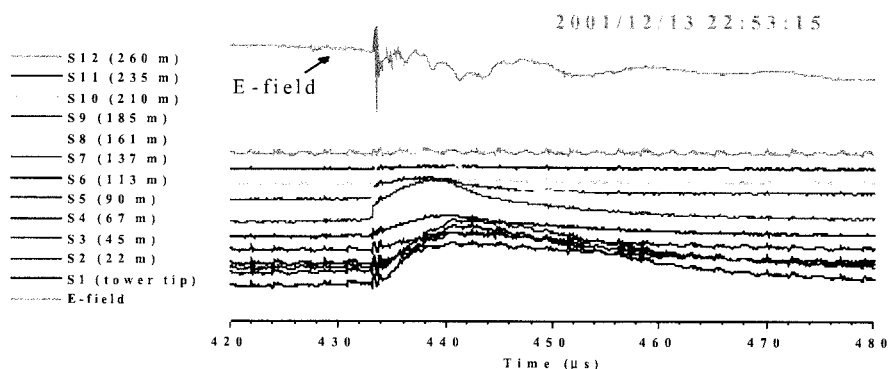


Figure 2 The E-field and the light signal for a pulse discharge with an initial dominant pulse.

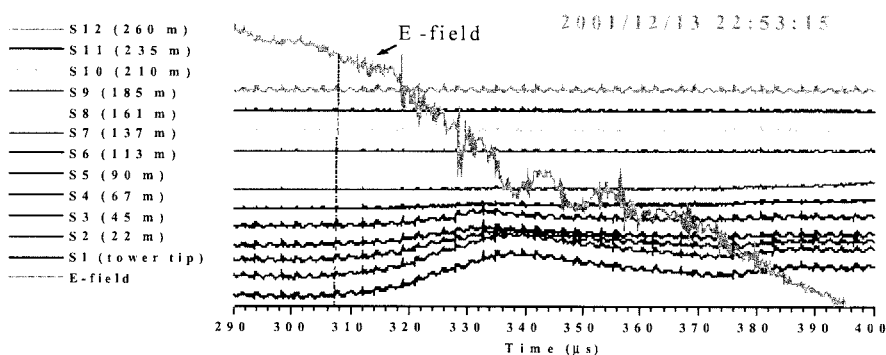


Figure 3 The E-field and the light signal for a pulse discharge without an initial dominant pulse.

classified into two types from their rise time and propagation features. Figure 2 shows an example of the first type of pulse discharges. As seen from the light signals, an initial dominant pulse appears to start at S8 and S9, and then propagate toward tower tip S1. The propagation speed is close to 1×10^8 m/s. The rise time measured at S8 is less than 1 ns. Followed the initial pulse, a number of radiation pulses can be seen in the E-field. Figure 3 shows an example of the second type of discharges. The rise time of the light pulse is more than 20 ns. Judging from the light signal, the pulse does not have any apparent propagation direction and speed. During the light pulse, numerous radiation pulses can be identified from the E-field signal.

It is inferred that those two types of discharges are involved in two different mechanisms. During the forward propagation of a positive leader, each time when the electric field at the leader tip becomes too small to sustain a continuous propagation, the leader will stop for a moment. During this period, the leader will accumulate energy to its tip and the electric field there will be recovered. Once the electric field reaches to a critical value, a breakdown will occur and trigger many small pulse discharges followed. This is the first type of discharge shown in Figure 2. Each time when the leader approaches to a region with negative space charge (opposite polarity with the leader), apparently the charge will be transferred to ground through

the leader. The neutralization process of space charge may correspond to the second type of pulse discharges. In this case, as seen in Figure 3, although there involved a great numbers of small discharges that occur at different times and possibly different locations, an initial dominant pulse does not occur.

4. A common mechanism for the propagation of pulse discharges

The observed data allow us to propose a common propagation mechanism for all types of pulse discharges associated with a conductive plasma channel. The general definition and characteristics of pulses discharges in lightning can be found in [2].

When a pulse discharge occurs at one end of a continuous current channel, the pulse would propagate along the channel most likely as an ionization wave. Followed this pulse discharge, many small discharge waves may be initiated to neutralize any nearby space charge. Meanwhile, the electric field change caused by all those discharges could influence, through space, not only every section of the channel but also the ground at a speed of light. Since both the channel and the ground are conductive, currents will be initiated at any section of the channel and propagate as waves. When the waves encounter any dissimilarity in conductivity along the channel, reflected waves would occur. All those waves certainly interfere each other. Although for each wave, there is physical meaning in speed, for an overlapping phenomenon composed by many waves with different characteristics, the physical meaning of propagation direction and speed should be very limited as pointed out below.

In the cases of leader pulses and return strokes, there exist an initial dominant pulse as shown in Figure 2. A speed can be defined only for the dominant pulse in its initial stage by neglecting the interference of other numerous current waves. After the initial pulse degrades and the dominance

disappears, speed will lose its physical meaning. This is the case similar to that shown in Figure 2.

For an M-component type of discharges, three cases can be considered. (1) When an M-component is the manifest to neutralize a space charge, numerous pulse discharges that occur at different time could be involved. Since there are no dominant pulse waves, neither speed nor propagation can be defined for this type of M-component. This is the case shown in Figure 3. (2) When an M-component is initiated as a dominant pulse discharge, for example, a breakdown between two leaders with opposite polarity inside cloud, the M-component will appear to propagate downward at its initial stage. However after the first pulse discharge degrades and loses its dominance, the M-component could not be characterized with speed and propagation any more. This is the case similar to leader pulses and return strokes. (3) As a rare case, when the first pulse discharge dominates until to ground, then a discharge like return stroke may be initiated.

5. Conclusion

The correlated sub-microsecond E-fields and high-speed images of three upward positive leaders from a high tower were presented. Analysis of those data allows us to propose a common mechanism for the propagation of all types of pulse discharges including leader pulses, return strokes and M-components.

References

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