A Study of Upward Positive Leaders Based on Simultaneous Observation of E-Fields and High-Speed Images

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Keywords : lightning discharge, leader

1. Introduction

Judging from propagation direction, lightning leaders are classified into downward leaders and upward leaders. Downward leaders usually initiate in cloud, while upward leaders from high ground objects. Due to this feature, upward leaders allow direct optical measurements easier and thus they provide a good opportunity for studying lightning initiation process. In literatures, several papers have reported such kind of measurements. By using an automatic lightning progressing feature observation system (ALPS), we have measured the correlated sub-microsecond E-fields and high-speed images of nine upward positive leaders that are initiated from high grounded structures 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 statistical study on the optical characteristics of upward positive leaders. This paper is to report some of the results.

2. Observation

Our observation of lightning was performed with two versions of ALPS that have been described in detail by Wang et al.. For the present study, the E-field information from a wide band (a few Hz-5 MHz) capacitive antenna was simultaneously recorded with the ALPS system. The observation was carried out in 2001 and 2003 winter seasons at two sites, referred as Nadachi and Mikuni in the present paper, both in Hokuriku area of Japan, a famous place for winter lightning. At the first site (Nadachi), the view target of ALPS is the tops of two windmills and their lightning protection tower. The windmills and the tower locate at the top of a mountain 270 m high above the sea level. At the second site (Mikuni), the view target of ALPS is the tops of two chimneys of thermal power plants. The chimneys locate nearly at sea level and are, respectively, 150 m and 200 m high. At both sites, the distances between the ALPS location and the targets are about 1 km, and the resultant spatial resolution is around 25 m.

3. Results and Discussions

A total of 62 events were recorded with ALPS in 2001 and 2003 winter seasons. Since some of the events are dart-leader/return stroke sequences and some are too weak or too noisy for analysis, only 9 events as shown in Table 1 are selected for the present

study. As an example, Fig. 1 presents 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 leader occurred at 2001/12/13 22:53:15. Based on the data as shown in Figure 1, we have obtained the speed for each leader and the results are shown in Table 1. It is found that all the leaders are initiated without any in-cloud discharge activity as their triggers.. We have also performed a statistical study on the pulses superimposed in the leader light signals.

Fig. 1. Light intensity waveforms as a function of time at various heights and the correlated fields for an upward leader observed

Table 1. List of the observed upward positive leaders and their average propagation speeds

Data Number	Time	Average speed (m/s)
NADA501	2001/12/30 09:57:10	1.0×10^6
NADA502	2001/12/30 12:27:22	1.8×10^6
NADA506	2002/01/29 02:41:30	5.7×10^5
NADA602	2001/12/13, 14:02:07	1.1×10^6
NADA603	2001/12/13, 20:58:55	1.5×10^6
NADA605	2001/12/13, 22:53:15	1.0×10^6
NADA709	2004/02/04, 22:11:29	5.3×10^5
MIKU603	2002/01/08 07:26:47	3.9×10^5
MIKU610	2002/01/23 23:41:23	6.9×10^5

A Study of Upward Positive Leaders Based on Simultaneous Observation of E-Fields and High-Speed Images

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Abstract We have measured the correlated sub-microsecond E-fields and high-speed images of nine upward positive leaders occurred in winter from high grounded –structures at Hokuriku areas of Japan. It is found that all the leaders are initiated without any in-cloud discharge activity as their triggers. The average leader speeds we measured are around 10^6 m/s. All the leaders appear to contain a few pulses soon after their initiations. Pulse rise time ranges from $3.1 \mu\text{s}$ to $71.4 \mu\text{s}$ with a GM (Geometric Mean) value of $27.2 \mu\text{s}$. Pulse decay time varies from $3.7 \mu\text{s}$ to $148.8 \mu\text{s}$ with a GM value of $30.9 \mu\text{s}$. Pulse time duration distributes from $12.6 \mu\text{s}$ to $208.3 \mu\text{s}$ with a GM value of $59.8 \mu\text{s}$. Most of the pulses are the same type of ICC (Initial Continuous Current) pulses. In addition, several correlations such as the light intensity just prior to each pulse versus pulse peak intensity are presented for the pulses.

Keywords : Lightning discharge, leader

1. Introduction

Judging from propagation direction, lightning discharge leaders are classified into downward leaders and upward leaders. Downward leaders usually initiate in cloud, while upward leaders from high ground objects. Due to this feature, upward leaders allow direct optical measurements easier and thus they provide a good opportunity for studying lightning initiation process. In literatures, several papers have reported such kind of measurements⁽¹⁾⁻⁽³⁾. By using an automatic lightning progressing feature observation system (ALPS), we have measured the correlated sub-microsecond E-fields and high-speed images of nine upward positive leaders that are initiated from high grounded structures 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 statistical study on the optical characteristics of upward positive leaders. This paper is to report some of the results.

2. Observation

Our observation of lightning was performed with two versions of ALPS that have been described in detail by Wang et al.⁽⁴⁾⁽⁵⁾. For the present study, the E-field information from a wide band (a few Hz- 5 MHz) capacitive antenna was simultaneously recorded with the ALPS system. The observation was carried out in 2001 and 2003 winter seasons at two sites, referred as Nadachi and Mikuni in the present paper, both in Hokuriku area of Japan, a famous place for winter lightning. At the first site (Nadachi), the view target of ALPS is the tops of two windmills and their lightning protection tower. The windmills and the tower locate at the top of a mountain 270 m high above the sea level with their heights being, respectively, 50 m, 50 m and 70 m as shown in Fig.1. At the

Fig. 1. Configuration of site 1

second site (Mikuni), the view target of ALPS is the tops of two chimneys of thermal power plants. The chimneys locate nearly at sea level and are, respectively, 150 m and 200 m high. At both sites, the distances between the ALPS location and the targets are about 1 km, and the resultant spatial resolution is around 25 m. The time resolution was set at 100 ns.

3. Observed Results and Discussion

A total of 62 events were recorded with ALPS in 2001 and 2003 winter seasons. Since some of the events are dart-leader/return stroke sequences and some are too weak or too noisy for analysis, only 9 events as shown in Table 1 are selected for the present study. As an example, Fig. 2 presents 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 leader occurred at 2001/12/13 22:53:15. All the signals are in

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relative units. As seen in Fig. 2, the leader light signals at the lower heights occur earlier in time, hence this leader propagates in upward direction. On the other hand, because our E-field antenna is reversed in polarity, from the E-field waveform in Fig. 2, the leader is identified to be positive. The remaining eight leaders have more or less similar waveforms as shown in Fig. 2. For simplicity, they are not presented in this paper.

Eight of the nine events in Table 1 allow us to measure their speeds at various heights. The results are presented in Fig. 3. Three of the leaders, MIKU603, NADA506 and NADA709, tend to have a constant speed. Two leaders, MIKU610 and DADA501 appear to propagate faster as they move up. While the remaining three leaders, NADA502, NADA603 and NADA605, tend to become slower at the beginning and faster later on.

The average speeds for all the nine leaders are summarized in Table 1. Compared with the previous results summarized by Rakov and Uman⁽⁶⁾, the speeds presented in this paper are slightly higher. It was known that leaders with higher speeds tend to have larger currents⁽⁷⁾. This may suggest that the leaders observed especially in site 1 have larger currents.

Table 1. List of the observed upward positive leaders and their average propagation speeds

Data Number	Location	Time	Average speed (m/s)
NADA501	Site 1, tower	2001/12/30, 09:57:10	1.0×10^6
NADA502	Site 1, Windmill 1	2001/12/30, 12:27:22	1.8×10^6
NADA506	Site 1, tower	2002/01/29, 02:41:30	5.7×10^5
NADA602	Site 1, Windmill 2	2001/12/13, 14:02:07	1.1×10^6
NADA603	Site 1, tower	2001/12/13, 20:58:55	1.5×10^6
NADA605	Site 1, tower	2001/12/13, 22:53:15	1.0×10^6
NADA709	Site 1, tower	2004/02/04, 22:11:29	5.3×10^5
MIKU603	Site 2, Chi.200 m	2002/01/08, 07:26:47	3.9×10^5
MIKU610	Site 2, Chi.200 m	2002/01/23, 23:41:23	6.9×10^5

Fig. 2. Light intensity waveforms as a function of time at various heights from S1 (tower tip) through S12 (260 m) and the correlated fields for an upward leader initiated from a high tower at 2253:15 on December 13, 2001 at Hokuriku area of Japan; All the waveforms are in relative units

Since a slower charge build-up allows time for corona to inhibit the initiation of an upward leader, Berger and Vogelsanger suggested that the high electric field needed for the initiation is rapidly created by an in-cloud discharge⁽³⁾. A detailed comparison between the E-fields and the high-speed images of the upward leaders shows that all the observed upward leaders started without any rapid E-field changes. This result does not support the suggestion made by Berger and Vogelsanger. Since strong wind could blow away much of the corona near the tip of a high structure or bring some space charge in opposite polarity approaching to the tip, wind may play an important role in triggering upward leaders.

Figure 4(a) and (b) present, respectively, the optical signals of the bottom channel section and the corresponding electric field

Fig. 3. Scatter plot of leader speed versus leader upward propagation distance

Fig. 4. The light intensity waveforms (a) and electric field changes (b) of three leaders measured in a single day

Fig. 5. Distribution of leader pulse rise time

Fig. 6. Distribution of pulse decay time

Fig. 7. Distribution of leader pulse duration time

change of three leaders recorded in a single day. Apparently, three leaders have very different intensities. As it is expected, the stronger the light signals, the bigger the corresponding electric field changes.

It is interesting to note in Fig. 4 that the three leaders have remarkably similar light and electric field changes at the very beginning 100 μ s. This may suggest that although leaders are much different in intensity their initiation condition could be the same.

As seen in Fig. 2 a few pulses are superimposed in the leader light signals. For each of the pulse, we have measured the pulse

Fig. 8. Scatter plot of pulse rise time versus light intensity just prior to each pulse

Fig. 9. Scatter plot of the light intensity just prior to each pulse versus pulse peak intensity

rise time, decay time, duration, light intensity just prior to the pulse, and also the pulse peak.

Figures 5-7 show, respectively, the distribution of pulse rise time, decay time and duration. Pulse rise time ranges from 3.1 μ s to 71.4 μ s with a GM value of 27.2 μ s. Pulse decay time varies from 3.7 μ s to 148.8 μ s with a GM value of 30.9 μ s. Pulse time duration distributes from 12.6 μ s to 208.3 μ s with a GM value of 59.8 μ s.

Most of the pulses analyzed above do not exhibit sharp rise time and well-defined propagation and they are the same type of ICC pulses⁽⁸⁾⁽⁹⁾. It is reported that some positive leaders exhibit pronounced stepping and some just continuous propagation without any stepping⁽²⁾⁽¹⁰⁾. The upward positive leaders observed in this study are likely to be classified as stepping ones due to the pulses, but it should be mentioned that the pulses analyzed above are significantly different to leader stepping pulses. Leader stepping pulses usually exhibit sharp rise time and well-defined propagation. This issue will be discussed in a future paper.

Figure 8 shows the scatter plot between the light intensity prior to the pulse and the pulse rise time. It appears that no significant relationship exists between these two parameters.

Figure 9 presents the scatter plot of the light pulse peak intensity versus the intensity just prior the pulse. It appears that the pulse peaks are moderately correlated with the light intensities prior to the pulses.

For each of the light pulse, we have also measured the electric field change caused by the pulse. Figure 10 shows the scatter plot between the light pulse time integral and the electric field change. The larger the light pulse time integral, the bigger the electric field change. Since both of the parameters are correlated with the

Fig.10. Scatter plot of the time integral of light pulse versus the electric field change caused by each pulse

charges transferred by the pulse discharges, the positive correlation is expected.

4. Concluding Remark

We have measured the correlated sub-microsecond E-fields and high-speed images of nine upward positive leaders occurred in winter from high grounded –structures. It is found that all the leaders we analyzed are initiated without any in-cloud discharge activity as their triggers and maybe at nearly same conditions. These results are very interesting and deserve to be verified in the future.

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