Abnormal Leader Processes in a Classically-Triggered Negative Discharge Observed with a Broadband VHF Interferometer and a Camera in 3D

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ABSTRACT: The Leader initiation and propagation processes observed in a negative rocket-triggered lightning discharge in southern China were analyzed and discussed. The observations included a broadband VHF lightning interferometer with a slow antenna located at 90 m in south to the rocket launcher and a video camera located at 1.3 km in west to the launcher. By combination of the video picture with the interferometer data, 3D evolutions of leader processes involved in this discharge were obtained and discussed.

INTRODUCTION

During last decades, observations based on high-speed optical and broadband electromagnetic sensors have significantly advanced our knowledge on leader processes in cloud-to-ground lightning flashes (e.g., Chen et al., 1999). In addition to high-speed optical sensors, the VHF interferometry technique is recently getting more and more popular in study of the features of lightning inceptions and developments (e.g., Dong et al., 2003). In following, we report the result of the initiation and leader processes of a rocket-triggered lightning flash observed by using a VHF broadband interferometer system in conjunction with a camera system.

LIGHTING DATA

The lightning discharge we analyzed was a rocket-triggered lightning discharge succeeded in the summer of 1999 during an experiment conducted near Guangzhou City in China (Dong et al., 2001). The observations included a broadband VHF lightning interferometer with a slow antenna located at 90 m in south to the rocket launcher and a video camera located at 1.3 km in west to the launcher. The lightning was triggered when the rocket ascended to the height of about 400 m and the ground electric field was negative just before the rocket launching.

Shown in Figure 1 is the observed data for this triggered lightning discharge. The left panel in the figure is a photograph of the discharge from the camera at 1.3 km away. The straight part in the photograph is the lightning channel left by vaporized wire, while the upper bent part is believed to be the

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channel formed by two successive leader-return stroke processes. The right panel in the figure is the data of the discharge recorded by the interferometer system at 90 m away, which includes the electric field change recorded with the slow antenna (a) and the VHF radiation source location in elevation (b) and azimuth (c). As the discharge was very close to the sensor the electric field changes were partly saturated, however, it is still evident that the discharge included a preliminary initiation process, followed by one M-component and two successive leader-return stroke processes, marked with P, M, R1 and R2 respectively.

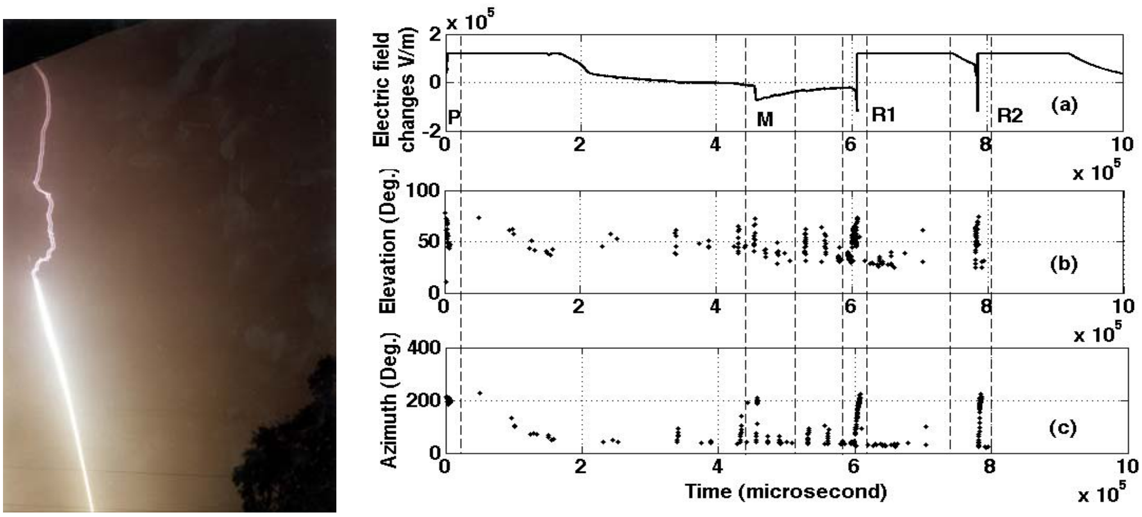


Figure 1: Raw data of the triggered lightning discharge analyzed. The left panel is a photograph of the discharge from a camera located 1.3 km in west to the rocket launcher. The right panel is the electric field changes (a) and the VHF radiation sources in elevation (b) and azimuth (c), of the discharge.

LIGHTING CHANNEL EVOLUTION

The photograph in Figure 1 is believed to be the image of luminous return stroke channel below cloud bottom. It may partly or even not reflect the channel of the initiation leader and the leaders preceding the strokes. On the other side, the VHF radiation sources are mainly associated with leader processes. Nevertheless, it is still possible to get a 3D leader channel evolution image by combining the still photograph from the camera with the time-resolved VHF source data in azimuth and elevation. A basic method for doing this is stated in following.

For a photograph of a lightning channel, each small channel segment in the photo produces a radial line pointing to the real lightning channel in space through the camera. And all such radial lines together may form a curved face in space (Face 1) that contains or just go bypass the leader channel. For the interferometer data, each pair of azimuth and elevation presents a radial line viewed from the interferometer through the leader channel in space and hence another curved face (Face 2) that contains the leader channel may be formed. Projection of Face 2 onto Face 1 may produce a 3D channel evolution image of a leader process. It may not be a complete 3D image but is definitely better than a 2D image for understanding of a leader process. With this method, the 3D channel evolutions for the three leader processes of the discharge in Figure 1 are rebuilt and discussed in following sections.

Preliminary initiation leader process: P

Figure 2 shows the rebuilt 3D channel (a) and the channel evolution speed (b) for the preliminary initiation leader process for the discharge in Figure 1. Only the part of the channel out of the cloud is shown. It is found that the initiation leader might start in the cloud and firstly propagated downward from about 930 m to 300 m high in a vertical manner and then moved in zigzag manner towards the tip of the triggering wire. Such a downward initiation leader process is not common in triggered lightning in literature.

The speed of the initiation leader varied from 3.7 to 0.3 $\times 10^6$ m/s as it descended from 930 m to 300m high (shown in black line in the figure) and as it moved in zigzag around the triggering wire tip (shown by black dash-dot-line in the figure). The lower speed in downward stage is corresponding to the bending channel parts around 500 m to 600 m high. The leader speed showed a general trend of decease as it descended with the time. It should be noted that the 3D channel rebuild here is just a projection of the observed VHF radiation sources to the curved face produced from the photograph, which might be optically invisible to the camera.

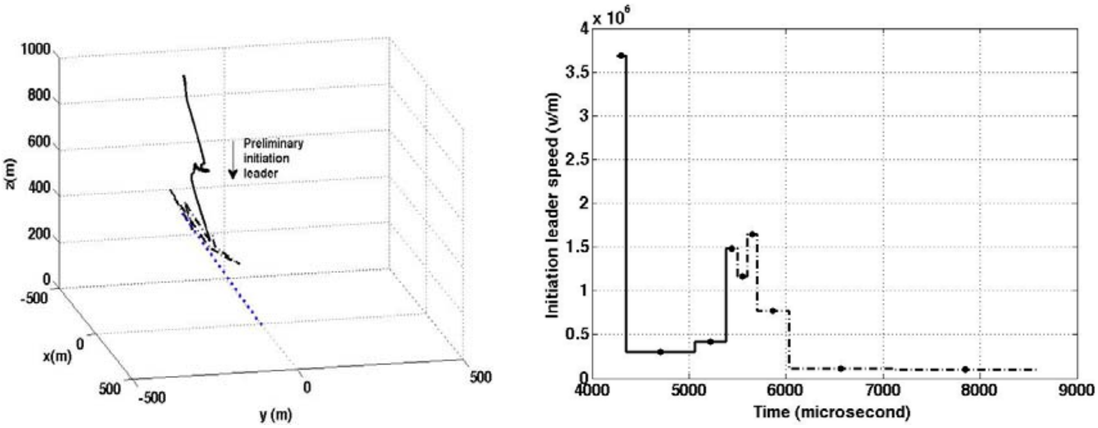


Figure 2: Rebuilt 3D channel (a) and the channel evolution speed (b) for the preliminary initiation leader of the discharge in Figure 1. The blue dash-line represents the triggering wire trace and the black solid-line and dash-dot lines represent the leader channel at different time stages.

The first leader-return stroke process: L1

Figure 3 shows an expansion of the electric field changes and VHF radiation source data for the out-cloud part of the first leader-return stroke process (R1) of the discharge in Figure 1. As shown in the figure, in the time span from 6.038 to 6.073 $\times 10^5$ μs, the leader process (L1) is characterized by a slow descending negative electric field change accompanying with intensive VHF radiations. In contrast to this, the leader process after this time span but before the return stroke shows a fast descending negative electric

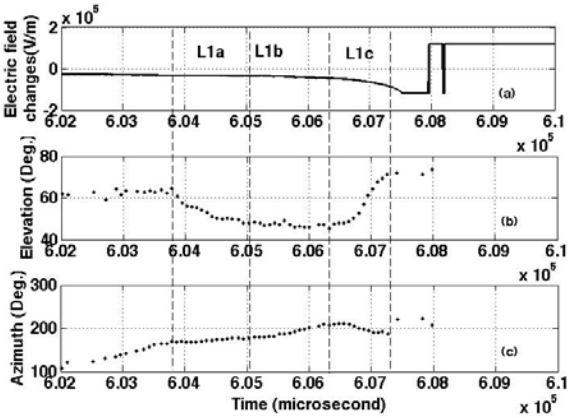
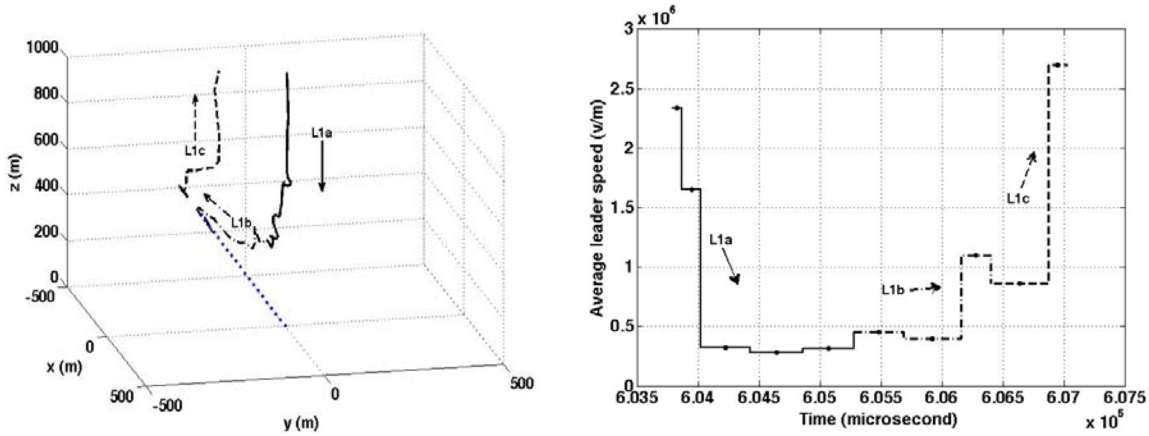


Figure 3: Expansion of the electric field and VHF data for the first leader-return stroke process in Figure 1.

field change with few VHF radiations. The former, which is with intensive VHF radiations, can be further divided into three stages, namely L1a, L1b and L1c respectively. As shown in the figure, the elevations show a trend of descending for L1a, but a horizontal trend for L1b and an ascending trend for L1c. While the azimuths show a trend of slow ascending for L1a and L1b but an opposite trend for L1c. As it will be revealed later on, the three stages have quite different space propagation features from each other.

Figure 4 shows the rebuilt 3D channel (a) and the channel evolution speed (b) for leader L1. It is found that the L1a is a downward propagation stage in virgin air with a relative lower speed, while the L1b is a horizontally moving stage around the melt wire trace and the L1c is an upward propagating stage along the trace of previous initiation leader channel with a relative higher speed. The L1c (upward) may be explained as a reflection of the L1a (downward) at the tip of the melt triggering wire trace into the trace of the previous initiation leader channel. Such a reflection process might be a special phenomenon for triggered lightning and be optically invisible to the camera, similar to the previous initiation leader. The speed for L1a shows a decrease from 2.32 to 0.32 $\times 10^6$ m/s as it descended, while that for L1c shows an increase from 0.85 to 2.7 $\times 10^6$ m/s as it ascended. The speed for L1b is in a range of 0.4~1.1 $\times 10^6$ m/s.



(a) (b)

Figure 4: Similar to Figure 2, but the rebuilt 3D channel (a) and the channel evolution speed (b) for the leader (L1) preceding the first return stroke.

The second leader-return stroke process: L2

Figure 5 shows an expansion of the electric field changes and VHF radiation source data for the second leader-return stroke process (R2) of the discharge in Figure 1. As shown in the figure, this leader process (L2) has a similar feature to that of L1 but with a shorter lasting time. Similar to L1, L2 is also divided into three stages, namely L2a, L2b and L2c respectively. The elevations show a trend of descending for L2a, horizontal for L2b and ascending L2c, while the azimuths show a trend of ascending for L2a and L2b and

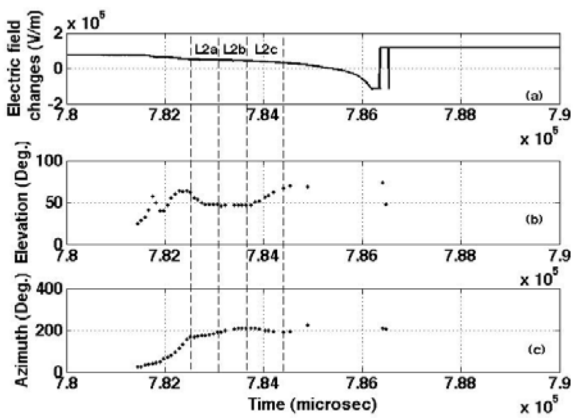
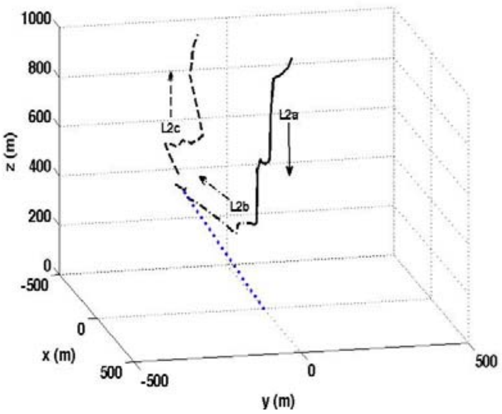


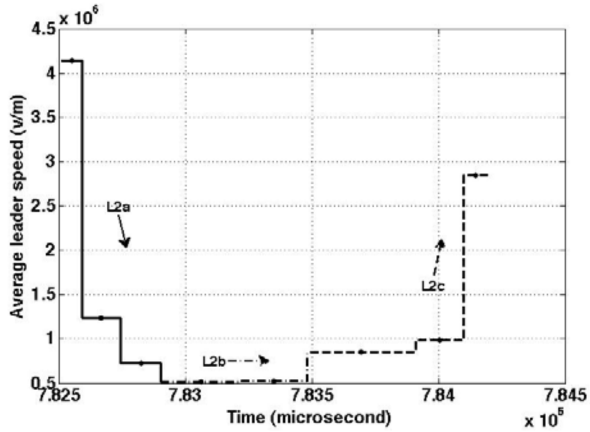
Figure 5: Expansion of the electric field and VHF data for the second leader-return stroke process in Figure 1.

descending for L2c, indicating the three stages are with different propagation features from each other.

Figure 6 shows the rebuilt 3D channel (a) and the channel evolution speed (b) for leader L2. The stage L2a propagated downward in a similar path to L1a but with a higher speed, while the L2b and L2c are quite similar to L1b and L1c in both the propagation path and speed. The speed for L2a shows a decrease from 4.13 to 0.5 $\times10^6$ m/s as it descended, and that for L2c shows an increase from 0.83 to 2.8 $\times10^6$ m/s as it ascended. The speed for L2b is in a range of 0.5~0.83 $\times10^6$ m/s.



(a)



(b)

Figure 6: Similar to Figure 2, but the rebuilt 3D channel (a) and the channel evolution speed (b) for the leader (L2) preceding the second return stroke.

CONCLUSIONS

The initiation leader process and two leader-return stroke processes involved in a triggered lightning discharge was analyzed based VHF broadband interferometer observations.

It was found that the initiation leader started inside the cloud and then propagated downward. As the leader descended to about 300 m high, it turned to move horizontally and finally attached to the tip of the triggering wire. The speed of the initiation leader decreased from 3.7 to 0.3 $\times10^6$ m/s as it descended.

The leader preceding the first return stroke (L1) included three stages: L1a, L1b and L1c. In stage L1a, the leader started inside the cloud and propagated downward, but with a different channel to that of the initiation leader. In stage L1b, as the leader descended to about 300 m high, it turned to propagate along the same zigzag portion of the previous initiation leader trace toward the triggering wire trace. In stage L1c, as the leader attached to the tip of the triggering wire trace, it turned to propagate upward along the same vertical portion of the previous initiation leader channel. The stage L1c might be a reflection of L1a at the tip of triggering wire trace due to different conductivities between the leader channel in air and the melt triggering wire trace. The speed for L1a showed a decrease from 2.32 to 0.32 $\times10^6$ m/s as it descended, while that for L1c showed an increase from 0.85 to 2.7 $\times10^6$ m/s as it ascended. The speed for L1b was in a range of 0.4~1.1 $\times10^6$ m/s.

The leader preceding the second return stroke (L2) behaved similarly to that of L1 but with higher speeds. The speed ranges were 0.5~4.13 $\times10^6$ m/s, 0.5~0.83 $\times10^6$ m/s and 0.83~2.8 $\times10^6$ m/s for the L2a, L2b and L2c respectively.

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