CONNECTION TO GROUND OF AN ARTIFICIALLY TRIGGERED NEGATIVE DOWNWARD STEPPED LEADER

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Abstract. This paper describes, based on current and electric field measurements, the sequence of events occurring during the "altitude" triggered lightning 9516 initiated at Camp Blanding (Florida). This experiment enables (1) the investigation of the bi-directional leader development from an electrically floating conductor, and (2) the attachment of a negative stepped leader to a grounded structure.

1. Introduction

The "classical" triggering technique involves the launching of a small rocket which spools out a thin copper wire connected to the ground. Such an experimental has been widely used to investigate the upward positive leader inception and development. The "altitude" triggering technique is used to study the bi-directional leader development from an ungrounded conductor spooled out in altitude several hundred meters above ground. A specific set-up is used to assure the connection of the negative part of the bi-directional leader to a grounded structure ; thus making possible a study of the lightning attachment process inherent in natural cloud-to-ground discharge but absent in classique triggered lightning. The present paper describes the general phenomenology of these various processes in altitude triggered lightning inferred from electrical field and current measurements.

2. Data

2.1. Experimental set-up

In the case of altitude triggered lightning, the rocket first spools out 50 m of grounded wire, followed by 400 m of Kevlar and, finally, a second (triggering) copper wire is extended. When this last wire has been trailed out over a sufficient length, a bi-directional leader initiates from its extremities [1]. An upward positive leader is initiated from the tip of the rocket and propagates toward the cloud. A few milliseconds later, a downward negative leader is initiated from the bottom of the triggering wire and propagates toward the ground. Its connection to ground is produced by an upward connecting positive leader initiated from the lower 50 m long grounded wire.

The current flowing through the 50 m long wire was measured by a shunt of 1 mΩ. The fast electric field variation was measured by two capacitive antennas A_1, A_2 placed at 50m from the lightning channel. Magnetic was measured by a sensor, placed at 55 m from the lightning channel.

2.2. Experimental results

Electric field measurements can be used as a guide to infer the main chronological sequence of events which occurred before the first return stroke (fig. 1).

- From time t_0 to t_1, the electric field at ground increases slowly with a mean slope of 30 kV/m/s (fig. 2a). This field rise at ground is most probably related to a positive leader extension from the top of the wire.
- At time t1, two small pulses (about 3.5 V/m each ; unresolved in fig. 2a) are superimposed to the continuous field increase. These pulses are consistent with a charge ΔQ of about 40 μC placed at 450 m above ground. They may therefore be associated with negative coronas inception at the lower end of the wire.
- From time t_1 to t_2, a further slow field variation is observed, similar to the one measured from t_0 to t_1, with a mean slope varying from 30 kV/m/s to 49 kV/m/s (fig. 2a).
- At time t_2, a fast stepped electric field variation is detected which can be attributed to a negative leader inception at the lower end of the wire (fig 2b). Each step is of about 15 V/m and is consistent with a charge of about 170 μC at 450 m above ground. After 8 steps, at time t_3, the negative leader development appears to pause.
- From time t_3 to t_4, the positive leader apparently continues as indicated by the further field increase after t_3 (fig. 2a). The increase of the electric field slope after t_3 (121 kV/m/s) relative to the slope prior to t_2 (30 to 49 kV/m/s) suggests that the positive leader accelerated following the downward negative leader inception.
- From time t_4, a negative leader resumes with a mean step field variation equal to 23.5 V/m (consistent with ΔQ=270 μC at 450m) with a time interval of 18.5 μs (fig. 2c).
- Current measurement at the bottom of the grounded wire indicates that a positive upward leader starts at time t_5 (fig. 3b), 1 ms after the negative stepped leader onset. At that time the electric field at ground reaches 10 kV/m. The positive leader development current exhibits pulses separated by 20 μs or so. The pulse peaks increase up to 200A at the junction (fig. 3b) and the DC component reaches 50 a few microseconds before the first stroke.
- At t_6, the contact between the stepped negative leader and the upward positive leader is established. The current rapidly increases to 5 kA (fig. 4a), apparently the start of the return stroke, and the electric field decreases from 44 kV/m to 37 kV/m (fig. 4b).
- The current is cut off after t_7 due to the high impedance of the exploding lower wire and reestablishes itself by t_8, allowing the return stroke to continue. After this first stroke, three more strokes with peak currents of few kA are observed. The altitude triggered lightning analysed here is further discussed by Uman et al. and Rakov et al. at this conference.

3. Summary

The altitude triggering technique offers an unique opportunity to study the bi-directional leader process similar to the one assumed to be involved in the aircraft-initiated lightning [2]. The coupling between the two leaders is likely evidenced by the acceleration of the positive leader (increasing of the electric field slope rate) following the negative leader inception.

The experiment described here enables the investigation of the connection to ground of the negative part of this bi-directional leader. The upward connecting positive leader development from the 50m wire has been analysed via the current measurements which confirm the discontinuous (pulsed) development of the upward positive leader as observed in classical triggered lightning using conducting wire connected to ground [3].

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References

[1] P. Laroche, V. Idone, A. Eybert-Berard, L. Barret, "Observations of bi-directional leader development in a triggered lightning flash." Int. Conf. on lightning and Static Electricity, April 1991, Cocoa Beach USA.

[2] V. Mazur "A physical model of lightning initiation on aircraft in thunderstorms", JGR Vol.94, N° D3, March 1989.

[3] A. Bondiou, P. Laroche, I. Gallimberti "Modelling of the positive leader development in the case of long air gap discharge and triggered lightning" 22nd Int. Conf. on lightning protection Sept. 1994, Budapest Hungary.

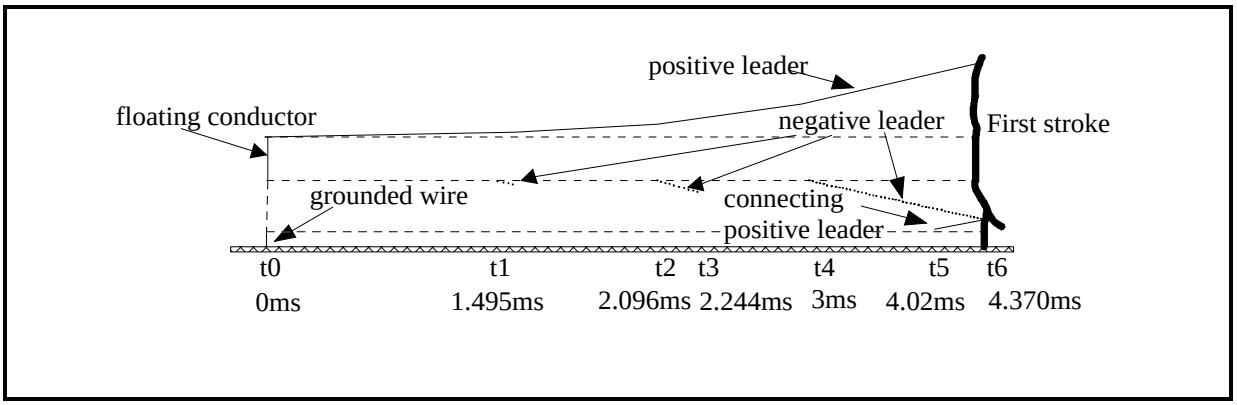

Figure 1: Chronological sequence of events during an altitude triggered lightning 9516 as inferred from current and electric field measurements.

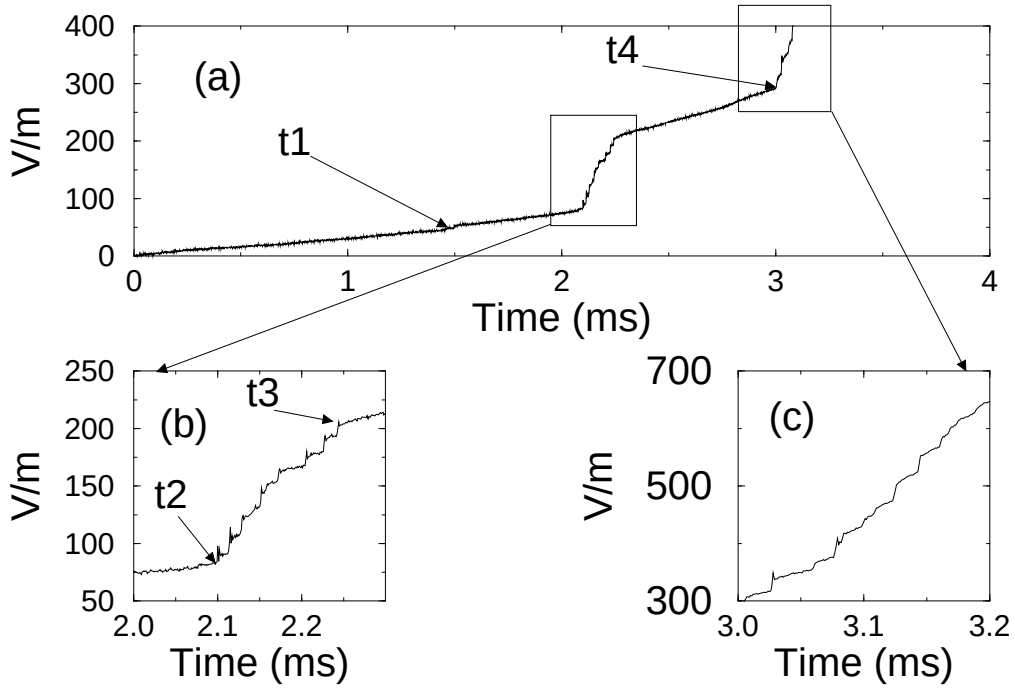

Figure 2: Electric field variation measured by antenna A_1 at 50m from the lightning channel.

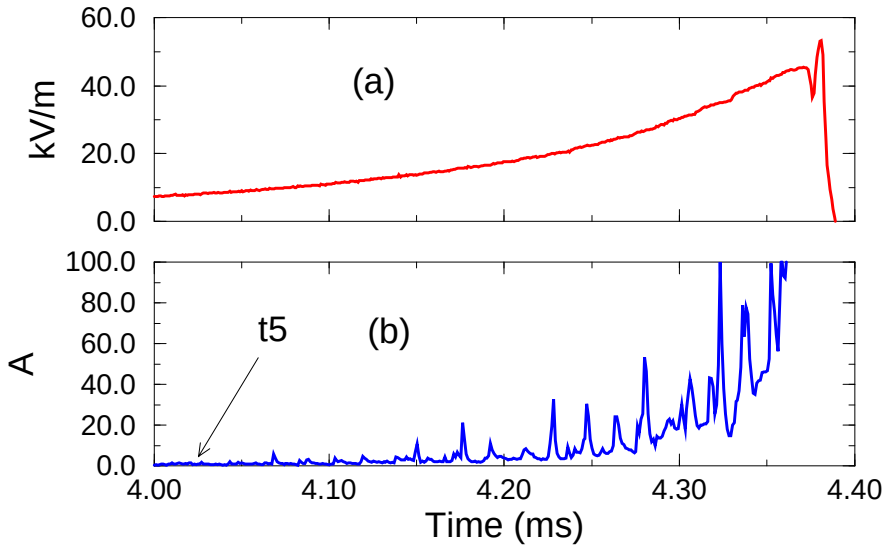

Figure 3: (a) Electric field variation measured by antenna A_2 at 50m from the lightning channel; (b) current produced by the upward connecting positive leader from the grounded 50m long wire .

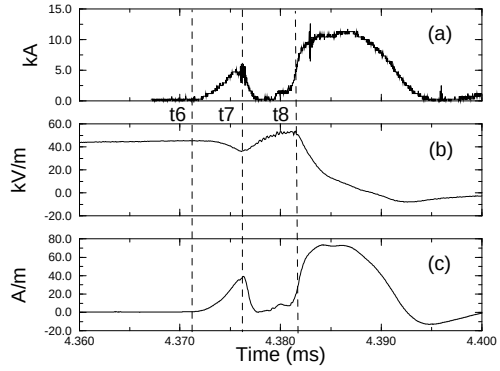

Figure 4: (a) current of the first return stroke; (b) Electric field variation measured by antenna A_2 at 50m from the lightning channel; (c) magnetic field at 50m from the lightning channel.