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LIGHTNING PROPERTIES FROM TRIGGERED-LIGHTNING EXPERIMENTS AT CAMP BLANDING, FLORIDA (1997 – 1999)

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Abstract: In this review, we present selected results from the triggered-lightning experiments conducted in 1997-1999 at the International Center for Lightning Research ant Testing (ICLRT) at Camp Blanding, Florida. The review is divided into the following four sections: (1) close lightning electromagnetic environment, (2) return-stroke speed profile within 400 m of ground, (3) dart-stepped leader, and (4) M-component mode of charge transfer to ground.

Keywords: Triggered Lightning, Electromagnetic Environment, Return-Stroke Speed, Dart-Stepped Leader, M component

1. INTRODUCTION

Experimental data presented here were obtained at the International Center for Lightning Research and Testing (ICLRT) at Camp Blanding, Florida, which is located approximately 45 km to the northeast of Gainesville, home of the University of Florida. A summary of lightning triggering operations conducted for various experiments at the ICLRT from 1997 to 1999 is presented in Table 1. Over the three-year period, the number of rocket launchers used varied from two to four, and the total number of triggered lightning discharges was 112 (from 30 to 48 per year). In 1999, two flashes were triggered in January, the first triggering in Florida winter. More information on the ICLRT at Camp Blanding, Florida, is found at web site http://www.lightning.ece.ufl.edu.

In this review, we present selected results from the experiments conducted in 1997-1999. Additional information on these and other experiments at ICLRT is found in Rakov et al. (1995a, 1998) [1, 2], Uman et al. (1997, 2000) [3, 4], Crawford et al. (1999) [5], Wang et al. (1999a, b, c) [6, 7, 8], Fernandez et al. (1999) [9], Bejleri et al. (2000) [10], and Mata et al. (2000) [11].

2. CLOSE LIGHTNING ELECTROMAGNETIC ENVIRONMENT

Measurements of electric fields at distances 10, 20, 30, 50, 110, and 500 m from the lightning strike point obtained in 1997 at Camp Blanding, Florida indicated that the leader field change varies approximately as inverse distance (r^{-1}) (Crawford et al. 1999) [5]. On the other hand, for the 1993 measurements at 30, 50, and 110 m, a weaker than inverse distance dependence was observed. Variation of leader electric field change with distance as r^{-1} is consistent with a more or less uniform distribution of charge along the bottom portion of the fully formed leader channel. Additional data acquired in 1998 and 1999 support, with a few exceptions, the r^{-1} dependence.

Table 1. 1997-1999 Triggered Lightning Experiments at ICLRT at Camp Blanding, Florida

Year	Launchers Used	Total Flashes Triggered	Flashes with Return Strokes	Positive or Bipolar Flashes	Time Period
1997	4	48	28	1	May 24–Sept. 26
1998	3	34	27	-	May 15, July 24-Sept. 30
1999	2	30	22	1	Jan. 23, June 26-Sept. 27
1997–1999		112	77	2	

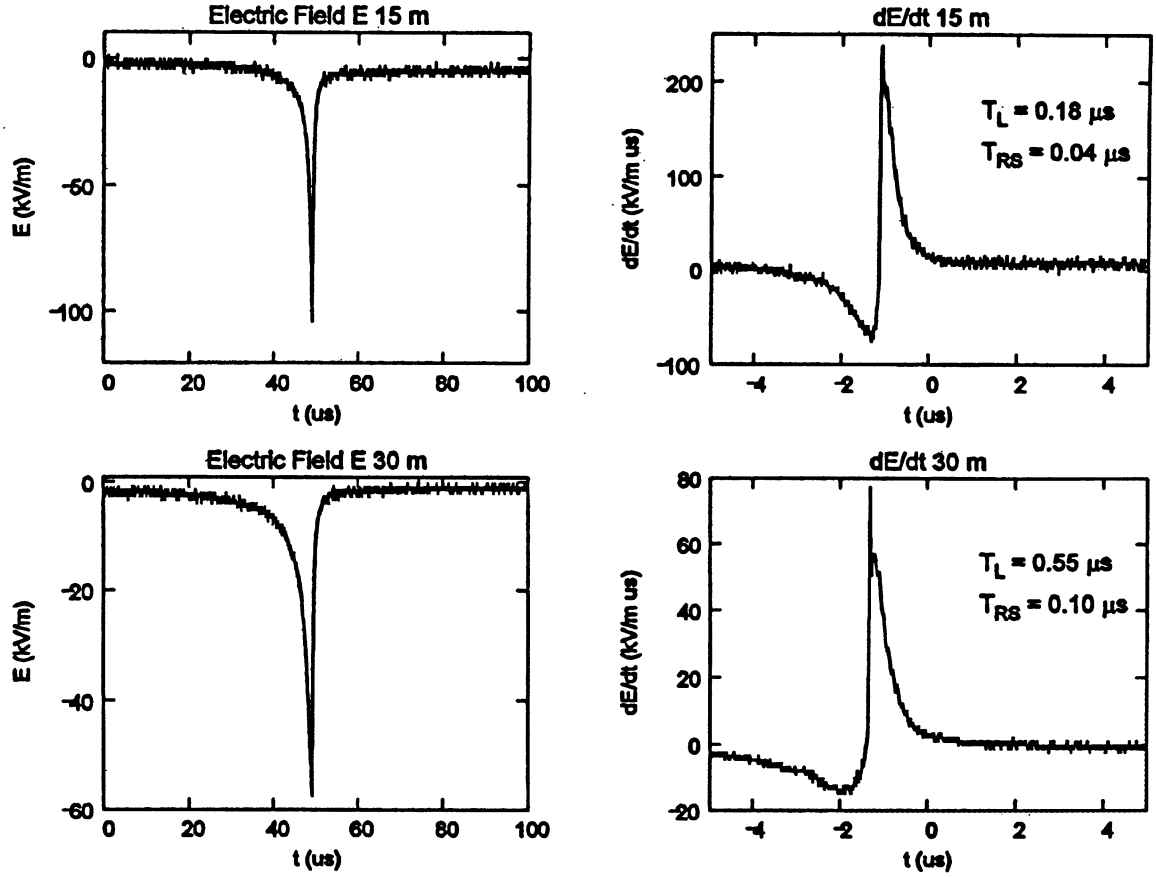

Figure 1. Electric field and electric field derivative (dE/dt) waveforms for stroke 2 in rocket-triggered flash S9918 measured at 15 and 30 m from the lightning channel at Camp Blanding, Florida.

From 1993 through 1998, the rocket launching systems used at ICLRT had a height of typically 3 to 7 m (including the lightning strike rod) and were placed on the ground or on top of a wooden tower. Electric and magnetic fields produced by triggered lightning were measured after they had propagated over sandy soil. In order to minimize the influence of the triggering structure and of propagation effects due to the finite soil conductivity, in 1999 we constructed a new triggering facility at ICLRT. In this facility, the launcher was placed below ground level and was surrounded by a buried metallic grid having dimensions of 70 m by 70 m. The grid had a mesh size of 5 cm by 8 cm and was buried at a depth of approximately 20 cm. The top of the underground launcher (about 4 m tall), which was nearly flush with the ground surface, was bonded via four symmetrically-arrayed metal straps to the buried grid. In order to increase the probability of lightning attachment to the instrumented launcher, a lightning strike rod was mounted on top of the launcher. The height of this rod above ground initially was 1 m and later was increased to 2 m. Electric and magnetic fields and their rates of change (time derivatives) were measured at distances of 15 and 30 m from the lightning strike rod. Electric field and electric field derivative data for a stroke that attached to the 1-m strike rod and exhibited a relatively straight and vertical channel are shown in Fig. 1. The E-field waveforms are displayed on a 100-µs time scale, while the dE/dt waveforms are displayed on a 10-µs time scale. This stroke transported negative charge to ground; its return-stroke current had a peak value of 15 kA.

The E-fields in Fig. 1 exhibit characteristic V-shaped waveforms with the bottom of the V corresponding to the transition from the dart leader stage to the return stroke stage. For the dE/dt waveforms, the zero crossing corresponds to the bottom of the V, so that the negative part of the dE/dt signature corresponds to the leader and the positive part to the return stroke. Note from Fig. 1 that at 15 m the dE/dt peak for the leader is a significant fraction of that for the return stroke. Uman et al. (2000) [4], who measured dE/dt at 10, 14 and 30 m at ICLRT in 1998 (the field propagation path was over sandy soil as opposed to propagation over a buried metallic grid), reported that for one event dE/dt for the dart leader at 14 m was more than 70% of the dE/dt for the corresponding return stroke.

The peak values of the E-field pulses in Fig. 1 are 102 kV/m at 15 m and 56 kV/m at 30 m, suggesting a distance dependence close to inverse proportionality. As discussed above, this result is consistent with the assumption of a uniform charge distribution along the leader channel within a few hundred meters of ground. For a uniformly charged leader, it is possible to find, from electrostatic considerations, the height H of the descending leader tip above ground at the time of maximum dE/dt (negative maximum in Fig. 1). This height for measurements at 15 m is about 11 m. Further, we can measure the time interval T_L between the leader dE/dt peak and the dE/dt zero crossing, the latter corresponding to the arrival of leader tip at ground, the presence of the 1-m strike rod being neglected. At 15 m, this time interval (travel time from a height of 11 m to ground) is 0.18 μs. Computing the ratio of H and T_L we find the effective downward dart-leader speed within 11 m of ground to be 6 x 10^7 m/s. If we formally apply the same electrostatic approach to the return stroke, we find an effective upward return-stroke speed of 2 x 10^8 m/s. Using the same procedure and measurements at 30 m (see Fig. 1) yields speed values of 4 x 10^7 m/s and 2 x 10^8 m/s for dart leader and return stroke, respectively. The values of speed for the dart leader are near the upper end of the range based on optical measurements (Jordan et al. 1992) [10]. This result appears to be reasonable since (1) our speed estimates are for the bottom few tens of meters of the channel, (2) optical measurements yield speeds averaged over some hundreds of meters, and (3) there is a tendency for the dart leader to accelerate as it approaches ground (Wang et al. 1999c) [8]. Interestingly, our speed estimates for the return stroke are consistent with both optical measurements (see Section 3 below) and with speed estimates based on the use of measured dI/dt and close dE/dt waveforms and of the transmission line return-stroke model (Uman et al. 2000) [4]. In the latter estimates it is assumed that the peak of the return-stroke dE/dt waveform at a few tens of meters from the channel is determined primarily by the radiation field component.

3. RETURN-STROKE SPEED PROFILE WITHIN 400 M OF GROUND

Two return-stroke speed profiles within 400 m of ground have been obtained at the ICLRT using the digital optical system ALPS (Yokoyama et al. 1990) [13]. These profiles are reproduced in Fig. 2. In this experiment, the time resolution of ALPS was 100 ns, and the spatial resolution was about 30 m. As seen in Fig. 2, the return-stroke speeds within the bottom 60 m of the channel for the two events are about 1.3 x 10^8 and 1.5 x 10^8 m/s. It is important to note that these latter measurements correspond to the time when the initial peaks of the channel-base current and electric or magnetic radiation field are formed. It is this value of speed that is needed for estimating current peak from measured radiation field peak and distance using simple return-stroke models (e.g., Rakov and Uman 1998) [14]. Previous optical measurements yielded speed estimates of about 1 x 10^8 to 2 x 10^8 m/s averaged over some hundreds of meters of the channel, leaving a room for doubt whether these average speed values were representative of the lowest tens of meters of the channel. Measurements presented in Fig. 2 demonstrate that return-stroke speeds averaged over lowest tens of meters and over hundreds of meters are similar.

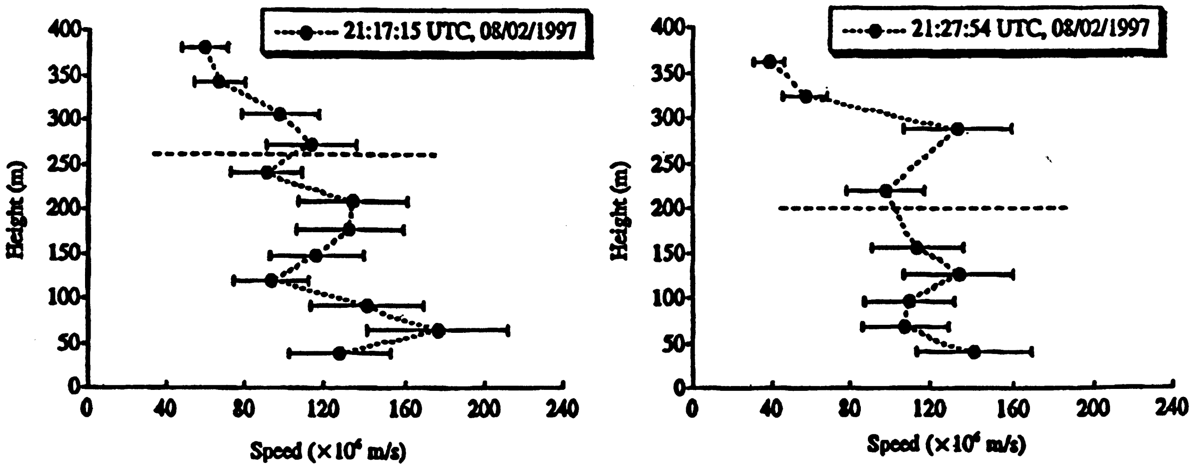

Figure 2. Propagation speed versus height for two return strokes in two different flashes triggered at Camp Blanding, Florida. Each solid circle represents a value of speed averaged over a 60-m section of the channel.

4. DART-STEPPED LEADER

Important new insights into the lightning leader stepping mechanism have been obtained from the light profile for one dart-stepped leader in triggered lightning recorded with the ALPS system (see Section 3 above). The lower portion of this profile, within 219 m of ground and 60 μs prior to the return stroke, is reproduced in Fig. 3. Individual step pulses in Fig. 3 can be traced over several height levels. For example, pulse 10 can be detected at five levels. While the leader tip moves in the downward direction, the step pulses appear to originate at the leader tip in a process of step formation (unresolved within the spatial resolution of 30 m) and propagate upward over a distance from several tens of meters to more than 200 m. The upward propagation speeds of the step pulses ranged from 1.9 x 10^7 to 1.0 x 10^8 m/s with a mean

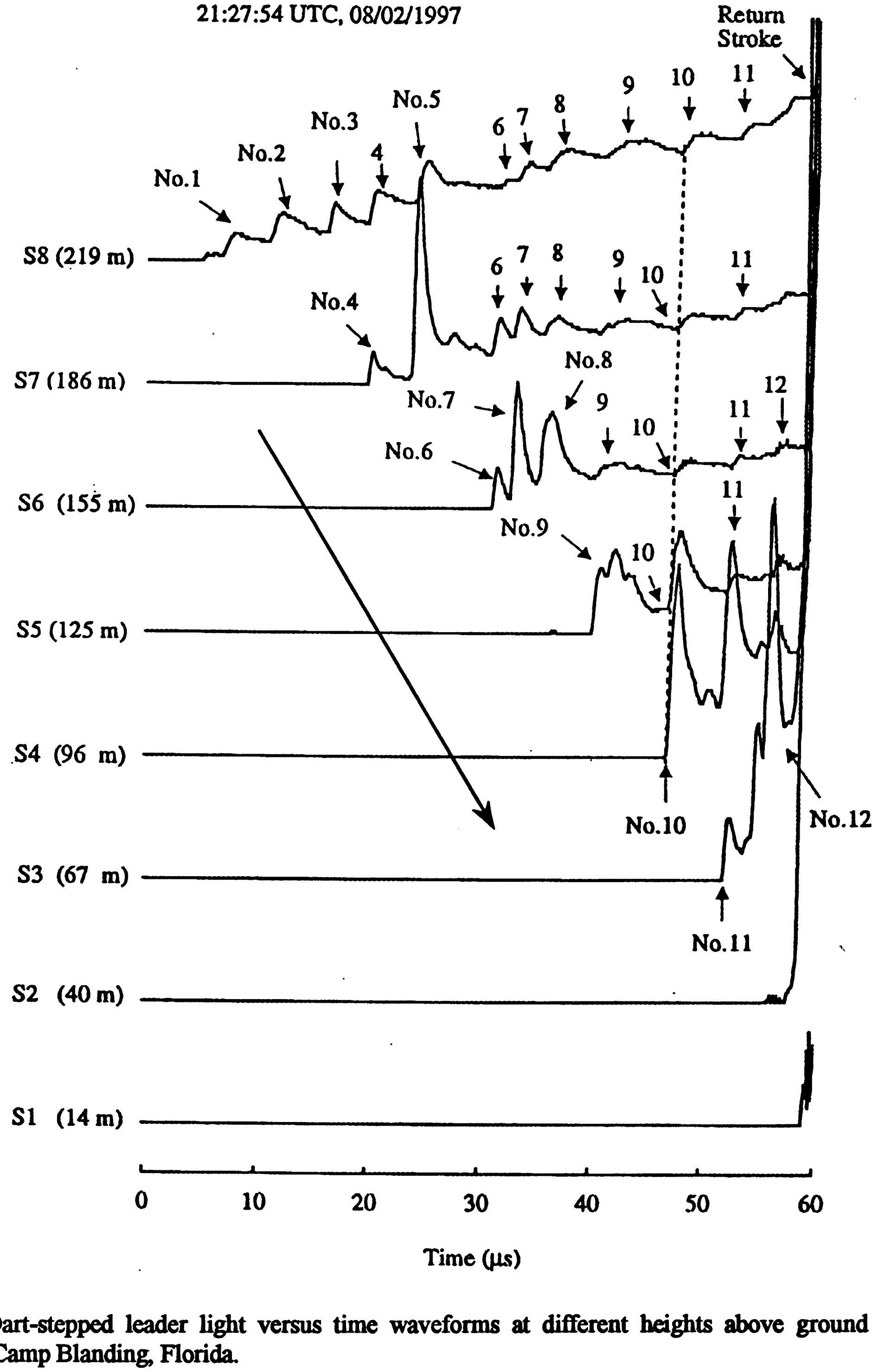

Figure 3. Dart-stepped leader light versus time waveforms at different heights above ground for a flash triggered at Camp Blanding, Florida.

value of 6.7 x 10^7 m/s, comparable to the return-stroke speed. The pulses attenuate significantly during their upward propagation, to about 10% of the original value within the first 50 m. The dart-stepped leader illustrated in Fig. 3 exhibited an increase in the downward extension speed from 2 x 10^6 to 8 x 10^6 m/s during its propagation from 200 to 40 m, with an average speed of about 2.5 x 10^6 m/s. Using this average speed value and the measured mean interstep interval of 4.6 μs, we can estimate an average step length of about 12 m, assuming that the leader channel extends downward only during the step-formation process. It has been previously inferred from multiple-station electric and magnetic field measurements that the formation of each step in a dart-stepped leader is associated with a charge of a few millicoulombs and a current of a few kiloamperes (Rakov et al. 1998) [2].

5. M-COMPONENT MODE OF CHARGE TRANSFER TO GROUND

Fig. 4 schematically shows current profiles for three modes of charge transfer to ground in subsequent lightning strokes: (a) dart leader/return stroke sequence, (b) continuing current, and (c) M-component. The M-component involves the superposition of two waves propagating in opposite directions. One wave moves toward ground, and the other wave, reflected from ground, moves toward the cloud. The amplitudes of these two waves are approximately equal, and the spatial front lengths are comparable with the distance between the lower cloud boundary and ground. The M-component mode of charge transfer to ground requires the existence of a grounded channel carrying a current of typically some tens to some hundreds of amperes. In contrast, the leader/return-stroke mode of charge transfer to ground occurs only in the absence of such conducting path to ground. Thus, the primary distinction between the two modes is the availability of a conducting path to ground.

As shown theoretically by Rakov et al. (1995a) [1] and confirmed experimentally by Crawford et al. (1999) [5], the M-component electric field varies with distance considerably slower than the dart leader electric field. The latter varies as r^{-1}, as noted in Section 2, while for the former the dependence in the distance range form 30 to 500 m is close to logarithmic. A few measurements at closer ranges indicate a stronger than logarithmic distance dependence, although for relatively large M-components. Besides "classical" M-components that occur during continuing currents following return strokes in cloud-to-ground flashes, the M-component type of charge transfer to ground, illustrated in Fig. 4, also occurs during the initial stage of both natural upward flashes and rocket-triggered flashes (Wang et al. 1999b) [7].

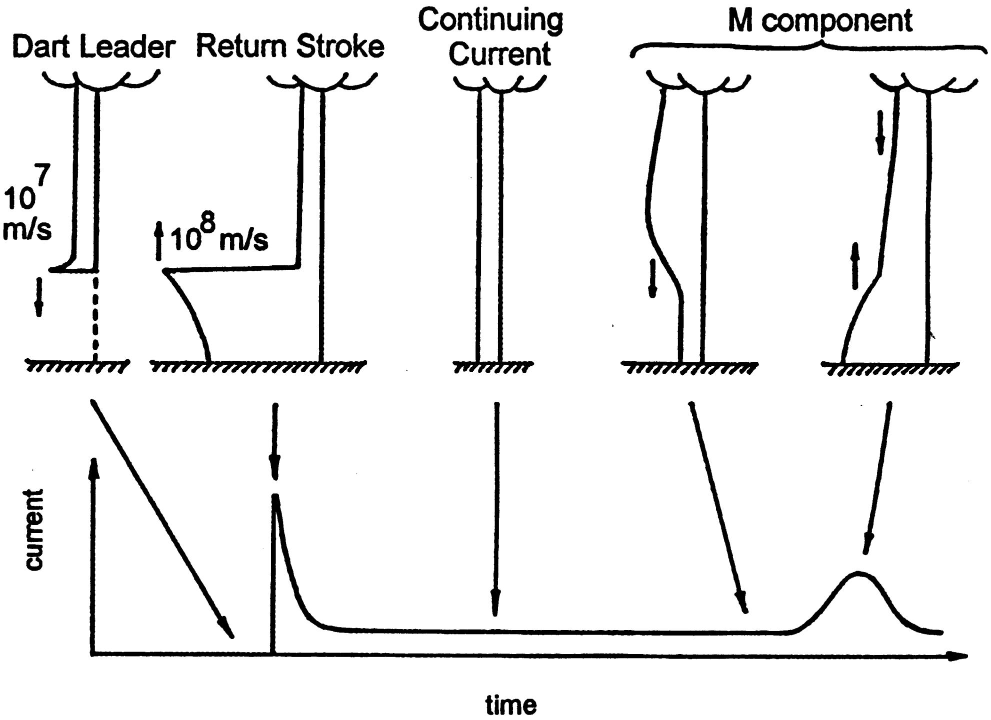

Figure 4. Schematic representation of current profiles for three modes of charge transfer to ground in subsequent lightning strokes: dart leader/return stroke sequence, continuing current, and M-component.

6. SUMMARY

The results of triggered-lightning experiments at the ICLRT at Camp Blanding, Florida have provided considerable insight into natural lightning processes that would not be possible to gain from studies of natural lightning due to its random occurrence in space and time. Among such findings are the characterization of the close (within tens to hundreds of meters) lightning electromagnetic environment, the return-stroke speed within lowest tens of meters of the lightning channel, new inferences regarding the lightning leader stepping process, and the discovery of the mechanism of the M-component mode of charge transfer to ground in lightning discharges.

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