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LUMINOSITY WAVES IN BRANCHED CHANNELS OF TWO NEGATIVE LIGHTNING FLASHES

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Abstract. The optical characteristics of two branched strokes of negative lightning flashes recorded by a high-speed digital optical system are presented. The first branched stroke had four visible branches. The branch light waves were initiated by the upward-moving return stroke wave in the main channel after it reached each branch. The light signals along the main channel and along the branch channels show significantly different propagation characteristics. The branch light signals show an irregular variation in rise time (more or less a decrease) as opposed to the gradual increase of the rise time of the return stroke light signal in the main channel with increasing height. The light signals at the branch tips can have a rise time as short as a few microseconds. The second branched stroke had two nearly identical channels spatially separated by about 200 m. Two return strokes originated independently from the ground along the two channels with a time difference of only 200 ns. The light signals along the two channels have remarkably similar waveforms and speed profiles. No superimposition effect of the return stroke waves is observed where the two upward-moving return stroke waves meet.

Key words: Lightning, Return Stroke, Branch

1. Introduction

First strokes of negative lightning flashes are generally characterized by numerous visible downward branches. It is probably these branches that make the return stroke radiation fields exhibit multiple peaks (Weidman and Krider, 1978). To understand better such return stroke radiation field signatures, the physical processes in the branches should be made clear. Using a streak camera, Schonland et al. (1935) have successfully resolved branches in several flashes. It was shown that all branches are initially formed during the downward development of leaders and then re-illuminated as a return stroke wave reaches the branch point. The re-illumination propagates outward following the branch channels previously created by the branched leader and finally catches up with the propagating leader tips. The re-illumination may reflect at the leader tips as reported by Schonland et al. (1935). The re-illumination process makes the branches appearing bright; otherwise they probably could not be viewed in most cases. If a branch touches the ground before the return stroke wave from the main leader (or branch) reaches the branched point and discharges it, an additional return stroke wave could be initiated from the ground. This will result in two strokes separated by a time of one millisecond or less as observed by Guo and Krider (1982) and by Rakov and Uman (1994). Using a high-speed digital camera system (ALPS), both types of branched strokes have been documented and presented here. Since the digital camera has much better time resolution than the film cameras previously used by Schonland et al. (1935), the documented data provide further insights into the properties of the branched strokes.

2. Data

The data used for the present study were recorded by the ALPS system during the summer of 1997 at the International Center for Lightning Research and Testing at Camp Blanding, Florida (Uman et al., 1997). The ALPS consists of a 16 × 16 pin photodiode array module and has a time resolution of 100 ns (Wang et al., 1998). Due to the limitation of the ALPS memory and thus the resultant total recording time at the time resolution of 100 ns, only the first strokes in natural lightning could be recorded. Among more than twenty natural lightning events obtained, only two show observable branches. Their still images, reconstructed from the ALPS recordings, are given in Figure 1. Each square (pixel) in Figure 1 corresponds to one diode of the 16 × 16 pin photodiode array. The scales shown in the figure are estimated by assuming that the cloud-base was 1.5 km high, a typical value for summer storms in Florida. The stroke that occurred at 18:41:36 UT, 7/8,1997 has four branches labeled from B_1 to B_4, while the main channel is labeled M. The stroke at 18:46:31 UT, 7/8,1997 shows two branched channels, and they are identified as L (left) and R (right).

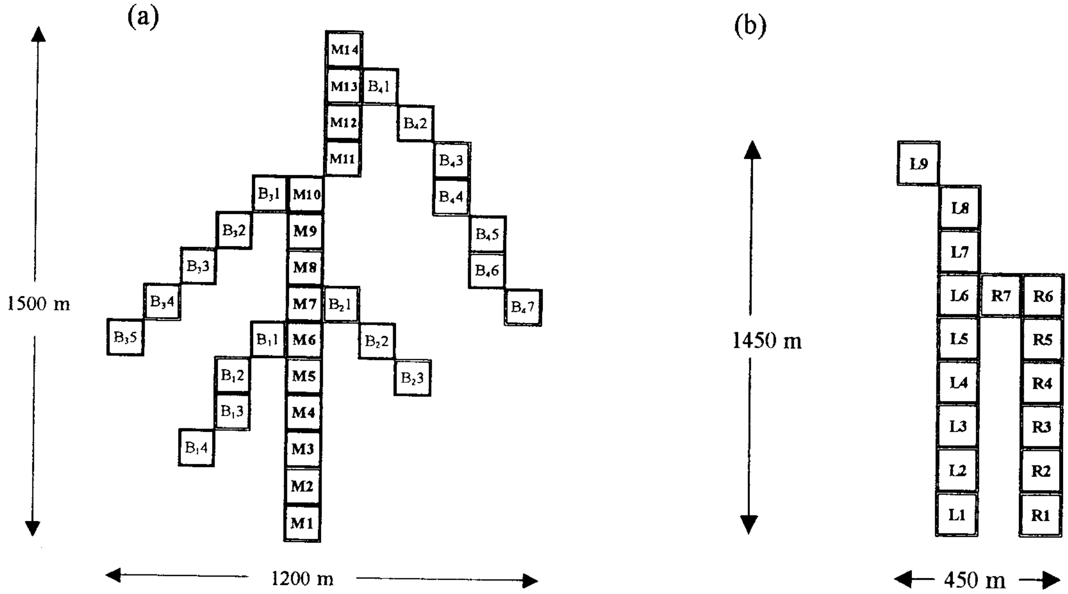


Figure 1 Still pictures of the branched-strokes recorded by ALPS and used for the present study. Each pixel corresponds to one diode in the photo diode array of ALPS. The letters inside the pixels are used for identification of different channel sections. (a) the stroke at 18:41:36 UT,7/8/1997 and (b) the stroke at 18:46:31 UT, 7/8/1997.

3. Results and discussions

Figure 2 presents the light waveforms as a function of time at various heights on the main channel of the 18:41:36 stroke. The various channel sections are indicated by the letters on the left of Figure 2. The letters are labeled sequentially from ground and correspond to those shown in Figure 1a. The straight distances (two dimensions) along the main channel to the centers of various channel sections, measured from the ground, appear in parentheses. Since this flash occurred in daytime, ALPS could not record its leader signal, that is, the waveforms

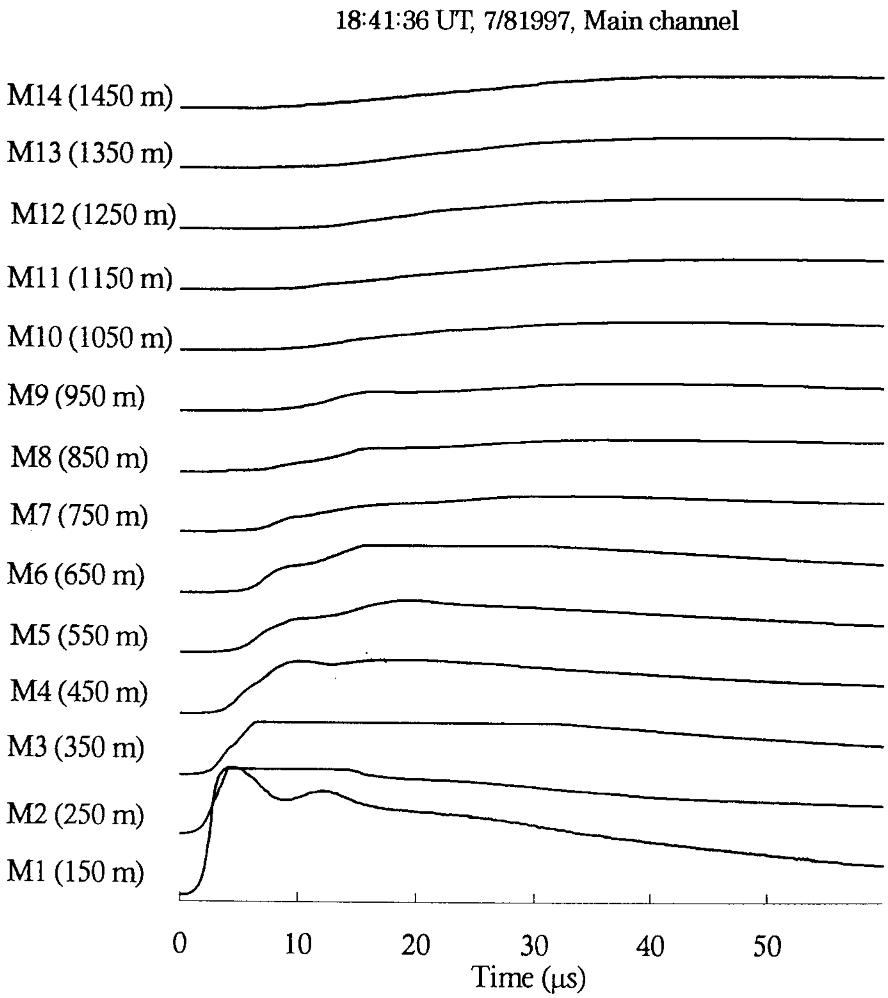


Figure 2. The light signals as a function of time at various heights of the main channel in Figure 1a.

shown in Figure 2 are only return stroke signals. As seen in Figure 2, the light signals occur later in time at progressively higher altitudes, and hence they are propagating upward. Apparently, the return stroke light signals along the main channel suffer a gradual attenuation (an increase in rise time and a decrease in magnitude) when moving upward. As an example, Figure 3 shows the light waveforms as a function of time for branches B_3 and B_4 at various distances along the branches from the main channel. The arrows in the figure show the starting point of the light signals along the branches. The starting points of $B_4$2 and $B_4$1 signals can not be identified. The waveforms prior to the arrows are caused by the scattered light from the main channel. As seen in Figure 3, the light signals occur later in time at progressively further distances from the main channel, and therefore they appear to propagate away from the main channel (outward). From Figures 1, 2 and 3, Branches B_3 and B_4 start, respectively, 14 μs and 15 μs after the onset of the main stroke when the main return stroke signals have already

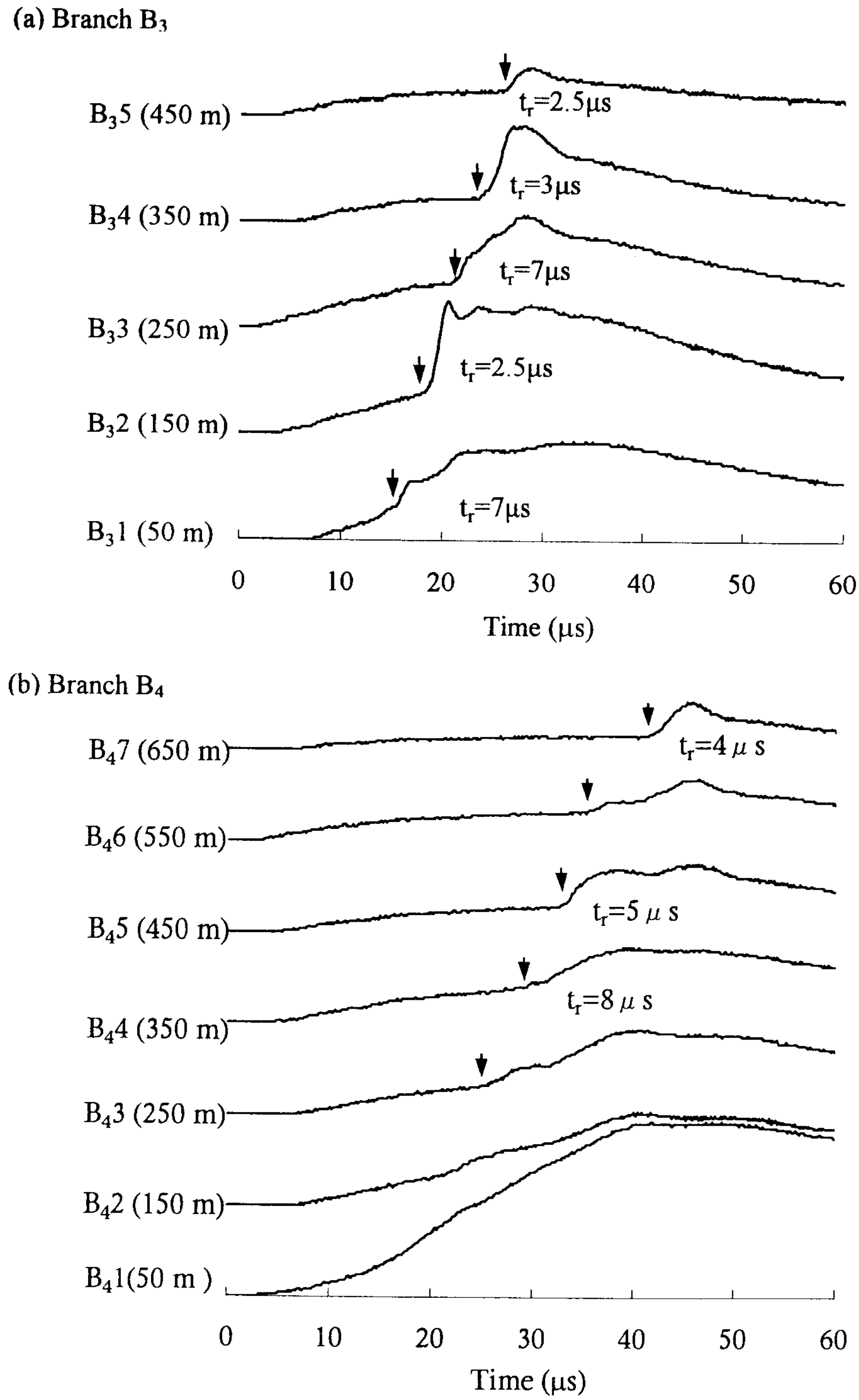


Figure 3 The light signal waveforms as a function of time at the various channel sections of branches B_3 and B_4 in the branched stroke shown in Figure 1a. (a) for branch B_3 and (b) branch B_4. Arrows indicate the starting points of the branch light waves. t_r represents the zero-to-peak rise time of the light signals.

reached the branching points. Clearly, the light signals in Figure 3 are caused by the propagation of return stroke waves along the branch channels. The zero-to-peak rise time of each signal has been measured and is shown in Figure 3. As seen in Figure 3, the branch light signals show an irregular variation of rise time as opposed to the gradual increase of the rise time of the return stroke light signal in the main channel. The branch light signals tend to become sharper as they propagate away from the main channel. Furthermore, as seen in Figure 3, the light signals along the branch channels could have a rise time as short as a few microseconds, comparable to the rise time reported for dart-leader light pulses by Jordan et al. (1997). Such branch waves could produce electric field radiation pulses with a rise time of a few microseconds. It is possible that along the main channel, the return stroke wave propagates from region with higher charge density to those with lower charge density, while along branch channels, the return stroke wave probably propagates from region with lower charge density to those with higher charge density. Such difference may account for why branch light signals do not suffer the same attenuation as the main channel signals. Conditions along the channel (conductivity) may also play a role.

To determine an average two dimensional return-stroke speed at a given channel section, the time difference between the initial fast rising portions of the light signals from its two neighboring channel sections are measured. The resulting error in speed is estimated to be less than 20%. Figure 4 shows the speed profiles for the light signals along the main channel and along branches B_3 and B_4. The average speed of the return stroke wave over the main channel is about 1×10^8 m/s; while over branches B_3 and B_4, the speeds are 5×10^7 m/s, 3×10^7 m/s, respectively. These results are in good agreement with those reported by Schonland et al. (1935).

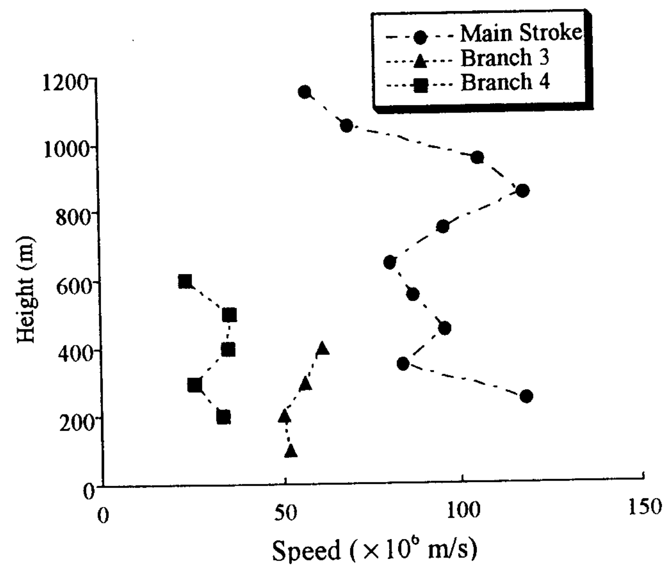
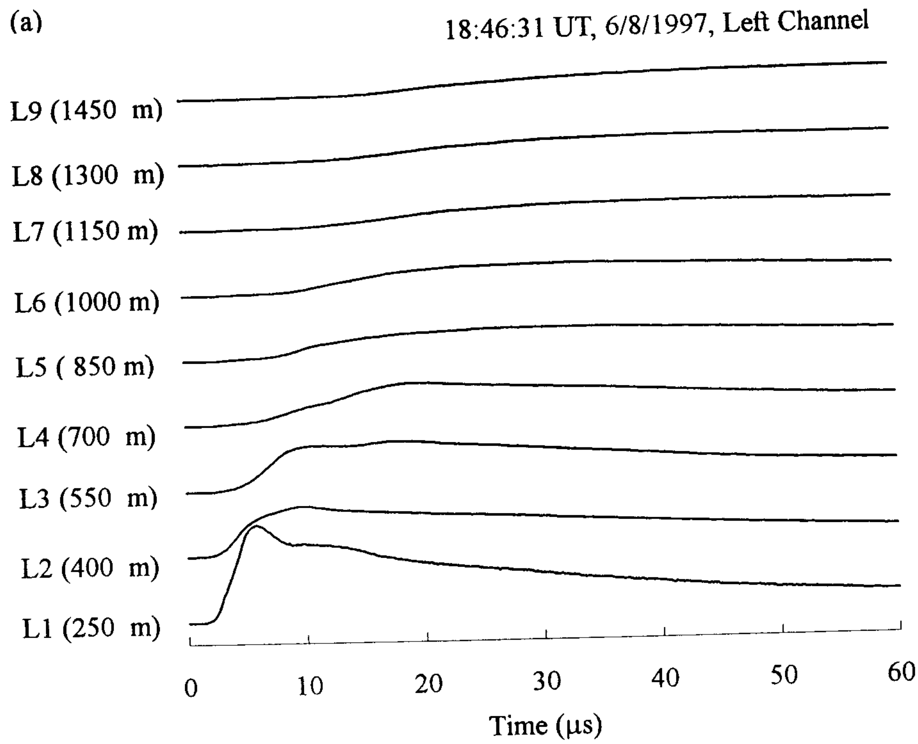


Figure 4 The propagation speed profiles of the stroke waves propagating along the main channel and the branches.

Figure 5 shows the light signals as a function of time at various heights of the two-channel stroke shown in Figure 1b. Figures 5a and 5b have the same time scale and the letters on the left of the figure correspond to those shown in Figure 1b. Since the light signals occur later in time at progressively higher altitudes, they are propagating upward. A careful comparison of Figures 5a and 5b shows that the onset of the waveforms at 250 m in Figure 5a is 200 ns prior to that of Figure 5b. This fact suggests that the left and the right return strokes are initiated within 200 ns of each other. Double ground strokes have been identified from the double electric field waveforms separated by time intervals of some tens to some hundreds of microseconds by Guo and Krider (1982) and by Rakov and Uman (1994). However, if two



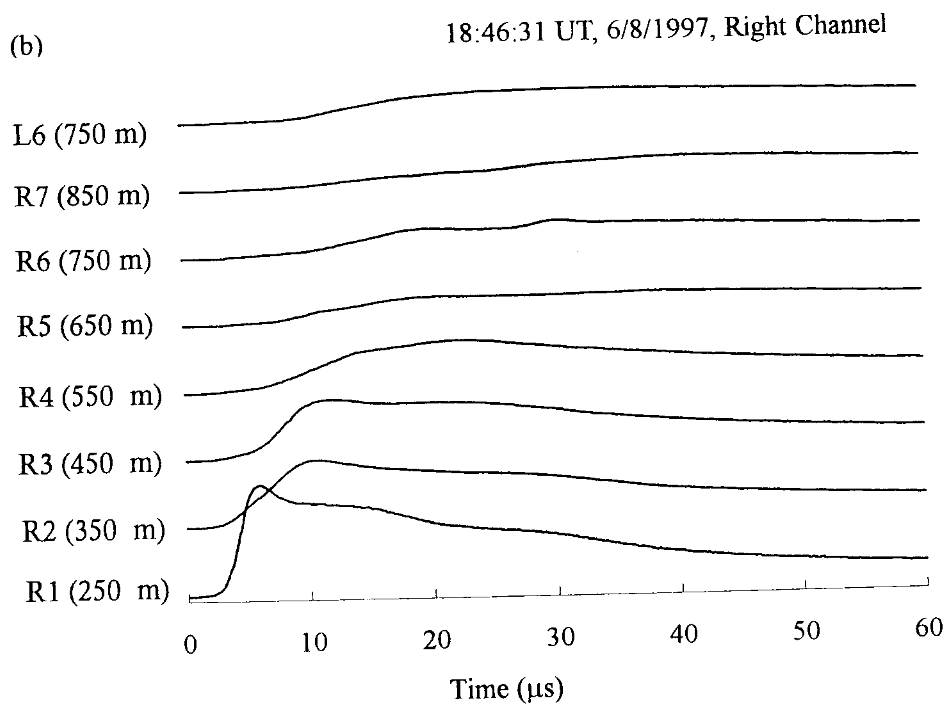


Figure 5 The light waveforms as a function of time along the two channels shown in Figure 1b. The letters on the left of this figure correspond to those in Figure 1b.

strokes separated by a time interval of several microseconds or less, such as the stroke shown in Figure 5, it will not be possible to identify them in electric field records. According to the authors' understanding, the double-channel stroke shown in Figure 5 exhibits the shortest time interval ever documented between the return-stroke waves propagating in two channels. As seen from Figure 5, the two strokes exhibit nearly identical light signals at the same height. Figure 6 presents the speed profiles for the left and right channels identified in Figure 1b. The return stroke waves along the two channels exhibit surprisingly similar speed profiles. These facts may suggest that a similarity holds for strokes developed in the same electric field environment. Although there are two waves appearing in the light signal of channel section R6, at the right channel section R7 at 1 km height where two return stroke waves merge, the light signal appears weaker rather than stronger than the light signals at the neighboring channel sections. It appears that the two return stroke waves did not linearly superimpose at the branched point. This result is certain to have significance for understanding the propagation characteristics of return stroke waves.

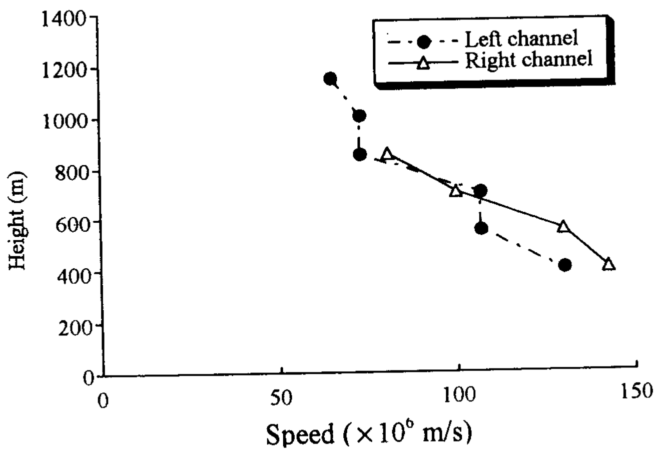


Figure 6 The speed profile of the return stroke waves along the double channel shown in Figure 1b.

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