High speed optical observation on the attachment processes of natural downward lightning discharges

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ABSTRACT: The attachment processes of the first strokes of 5 natural lightning discharges, recorded by using a high speed optical system specifically designed for observing the lightning attachment process, have been reported. Among the 5 lightning discharges, 3 occurred within the testing site of ICLRT and 2 several kilometers away according to NLDN. All the first return strokes are found to initiate at a height above the ground. Return strokes with larger peak current tend to initiate higher, similar to the results previously obtained for rocket triggered strokes.

INTRODUCTION

As shown in recent measurements for rocket triggered lightning, lightning attachment processes to flat ground or a low structure (as opposed to tall structures) usually occurred over a very limited vertical scale and at a very short time interval [e.g., Wang et al., 2013]. Given the random nature of a natural downward lightning, an optical observation on its attachment process with sufficient spatial and time resolution is extremely difficult. Using a high speed optical system specifically designed for observing the lightning attachment process (called LAPOS), we have been trying such observation since the summer of 2011 at the International Center for Lightning Research and Testing (ICLRT), Camp Blanding, Florida. ICLRT testing site covers an area about 1 km×1 km and its current facilities have been recently reported by Pilkey et al.[2014]. So far, we have recorded more than 20 rocket-triggered lightning flashes and 30 natural downward lightning flashes. Part of our results for the rocket triggered lightning have been published in JGR [Wang et al., 2013; 2014]. Among the 30 natural downward lightning flashes, 3 hit within the testing site. In this paper, we report our preliminary results on the attachment processes of 5 natural negative lightning flashes which include the 3 onsite ones.

OBSERVATION AND DATA

The high speed optical system used in the present study is a type of photodiode-fiber optics array system specifically designed for observing the lightning attachment process. The detail of the system has been previously reported by Wang et al. [2011; 2013]. One major advantage of the system is that it has a wide horizontal view so that for a similar vertical view properly covering the height range where lightning

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attachment process occurs, more natural lightning discharges could be recorded. In addition, it has a wide dynamic range by using alternatively sensitive and insensitive photodiodes in the array, so that in most cases both leader and return stroke light waveforms of a lightning event can be observed simultaneously. Three LAPOSs have been set up since the summer of 2011. Table 1 lists the 5 lightning discharges, three striking onsite at ICLRT and two occurring several kilometers from the ICLRT according to the NLDN, analyzed in this paper.

Table 1 Data list

Lightning No.	Time (UT)	Distance from LAPOS	Stroke multiplicity	Peak current of the first stroke
A	22:42:53,11/01/2014	630 m	3	-76.3 kA
B	21:02:00, 31/07/2011	340 m	1	-29.8 kA
C	17:52:02, 23/03/2013	395 m, 472 m	1	-8.9 kA
D	23:48:59, 12/08/2012	5.4 km	3	-67.0 kA
E	23:53:33,12/08/2012	6.6 km	2	-55.4 kA

RESULT

Lightning A (onsite)

This lightning hit on ground 630 m away from our optical observation system LAPOS at 22:42:53 (UT) on January 11, 2014. It contained three return strokes. According to NLDN, the peak currents of the three return strokes are -76.3 kA, -27.7 kA and -8.2 kA. Figure 1a shows the light intensity from seven different channel heights of the first leader/return stroke sequence recorded through sensitive photodiodes. Time 0 is arbitrarily chosen around the starting point of the return stroke. As seen in this figure, the light

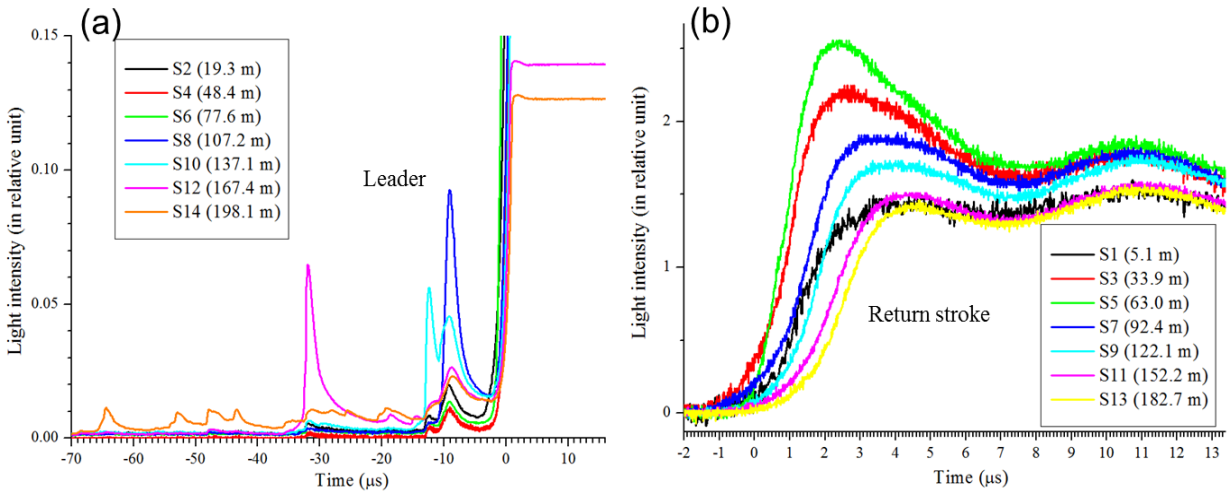

Figure 1. The light intensity from different channel heights of the first leader/return stroke sequence of lightning A. (a) leader part from sensitive channels of LAPOS and (b) return stroke part from insensitive channels.

first appeared at S14, about 198 m above the ground level. Then the light appeared at S12 (167 m), S10 (137 m), and S8 (107 m). These light signals are produced by its leader and clearly indicate that a stepped leader is propagating downward to the ground. Its downward speed measured from S14 to S8 is about 1.7 $\times 10^6$ m/s. The return stroke started about 10 μs after its last leader pulse occurred at the height S8 (107 m). Figure 1b presents the return stroke light intensity waveforms from seven different channel heights recorded with insensitive photodiodes. As seen from Figure 1b, although there are some lights first appeared at S3 (34 m) and S7 (92 m), the main light started at S5 (63 m) and then propagated into two directions with one being from S5 to S3, S1 and another from S5 to S7, S9, S11, S13. The return stroke initiation height can be estimated with the method given by Wang et al. [2013] to be about 90 m above the ground.

Lightning B (onsite)

This lightning hit on ground 340 m away from LAPOS at 21:02:00 (UT) on July 31st, 2011. It is a single stroke flash. According to NLDN, the peak return stroke current is -29.8 kA. Figure 2 shows its leader/return-stroke light intensities from various heights. The impulsive lights due to leader steps can be clearly identified in Fig.2. The stepped leader propagated to the ground with an average speed of 7.5×10^5 m/s. The last step of the leader occurred at S6 with a height of around 42 m above the ground. The return stroke light signals appeared saturated even in the insensitive channels due to a wrong setting in the LAPOS scope. Nevertheless, the data still allows us to estimate the return stroke initiation height and the result is about 27 m above the ground.

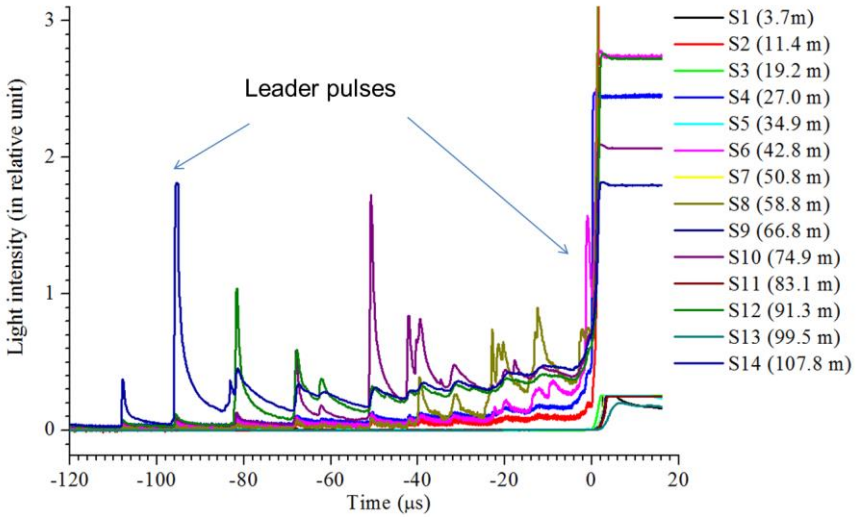

Figure 2. Leader/return-stroke light signals from various height of lightning B.

Lightning C (onsite)

This lightning discharge occurred with two separate strokes, with one of them striking on a pine tree about 4 m tall 472 m away from LAPOS 2 and another seemingly striking on the ground 395 m from LAPOS 3 at 17:52:02 on March 23rd, 2013. Figure 3 gives its leader/return stroke light records from

various heights of lightning C, with (a) for the strike on the pine tree and (b) on the flat ground. These two strikes occur with a time difference of less than 1 microsecond. It was interesting to note that their leaders propagated almost at identical speeds, with one (a) being 2.7×10^5 m/s and another (b) 2.6×10^5 m/s. Figure 4 shows the light records several microseconds around the two return strokes. Both return strokes started at a height of about 10 m above the ground.

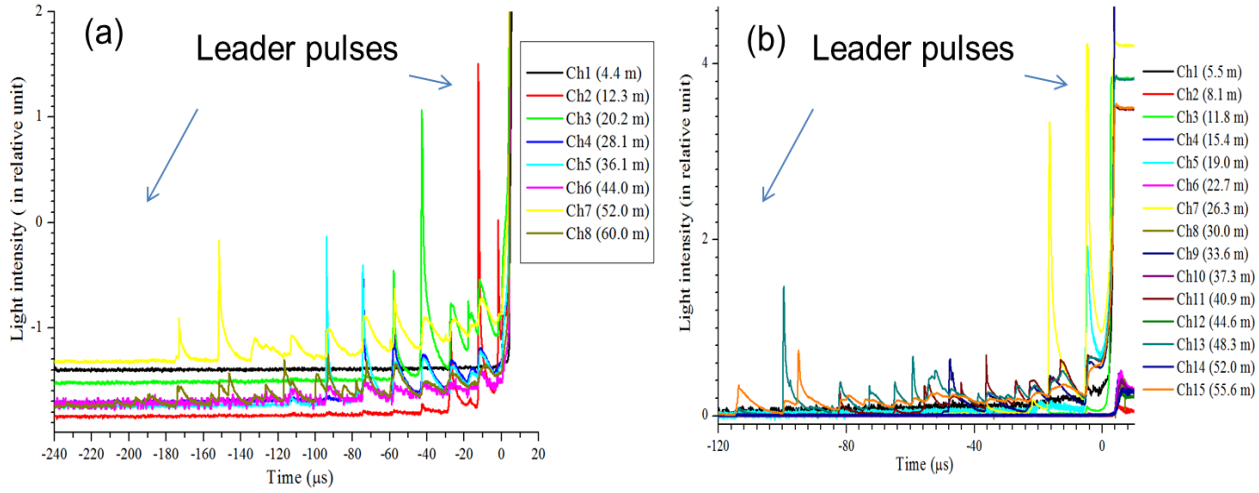

Figure 3. Lear/return-stroke light signals from various height of lightning C with (a) for the strike on the pine tree and (b) on the flat ground.

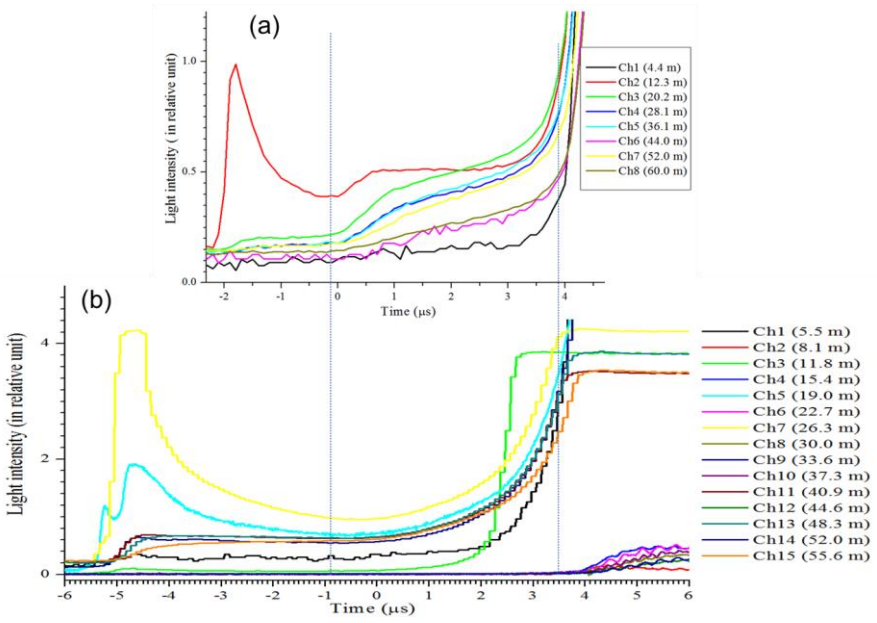

Figure 4. Return-stroke light signals from various height of lightning C with (a) for the stroke on the pine tree and (b) for the stroke on the flat ground. .

Lightning D (offsite)

This lightning discharge occurred at 23:48:59 on August 12, 2012 and contained three return strokes. According to NLDN, the lightning hit a location 5.4 km away from our optical observation system. Figure 5 shows the light intensity from various heights of its stepped leader/first return stroke. Downward leader pulses have reached at least to the height of 137 m above the ground, and upward return stroke can be seen at S4-S14. According to our estimation, S1 and S2 should be behind trees and their signals are just a kind of scattering light from surroundings. The leader speed estimated from S7 to S3 is about 1×10^{6} m/s and the return stroke speed estimated from S4 to S14 is 7.5×10^{7} m/s. The return stroke is estimated to start at a height of about 85 m.

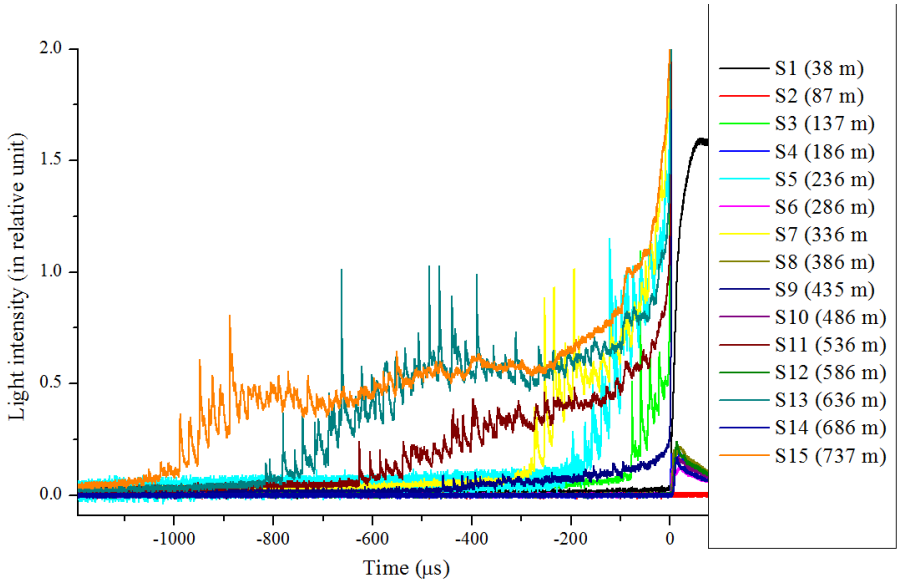

Figure 5. The light intensity from different channel heights of the first leader/return stroke sequence of lightning D

Lightning E (offsite)

This lightning discharge occurred at 23:53:33 on August 12, 2012 and contained two return strokes. According to NLDN, the lightning hit a location 6.6 km away from our optical observation system. Figure 6 shows the light intensity from various heights of its stepped leader/first return stroke. Downward leader pulses have reached at least to the height of 167 m above the ground, and upward return stroke can be seen at S4-S14. According to our estimation, S1 and S2 should be behind trees and their signals are just a kind of scattering light from surroundings. The leader speed estimated from S9 to S3 is about 5.1×10^{5} m/s and the return stroke speed estimated from S4 to S14 is 1.2×10^{8} m/s. The return stroke is estimated to start at a height of about 110 m. As a comparison, the leader and the return stroke speeds for the second stroke have also been estimated and are 6.8×10^{6} m/s and 1.6×10^{8} m/s, respectively. The second return stroke is estimated to start at a height of 35 m above the ground.

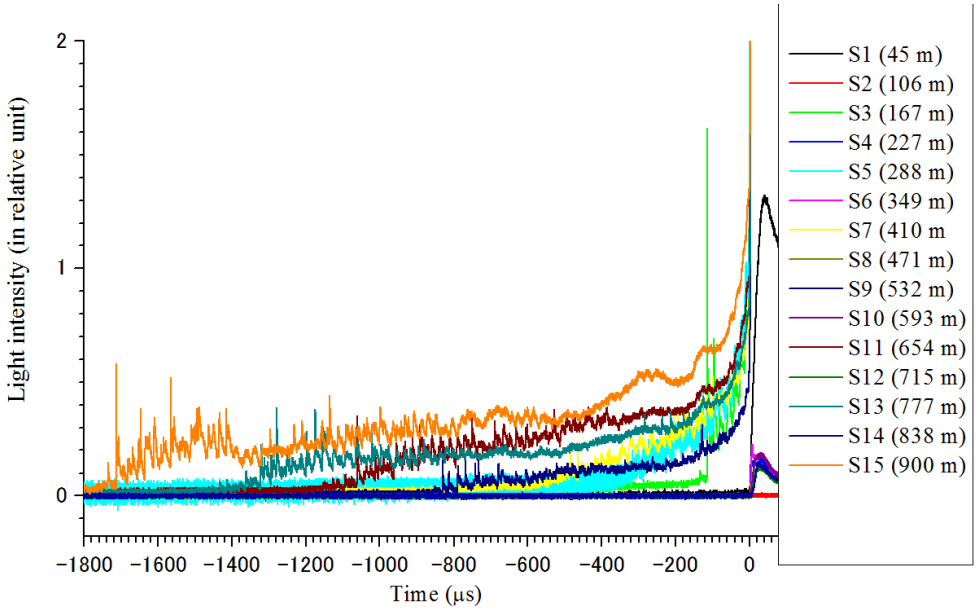

Figure 6. The light intensity from different channel heights of the first leader/return stroke sequence of lightning E.

CONCLUDING REMARKS

The attachment processes of the first strokes of 5 natural lightning discharges have been reported. All the five return strokes initiated at a height above the ground. Return strokes with larger peak current tend to initiate higher, similar to the results previously obtained for rocket triggered strokes. In the final presentation, more detailed results will be reported.

ACKNOWLEDGMENTS

This work was supported by Ministry of Education, Culture, Sports, Science, and Technology of Japan (Grant number: 23403007), National Science Foundation, and the U.S. program DARPA NIMBUS. Authors would like to thank T. Watanabe and H. Ishikawa for their help in setting up the high speed optical observation equipment. NLDN-estimated peak currents were provided by Vaisala Inc. (J. A. Cramer).

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