Lightning Attachment Process Parameters Measured by Using LAPOS

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***Abstract*— Using a high speed optical imaging system called LAPOS, we have observed the lightning attachment processes of 19 negative and 2 positive CG. We have obtained not only their stepped leader speeds and the return stroke speeds near the channel bottoms, but also their return stroke initiation heights. Most of the negative first return strokes exhibited an initiation height of 40 m or so. Return strokes with bigger peak current tend to initiate higher. For one positive first stroke, although its peak current is much larger than all the negative counterparts, its initiation height is smaller than most of the negative ones.**

Keywords-lightning attachment process; stepped leader; return stroke; return stroke initiation height

I. Introduction

As pointed out by Tran and Rakov [1], the lightning attachment process, which can be viewed as the transition from leaders to return stroke, is one of the most poorly understood processes, primarily due to the difficulty in its observation. 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 [2]. So far, we have recorded more than 30 rocket-triggered lightning flashes and 21 natural downward lightning flashes which are analyzable. Part of our results have been published previously [3-5]. In this paper, we report the results on the attachment processes of the 21 natural lightning flashes.

II. Observation and Data

A. Observation

Since July of 2011, three LAPOSs, named LAPOS1, LAPOS2, and LAPOS3 have been set up at ICLRT to observe the lightning attachment process of both rocket-wire-triggered and natural lightning discharges [2-5]. LAPOS employs a type of photodiode-fiber optics array system specifically designed for observing the lightning attachment process and its specification has been described in previous publications [2-5]. LAPOS has three main features of wide horizontal view, wide dynamic range and high sampling rate.

B. Data

During the observation periods, 19 negative and 2 positive lightning flashes were recorded by LAPOS and they are listed in Table 1 and Table 2, respectively, where return stroke peak currents and locations were determined by NLDN (National Lightning Detection Network). Of the 19 negative flashes, the largest peak return stroke current reached to 103 kA. In contrast, the peak return stroke currents of the two positive flashes are 197 kA and 145 kA, respectively.

III. Results

Among the 19 flashes shown in Table 1, 3 struck on-site at the ICLRT and their luminosity waveforms have been presented in [5]. As an example, Figure 1 shows the LAPOS3 luminosity waveform of an offsite negative lightning leader/return stroke sequence where S1-S7 signals were sampled at 10 MS/s and S8-S15 were sampled at 100 MS/s with odd number channels being sensitive and even number channels insensitive. Each of the channel sections has a vertical height of about 45 m with the section central heights ranging from 35 m to 684 m above ground level. In Figure 1 the leader stepping pulses, similar to those reported in [6, 7], can be tracked down at the height of S3 (127 m). From the inset of Figure 1, return stroke luminosity propagated upward from S4 to S14.

Figure 2 shows the LAPOS2 luminosity waveform of an offsite positive lightning leader/return stroke sequence. All LAPOS2 channels were sensitive and sampled at 10 MS/s. In its leader stage, a few pulses can be identified. These pulses suggest that the positive leader propagated in stepped mode from S5 to S3 [8].

A. Leader speeds

Figure 3 shows the speeds of the negative stepped leader. The speeds are slightly larger than those reported in [9]. Such discrepancy may have been caused by the fact that our LAPOS tended to record lightning flashes with bigger peak return stroke currents. For the two positive CGs, we are able to measure the leader speed for only one of them. The resultant speed is 4.5×10^6 m/s, bigger than all the negative counterparts.

TABLE I. DATA LIST AND THE OBSERVED RESULTS OF 19 NEGATIVE CLOUD TO GROUND FLASHES RECORDED BY LAPOS

Time (UT)	Distance (m)	Return stroke No.	Leader type from luminosity observations	Leader speed (overall) (10^6m/s)	Leader speed (lowest channel section) (10^6m/s)	Upward return stroke speed (10^8 m/s)	Downward return stroke speed (10^8 m/s)	Stroke peak current (kA)	Height of the lowest channel(m)	Return stroke initiation height(overall) (m)	Return stroke initiation height (lowest channel section) (m)
21:02:00 31/7/2011	312	1	Stepped	0.71	0.76 (S9→S7)	0.38	0.1	29.8	41	25	23
21:29:33 7/7/2012	2126	1	Stepped	0.67	2.8 (S11→S5)	0.81	-	20.6	81	63	61
17:19:00 19/7/2012	3751	1	Stepped	0.44	0.54 (S2→S1)	1.9	-	25.8	87	20	6
1:22:51 3/8/2012	7313	1	Stepped	0.71	0.87 (S2→S1)	1.3	-	85.4	167	23	-
1:26:16 3/8/2012	6652	1	Stepped	0.68	0.85 (S2→S1)	0.7	-	48.7	152	20	-
		2	-	-	-	1.0	-	12.7	-	-	-
23:48:59 12/8/2012	5438	1	Stepped	0.57	0.8 (S3→S1)	0.63	-	67	127	82	66
		2	Dart -Stepped	7.6	7.9 (S3→S1)	1.4	-	29.2		26	24
		3	Dart	13	14 (S3→S1)	1.3	-	9.3		12	6
23:53:33 12/8/2012	6557	1	Stepped	0.43	0.5 (S7→S3)	0.92	-	55.4	159	106	100
		2	Dart -Stepped	9.2	9.2 (S5→S3)	1.2	-	10.2		39	39
16:41:44 16/8/2012	12737	1	Stepped	0.73	0.73 (S3→S1)	2.1	-	103.1	290	114	114
		2	Dart	8.8	8.8 (S3→S2)	1.1	-	26.7	500	22	22
		3	Dart -Stepped	8.9	15 (S2→S1)	1.9	-	30.6	290	45	36
		4	Dart -Stepped	18	21 (S2→S1)	1.4	-	50.5		56	39
		5	Dart	12	19 (S2→S1)	1.3	-	53.2		59	-
		6	Dart -Stepped	16	12 (S2→S1)	1.9	-	7.9		11	50
17:35:42 17/8/2012	2939	1	Stepped	0.48	0.65 (S2→S1)	1.4	-	28	68	27	16
		2	Dart	-	-	0.81	-	8.3		-	-
18:37:59 20/8/2012	6180	1	Stepped	0.65	1.6 (S5→S3)	0.69	-	57.4	156	153	149
19:02:55 20/8/2012	2899	1	Stepped	1.3	1.6 (S5→S3)	2.7	-	51.5	74	54	48
20:40:13 4/10/2012	5200	1	Stepped	0.45	0.67	1.4	-	63.8	120	37	-
		2	Dart	11	14 (S3→S1)	1.2	-	11.6		6	-
17:52:02 23/3/2013	395*	1	Stepped	0.31	0.86 (S7→S5)	1.6	-	8.9	10	8	6
	472*	1	Stepped	0.28	0.77 (S11→S7)	1.2	-	8.9	20	17	7
22:42:53 11/1/2014	716	1	Stepped	1.9	2 (S11→S9)	0.97	1.2	76.3	118	96	90
		2	Dart - Stepped	29	34 (S11→S9)	1.2	-	27.7	84	22	9
		3	Dart	19	24 (S11→S9)	2.3	-	8.2		38	27
14:32:22 29/3/2014	3000	2	Dart	-	-	1.5	-	4.6	-	-	-
18:32:26 10/7/2014	1044	1	Stepped	0.63	0.95 (S7→S5)	1.6	-	35	75	68	64
18:02:23 25/7/2014	3184	1	Stepped	1	2.3 (S7→S5)	1.5	-	16.8	100	74	45
19:02:30 24/8/2014	2441	1	Stepped	0.71	0.92 (S7→S3)	1.6	-	45.5	106	88	83
2:28:37 10/7/2015	5924	1	Stepped	0.83	1.1 (S5→S3)	2.1	-	92	253	209	195

TABLE II. DATA LIST AND THE OBSERVED RESULTS OF 2 POSITIVE CLOUD TO GROUND FLASHES RECORDED BY LAPOS

Time (UT)	**Distance (m)**	**Return stroke No.**	**Leader type from luminosity observations**	**Leader speed (overall) (10^6m/s)**	**Leader speed (lowest channel section) (10^6m/s)**	**Upward return stroke speed (10^8 m/s)**	**Downward return stroke speed (10^8 m/s)**	**Stroke peak current (kA)**	**Height of the lowest channel(m)**	**Return stroke initiation height(overall) (m)**	**Return stroke initiation height (lowest channel section) (m)**
18:15:59 17/8/2012	4920	1	Stepped	4.5	4.7 (S2→S1)	1.4	-	196.7	109	28	24
14:32:22 29/3/2014	3000	1	Stepped	-	-	1.3	-	145	122	-	-

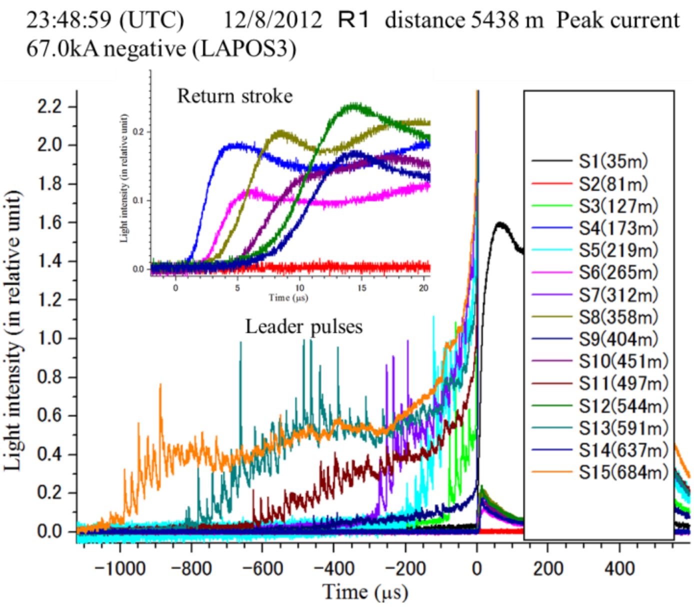

Figure 1. Luminosity waveforms of an example negative stepped leader/first return stroke sequence observed by LAPOS.

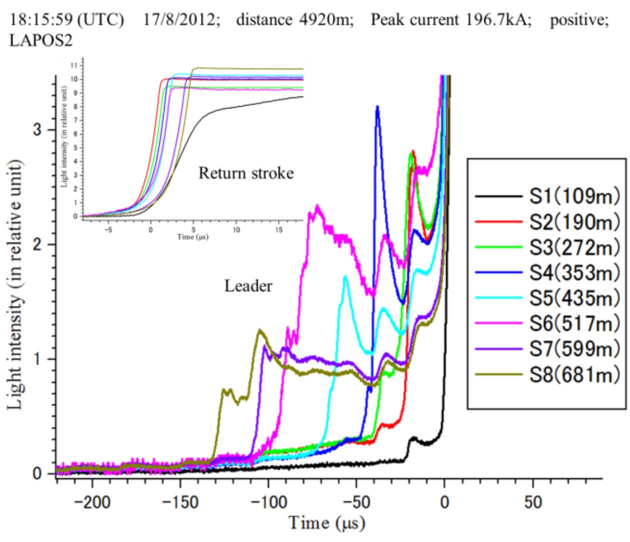

Figure 2. Luminosity waveforms of an example positive leader/first return stroke sequence observed by LAPOS.

B. *Return stroke speeds*

Figure 4 shows the speeds of the negative return strokes. The return stroke speeds are similar to those measured so far at

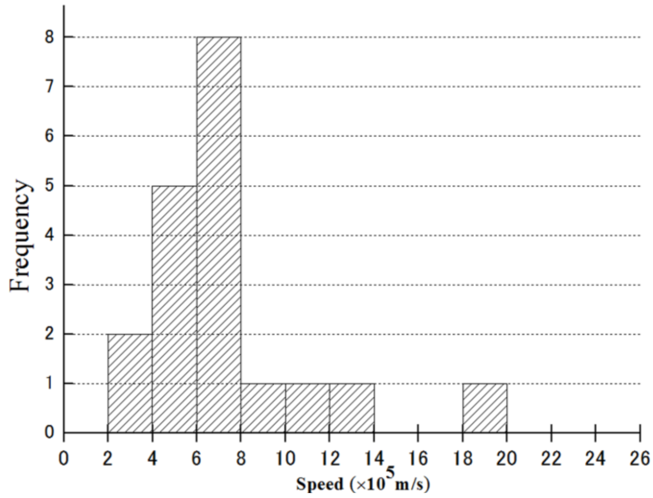

Figure 3. Histogram of average 1-D speeds of 19 negative stepped leaders.

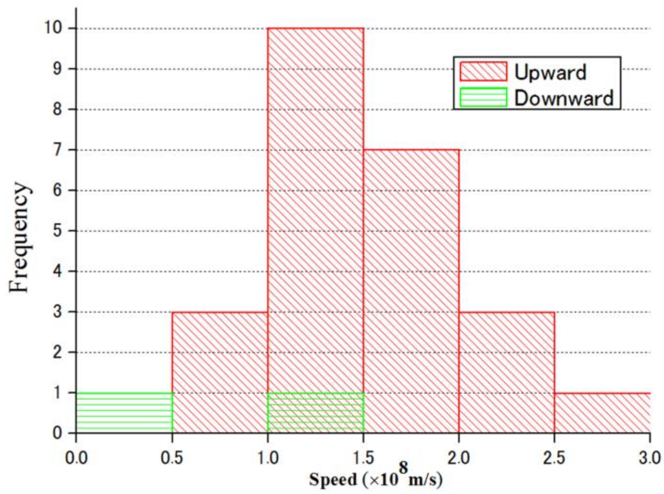

Figure 4. Histogram of average 1-D speeds of return strokes with 24 for upward part and 2 for downward part.

the channel bottoms of rocket triggered strokes [10, 11]. For the two positive CGs, their return stroke speeds are 1.4×10^8 m/s and 1.3×10^8 m/s, respectively, similar to those of negative return strokes as observed in [12].

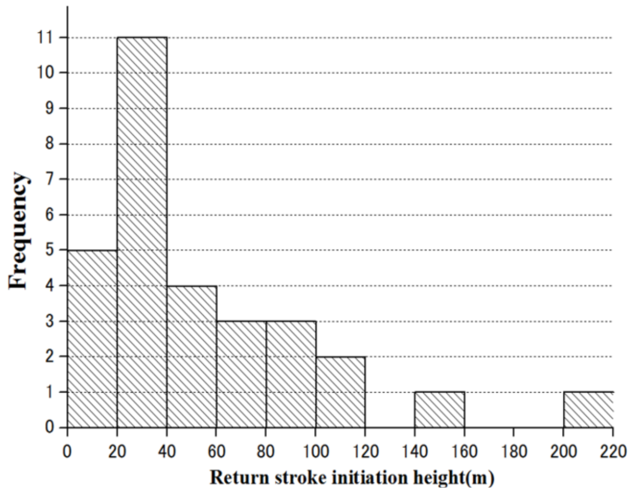

Figure 5. Histogram of return stroke initiation height.

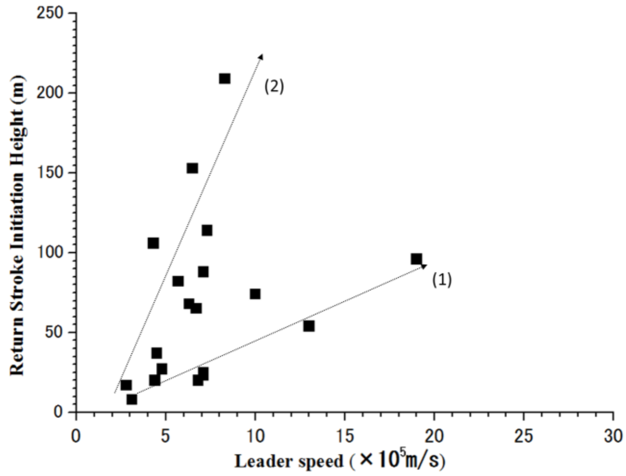

Figure 7. Scatter plot of return stroke initiation heights versus average 1-D stepped leader speed.

C. Return stroke initiation heights

Figure 5 shows the return stroke initiation height for the negative CG. Most of the first return strokes exhibited an initiation height of 40 m or so. For the two positive CGs, we are able to measure the initiation height for only one of them. The resultant height is 28 m, smaller than most of the negative counterparts. This observed fact indicates that the protection radius of a lightning rod is much smaller for positive lightning than for negative lightning.

D. Correlation between return stroke initiation height and peak return stroke currents and leader speeds

Figure 6 shows the scatter plot between the return stroke initiation height and the return stroke peak current for negative CG. Similar to those reported before [3-5], return strokes with bigger peak current tend to initiate higher. Figure 7 presents the scatter plot between the return stroke initiation height and the speeds of their preceding stepped leaders for negative CG. As shown in this figure, it seems that there are two separable trends in the correlation between the return stroke initiation height and the stepped leader speed. Within each of the trend, a faster stepped leader tends to initiate a return stroke with a bigger initiation height.

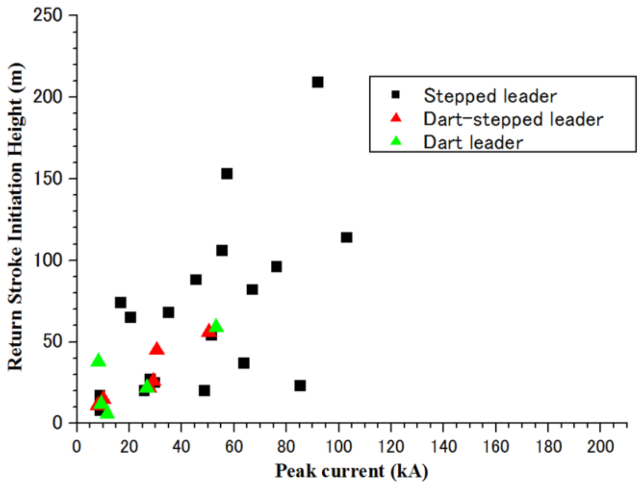

Figure 6. Scatter plots of stroke initiation height versus peak return stroke current.

IV. CONCLUSIONS

Lightning attachment processes of 19 negative and 2 positive CG have been measured by using LAPOS. Most of the negative first return strokes exhibited an initiation height of 40 m or so. Return strokes with bigger peak current tend to initiate higher. For one positive first stroke, although its peak current is much larger than all the negative counterparts, its initiation height is smaller than most of the negative ones.

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