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CHARACTERISTICS OF VERTICAL E-FIELD WAVEFORMS ASSOCIATED WITH RETURN-STROKES ON SOUTHEASTERN SEA OF KYUSHU IN JAPAN

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1. INTRODUCTION

The use of the lightning locating systems (LLS) has widely spread [Cummins et al. (1998a, 1998b)], and the regional variation of the ground flash density and that of the return-stroke current peak is reported [Schulz et al. (2005), Suda et al. (2002), Honma et al. (1998), Shinjo et al. (1997)].

It has been shown that the estimated peak current for negative first strokes in cloud-to-ground flashes, bringing down negative charge to ground, is higher over salt water than over land and that there is a clear discontinuity at sea: land interfaces whereas positive flashes do not show similar behavior [Cummins et al. (2005)]. Evidence is provided that the primary effects of this phenomenon are in the attachment process [Cummins et al. (2005)].

Murray et al. (2005) have reexamined the fine-structure of the dE/dt and E waveforms in the dataset described by Willett et al. (1998) and Willett and Krider (2000) with the goal of qualifying this structure on a time-scale of tens to hundreds of nano-seconds. They found that about 37% of the electric field waveforms produced by first strokes striking ocean water include multiple peaks in dE/dt that occur within 1 μs of the dominant peak. The average amplitude of the associated E-field waveforms is 36% larger than the amplitude of the waveforms containing a single, large peak in dE/dt. Murray et al. have suggested that the multiple pulses in dE/dt could be produced by multiple upward leaders closely-spaced in space and in time.

In this paper we compare the inland and the maritime return-stroke current in southern Kyushu by using the data obtained by JLDN [Ishii et al. (2005)]. The authors also discuss the characteristics of the electric field waveform associated with maritime negative first strokes during the convective thunderstorm in summer.

2. COMPARISON OF PEAK CURRENT ESTIMATED BY JLDN

2.1 Data subject to analysis

Figure 1 shows the location of the area subject to analysis of the peak current estimated by JLDN. The area is about 36000km^2 (190km from the east to the west and 190km from the north to the south) and the return strokes at the area from July to September in 2006 are subject to analysis. The return strokes estimated to have the current peak from –10 to +15 kA are left out of scope since these might possibly be associated with cloud strokes.

Figure 1 Areas subject to analysis of return-stroke current peaks estimated by JLDN

Except the return strokes occurring within 200ms in time and within 1km in space from the preceding stroke, all the negative strokes are regarded as first strokes. The negative strokes striking within 100m in space and within 30ms in time from the preceding strokes, satisfying additional condition that the preceding strokes are within the error ellipse, are regarded as subsequent strokes. With respect to positive strokes, all the strokes are regarded as first strokes because the subsequent strokes rarely occur.

2.2 Estimated peak current

Figure 2 shows the 50% values of the peak current associated with negative first and subsequent strokes, as well as that for positive strokes. With respect to maritime strokes, the number of the data subject to analysis is 25607, 65 and 1657 for negative first and subsequent strokes, and positive strokes, respectively. In the case of the inland strokes, the number of the data subject to analysis is 16726, 58 and 861 for negative first and subsequent strokes, and positive strokes, respectively.

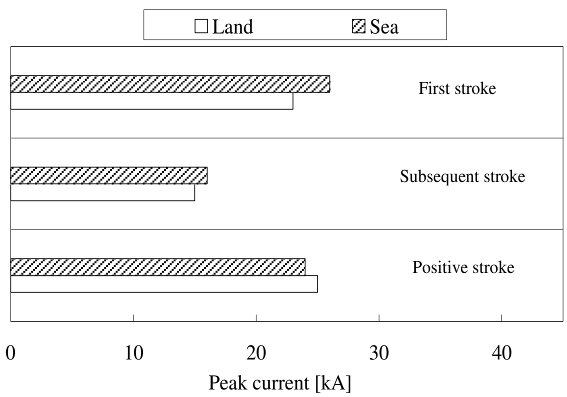


Figure 2 Peak current for inland and maritime strokes

In the case of negative first strokes, the 50% value of the maritime strokes, 26kA, is higher than that of the inland strokes, 23kA, by 13%, whereas in the case of negative subsequent strokes, the 50% values of maritime strokes, 16kA, is almost the same as that of inland strokes, 15kA. In the case of positive strokes, the 50% value of maritime strokes, 24kA, is also almost the same as that of the inland strokes, 25kA. The trend that the difference between the estimated peak current associated with maritime and inland strokes can be found in the case of negative first strokes only is the same as the results on strokes in the south and the east of the USA observed by the NLDN [Cummins et al. (2005)].

3. ANALYSIS OF E-FIELD WAVEFORM ASSOCIATED WITH MARITIME STROKES

3.1 Waveform subject to analysis

We measured the electric field waveform at four points in southern Kyushu [Michishita et al. (2004), Harada et al. (2006)]. When one estimates the field waveform parameters produced by lightning, it is important to minimize the influence of propagation of the electromagnetic waves over the land as much as possible. Therefore, the E-field waveforms obtained at a seashore station at about 300m from the shoreline are subject to analysis. The location of the seashore station at Shibushi is shown in Fig. 1.

There are two types of the measuring system at the seashore station. In one system, the E-Field waveforms were measured in the frequency range from 1.8kHz to 2.5MHz and were sampled every 40ns with the resolution of 12 bits. The total recording time of this system was 160ms. In the other system, both the E-Field and B-Field waveforms were measured in the frequency range from 1kHz to 10MHz and were sampled every 40ns with the resolution of 10 bits. The total recording time was 8ms. Most of the waveforms subject to analysis in this report are obtained by the latter system except those associated with negative subsequent strokes.

3.2 Method of Analysis

The authors calculate the time derivative of the electric field waveforms observed at the seashore station and classified strokes following Murray et al. (2005) who categorized the strokes in reference to the pulses in the time derivative of the E-Field waveforms in the time range from -4 to 1 microseconds of the dominant peak. The S/N ratio of our dataset is higher than that of the dataset analyzed by Murray et al. (2005) therefore the authors categorized the strokes in reference to the subsidiary pulse whose amplitude is higher than 30% of the dominant peak.

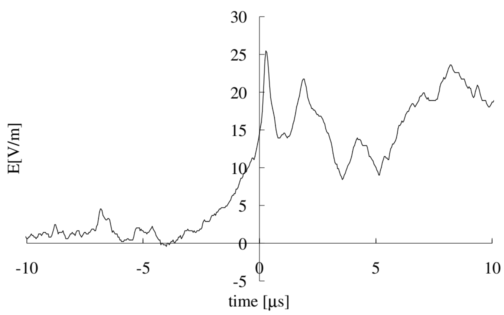
The event producing one or more pulses in dE/dt waveform within ±1μs of the dominant peak will be termed "Type B" strokes. The events producing one or more pulses in the interval -4μs to -1μs before the dominant peak with no pulses within ±1μs of the dominant peak will be termed "Type C" strokes. The events having a single large pulse in dE/dt in the time interval from -4μs to +1μs corresponding to the fast transition in E [Weidman and Krider (1978)], will be termed "Type A" strokes.

Figures 3, 4 and 5 show examples of E-field and its time-derivative waveforms associated with "Type A", "Type B" and "Type C" strokes, respectively. The three types of the fields are suggested to be produced by multiple, closely-spaced (in time and space) upward leaders in the attachment process of the downward-going leader to the surface of the ground [Murray et al. (2005)].

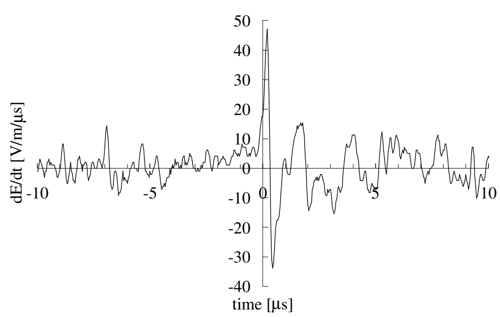
In this paper, only the field waveforms obtained during the convective thunderstorm are subject to analysis and the propagation distance over the land for these waves was from 300m to 385m.

3.3 Negative first strokes

The statistics of the peak E and peak dE/dt associated with negative first strokes dependent on the categorized types are shown in Table 1, together with values reported by Murray et al. (2005).

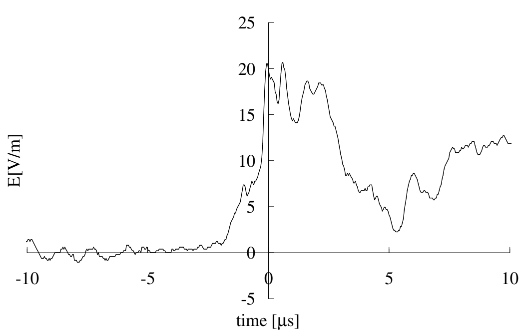


(a) E-Field

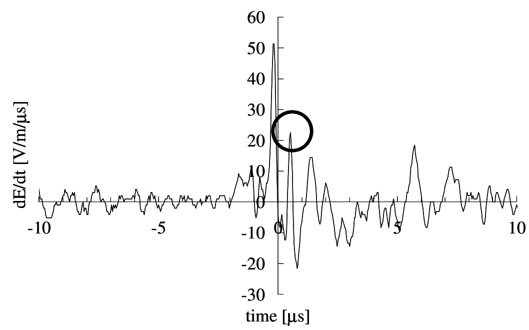


(b) dE/dt (calculated)

Figure 3. Examples of E-field and its time-derivative waveforms associated with “Type A” stroke.

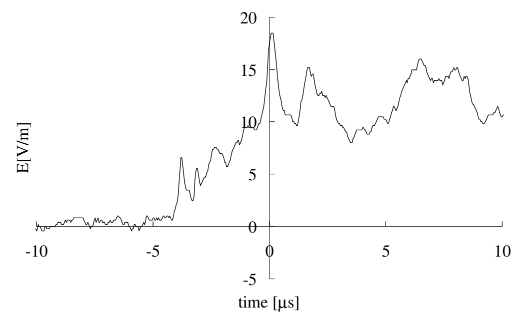


(a) E-Field

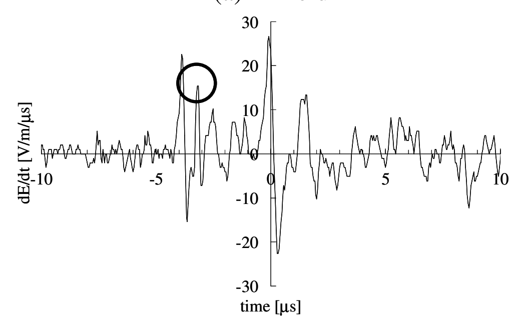


(b) dE/dt (calculated)

Figure 4 Examples of E-field and its time-derivative waveforms associated with “Type B” stroke.



(a) E-Field



(b) dE/dt(calculated)

Figure 5. Examples of E-field and its time-derivative waveforms associated with “Type C” stroke.

The ratio of the frequency of occurrence for each type agrees with that reported by Murray et al. (2005) with the discrepancy of less than 6%. Compared with the ratio of the frequency by Murray et al. (2005), that for Type B and C strokes is relatively higher in our dataset. This is because the strokes generating high range-normalized field, resulting from the long distance to the striking points, are predominantly subject to analysis in our dataset.

Table 1 Parameters of E-field waveform for negative first strokes.

		Type A	Type B	Type C
Frequency	number	75 [45]	110 [49]	83 [37]
	ratio[%]	28 [34]	41 [37]	31 [28]
100km E [V/m]	Average (Standard deviation)	15 (5.6) [7.6 (2.8)]	19 (6.1) [11 (5.5)]	19 (7.1) [8.7 (3.7)]
	90%value	9.3	11	10
	50%value	13 [7.4]	18 [9.0]	16 [7.6]
	10%value	23	27	31
100km dE/dt [V/m/μs]	Average (Standard deviation)	32 (11)	33 (11)	32 (12)
	90%value	18	19	18
	50%value	32	31	31
	10%value	47	45	50
Distance [km]	Average (Standard deviation)	82 (33)	94 (32)	95 (32)

[ ]: values reported by Murray et al. (2005)
100km E: E-field peak range-normalized to 100km
100km dE/dt: dE/dt peak range-normalized to 100km

With respect to the peak E (100km E in Table 2), normalized at the distance of 100km by using the inversely proportional relationship to the distance, the 50% value for Type B and C strokes are higher than that for Type A stroke by 38 to 23%, respectively. This trend is the same as that shown by Murray et al. (2005).

Figure 6 shows the peak dE/dt (range-normalized to 100km) dependent on the rage for all 268 first strokes in our dataset. There seems no correlation between the peak dE/dt and the range to the negative first strokes. Therefore, we suppose that the fields are similarly influenced by the propagation over the land for the distance of 300 to 385m, since such an influence of the propagation is not negligibly small as reported by Michishita et al. (1996a).

Figure 7 shows the relation between the peak E and the peak dE/dt for each type of strokes. There is some relation for Types A and B but Type C. The characteristic rise time for Type A, defined as the slope of the peak E versus peak dE/dt, was 220ns, which was longer by 38% than the time, 160ns, evaluated for the dataset of Murray et al. (2005). One of the reasons is the propagation effect over the land on our dataset and another is the long sampling interval of 40ns of our recording system.

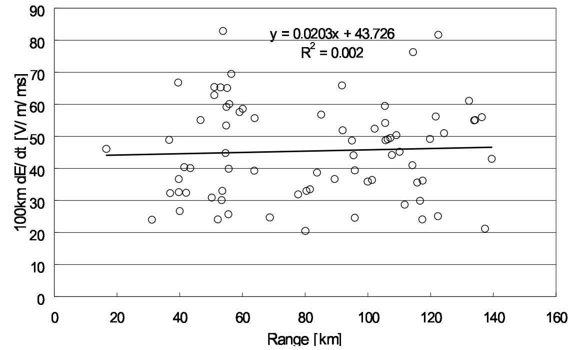


Fig. 6. Peak dE/dt (range-normalized to 100km) dependent on the range for 268 first strokes.

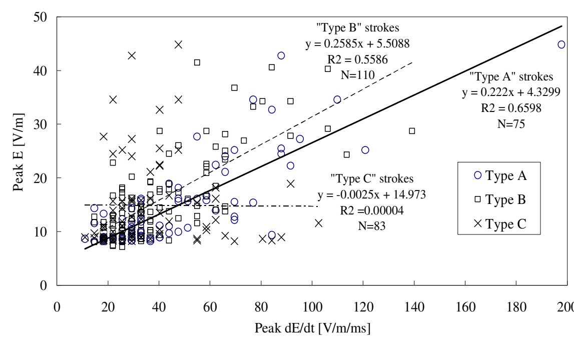


Figure 7. Peak E vs. the (dominant) peak dE/dt for negative first strokes.

3.4 Negative subsequent strokes

Table 3 shows the frequency of occurrence of each type of strokes and the peak E range-normalized to 100km, together with those of preceding first strokes.

With respect to the negative subsequent strokes, 90% of the strokes are Type A strokes, although in the preceding first strokes about half of the strokes are Type A strokes. This might be caused by the difference in the attachment process of the downward-leader to the surface in the negative first and subsequent strokes. The number of data for Types B and C is as little as two, therefore, the statistics other than the frequency of occurrence are not shown in Table 2.

There was no correlation between the peak dE/dt and the range to the subsequent strokes as in the case of negative first strokes.

Table 2. Parameters of E-field and dE/dt waveforms associated with negative subsequent strokes.

		Type A	Type B	Type C
Frequency	number	40[16]	2 [9]	2 [8]
	ratio[%]	91[48]	4.6 [27]	4.6 [24]
100km E [V/m]	Average (Standard deviation)	8.9 (3.4)	-	-
	50%value	8.8 [14]	-	-
Distance [km]	Average (Standard deviation)	38 [37] (18)	-	-

[ ]: Data for preceding first strokes.

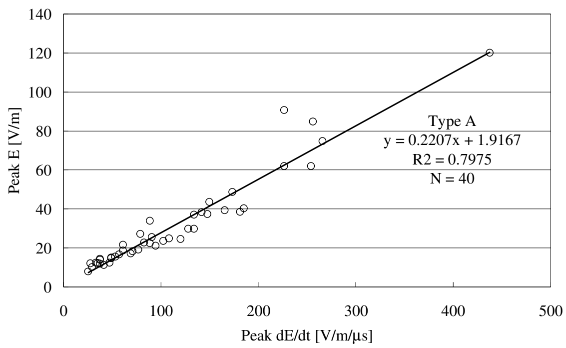


Figure 8. Peak E vs. peak dE/dt for negative subsequent Type A strokes.

Figure 8 shows the relation between the peak E and the peak dE/dt associated with Type A negative subsequent strokes. The characteristic rise time was 221ns, which is almost the same as in the case of negative first strokes. This is because of the propagation over the land, working an influence on the field waveforms like a low-pass filter.

3.5 Positive strokes

Table 3 shows the frequency of occurrence of each type of strokes and the peak E range-normalized to 100km in association with positive strokes. As in the case of negative subsequent strokes, 80% of the positive strokes are Type A strokes, and the Type B and Type C strokes rarely occur. The number of data for Type B and C strokes is as little as 8 and 3, respectively, therefore, the statistics other than the frequency are not shown in Table 3.

There was no correlation between the peak dE/dt and the range to the subsequent strokes as in the cases of the negative first and subsequent strokes.

Table 3. Parameters of E-field and dE/dt waveforms associated with positive first strokes.

		Type A	Type B	Type C
Frequency	number	43	8	3
	ratio[%]	80	15	5.6
100km E [V/m]	Average (Standard deviation)	19 (9.6)	-	-
	50%value	16	-	-
Distance [km]	Average (Standard deviation)	92 (19)	-	-

Figure 9 shows the relation between the peak E and the peak dE/dt associated with Type A positive first strokes. The characteristic rise time was 292ns, which was longer than that of negative strokes. This is because the rise time of the fast transition associated with positive strokes is intrinsically longer than that associated with negative strokes [Michishita et al. (1996b)].

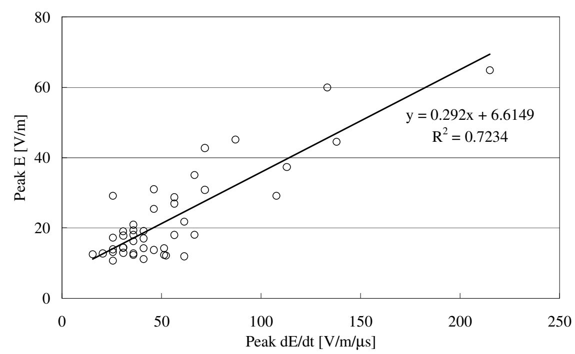


Figure 9. Peak E vs. peak dE/dt for positive Type A strokes.

3.6 Discussion

In the case of negative first strokes, 70 % of the strokes are Type B and C strokes, having multiple pulses close to the dominant peak in time, whose amplitude is higher by 10-30% than the amplitude of Type A strokes. As for the negative subsequent strokes and the positive strokes, most of the strokes are Type A strokes. Therefore, the high frequency of occurrence of Type B and C strokes might be one of the causes of the observed difference between the maritime and inland stroke currents in case of negative first strokes.

4. CONCLUSION

In this paper we compare the inland and the maritime return-stroke current in southeastern part of Kyushu by using the data obtained by JLDN. In case of negative first strokes, the maritime return-stroke current is higher than the inland stroke current in contrast to the cases of negative subsequent and positive first strokes.

The authors investigate characteristics of the electric field waveforms associated with maritime negative and positive strokes in summer. As a result, it is pointed out that high frequency of occurrence of time-derivative of E-field waveforms having multiple pulses close to the dominant peak might be one of causes of the observed difference between the maritime and inland stroke currents in case of negative first strokes.

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