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ELECTRIC FIELD WAVEFORMS OF UPWARD LIGHTNING FORMING HOT SPOT IN WINTER IN JAPAN

Mikihisa SAITO Masaru ISHII Fumiyuki FUJII
The University of Tokyo, Tokyo, Japan

Akiko. SUGITA
Franklin Japan, Co, Sagamihara, Japan

1. INTRODUCTION

In Japan, transmission lines or wind turbines in the coastal area of the Sea of Japan have suffered from higher frequencies of serious troubles by lightning in winter than those in summer because of existence of frequent upward lightning strokes (Ishii et al., 2009, 2011; Natsuno et al, 2010; Shinjo et al., 2006; Sugimoto et al., 2006).

Concentration of lightning hits to tall structures is occasionally observed by Lightning Location System (LLS) in the coastal area of the Sea of Japan in winter. Such concentration is named a “hot spot” (Ishii et al., 2011). The detected lightning strokes forming hot spots are presumably related to upward lighting discharges; therefore, associated electric field waveforms may have different characteristics from those of ordinary downward cloud to ground (CG) strokes.

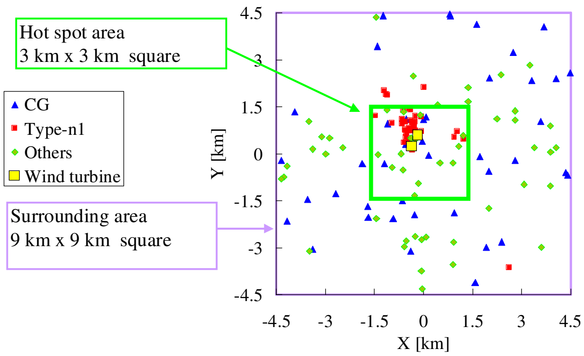
Electric field waveforms associated with lightning discharges forming a hot spot around tall structures, detected by LLS, are investigated and are reported on.

2. OBSERVATION

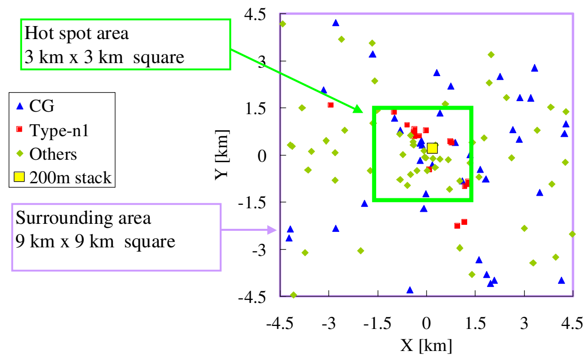
Analyzed LLS data were obtained by Japanese Lightning Detection Network (JLDN) (Ishii et al., 2005), which is a large-scale single lightning detection network operated by Franklin Japan Co. The Fukui network for observation of lightning electromagnetic fields, comprising 8 VHF receivers, 5 fast antennas(FA) and 8 slow antennas(SA) on the coast of the Sea of Japan at about 36°N and 136°E (Saito et al., 2009), provides e-field waveforms and VHF source location data. The VHF receivers compose a lightning mapping array (LMA), whose standard deviations of location error of VHF radiation sources by the TOA method are mostly within 0.5 km in the vertical and horizontal directions for the data in this paper.

3. HOT SPOTS OBSERVED IN WINTER

Analyses have been carried out at two hot spots. One is at Mt. Kunimidake, which is a 640 m mountain at about 14 km from the Fukui network with two 75 m high wind turbines on its top. The other is at Fukui thermal plant with a 200 m stack on the seashore, located within the Fukui network.



(a) Mt. Kunimidake (75 m high two wind turbines on mountain of 640 m)



(b) Fukui thermal power plant (200 m high stack on sea shore)

Fig 1 Lightning strokes located by JLDN around high structures with records of e-field waveforms in winter. (Dec.2002 ~ 2005, Jan 2003 ~ 2006)

Fig. 1 shows location of lighting strokes simultaneously observed by the Fukui network and JLDN around the two hot spots. These data were observed in December from 2001 to 2005 and January from 2002 to 2006. Table 1 and Table 2 show the results of classification of types of electric field waveforms.

Atmospheric sign convention is employed in this paper, and a negative discharge is characterized by the field change of positive direction, which means downward movement of negative charge. This definition of the polarity is the same as that employed by LLS.

Electric field waveforms of Types n1~n4 and Types p1~p3 are shown in Fig. 2 and Fig. 3, and detailed explanation is given in the next section. Polarities of two data classified as Type p1 and Type p3 were wrongly interpreted by JLDN. A GC (Ground to Cloud) stroke is a high current upward lightning stroke associated with an intense electromagnetic pulse (Ishii et al., 2009). All the GC strokes in Tables 1 and 2 had estimated peak currents exceeding 60 kA in absolute values, if the same empirical formula to convert electric field to source current magnitude employed for negative CG strokes is applied. Return stroke waveforms (CG) are more often seen in surrounding areas.

Table 1 Classification of electric field waveforms associated with lightning strokes located around Mt. Kunimidake.

	Hot spot area	Surrounding area
Negative		
Type n1	32	5
Type n2	1	5
Type n3	9	6
Type n4	5	4
CG	6	11
GC	1	2
Positive		
Type p1	1	3
Type p2	1	6
Type p3	4	2
CG	2	23
GC	1	4
Sum	63	71

Table 2 Classification of electric field waveforms associated with lightning strokes located around Fukui thermal power plant.

	Hot spot area	Surrounding area
Negative		
Type n1	15	3
Type n2	7	3
Type n3	11	6
Type n4	2	5
CG	8	15
GC	1	2
Positive		
Type p1	0	0
Type p2	1	6
Type p3	1	13
CG	4	12
GC	0	2
Sum	50	67

4. CHARACTERISTICS OF ELECTRIC FIELD PULSES ASSOCIATED WITH HOT SPOTS

Electric field waveforms classified as Type n1 are characterized by a narrow pulse having short zero-crossing time and are preceded by noisy variation. This electric field waveform resembles to that associated with a subsequent return stroke, preceded by a dart leader; however, width of half maximum of the narrow peak of Type n1 is only several μs, which is quite different from the pulse widths of ordinary subsequent return strokes.

Out of 55 Type n1 strokes in Tables 1 and 2, 47 strokes were located in the hot spot areas as shown in Fig. 1. At more than 90% of the Type n1 strokes, estimated absolute peak current values are less than 20 kA. As Type n1 strokes were occasionally observed successively, they are grouped as a flash if successive strokes are located within 0.5 s. Then the number of flashes including Type n1 is 25 compared with the number of strokes, 55.

The proportions of Type n1 strokes among all the strokes forming hot spots were different at Mt. Kunimidake and Fukui thermal power plantk, about 50% and 30%, respectively. It is too early to speculate the reason.

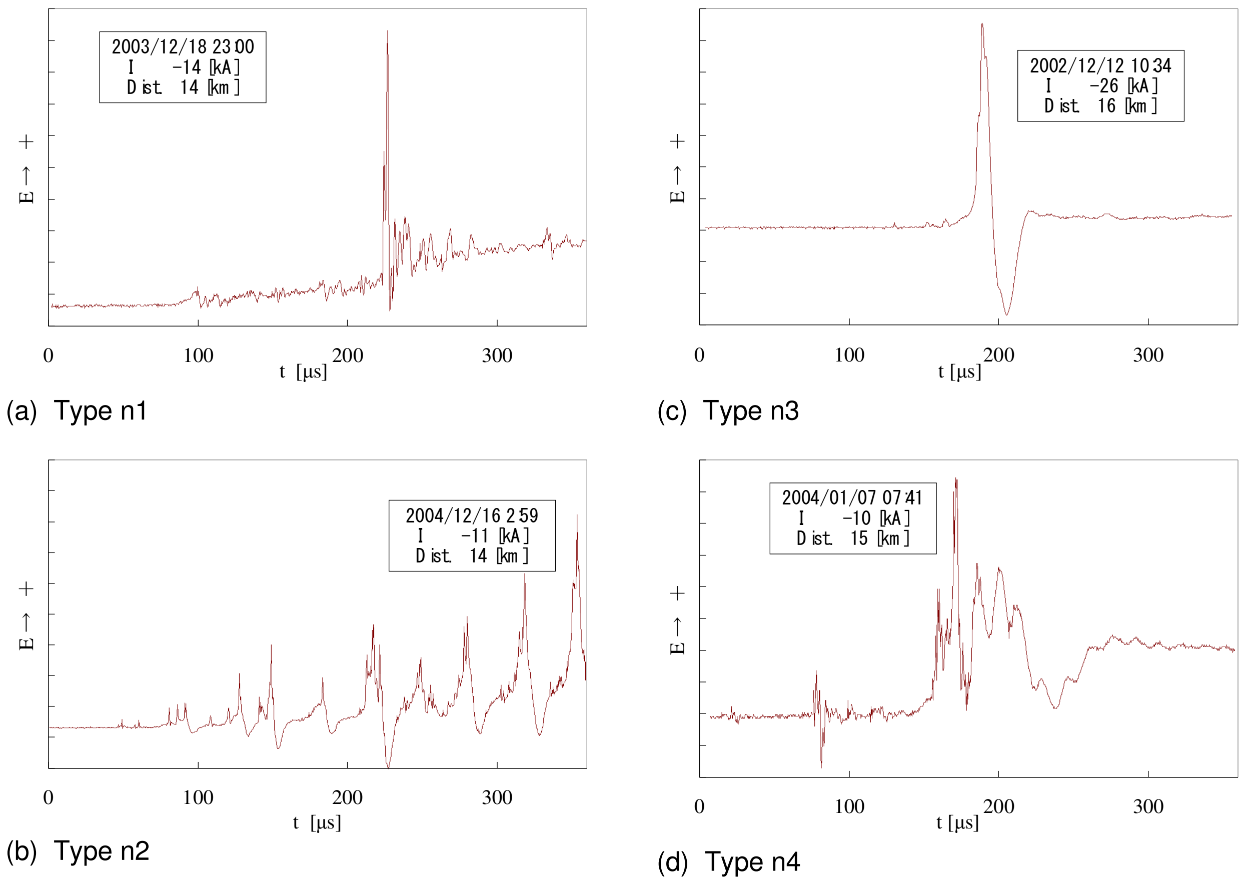


Fig.2 Examples of electric field waveforms of Type n1 ~ n4.

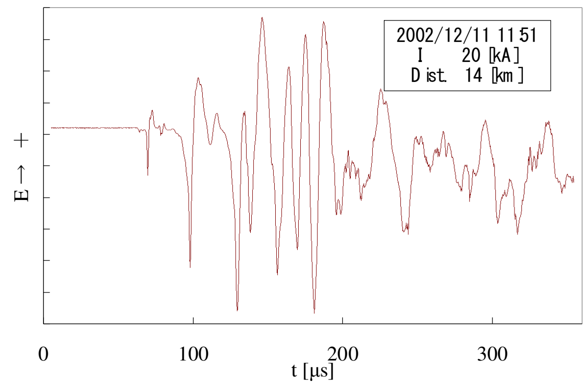
Type n2 waveform is characterized by successive bipolar pulses as shown in Fig. 2(b). This type of field changes is sometimes observed at in-cloud discharges. Estimated absolute peak current values were less than 20 kA at all data.

Type n3 waveform is the same as that of –GC strokes except the magnitude of its peak, and is characterized by an isolated bipolar pulse. Strokes associated with equivalent absolute peak currents less than 60 kA are counted as Type n3 strokes. More than 80% of estimated absolute peak currents of this type were less than 30 kA.

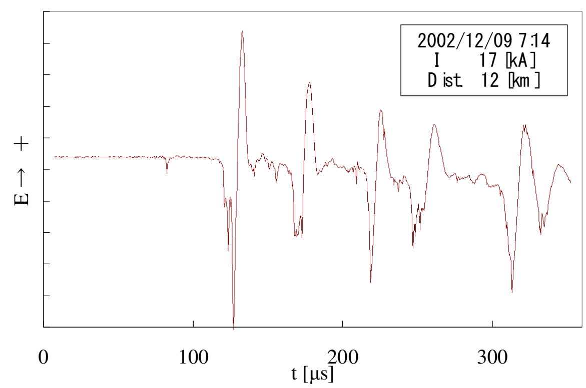
Type n4 waveform has a longer peak to zero crossing time than those of –GC or Type n1~n3 strokes, and usually interpreted as normal negative return stroke (–CG) by LLS, though the waveform is not like that from a return stroke. It is not preceded by field changes of a stepped leader or dart leader, and pulses superimpose in the beginning of the main pulse. The estimated peak currents were less than 30 kA.

Type p1 waveform, shown in Fig. 3(a), is characterized by successive pulses not so regular as those of type n2 or p2. They are more often seen in the surrounding areas, so they may not be related to upward lightning. Type p2 and p3 waveforms resemble Type n2 and Type n3 except the polarity. Most of the estimated peak current amplitudes of Type p1~p3 strokes were less than 20 kA.

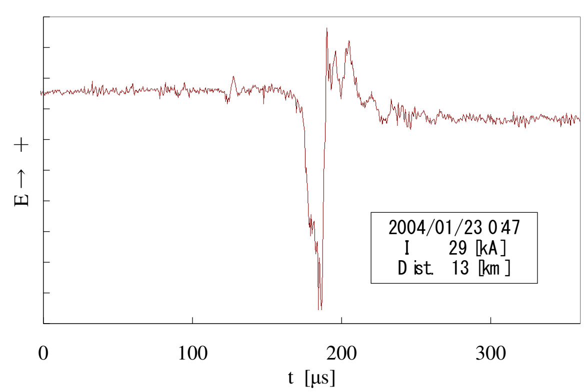
Fig. 4 shows results of waveform discrimination by JLDN depending on the classification of waveforms of this paper. Although electric field waveforms of Type n1 waveform is quite different from return stroke waveforms, most of Type n1 strokes were interpreted as CG strokes. The different results in interpretation of n3 and –GC or p3 and +GC waveforms may come from participation of distant sensors in the observation of GC waveforms. At distant sensors, waveform characteristics differ from ordinary return strokes may be attenuated due to the propagation effect.



(a) Type p1



(b) Type p2



(c) Type p3

Fig.3 Examples of electric field waveforms of Type p1~p3.

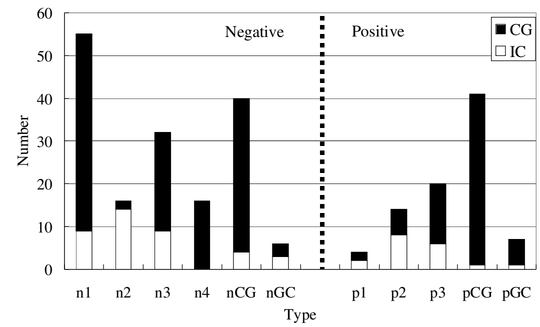


Fig.4 Interpretation of field waveforms by JLDN depending on the type of lightning stroke.

5. UPWARD LIGHTNING DISCHARGES OBSERVED BY CURRENT SHUNT

Data observed by a current shunt at a 200 m stack of Fukui thermal power plant were compared with data observed by the Fukui network to investigate the relationship between the record of lightning current and electric field waveforms. For the moment, only the trigger times of the current measuring system are available, so electric field waveforms within 300 μs of the trigger times are surveyed. Analyzed 16 data were obtained in December of 2001 and 2002, and January of 2002 and 2003.

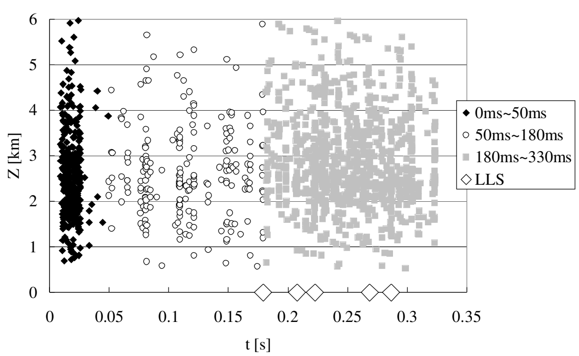
Table 3 shows the results. Numbers in parentheses indicate the number of detection by JLDN in Hot spot area. 9 data labeled “none” are not associated with notable electric field pulses around the trigger times. Only one data among these 9 trigger events, JLDN detected a stroke several tens of ms after the triggered time. Types n1, n2, n3 and p1 may be related to upward lightning.

Table 3 Types of electric field waveforms observed around the trigger time of current measuring system at Fukui thermal power plant.

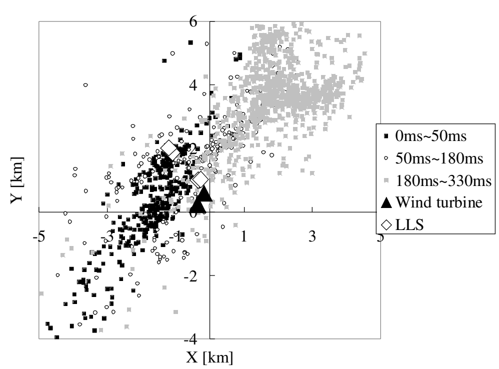
Type	Number
n1	2 (1)
n2	3 (3)
n3	1 (1)
p1	1 (0)
none	9
Sum	16 (5)

6. ELECTROMAGNETIC OBSERVATION OF TYPE n1 STROKES

Fig. 5 shows an example of three-dimensionally located VHF sources of a flash located in a hot spot area by JLDN, which contained five Type n1 strokes. Fig. 6 shows the electric field waveform of the same flash observed by a slow antenna. The symbol marked “LLS” in Fig. 5 and arrows in Fig. 6 indicate the time and locations of the Type n1 lightning strokes located by JLDN.



(a) Time variation of height of located VHF sources.



(b) Horizontal projection of located VHF sources

Fig. 5 An example of three-dimensionally located VHF sources.(2003/12/18 2300)

As VHF sources were located near the wind turbines at the beginning of this flash, it probably started with an upward leader from a wind turbine. The lightning strokes located by JLDN were observed about 200 ms after the beginning of the flash. Charge transfer of the flash from cloud to ground during 50 to 300 ms can be estimated from the location of VHF sources and the electric field change observed at a single station, shown in Fig. 6, and was about 20C (Saito et al., 2009). This value is not large for upward lighting observed in winter in the coastal area of the Sea of Japan (Ishii et al., 2012).

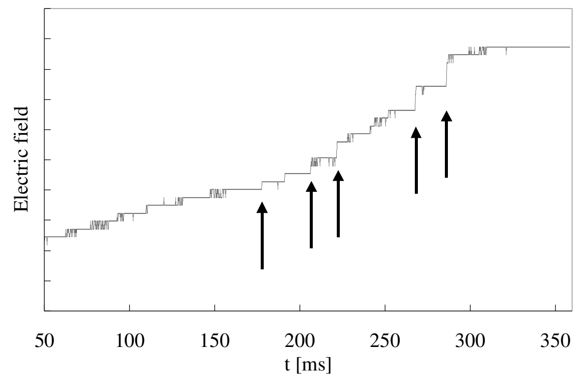


Fig. 6 Variation of electric field associated with the same flash as Fig. 5 observed by slow antenna (0ms ~50ms were not recorded).

Type n1 strokes were mostly located within the hot spot area as shown in Tables 1 and 2, showing contrast to other types of strokes such as n2, n3 and p1. It is inferred that most of Type n1 strokes are associated with upward lighting discharges. They are detected as CG strokes by Vaisala’s LLS in its standard setting. But the characteristic field waveform of Type n1 stroke may be indication of upward lightning discharge. It will be possible to distinguish Type n1 waveform from other lightning EMP waveforms at modern LLS.

7. CONCLUSIONS

Electric field waveforms of lightning strokes forming hot spots around tall structures observed in winter in the coastal area of the Sea of Japan are investigated.

Characterized narrow electric field pulses were frequently located by LLS around high structures. These narrow pulses are probably associated with upward lighting discharges, and can be distinguished easily from ordinary downward return strokes or in-cloud discharges. Detection of the narrow pulses may be useful to detect upward lighting flashes, though this type of a flash may not transfer large amount of charge to ground.

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