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Extremely Long Lightning Channels Observed in Hokuriku During Winter Thunderstorm Season

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Abstract

We have been observing LF electromagnetic waves associated with lightning around Toyama Bay in winter thunderstorm seasons. From received LF signals at 7 stations, their sources are located in 3D using time of arrival method. Lightning flashes with the length of over 100km are detected in the observation results. Unlike general lighting discharges in winter, many return strokes are recorded along LF electromagnetic wave sources.

1 Introduction

With the development of information-communication technology society, the damage of electronic devices caused by lightning discharges has a great effect on our daily life. In addition, lightning strokes to power infrastructure facilities such as transmission lines may cause power outages over a wide area. Lightning observations have being actively conducted in various places to reduce the damages and harms.

There are many observation devices for electromagnetic waves radiated by lightning discharge from ELF band to UHF band. In the ELF and VLF bands, it is possible to observe a wide area of several thousand kilometers, but it is difficult to observe cloud discharges. In the VHF and UHF bands, it is possible to observe the process of lightning discharge in detail. However, the observation range is limited to about several tens of kilometers, and it is difficult to follow a whole thunderstorm from the cumulus to dissipating stages. In the LF band, on the contrary, the observation range is two hundred kilometers or more for the phenomena with accompanying a large current such as a return stroke. In addition, the lightning processes of both cloud-to-ground (CG) and cloud-to-cloud (CC) flashes can be observed by this frequency band.

Many thunderstorms are grown in the coast of Hokuriku region, because updrafts are generated by the winter monsoon from Siberia and the warm current on the Sea of Japan. For this reason, the Hokuriku is known as a rare region in the world where lightning discharges occur in winter. Thunderstorms in winter tends not to grow vertically but horizontally. The high percentage of positive and low multiplicity of lightning strokes are often observed [1]. It is also known that the discharge energy is large and serious damage are occurred. Considering that the lightning flashes with long length in winter and also occurs on the Sea of Japan, it is necessary to construct a wide-range observation system to understand these phenomena.

The authors consider that the area around Toyama Bay, where both summer and winter lightning can be observed, and where observation instruments can be placed around the bay, are suitable for lightning observation. Electromagnetic observation network in LF band has been deployed to conduct lightning observations in this area. This paper introduces lightning flashes with the length of over 100km, and discuss the results combine with the observation results of the lightning location system (LLS) [2].

2 LF Lightning Observation Network

In order to observe lightning in winter in a wide range and in detail, the authors have installed the LF band receivers around Toyama Bay at intervals of from several km to several tens of kilometers. The LF observation network can locate the radiation sources of the impulsive electric field change using the time-of-arrival method. Figure 1 and Table 1 shows the configuration of the LF band receiver and its specifications, respectively. Each LF band receiver consists of a capacitive circular flat plate antenna, low-pass filter (LPF), analog-to-digital converter board (ADC), a global positioning system (GPS) receiver, and a personal computer (PC). In this study, a circular flat-plate antenna is adopted in consideration of the influence of corona discharge. The LF band electromagnetic waves received by the antenna passes through an LPF with a cutoff frequency of 500 kHz, is converted from analog to digital, and is recorded on a PC. The waveforms for every 200ms can be recorded as one data set without dead time. The resolution and the bandwidth are of 16-bit and 800 Hz to 500 kHz, respectively.

In the winter thunderstorm season in 2016, LF band receivers had been installed at the seven sites as shown in Figure 2. Time synchronization between receivers was realized using GPS signals with an accuracy of 1μs or

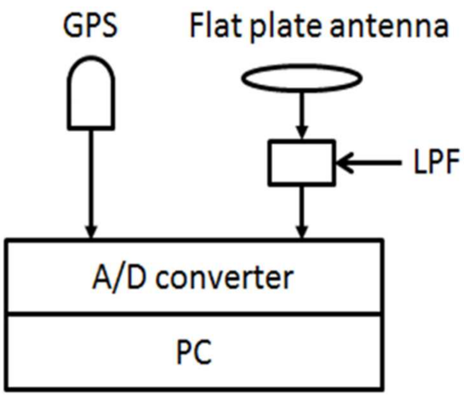

Figure 1. Block diagram of a LF sensor.

Table 2. Specifications of a LF sensor.

Antenna type	Capacitive circular flat plate
Frequency band	800Hz to 500kHz
Time constant	156.75μs
Sampling frequency	4MHz
Recording time	200ms
Resolution	16-bit

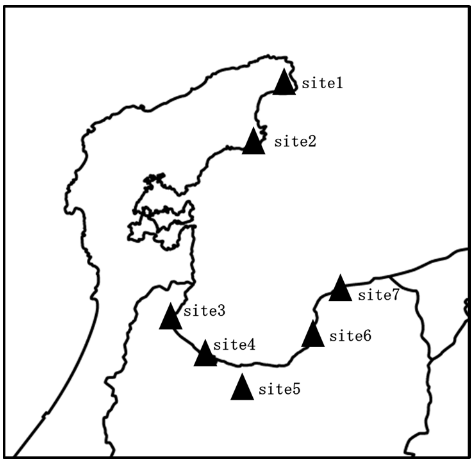

Figure 2. Locations of LF sensors.

less. LF signals recorded at five or more sites are analyzed in this study.

3 Case Study for Observation Results

Figure 3 shows a two-dimensional location map of the LF pulse radiation source observed at 5:25:25 on December 6, 2016. According to Fig. 3, discharge processes from (36.2° N, 136.5° E) to (37.5° N, 138.3° E). The discharge progress distance of this lightning flash was extend to about 220km. However, the position of the pulse has not been located between 36.5° N and 137.1° E to 36.9° N and 137.4° E. Because pulses were detected by less than 5 receivers only. In this case also a streak of rain clouds running parallel to the Japanese archipelago extends over the Hokuriku region at the time of the lightning discharge. Figure 4 shows the two-dimensional location map together with the lightning stroke positions located by LLS. Table 2 shows the lightning location time and the estimated current value by LLS during the radiation of the LF pulse in this case. The sign of lightning current indicates the polarity of electric charge lowered to the ground by the stroke. LLS record 22 strokes in this case. Twelve and 10 of them were positive and negative strokes, respectively. In the former part of this event, 1st to 11th stroke, positive strokes are dominant. Negative ones are dominant in the later part, 12th to 22nd, conversely. The former strokes except for 3rd and 7th strokes are located along the LF radiation sources within about 600ms. Third and 7th strokes are located away from the LF sources. LLS detected the negative current as the 7th stroke, and the electric field waveform of the stroke recorded by a LF

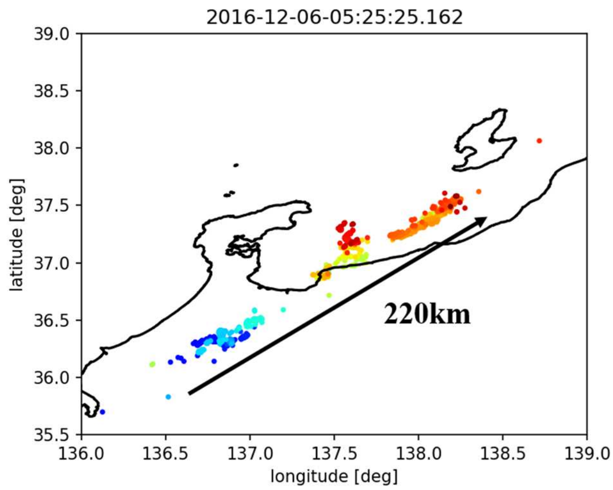

Figure 3. Two-demensional location map of LF radiation sources. The color represents its time development.

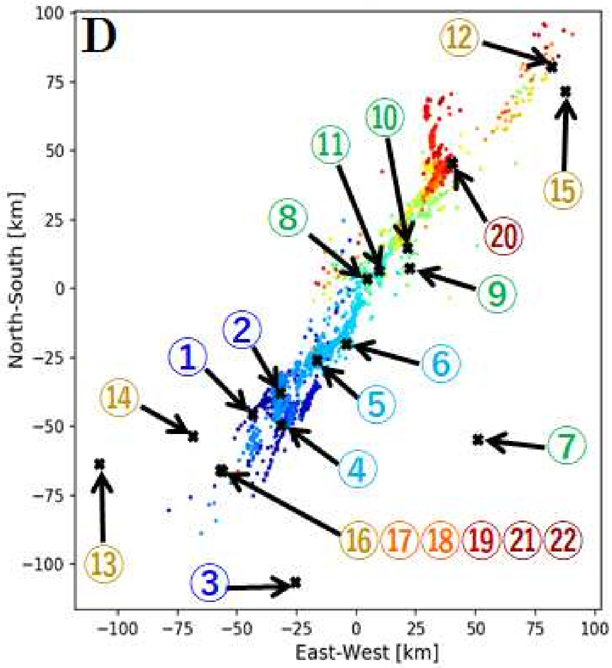

Figure 4. Locations of return strokes by LLS superimposed on LF sources.

Table 2. Estimated times and the peak currents of return strokes.

Number	Estimated time	Lightning current(kA)
①	5:25:25.368	+38.0
②	5:25:25.369	+20.7
③	5:25:25.372	+6.9
④	5:25:25.654	+26.7
⑤	5:25:25.732	+10.7
⑥	5:25:25.754	+9.6
⑦	5:25:25.869	-65.1
⑧	5:25:25.870	+242.7
⑨	5:25:25.923	+40.6
⑩	5:25:25.923	+41.5
⑪	5:25:25.938	+10.1
⑫	5:25:26.011	-30.6
⑬	5:25:26.013	-19.9
⑭	5:25:26.013	-2.4
⑮	5:25:26.062	+14.6
⑯	5:25:26.186	-19.5
⑰	5:25:26.223	-15.1
⑱	5:25:26.253	-12.8
⑲	5:25:26.483	-21.0
⑳	5:25:26.542	+41.0
㉑	5:25:26.615	-31.7
㉒	5:25:26.642	-14.9

receiver is shown in Figure 5.

The later strokes except for 12th, 15th, and 20th strokes are dominant negative and are located near the discharge initiation point near 36.2° N and 136.5° E. Although the LF pulse associated with these strokes were not located, the electric field change associated with the lightning stroke was observed at the Toyama receiver. The radiation source wasn't located, because the LF pulse was not recorded by more than five receivers. Near 12th and 15th strokes, a slight LF pulse was located. The 20th stroke was located at many LF source locations. However it isn't considered a subsequent stroke, as it is recorded 600ms after the 11th stroke. The positive 15th and 20th strokes were located among mainly negative strokes. LLS detected the positive current as the 15th and 20th strokes.

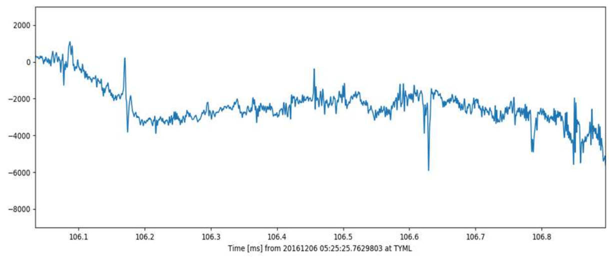

Figure 5. E-field change relating to the 7th stroke in LF band.

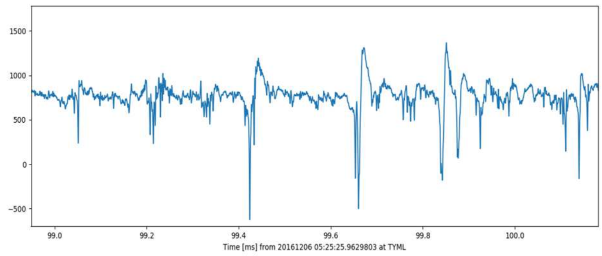

Figure 6. Similar with Figure 5 but for the 15th stroke.

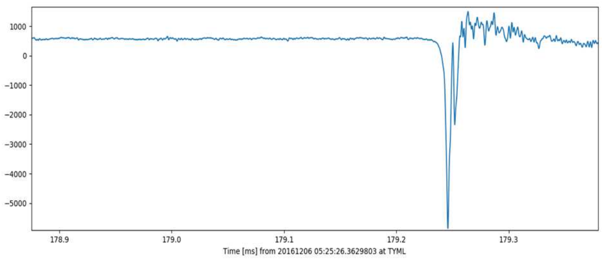

Figure 7. Similar with Figure 5 but for the 20th stroke.

The electric field changes of the stroke recorded by a LF receiver are shown in Figs.6 and 7.

4 Discussion and Conclusions

Extremely long lightning channel over 100km like the case described in Section 3 were observed at least 21 cases in December 2016 and January 2017. It is considered that more cases have actually occurred in the cases. In the 21 cases, LLS recorded more than 3 strokes at a maximum of 22 strokes. In 21 observed cases, LLS recorded a total of 202 lightning strokes, of which 121 were positive and 81 were negative. In addition, there are 17 cases where the maximum current value is over 100 kA. Some of them exceed 600 kA. LLS recorded lightning stroke of different polarities in one flash, and the electric field changes also show the same polarities. It was found that lightning strokes of different polarities occurred in one flash.

The Hokuriku region in winter is an environment where thunderstorms are likely to occur due to the effects of the Siberian Air Mass and the Tsushima Current. Extremely long lightning channel over 100km described in this paper are all generated by streak thunderclouds extending parallel to the coastline. Conversely, since there is no extremely long lightning channel over 100km except for streak clouds, it is conceivable that a unique charge structure in a streak cloud parallel to the coastline. In addition, in all 21 observed cases, multiple lightning stroke were recorded by LLS, so extremely long lightning doesn't occur in IC and single stroke flash.

6 Acknowledgements

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7 References

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