Fourier spectra of positive lightning fields
during winter thunderstorms

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Abstract The magnetic radiation fields produced by positive lightning return strokes during winter thunderstorms in Japan have been Fourier-analyzed to determine amplitude spectra from 100 kHz to 10 MHz. The fields were recorded at the tip of a peninsula where the field propagation from the lightning sources to the recording site was entirely over salt water. The spectra for positive return strokes show an f^{-1} frequency dependence from 100 kHz to 400 kHz, an f^{-2} dependence between 400 kHz and 2 MHz. In the 100 kHz to 2 MHz range, the spectra of the initial fast transition in positive return strokes are surprisingly different from those of negative return strokes, which were reported previously.

1. Introduction

The electric and magnetic fields produced by lightning return strokes have been studied for many years, but it is only these ten years that time-domain waveforms of the salient processes called submicrosecond phenomena have been measured with sufficient time-resolution (Weidman and Krider, 1980, Oishi et al., 1986). The mathematical models have been developed to describe these fields in terms of the channel currents (Lin et al., 1980, Uman, 1985), and the excellent agreement between observed fields and calculated fields by using these models is shown. Nevertheless, these previous reports were restricted to the negative lightning return strokes during summer thunderstorm.

On the other hand positive lightning during winter in Japan often causes the serious issue concerning to power transmission lines in Hokuriku district. This district is quite well known as one of the most active winter thunderstorm area in the world. Moreover many of power plants are concentrated in this area. Under this situation realistic models of positive return stroke currents are eagerly expected for the purpose of the protection of power transmission lines from troubles caused by the positive return stroke. From this point, measurements of electric and magnetic fields produced by positive return strokes using sufficient time resolvable apparatus have been consecutively carried out in this district during these several winters. On the way to the goal, which is a proposal of current models of the positive return stroke, the risetime of the fast transition of the return stroke fields and the Fourier spectra are discussed in this letter.

2. Measurement and Data

Figure 1 Map of striking points on December 3rd recorded by LLP system. Observation site (Inecho) is indicated by an arrow. $\odot$, $\boxtimes$ show striking points of negative lightning and positive lightning respectively.

The winter thunderstorm observation were carried out at Inecho, which is a small fishing village and is located at the tip of so called the Tango peninsula and it is indicated by an arrow in Figure 1, in Kyoto Prefecture from November 12th through December 23rd in 1986. The schematic diagram of measurement apparatus is shown in Figure 2. The electric field sensor, E sensor, consisted of a circular flat plate antenna and the magnetic field sensor, B sensor, one turn loop antenna. Both E and B fields are digitized by a two-channels transient recorder every fifty nanoseconds and are recorded on magnetic floppy disks. The bandwidth of the whole system is enough wide to discuss the recorded submicrosecond phenomena, that means the fast transition of both E and B fields can be detected by this system. These sensors

Figure 2 Schematic diagram of the observation apparatus which is set up at the tip of the Tango peninsula. This system is controlled by personal computer and observation can be carried out automatically.

were set up at the top of small hill which is faced to The Sea of Japan. Since the observation site is faced to the salt water, the recorded results can be considered not to be significantly affected by the ground wave propagation. In other words the recorded E and B fields should be consider-

ed to contain the complete information as the sources of return stroke currents. Moreover some of striking points can be recognized with the output of the LLP system, which has been set up to monitor the activity of thunderstorms of the Hokuriku district, by Kansai Electric Power Co., Inc. From 17:00 to 24:00 (LT.) on December 3rd, thunderstorms formed over the Sea of Japan and the distribution of striking points of return strokes is shown in Figure 1 as the position analyzed results of the LLP system. It should be noted that the distribution of striking points was almost parallel to the coast line of Honshu Island and the distance from the coast was about 100-200 km. During these thunderstorms the thirty-eight lightning return stroke fields could be recorded at Inecho observation site. Unfortunately due to the lack of amplification gain of the electric fields sensor, amplitudes of recorded E fields were too small to discuss quantitatively. Concerning B fields the useful results were obtained. Nevertheless, the recorded E fields were available to judge the polarity of return strokes. Out of 38 strokes fifteen are positive cloud to ground strokes and still more three can be identified by the position analyzed (PA data) results of the LLP system. Since no thunderstorm activity over the land is noticeable on the map of Figure 2, it can be concluded that the all fifteen strokes should be completely on the sea. One of the typical traces of B signals is shown in Figure 3. The bottom trace is whole recorded B fields, and the top one, which time axis is extended four times of the bottom, is a fraction of the bottom one.

Figure 3 Recorded B signal of a positive return stroke. The bottom trace is whole recorded data and the top trace is extended from 25 microseconds through 75 microseconds.

All of the fifteen B signals are similar to the trace in Figure 3 and are composed of the slow front and the fast transition as be seen in Figure 3. It should be noticed that this characteristics are almost the same as the characteristics of the negative return strokes reported by Weidman and Krider (1980) besides the interval of duration. All of the fifteen strokes are summarized in Table 1 with the striking time and the 10-90 % risetimes of fast transition.

Table 1. Summary of the recorded data and the average (12/03/87)

Time	Risetime	Distance	
181824	520 (nanoseconds)		
181951	350	130 (km)	LLS 181937 +490 (kA)*
182218	450		
204104	495		
204554	395	98	LLS 204540 +100
215321	565	103	LLS 215307 +164
215334	770		
220730	530		
223407	575		
223814	540		
224556	620		
230452	715		
230513	510		
233342	720		
233516	800		

(* Though this value is estimated by LLS, it seems to be anomalous.)

Fast transition risetime (10-90%)	Average	570 (nanoseconds)
	Standard deviations	130
in Florida (by Weidman et al.)	Average	90
(over sea)	Standard deviations	40
in Japan (by Oishi et al.)	Average	250
(over land)	Standard deviations	60

The 10-90 % risetimes are estimated following to the same definition by Weidman and Krider. It is found that the risetimes are ranging from 350 to 800 nanoseconds with a mean of 570 nanoseconds and a standard deviation of 130 nanoseconds. If these results are compared with those of Weidman and Krider (1980), it is easily found that the mean of risetimes of lightning fields produced by positive return strokes in Japan is six times larger than that of negative lightning fields. As already mentioned, the recorded B fields are not affected by the ground wave propagation, that means, the source currents of positive lightning may possess the much slower risetimes than those of negative lightning. Actually the observation of summer negative lightning were carried out during the summer in 1985 at the center of the plains of Kanto (Oishi et al., 1986) and the average and standard deviation of risetimes of fields for the close lightning has been obtained as shown in Table 1. It should be noticed that these fields were really affected by the ground wave propagation. Nevertheless, the average of negative stroke's risetimes observed in 1985 is twice faster than that of positive's observed in 1986. Then it is concluded that from the view point of statistics the positive return stroke currents maintain the slower risetimes than the negative ones. To make the difference clear a trace of a negative stroke signal recorded at Inecho site is shown in Figure 4. If the careful attention is paid at both, negative and positive return stroke fields, fast transition one can easily find that the positive field is clearly slower than negative. Still more, this results are consistent with the results reported previously by Hojo et al. (1985).

3. Fourier Analysis

The amplitude spectra of B signals were computed using the fast Fourier transform (FFT) on 1024 equally spaced samples. For some return strokes, the B signals had to be truncated at the end of a few ten microseconds

Figure 4 Recorded B signal of a negative return stroke.

Figure 5 Averaged Fourier spectra of fifteen positive return strokes. Thick solid line shows calculated spectra and thin solid lines show the limits of the standard deviation.

recording interval because the fields occasionally had not yet returned entirely to zero. Since the effect of window is not desirable, the procedure of truncation is perfectly performed as the same way suggested by Preta et al., (1985). Actually individual distribution of amplitude spectra shows the interesting characteristics according to each recorded B signal but it is assumed that using statistics is more fruitful to discuss the physical meaning. Accordingly all of the fifteen signals are Fourier-analyzed and each calculated Fourier component is averaged and the result is shown in Figure 5. The thick solid line is the averaged Fourier spectra and thin solid line their standard deviations. It is clear that the spectra of positive return strokes show an f^{-1} frequency dependence from 100 kHz to 400 kHz, an f^{-2} dependence between 400 kHz to 2 MHz. Weidman and Krider (1981), Weidman et al., (1986) indicated that the turning frequency from f^{-1} to f^{-2} frequency dependence is 2 MHz for the negative return strokes. It is recognized that the difference between negative return strokes and positive ones in Fourier spectra region is quite large. In the previous section on the phenomenological difference, that is the risetimes, between the positive return strokes and the negative ones are shown and discussed in detail. It is considered that the difference in the frequency region is exactly related with the difference of mean risetimes. In other word the difference between negative and positive can also be shown in Fourier spectra region.

4. Conclusion

In this letter the risetimes of positive return strokes during winter thunderstorm in Japan were estimated by analyzing the recorded B signal and were compared with the previous reported negative strokes. It is found that the mean risetimes of positive strokes is six times slower than that of negative strokes. Fourier-spectra were also calculated and frequency dependence was discussed in detail. The spectra for positive return stroke showed an f^{-1} frequency dependence from 100 kHz to 400 kHz, an f^{-2} dependence between 400 kHz to 2 MHz.

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