Locating Global Lightning from a Single Station Based on ELF Transient Observation

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1. Introduction

In the spherical Earth-Ionosphere cavity, there are many resonant modes of ELF waves , which are called Schumann Resonances (SR). These resonance modes are caused by global lightning activity in which nearly one hundred lightning discharges take place in a second. In this study, we are interested in a very large cloud to ground (CG) lightning which excites the cavity strongly, and that is detected as an electromagnetic transient propagating around the globe well above the background SR level. Therefore, we expect to derive the global spatio-temporal distribution of lightning from a single station, if we use ELF transient data. We have recorded these ELF transients with vertical electric and two horizontal magnetic field components at a station, Moshiri in Hokkaido, Japan for analysis. These data have enabled us to calculate the bearing of the event and the source-receiver distance and to derive a global map of the positive and negative CG lightning, respectively.

2. ELF Transients

The lightning is approximately an electromagnetic impulse, so we notice an electromagnetic signal at ELF range caused by even relatively distant lightning strokes. In addition to the continuous background, signal appears at 8Hz, 14Hz, 20Hz and so on, as called Schumann Resonances; occasionally a very large lightning whose amplitudes are several times greater than the background resonances, will induce transient signals, and we can deduce the characteristics of lightning source by means of such ELF transients. We show the ELF spectral components of an electromagnetic wave using the mode theory for the uniform spherical Earth-Ionosphere cavity by Wait [1962] and Galejs [1972]. The electric and magnetic field components for TEM or TM zero-order mode are calculated by the following formulas (Jones [1970]);

$$E_z = i\frac{I(f)ds\,n(n+1)P_n^0(-\cos q)}{4a^2 e_o 2pfh\sin(pn)}\left[\frac{\mathrm{V}}{\mathrm{m}\cdot\mathrm{Hz}}\right] \qquad (1)$$

$$H_f = i\frac{I(f)ds\,P_n^1(-\cos q)}{4ah\sin(pn)}\left[\frac{\mathrm{A}}{\mathrm{m}\cdot\mathrm{Hz}}\right] \qquad (2)$$

In Eqs.(1) and (2), P_n is Legendre function with complex order, $I(f)ds$ is the current moment of the source, q is the angular distance between the source and receiver, a is the Earth's radius, h is the height of the ionosphere, e_o is the free-space permittivity, and ν is the complex eigenvalue which describes the propagation characteristics.

Our recording system has a cutoff frequency of 800Hz and the sampling rate is 2kHz. We set the trigger threshold as 10 times larger than its standard deviation plus mean value, and we record 250ms of data before and 1000ms after the trigger point, resulting in a frame of 1250ms for one event.

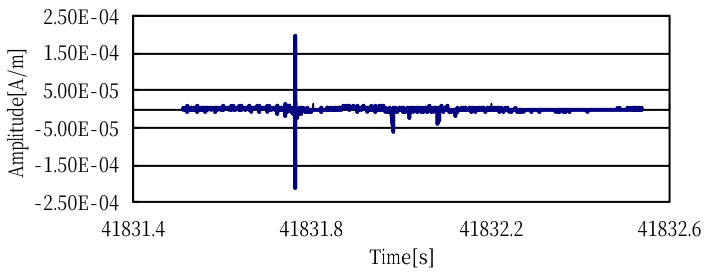


Figure 1. The waveform of an ELF transient (magnetic field E-W component)

3. Data Processing

3.1. Finding the Bearing and Range

In this study we assume the ELF transients as a linear-polarized wave, and the crossed-loop method was used to determine the bearing to the event. In order to avoid the effect of noise (for example, power line harmonics), we remove easily the frequency components contaminated by those noises by means of FFT analysis. Then, we take only the wave whose phase difference between two horizontal magnetic components (Hew, Hns) is less than ±50°, which is considered to be nearly linearly polarized. The direction of magnetic vector is derived by two magnetic horizontal field components using the crossed-loop method with an ambiguity of 180°. This ambiguity is resolved by calculating the Poynting vector, $\vec{E}\times\vec{H}$. The coordinate system used in this study is shown in Figure 2.

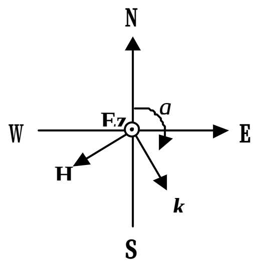


Figure 2. The coordinate system used in this study (q : bearing angle)

3.2. Finding the Range

The distance from the source to receiver was derived from the frequency dependence of wave impedance. This formula for the wave impedance is obtained from Eqs.(1) and (2) ;

$$Z(f) = -i\frac{n(n+1)P_n^0(-\cos q)}{ae_0\, 2pfP_n^1(-\cos q)} \quad [\Omega] \qquad (3)$$

The wave impedance depends only on the source–receiver distance and can be used to determine the range. Figure 3 shows the amplitude of theoretical wave impedance spectrum for the source-receiver distances of 6Mm and 12Mm. To determine the range, we take the cross correlation between the frequency dependence of the recorded impedance and the theoretical one and also we calculate each peak to peak frequency separation of wave impedance, to be correlated with the experimental one.

(a) (b)

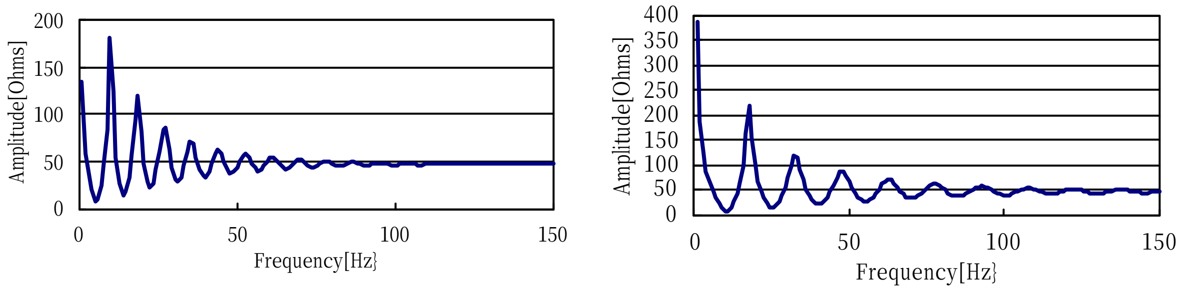
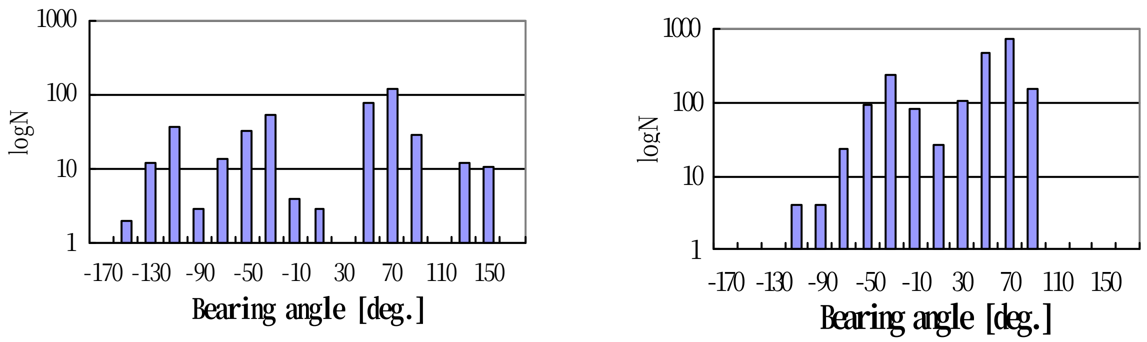


Figure 3. Amplitude of theoretical wave impedance for (a) 6Mm and (b) 12Mm

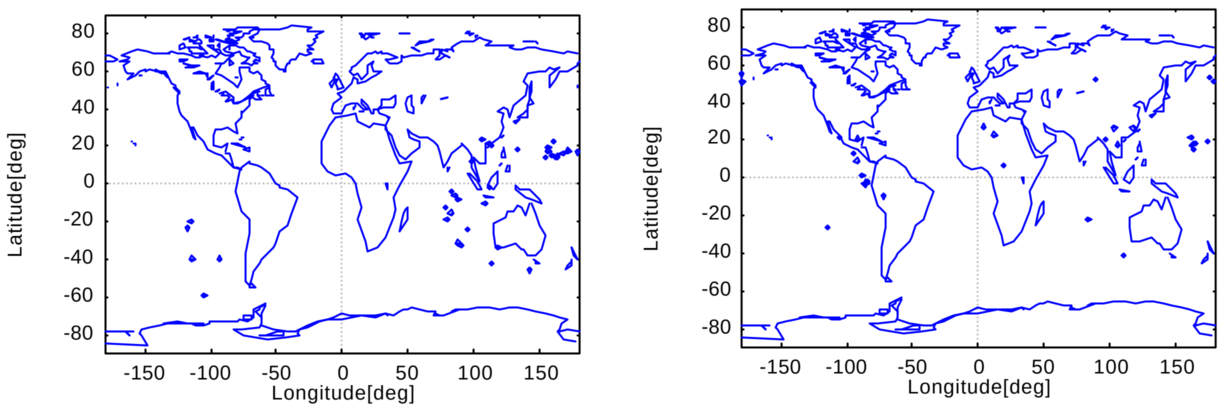
4. Results

The histogram of the number of lightning versus azimuthal direction on August 15,1999 is shown in Figures 4(a) and 4(b). Figure 5 illustrates a global map for August 15, 1999 using the range and bearing determined as above. Figure 6 shows the global lightning map by satellite observation of the optical events (OTD) on the same day.



(a) (b)

Figure 4. Azimuthal distribution of (a) positive and (b) negative events



(a) (b)

Figure 5. Global lightning map for August 15, 1999 of (a) positive and (b) negative lightning

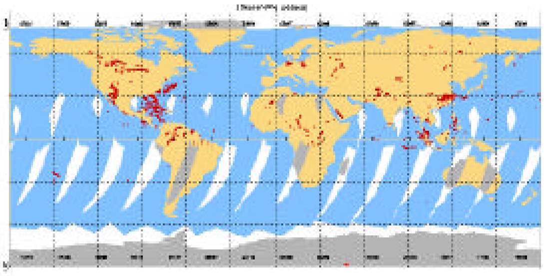


Figure 6. The global lightning map by satellite observation of the optical events (OTD) for August 15,1999

5. Discussion

Comparing Figure 4a with 4b, we can expect that the positive lightning discharges arrive at the observer from all over the world, while most of the negative lightning discharges are found from the arrival angles between -90° and 90°. So, those negative lightning discharges come from relatively short distance around Asia and Australia. Secondly, according to Figures 5 and 6,the most lightning is located in America, Africa, and Asia on both of these maps during one day period. Therefore, global lightning map shown in Figure 5 is acceptable, and these methods to determine the range and bearing from a single station based on ELF transients are found to be effective. However, for the wave propagated within 2Mm range, the wave impedance oscillation is so fast that we cannot determine the range. This problem will be solved by the use of Rhode Island (U.S) observation, and then we can make the complete global lightning map. Furthermore, we can see from Figure 5 that the negative lightning propagates from the region within 7Mm,while the positive lightning propagates from all over the world. This result is consistent with that of Figure 4.

6. Future Works

- We will derive the charge moment by using the present measurements and discuss the relationship between the estimated charge moment with the location of the lightning.
- Comparing our ELF result with the derived range and bearing based on Schumann Resonance, we will analyze the characteristics of propagation.
- For the wave propagating from the region around 7Mm distance from the source, we will compare the calculated distance with the result derived by means of another method based on the measurement of time difference between VLF component and ELF slow tail.
- We will discuss the difference of the propagation characteristics between the positive and negative lightning.
- We will consider the polarization error in direction finding and calculate the range and bearing of elliptical-polarized transients.

References

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