OBSERVATIONS OF PRECURSORY SIGNATURE OF EARTHQUAKE IN JAPAN BY IONOSPHERIC SOUNDER SATELLITE

Toshio Utsunomiya

Department of Communications Engineering, The National Defense Academy
1-10-20 Hashirimizu, Yokosuka 239-0811, Japan
utnomiya@nda.ac.jp

ABSTRACT

According to the Kushida's method, it is considered that extraordinarily high density plasma generates in the ionosphere over the epicenter. If the effect has an influence on upper ionosphere or magnetosphere, it must be detected by satellites. Extrapolating the electron density on the orbit of satellite, the plasma frequency near the satellite in the precursory period is estimated to be ten times as high as that at ordinary times. By investigating many ionograms, it is shown that earthquake occurs from one hour to one day after the precursory signal ceases.

INTRODUCTION

Since the earth and the ionosphere are considered to be conductors, we may safely say that they form a kind of capacitor whose electrodes are spherical shells. Therefore, it is considered that the ionosphere plays the role of probe to detect the electromagnetic disturbance like fluctuation of electric charge and magnetic field on the earth.

Various methods utilizing electromagnetic phenomena to grasp precursory signatures of earthquake have been proposed so far. They are roughly classified into two groups; one is a group in which light or electromagnetic wave emitted directly on account of the microfracture of rock at the seismic center is observed, and another is a group in which an artificially transmitted electromagnetic wave is received that is affected by electromagnetic disturbance accompanied with the earthquake [1].

One of the latter group of electromagnetic methods is Kushida's method utilizing FM broadcasting electromagnetic waves. According to the Kushida's method, it is considered that extraordinarily high density plasma generates in the ionosphere over the epicenter.

On the other hand, if the effect of high density plasma generation has an influence on upper ionosphere or magnetosphere, it must be detected by ionospheric topside sounder satellites. In the upper ionosphere or magnetosphere, the higher the altitude becomes, the lower the electron density becomes. Therefore, by extrapolating the electron density on the orbit of satellite, the plasma frequency near the satellite in the precursory period is estimated to be much higher than that at ordinary times. Considering the estimation about plasma frequency like this, propagation property of cyclotron harmonic waves have to be changed in the precursory period. This variation can be utilized for prediction of the earthquake as precursory signature.

By investigating many ionograms and processing length of spikes for cyclotron harmonic waves statistically, it is found that it is possible to predict temporarily occurrence of the earthquake by the precursory signal recorded on board the satellite accompanied with the electromagnetic disturbance on the earth.

KUSHIDA'S METHOD

Kushida had been observing meteors by using FM broadcasting electromagnetic waves. A trail is generated when a meteor streams. Since the trail is made from plasma tube, the FM broadcasting wave is reflected and received. Therefore, the number of occurrence times of meteor is counted. He discovered that FM broadcasting wave, which cannot be received usually, had been received for several days before occurrence of the earthquake on account of anomaly in the ionosphere over the epicenter [2]. From this, he asserts that it is possible to predict occurrence of the earthquake locally as well as temporarily by monitoring usually received signals of many FM broadcasting stations dotted with Japan [2].

BASIC PRINCIPLE

Whether cause is made clear or not, we cannot help supporting the fact that extraordinarily high density plasma generates in the ionosphere over the epicenter and makes the FM electromagnetic wave reflect which penetrates the ionosphere usually. This shows that the plasma frequency at the maximum point of electron density is superior to the frequency of the FM wave.

If the effect has an influence on upper ionosphere or magnetosphere, it must be detected by the satellites. Since the FM waves are reflected, the maximum electron density in the ionosphere is estimated. Furthermore, in the upper ionosphere or magnetosphere, the electron density in the vicinity of the orbit of satellite can be extrapolated, since the higher the altitude becomes, the lower the electron density becomes. Therefore, it is found that the plasma frequency near the satellite in the precursory period is estimated to be much higher than that at ordinary times.

According to the propagation mechanism of cyclotron harmonic waves trapped in the ionosphere or magnetosphere formerly proposed by the author, the higher the plasma frequency becomes, the less the cyclotron harmonic waves can be trapped. Consequently, the length of spikes becomes shorter, as the plasma frequency in the vicinity of the satellite becomes higher [4]. From this, it is expected that change of length of spikes is utilized as a precursory signature of the earthquake.

ESTIMATION OF ELECTRON DENSITY

Since the FM electromagnetic waves up to 90 MHz are reflected, the maximum electron density at the maximum point of electron density where altitude is about 350 km is estimated to be 1.00×10^8 cm^{-3}. Using this value, the electron density in the vicinity of the orbit of satellite whose altitude is about 1400 km is extrapolated to be 1.26×10^6 cm^{-3} with approximated representation of electron density distribution given by the author shown in Fig. 1 [3]. Then, it is found that the plasma frequency near the satellite in the precursory period is estimated to be ten times as high as that at ordinary times.

TRAPPING MECHANISM OF CYCLOTRON HARMONIC WAVE

The author has proposed that the cyclotron harmonic wave is trapped at the minimum point of the magnetic field like the magnetic equator plane and the trapped wave has a meandering path as shown in Fig. 2 [4]~[6]. Since the wave can come across the antenna of the sounder many times such as points P, Q, and R in Fig. 2, a totalled long spike which consists of superposed spikes at even intervals is consequently recorded in the ionogram, which is shown in Fig. 3. Fig. 4 shows a typical example for ISIS-II ionogram in which the totalled long spike for the third cyclotron harmonic wave is recorded.

On the other hand, the condition for the nth cyclotron harmonic wave to be trapped is given by an inequality as

$$f_P < \sqrt{n^2 - 1}\ f_H . \qquad (1)$$

Here, f_P and f_H denote plasma and cyclotron frequencies, respectively. n is a positive integer standing for the nth harmonic [4]. As mentioned earlier, if plasma frequency increases extraordinarily due to the precursory activity of the earthquake, the condition to be trapped becomes not to be satisfied. Therefore, it is expected that the cyclotron harmonic wave tends not to be trapped and then corresponding spike becomes shorter.

ANALYSIS OF IONOGRAMS AND DISCUSSION

From this point of view, we investigate many ionograms of ISIS-II satellite before and after three huge earthquakes in detail. In Fig. 5 plotted are both frequency and length of spike for third cyclotron harmonic wave in the ionograms observed for total 13 days before and after occurrence of the first earthquake, "1974 Earthquake off Izu Peninsula, M 6.9" that occurred at 34.6° N, 138.8° E in 1974/05/09/08:33:27 UT selected as an example of huge earthquakes.
Since the satellite always takes ascending orbit in this case, the geomagnetic field becomes stronger and then frequency for the third cyclotron harmonic wave $3f_H$ increases during one pass. On the contrary, it is found that the length of spike for $3f_H$ tends to decrease during one pass. Paying attention to the initial length of spike for $3f_H$ in one pass when the satellite passes over the Islands of Japan, it is found that the initial length of spike, which is longest in one pass, becomes decreasing toward occurrence time of the earthquake and then the length of spike recovers suddenly to be long on the way of the last pass one hour before occurrence of the earthquake. Cause that the initial length of spike for $3f_H$ becomes decreasing is considered to be that since the trapping condition (1) does not hold or the left side of the inequality approaches its right side sufficiently even if the condition is satisfied, the third cyclotron harmonic wave becomes hard to be trapped.
As for the other two examples of huge earthquakes, since the satellite takes descending orbit, the magnetic field becomes weaker and then frequency for the third cyclotron harmonic wave $3f_H$ decreases during one pass inversely in ascending orbit. On the contrary it is also found that the length of spike for $3f_H$ tends to increase during one pass and then the final length of spike is longest in one pass in case of descending orbit. Therefore, the final length of spike for $3f_H$ in one pass has to be considered instead of the initial length of spike in case of ascending orbit. Similarly to the first example, the earthquake occurs from half a day to one day after the descending length of spike recovers. As a result, it is shown that we can predict temporarily occurrence of the earthquake by observing ionogram data.

CONCLUSION

Since the electron density of plasma in the upper ionosphere or magnetosphere over the epicenter increases extraordinarily several days before occurrence of the earthquake, the cyclotron harmonic wave tends not to be trapped and consequently the initial length of spike for $3f_H$ in one pass of the satellite becomes decreasing toward occurrence time of the earthquake. The decreasing period corresponds to the precursory period in the Kushida's method. And the earthquake occurs from one hour to one day after decreasing length of spike recovers. This period between recovering time and occurrence time corresponds to the calm period in the Kushida's method.
As a result, we may safely say that this method utilizing ionogram data on board the satellite as precursory signature is available for the temporary prediction of occurrence of the earthquake. If we use this method together with other methods, this becomes a more powerful prediction method for occurrence of the earthquake.

REFERENCES

[1]M. Hayakawa: Technical Report of IEICE, Japan, SANE2001-63, Oct. 2001.
[2]Y. Kushida and R. Kushida: RIKEN Rev., No. 19, pp.152-160, 1998.
[3]T. Utsunomiya: IECE Trans., Vol. J64-B, No. 2, pp.103-110, 1981; or Electronics and Communications in Japan, Vol. 64-B, No. 2, pp.47-54, 1981.
[4]T. Utsunomiya: IECE Trans., Vol. J64-B, No. 5, pp.361-368, 1981; or Electronics and Communications in Japan, Vol. 64-B, No. 5, 1981.
[5]T. Utsunomiya: IECE Trans., Vol. J66-B, No. 4, pp.437-444, 1983; or Electronics and Communications in Japan, Vol. 66-B, No. 4, 1983.
[6]T. Utsunomiya: IEICE Trans., Vol. E83-B, No. 4, pp.838-849, 2000.

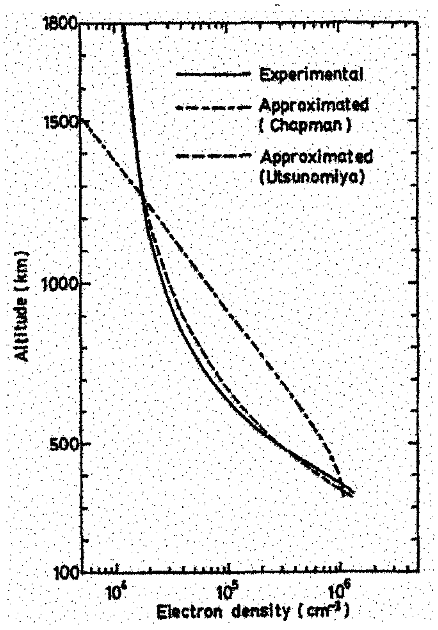

Fig. 1 Electron density distribution in the upper ionosphere.

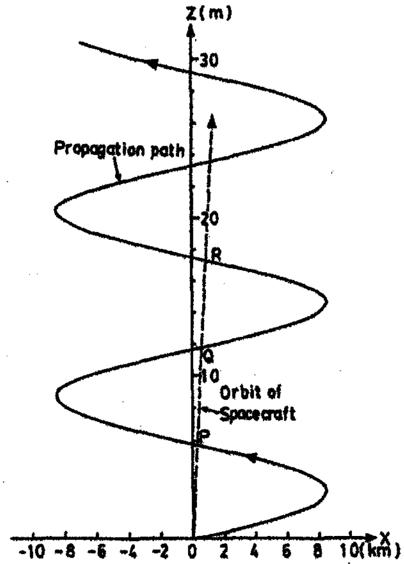

Fig. 2 Crossing between a meandering path of wave and the orbit of satelite.

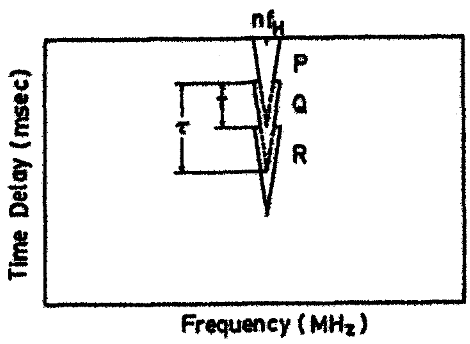

Fig. 3 Pattern of long spike consisting of superposed spikes at even intervals.

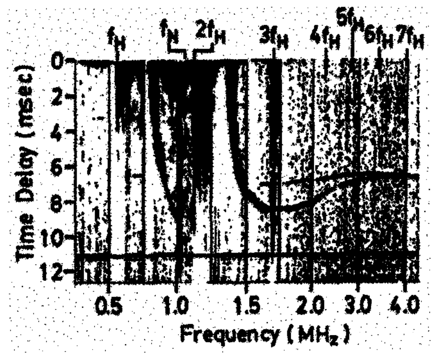

Fig. 4 Long spike for $3f_H$ observed in the ionogram.

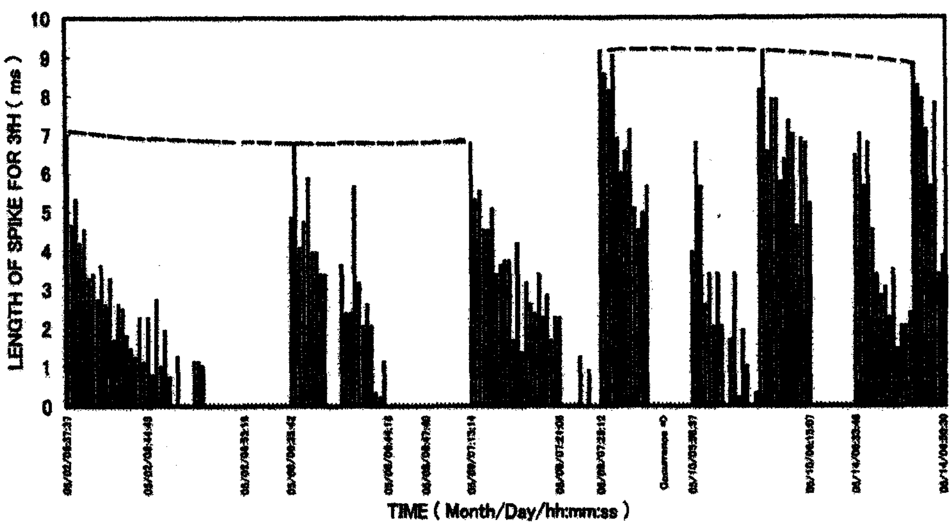

Fig. 5 Change of length of spike for $3f_H$ before and after occurrence of the earthquake (1974/05/09/08:33:27 Earthquake-off-Izu-Peninsula, M 6.9).