Seismo-Ionospheric Perturbations, and the Precursors to the 2011 Japan Earthquake

Masashi Hayakawa
The University of Electro-Communications,
Advanced Wireless Communications Research Center
Tokyo, Japan
hayakawa@hi-seismo-em.jp

Abstract—The ionospheric perturbations have been found to take place prior to an earthquake (EQ) (with magnitude greater than 5.5 (or so) and with shallow depth), on the basis of the long-term VLF/LF subionospheric propagation. Then, there have been presented the precursors to the recent 2011 Japan EQ. That is, the ionospheric perturbation was definitely found on the basis of two completely different phenomena ((i)subionospheric VLF/LF propagation anomaly and (ii)ULF magnetic field depression). Further, atmospheric ULF/ELF radiation was observed a few days before the EQ.

Keywords—earthquake precursor; earthquake prediction; ionospheric perturbation; subionospheric VLF/LF propagation; ULF depression; atmospheric ELF radiation

I. INTRODUCTION

Short-term earthquake (EQ) prediction was based on the measurement of crustal movements with seismometers etc. in the field of seismology for many years, but this mechanical method is recently concluded to be not so effective in short-term EQ prediction. On the other hand, a new method of using different electromagnetic phenomena has been extensively studied during the last decades [1-3], which is found to be promising for short-term EQ prediction. Based on the long-term observations, it is found that the ionospheric perturbation (both in the lower bottom and upper F layer) among many precursors is closely correlated with EQs [4,5], which means that it is ready to be used for the practical EQ prediction.

The purpose of this paper is composed of two parts. The first part is to indicate a definite statistical correlation between ionospheric perturbations as found from subionospheric VLF/LF propagation anomalies and EQs (with shallow and large magnitude [4]. Secondly, we present the precursors to the recent Japan EQs. Ionospheric perturbations are studied as two independent physical phenomena (i)subionospheric VLF/LF propagation anomalies and (ii)ULF magnetic field depression) [6]. Finally, we show our latest results on the atmospheric ELF radiation as an additional precursor of atmospheric perturbation signature.

II. IONOSPHERIC PERTURBATIONS AS FOUND FROM SUBIONOSPHERIC VLF/LF PROPAGATION ANOMALIES: STATISTICAL CORRELATION

Subionospheric VLF/LF signals propagate in the Earth-ionosphere waveguide, and the reflection height is located in the D/E region of the ionosphere.

Any perturbations due to different agents (e.g., solar flares etc.) can be identified as a propagation anomaly in VLF/LF data [7,8]. We have suggested EQs as the most recent effect. Since the discovery of a very significant EQ signature for the Kobe EQ [9], we have established a VLF/LF network in Japan within the framework of NASA’s Earthquake Remote Sensing Frontier project. We have established several VLF/LF receiving stations within Japan, and at each receiving station we receive 5 transmitter signals (two Japanese transmitters, JY (Fukushima, 40kHz) and JII (Miyazaki, 22.2kHz)) and three American transmitters (NWC(Australia), NPM(Hawaii), and NLK(Seattle, USA)). The continuous observation has been performed for about 15 years, and this kind of continuous observation is of essential importance in establishing a significant statistical correlation [3].

Hayakawa et al. [4] have selected different propagation paths and seven years with good quality. As an analysis method, we use the nighttime fluctuation method, in which we pay attention only to the nighttime data. That is, we use $dA(t)=A(t)-<A(t)>$ where $A(t)$ is the amplitude at a time $t$ on a current day and $<A(t)>$ is the running average at the same time $t$ over ±15 days (before and after the relevant day). We estimate the trend as defined as the average of nighttime amplitude, and dispersion. This nighttime fluctuation analysis method is an alternative one of the terminator time method [4].

Fig. 1 illustrates the statistical result based on the superimposed epoch analysis (using above 50 events), which shows that the trend is decreased distinctly about one week before an EQ (with magnitude greater than 6.0) only for shallow ones (in full line). While, for the deep EQ (in thin line) there is no significant correlation between the VLF/LF propagation anomalies and EQs. The decrease exceeds -2.0 standard deviation. Also, the dispersion exhibits a significant enhancement before an EQ, though not shown as a graph here.

Copyright 2014 IEICE
The mechanism why such ionospheric perturbations are formed before an EQ, is poorly understood, but this mechanism will be discussed in the context of lithosphere-atmosphere-ionosphere coupling (i.e., (1) electric field hypothesis and (2) atmospheric oscillation channel) [1].

III. PRECURSORS TO THE 2011 JAPAN EQ (IONOSPHERIC AND ATMOSPHERIC PERTURBATIONS)

In addition to the statistical study as given in [4], it is highly required to perform a case study for a huge EQ. Of course, our recent concern is the latest 2011 Japan EQ.

There happened an extremely huge EQ (with magnitude of 9.0) under the sea bed in the Pacific Ocean off the Tohoku area of Japan. This EQ took place at 14:46:18 LT on 11 March 2011 with its epicenter at the geographic coordinates (36°6.2’N, 142°51.6’E) as shown in Fig. 2 and with its depth of 20km. This EQ is a very typical oceanic EQ of the plate type, which is very different from the fault-type such as the Kobe EQ.

There are two independent physical phenomena which can be explained in terms of the same ionospheric perturbations in Section A [10], and Section B deals with the ELF radiation as an atmospheric precursor [6].

A. Ionospheric precursors

1) VLF/LF ionospheric perturbations

Among many propagation paths, we indicate only one Figure illustrating the most favorable result for the Chofu (CHF) among the propagation paths from Japanese receiving stations (Chofu(CHF), Kasugai(KSG) and Kochi(KCH)) to the American transmitter NLK. Fig. 3 shows that the trend (nighttime amplitude) exhibits a significant depletion on March 5 and 6 before the EQ. The decrease is very extensive, exceeding down to -4σ (σ: standard deviation), suggesting the approach of a huge EQ any way in the sea, but we do not know its position.

2) ULF magnetic field depression

The physical phenomenon of ULF magnetic field depression was found by Schekotov et al. (2006) [11] based on the observation during four-years data in Japan and two-years data in Russia. This phenomenon has been investigated for this EQ as well.

We are interested in the behavior of the horizontal H magnetic field component of magnetospheric ULF fluctuations. The maximum depression is known to be usually observed in the immediate vicinity of local nighttime. In this paper we use the local nighttime data around T=3hLT. The value of absolute depression “Dep” is calculated as,

\[ \text{Dep} = \frac{1}{\langle U^2 \rangle} \int \frac{\Delta F}{\Delta T} \]

where in the denominator we have squared output signal U by the sensor in the frequency band of ΔF=0.03-0.05Hz over the midnight ΔT=3h ± 2h LT. As a measure of relative depression (further simply depression) for the i-th date, the following value

\[ \delta \text{Dep}_i = \frac{\text{Dep}_i - \frac{1}{N} \sum_{j=1}^{N} \text{Dep}_j}{\frac{1}{N} \sum_{j=1}^{N} \text{Dep}_j} \]

is adopted to analyze. The denominator indicates the average value, while the numerator indicates the deviation from the mean.

Fig. 4 illustrates the temporal evolution of δDep at three observatories during December 2010 to June 2011. We can identify a clear maximum on March 6 in all stations, and the enhancement is most obvious only at KAK closest to the EQ epicenter.
Fig. 3. Temporal evolutions of propagation characteristics for the most important propagation path (NLK-CHF). Pay attention to the period from March 1 to March 12, to find a precursor to the 3.11 EQ. The two panels are (1) trend and (2) dispersion normalized by the standard deviation (σ). An significant anomaly is indicated in the figure. Very large increases in dispersion on February 1 and afterwards are not important because no corresponding significant decreases in trend are observed.

3) Two independent phenomena by means of a single effect of lower ionospheric perturbation

The anomaly in subionospheric VLF/LF propagation in (A) is well known to be accounted for with the lower ionospheric perturbation.

Also, the latter ULF depression is found to be attributed to the enhanced ionospheric absorption of magnetic ULF waves (of magnetospheric origin) observed on the ground [1].

We have investigated the solar activity and magnetic activity during the relevant period. There was a small geomagnetic activity, but the days of anomalous ionospheric perturbation were relatively geomagnetically quiet. So that, these anomalies are likely to be linked with the EQ.

B. ELF radiation

Based on the data from Chubu University network composed of three-stationed UFL/ELF stations (Nakatsugawa, Shinojima and Izu), we have found a clear anomaly of ELF radiation of atmospheric origin before the EQ [6]. The detection of such atmospheric ELF radiation is based on the analysis of a particular parameter (AS) as given in [11].

Fig. 5 illustrates the direction finding result for the atmospheric ELF radiation at the frequency ~9 Hz on a particular day of March 6 when the atmospheric radiation is most enhanced. The azimuths of ELF radiation measured from three observatories (Nakatsugawa, Shinojima, and Izu) are plotted, which are likely to be directed to the epicentral region of the EQ.

IV. CONCLUSION

In this paper we have presented our latest results on the precursor to an EQ. Firstly there has been shown the statistical correlation of VLF/LF ionospheric perturbations with EQs with large magnitude (M ≥6) and shallow depths. The establishment has led us to make a venture business company, “Earthquake Analysis laboratory” which has started the release of EQ prediction information to the public through mobile phones. Next, a case of the recent 2011 Japan EQ has been extensively shown: the ionospheric perturbations have been identified by the two independent physical phenomena, (i) subionospheric VLF/LF propagation anomaly, and (ii) ULF magnetic field depression. In addition to this ionospheric effect, the atmospheric ELF radiation was observed nearly on the same days before the EQ.

Fig. 4. Upper panel: Dst index of geomagnetic activity (in blue) and the occurrence of EQs with Mw>5. A yellow star means one EQ, and its corresponding magnitude is given by its height. The 2nd, 3rd and 4th panels refer to the temporal evolutions of δDepMMB, δDepKAK and δDepKNY at three Japanese stations. Two vertical red dashed lines indicate the times of EQs occurred on December 21, 2010 and on March, 11 2011 (our main target).
As further works, we are now studying the temporal evolution of crustal movement (by GPS data) in comparison with that of electromagnetic anomalies in this paper. Also, further studies are highly required on the source of atmospheric ELF radiation.

REFERENCES


