Ultra-Low-Frequency Magnetic Field Depression for Three Huge Oceanic Earthquakes in Japan and in the Kurile Islands

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***Abstract*—The depression (reduction in amplitude) of ULF (ultra-low-frequency) magnetic field variations observed on the Earth's surface is found for the recent huge Japan earthquake (EQ) (magnitude(M) ~ 9.0) on March 11, 2011 which is a typical oceanic EQ of the plate type. In order to confirm the presence of such a ULF depression, we have also studied the additional two huge oceanic EQs in the Kurile islands (M≅8), and similar ULF depressions have also been detected. This suggests that such a ULF depression seems to be a universal phenomenon for huge (M=8-9) EQs even occurred in the sea bed of subduction region.**

Keywords—ULF magnetic field depression; oceanic EQs; EQ precursor; EQ prediction

I. INTRODUCTION

It is recently thought based on the extensive studies during the last few decades that electromagnetic phenomena do appear prior to an earthquake(EQ) [1-3], including the lithospheric phenomena (such as geoelectric field, ULF(ultra-low-frequency, frequency less than 10Hz, but mainly in the mHz range) electromagnetic emissions, etc.), and seismo-atmospheric and –ionospheric perturbations. The most convincing effect at the moment might be the ionospheric perturbations as detected by subionospheric VLF/LF propagation, because there has been established a significant statistical correlation between the ionospheric perturbations and inland EQs with magnitude(M) greater than 6.0 and with depth smaller than 40 km [4].

Among the lithospheric effects, the ULF electromagnetic emissions are found to be promising for EQ prediction, though the number of events is not so abundant as compared with the ionospheric perturbations mentioned above [5-7]. The first ULF event was observed for the Spitak EQ in 1988 [8,9], and Fraser-Smith et al. (1990) [10] found an evidence of ULF signature of the 1989 Loma Prieta EQ (M=7.2). Hayakawa et al. (l996) [11] then found the ULF emissions in the case of the 1993 Guam EQ (M=8.0). Later ULF studies have been summarized in [3,5,12], though there have recently been published few papers casting a doubt to the presence of seismogenic ULF emissions [13,14].

A different type of ULF anomaly of EQ effects has been found by Molchanov et al. (2003) [15] and Schekotov et al. (2006) [16]. Being completely different from the above seismogenic lithospheric ULF emissions, this new effect is a phenomenon in the form of depression in the amplitude of ULF magnetic field fluctuations observed on the ground (probably, generated in the magnetosphere) a few days before an EQ. Schekotov et al. (2006) [16] have performed an extensive study on this effect on the basis of observations in Russia (Karymshiro) during the four-year period of June 21, 2000 through June 6, 2004 and those in Japan (Matsukawa) during the two-year period from October 22, 2001 to October 26, 2003. Their result was based on the analyses of 38 EQs (mainly oceanic EQs) with M in a range from 4.5 to 7.0 in Russia and of 22 separate EQs (mainly inland) with M from 5.5 to 8.3 in Japan.

The construction of this paper is as follows. In order to examine whether this kind of ULF depression is universal for other oceanic EQs, we have examined the ULF fluctuation data for additional two huge EQs (M≅8) in the Kurile islands again of the plate type. It is found that similar ULF depressions have been identified for these EQs as well, and we can conclude that ULF depression is universal even for oceanic EQs.

II. DATA ANALYSIS PROCEDURE

Following the main characteristic of our target phenomenon summarized in above Introduction, we are interested in the behavior of the horizontal H magnetic field component of ULF fluctuations (highly likely to be of magnetospheric origin). As already noted in the Introduction, the maximum depression in the horizontal component is usually observed in the immediate vicinity of local midnight. So the intervals of data analysis should be chosen carefully in such a way that all the observatories are situated at the same LT. We have to think of the LT intervals with low level of electromagnetic environmental noises (e.g., trains, electric motors, other similar equipments, etc.) and we choose the LT close to local midnight. The optimum time is found to lie in the vicinity of LT = 3h for each site as based on our previous measurements [16]

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The value of absolute depression Dep in the horizontal component of ULF magnetic field variations is calculated as,

$$\mathrm{Dep} = \frac{1}{\langle U^2 \rangle_{\Delta T}} \tag{1}$$

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

$$\delta \mathrm{Dep}_i = \frac{\mathrm{Dep}_i - \frac{1}{N}\sum_{j=i-N}^{j=i-1} \mathrm{Dep}_j}{\frac{1}{N}\sum_{j=i-N}^{j=i-1} \mathrm{Dep}_j} \tag{2}$$

is adopted to analyze. Here N is the filter parameter equal to the number of preceding days for averaging. In the present study N=5 is taken. The denominator stands for the average, and the numerator indicates the deviation from the average. All the parameters in Eq. (2), i.e. N, ΔT and ΔF are chosen so as to maximize the success of forecast.

The above terminology of the success of forecast means that any precursor exceeds a certain threshold level, provided sufficient reliability of the forecast. Realibility of the forecast can be estimated by the method described by Console (2001) [17], in which the value of probability gain (PG) is used as a criterion of the reliability. The PG depends on the statistics of detection (success rate, alarm rate), the total duration interval of observations, and the alarm interval of the precursor (5 days in the case of our ULF depression). Then the precursor is considered to be reliable if PG>1. It is possible to find the maximal value of PG by changing the threshold level, but this procedure is possible only for sufficient statistics.

Further comments on the parameters (N, ΔT and ΔF) in Eq. (2) are given below one by one.

First as for the number of averaging days N, in order to detect an impulsive signal (our depression) effectively it should be chosen to decrease the influence of long-term variation of ULF depression caused by the variation of background seismicity or the long-term variation of the magnetic fields. Actually δDep of Eq. (2) works as a high-pass filter with cutoff frequency ~ 1/N. Now this parameter, N was chosen by changing its value in such a way to obtain higher ratio of the precursor value to the background for a previous remarkable EQ on December 21, 2010.

Then, the optimal time window ΔT was estimated in our previous study, and it is found that the vicinity of local midnight is suitable. Unfortunately this choice was impossible in Japan, which is strongly contaminated by high level industrial interferences at that time. So that, the time window was shifted from local midnight to 3h in the morning. We have used the same time window (ΔT = 3h±2hr LT) for all magnetometers, which gives us a possibility to obtain the response suitable for a comparison of results at the three observatories. However, the magnetometer at Kakioka has less "sensitivity" to the depression due to very high level of interference.

The last parameter of frequency window ΔF was chosen from our previous results, which indicate maximal depression at these frequencies before an EQ. We have tested the correctness of this choice for an example of the same previous remarkable EQ with M = 7.4 on December 21, 2010.

III. ULF DEPRESSION FOR TWO HUGE EQS IN THE KURILE ISLANDS

Hayakawa in this session is going to present the electromagnetic precursors to the 2011 Japan EQ, including the detailed description of ULF depression. It is found that there is observed a clear depression of ULF waves on the ground on March 6, 2011, with its maximum value at KAK as compared with the data at MMB and KNY. In order to conform the validity of this precursor, we intend to study the similar oceanic EQs in the Kurile islands.

Two huge (M≥8) EQs happened in the Kurile islands as shown in Fig. 1, which are summarized as follows. The 1st EQ happened on November 15, 2006 (11h 14m 14s LT) at the geographic coordinates (46.59°N, 153.27°E). Its magnitude was M=8.3 and its depth was ~ 10km. The second EQ, which was highly likely to be one of aftershocks of the 1st EQ, occurred on January 13, 2007 (04h 23m 21s LT) at the geographic coordinates (46.24°N, 154.52°E), nearly at the same place as the 1st EQ (or main shock). The magnitude of this EQ was M=8.1 and its depth was again 10km. The location of these two EQ epicenters is plotted in Fig. 1 as circles. These are of the same type of oceanic EQs as the 2011 Japan EQ treated in the previous section. It is extremely worthwhile for us to investigate whether the similar ULF depression is really observable for these two EQs.

A. ULF Data, Analysis Period and Data Analysis Procedure

We have used the same ULF observatories in Japan as in the case of the 2011 Japan EQ; MMB, KAK, and KNY in Fig. 1.

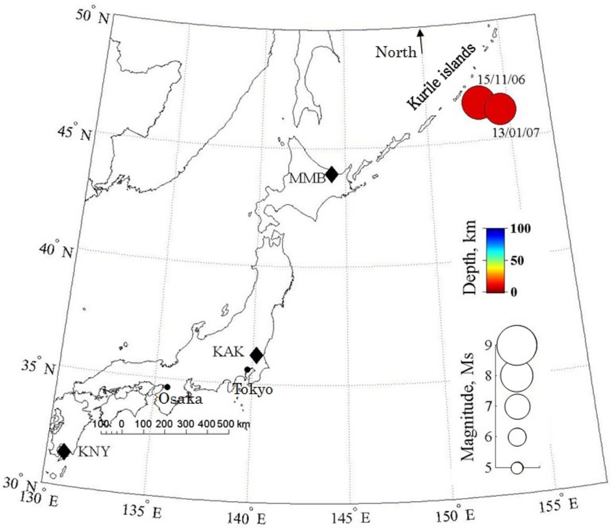

Fig. 1. The epicenters of two huge EQs in the Kurile islands and three ULF observatories in Japan

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The analysis period is seven months from September 1, 2006 to March 31, 2007, including the two huge EQs in the Kurile islands.

Then, the analysis procedure is exactly the same as in the case of the 2011 Japan EQ in Section Π. That is, we have used the same LT intervals and also the same equation (2) with the same parameters.

B. *Observational Results for the Two EQs in the Kurile islands*

Fig. 2 illustrates the analysis results for the two huge EQs in the Kurile islands. In the top panel of Fig. 2, we have plotted the geomagnetic activity measured by Dst and the EQ magnitude. The bottom three panels refer to the analysis results on the ULF depression during our period. The 2nd panel refers to the result for MMB in Hokkaido, the 3rd, KAK, and the fourth, KNY. The two vertical broken lines indicate the occurrence times of two EQs.

It is seen from Fig. 2 that the ULF depression at MMB in Hokkaido exhibits remarkable changes just around the two EQs. As for the first, probably, main shock of the EQ, we have found a clear and isolated ULF depression about 10 days before the EQ. In addition to this precursory peak, there are observed some ULF depressions even after the EQ. As for the 2nd EQ (probably one of the aftershocks of the 1st EQ), there exist some anomalous behaviors at MMB. That is, the first anomaly (two peaks in δDep) in the end of December 2006 and an additional enhancement 6 days before the EQ. Also, we find a noticeable enhancement just around the EQ, δDep value being upto nearly 14. How about the corresponding results for other stations (KAK and KNY) ? By looking at the δDep at KAK (3rd panel of Fig. 2), we find that there is completely no response, no ULF depression even just around the two EQs. On the other hand, it looks that there are some corresponding responses at KNY because the peaks of δDep here at KNY are likely to be synchronous with those at MMB, even though the station of KNY is located in Kyushu island, far away from the EQ epicenter.

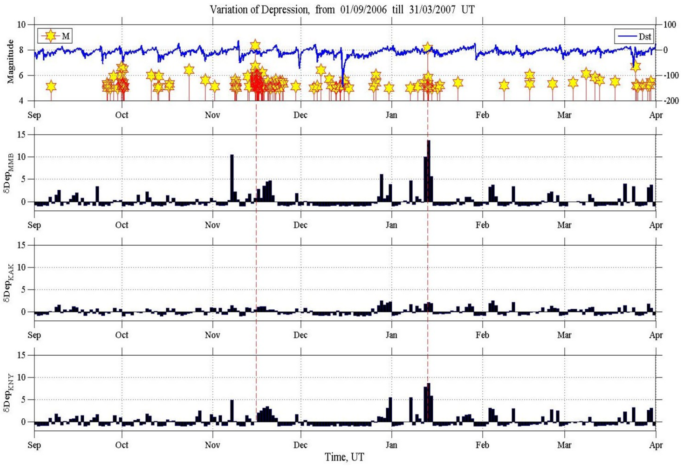

Fig. 2. ULF magnetic field depressions for two EQs in the Kurile islands. The temporal evolutions of geomagnetic activity (Dst) and EQ magnitudes (top panel), and of δDep at three stations in Japan (2nd to 4th panels). The vertical dotted lines indicate the occurrence times of two EQs of our concern.

We can here summarize the ULF depression results for the two huge (M≧8) EQs in the Kurile islands.

1) *The depression of ULF horizontal magnetic field (of magnetospheric origin) was observed very remarkably for the two huge EQs in the Kurile islands.*
2) *The characteristics of those ULF depressions seem to be quite similar to that for the 2011 Japan EQ, including the same frequency, nearly the same lead time, or so.*
3) *The depressions for these two EQs were found to be most enhanced at the station of MMB in Hokkaido, while some synchronous effect is detected as well at KNY.*

IV. DISCUSSION

Below we try to discuss briefly the results for the 2011 Japan EQ, and then we move on to the corresponding results for the two EQs in the Kurile islands.

Here we discuss whether the peak in ULF depression observed at Japanese observatories on March 6, 2011 is a possible precursor to the huge EQ on March 11, 2011, though not shown here as graphs. The timing of our ULF anomaly is the simplest of the three parameters of EQ prediction. Using the former statistical information on ULF depression, an EQ will happen 1-5 days after the peak of δDep, i.e., from 7 to 11 of March. The second question on the EQ localization is more complicated because of spatial electromagnetic interferences and of the scale of the EQ preparation zone. The peak of δDep at KAK is higher than that at other two stations (MMB and KNY), so that we can assume that the EQ place should be closer to KAK. The magnitude estimation is the most difficult task. An approximate linear relationship does exist between the value of δDep and EQ magnitude [3,16], and we can say that the magnitude of an expected event is essentially higher, probably larger than 7. More information can be extracted from the small difference in depression between three stations located at distances almost two thousand km. The expected magnitude for such a scale of preparation zone is in a range from 7 to 8 [18].

Here we discuss the corresponding results on ULF depression for the additional two huge EQs in the Kurile islands. It seems that the 2nd EQ is one of the aftershocks of the 1st EQ (main shock). Even in this situation, we are happy to have found very clear precursory enhancements of ULF magnetic field depression for both of EQs. Also, the characteristics of those ULF depressions are found to be very similar to those for the 2011 Japan EQ. So that, we can conclude that such a ULF depression seems to be a universal phenomenon even for huge oceanic EQs, and it is plausible that these effects might be a possible EQ predictor.

As for the generation mechanism on the depression of ULF magnetic field components, two hypotheses have already been proposed [3,16]. The first possibility is the decrease in penetration coefficient of ULF fluctuations of Alfven mode waves originated in the magnetosphere due to the turbulent increase in the effective Pedersen conductivity in the ionosphere. The second hypothesis is a change in wave number (**k**) distribution of the source ionospheric turbulence. Whatever the hypothesis is more plausible (probably the 1st

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linear hypothesis is more acceptable), the depression of ULF horizontal magnetic field components of magnetospheric ULF fluctuations is apparently considered to be due to the precursory ionospheric disturbances; that is, a kind of seismo-lower-ionospheric effects. We have found the clear depression on March 6 for the 2011 Japan EQ. In good accordance with this inference, we have already found and published that the lower ionosphere was definitely perturbed on March 5 and 6 as based on subionospheric VLF/LF propagation on the propagation paths from the Americal transmitter (NLK, Seattle USA) to Japanese VLF/LF stations (Chofu, Kasugai and Kochi) [19]. Because there have been accumulated a lot of evidences of seismo-lower-ionospheric perturbations by means of subionospheric VLF/LF propagation anomalies [4], it is highly likely that the lower ionosphere is really disturbed during these days, so that this is not an accidental coincidence and it would give a strong support to the ULF depression result.

Finally we have to mention that it seems that there are so many things to elaborate the present work, including the detailed study on the spatial scale of the phenomenon, what kind of ionospheric perturbation could result in the observed depression of the ULF horizontal magnetic field component ? etc.

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