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Seismo-ionospheric depression of the ULF geomagnetic fluctuations at Kamchatka and Japan

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Abstract

We study preseismic behavior of the ULF geomagnetic variations at Karymshino (E158.13, N52.83), Russia, and Matsukawa (E140.94, N39.88), Japan. A depression of ULF power around local midnight is registered several days before strong isolated earthquakes. The relative depression, i.e. $\delta D = (\frac{1}{G} - \langle\frac{1}{G}\rangle)/\langle\frac{1}{G}\rangle$ has been analyzed, where the absolute depression is defined as a sum of inversed values of spectral power densities of horizontal components (where $\frac{1}{G} = 1/P_{hh}$ and P_{dd} are the mean spectral densities of H and D components) in a sliding window ±(10–15) days. At Karymshino the most evident effect is found 3 days before an earthquake for the 0.5 h vicinity of local midnight in the frequency range 0.02–0.05 Hz. The data from Matsukawa are used to estimate the spatial scale of the effect and its local nature has been confirmed. Furthermore there is a definite correlation between the depression value and index of seismic activity. Thus, the analysis supports a hypothesis on seismic origin of the observed ULF geomagnetic field depression preceding an earthquake.

Keywords: ULF geomagnetic variations; Preseismic; Spectra

1. Introduction

Our previous paper (Molchanov et al., 2003) has indicated an effect of the depression of the amplitude of geomagnetic variations in the frequency range 0.003–0.1 Hz preceding several days near-by earthquakes. While an explanation of the effect was suggested (Molchanov et al., 2004), some doubts are left because there were many papers on the intensification of ULF magnetic field intensity before earthquakes (e.g. Fraser-Smith et al., 1990; Hayakawa et al., 1996; Uyeda et al., 2002; Kopytenko et al., 2002).

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2. Results of observation

In the present work, the analysis of the preseismic depression is drastically extended to 4 years of observation (2000–2004) in Karymshino observatory at Kamchatka, instead of nearly one year as it was in the previous paper, and further two years of observations (2001–2003) in Japan are added. Variation of the field depression is studied

$$\delta D = (1/G - \langle 1/G\rangle)/\langle 1/G\rangle$$

where

$$1/G = 1/P_{hh} + 1/P_{dd}$$

P_{hh}, and P_{dd} are mean spectral densities of H and D magnetic field components averaged over 1 h interval around local midnight, and $\langle 1/G\rangle$ is the one month mean running depression. The cross-correlation functions between the two quantities (δD and K_s) are calculated, where K_s is a seismic index proportional to the flux of the seismic energy in an observational point.

An example of preseismic depression is shown in Fig. 1. The period of data is about one month and a half from April 1 to May 18, 2002 in Fig. 1. The top panel illustrates the temporal evolutions of two indices, K_s and K_p. The second from the top refers to the ratio of Z/G (G: total horizontal magnetic field and is given by $G = \sqrt{H^2 + D^2}$), the third, $1/G$ reflecting the field depression, and the final fourth, an inverse of the coherence between the two horizontal magnetic field components (H, D). Three possible time intervals when the field depression (or enhanced

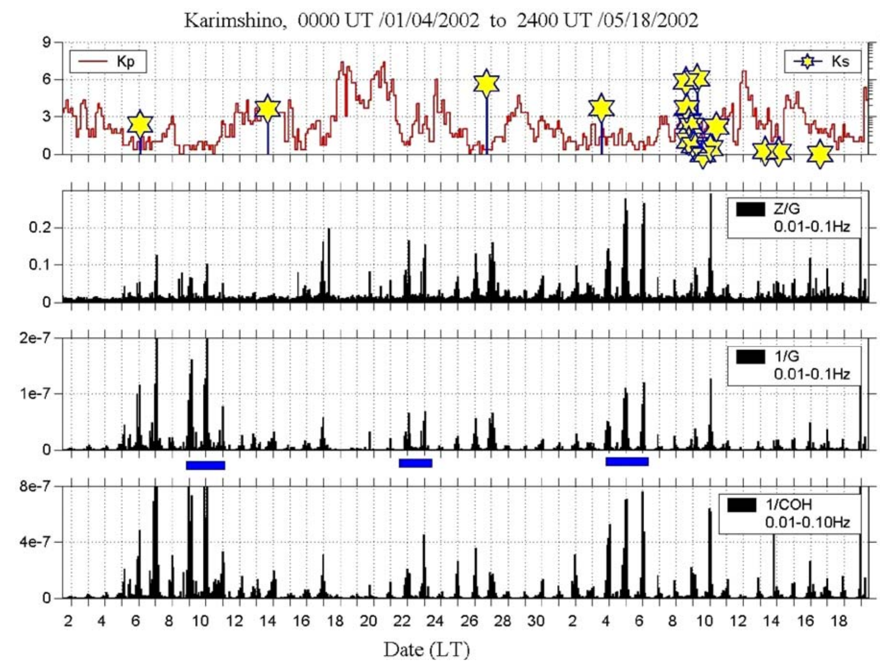

Fig. 1. Upper panel – K_s and K_p indices, next panels (from top to bottom) – impedance relation Z/H, field depression $1/G$, and inverse of coherence of two horizontal magnetic field components.

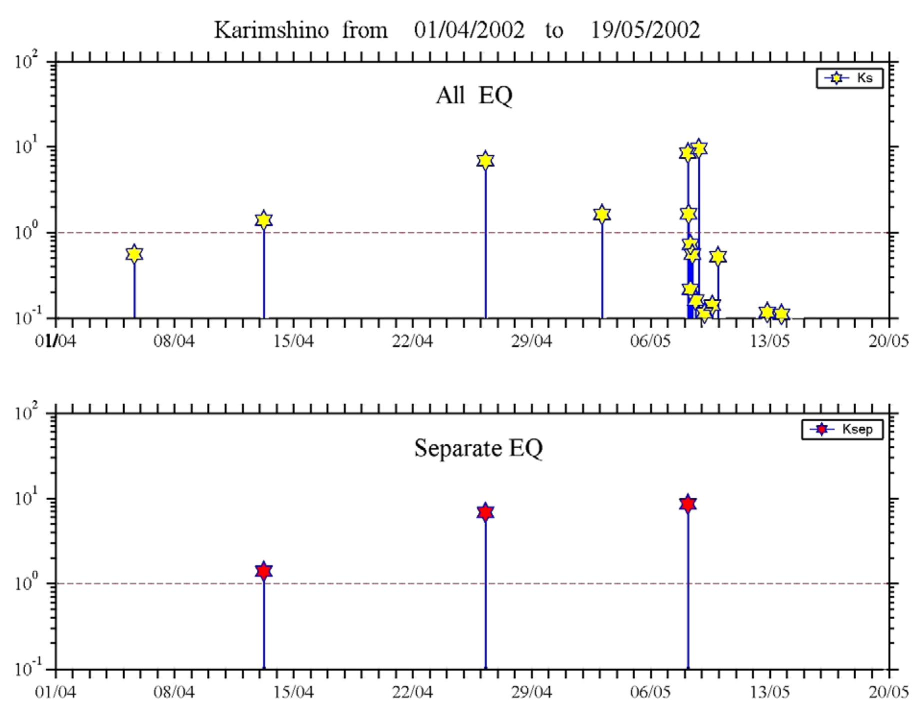

Fig. 2. Top: K_s index for EQs; the accepted threshold $K_s = 1$ is shown by dashed line. Bottom: maximal EQs with $K_s > 1$ in the ±7 day interval.

$1/G$) is seen, are indicated as horizontal bars on the abscissa of the plot of $1/G$. This figure is the result at a particular frequency of 0.01–0.1 Hz. The preseismic effect is uncertain for earthquake series and only isolated earthquakes are chosen for the further analysis, the selection technique is illustrated in Fig. 2. The nearly same time interval with Fig. 1 is plotted in Fig. 2, and the bottom panel in Fig. 2 indicates the isolated events satisfying the above criterion. Not only aftershocks are excluded but also foreshocks. As is explained in Fig. 2, the earthquakes with maximum K_s in a window ±7 days are retained, provided that $K_s \geqslant 1$. Cross-correlation between such isolated earthquakes and the depression of the magnetic field is shown in Fig. 3. The cross-correlation function $\delta D * K_s$ is shown in the left panel, and averaged variation of depression is shown in the right panel. Both curves are found to have a clear maximum 3 days before the EQ.

In order to validate the statistical stationarity of the effect the interval of observations is divided into 4 one-year intervals and the cross-correlation functions are calculated for each interval (the bottom panel of Fig. 4). The clear maximum 3 days before the EQ is found for the 1, 3 and 4 intervals as well as for the whole period of observations. As for the second interval, we have found that additional maxima comparable with the "3-day" maximum occur. Thus, no meaningful effect is found for the second interval. Probably, this is because of low level of the nighttime geomagnetic activity during the second interval (see the upper panel of Fig. 4).

The power spectra of the depression of the magnetic field for a relatively large EQ on 16/06/2003 ($K_s = 15.6$) are presented in Fig. 5. In the top-panel we have illustrated the corresponding variations of δD, K_p and K_p (On the left) of this EQ and its epicenter is given on the left. The depression 3 days before the EQ is shown in the left panel. The bottom seven panels of Fig. 5 cover the interval from June 9 to June 15, 2003. In each panel, we have plotted the frequency spectra of the magnetic field intensity at day and

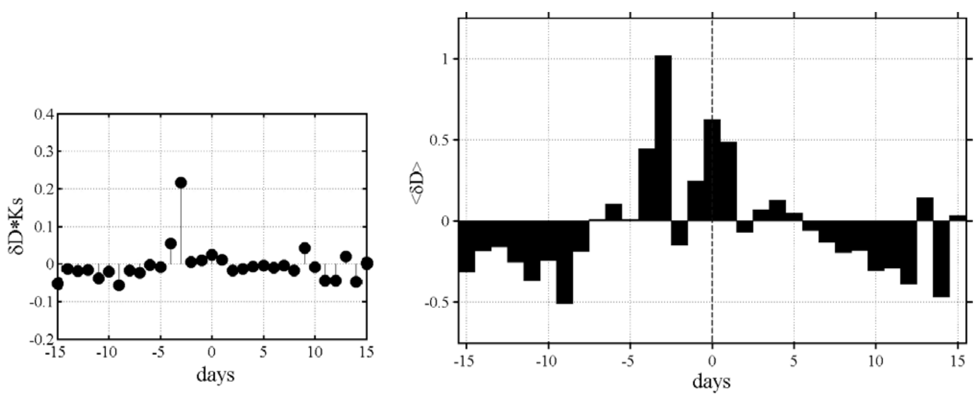

Fig. 3. Left: cross-correlation between K_s of the selected EQs and the variation of the field depression for the whole period of observations. Right: variation of the field depression averaged over all the selected EQs.

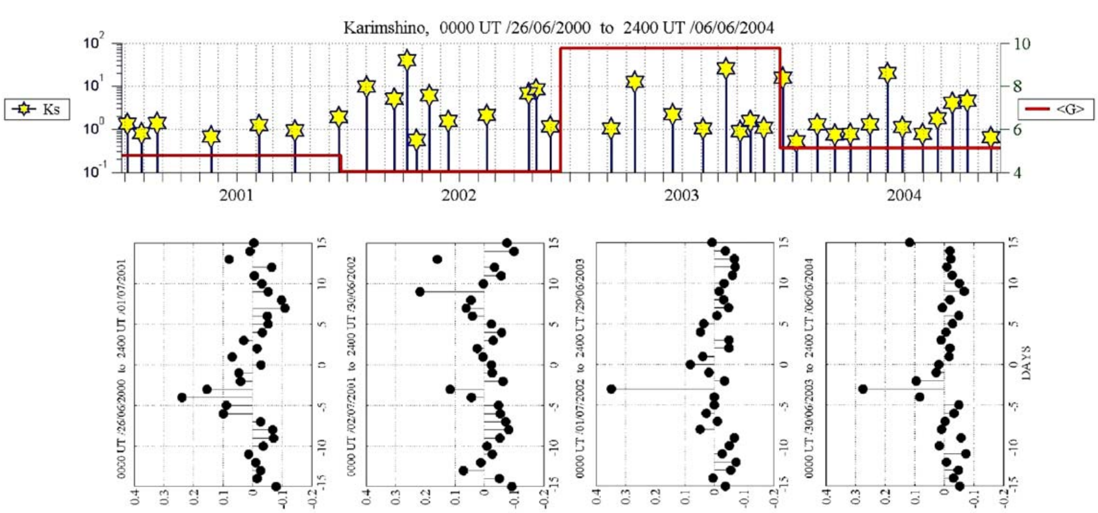

Fig. 4. Top: K_s index for EQs and year-mean field magnitude (G) at the frequency range 0.03–0.5 Hz in the ±0.5 h vicinity of the local midnight. Bottom: cross-correlation functions between δD for each year interval.

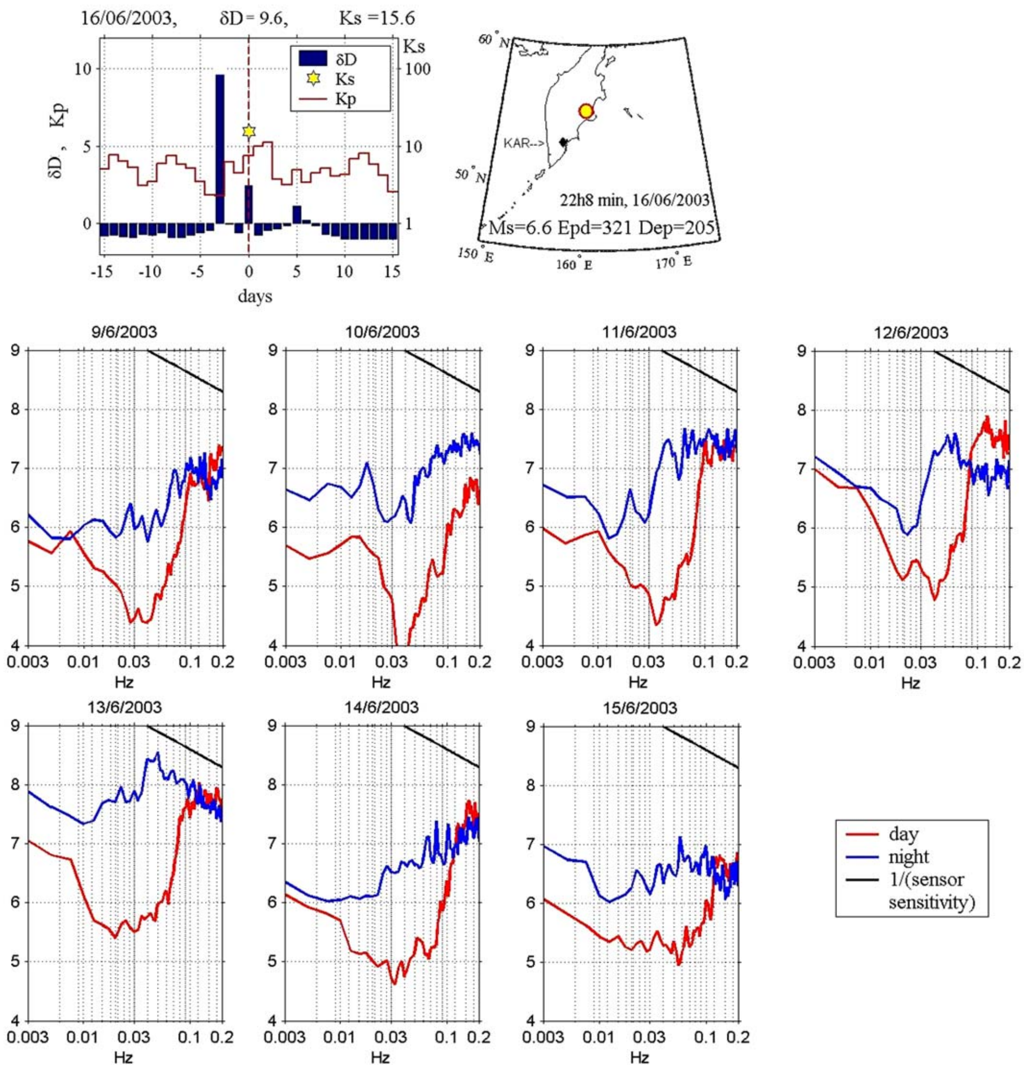

Fig. 5. Top: An example of variation of the field depression δD, K_p and K_s (left) for a large EQ on 16 June, 2003 and its map with parameters of the EQ. Bottom: depression spectra for local noon (red) and midnight (blue). As usual, the night-time depression (inverse amplitude) is larger than daytime and both are below inverse sensitivity. Maximum night-time depression occurs on the night of June 13, 3 days before the EQ. Black line shows the inverse sensitivity of the magnetometer. (For interpretation of the references in color in this figure legend, the reader is referred to the web version of this article.)

night for each days. A comparison of those spectra for about one week before the EQ, suggests that the depression of intensity is very obvious at local noon and midnight time 1–7 days before the EQ. And the maximum depression is observed especially in the frequency range 0.02–0.05 Hz 3 days before the EQ.

Waveforms of the horizontal magnetic field component D for this EQ event are shown in the left part of Fig. 6, and the corresponding spectra of components are shown in the right part of Fig. 6. We have confirmed that the signal amplitude decreases essentially and, correspondingly, the depression spectra are maximal 3 days before the EQ.

The dependence of depression (δD) on K_s is demonstrated in Fig. 7 for a few different combinations of earthquake parameters; (a) $M_s > 4$ and depth <50 km, (b) $M_s > 5.5$ and depth <300 km and (c) $M_s > 5.5$ and depth <50 km. It can be seen from the comparison of the three panels in Fig. 7 that K_s dependence becomes more or less clear for the magnitude value $M > 5$ and the correlation is found to be more enhanced for EQ depth less than 50 km.

The interrelation between the field depression and EQs for the two years of observations at the Japanese station of Matsukawa is analyzed with the same technique and the corresponding results are plotted in Fig. 8. The left two panels illustrate the temporal evolution of $\langle \delta D \rangle$ around the earthquake day. While, the right top indicates the correlation between the magnetic field at Kamchatka and the Japanese EQs and the right bottom, between the Matsukawa magnetic field and Kamchatka EQs. The period of analysis is form October 22, 2001 to October 26, 2003 (about two years). The "3-day" depression effect is also found for this data both for the two stations of Kamchatka and Matsukawa. It is seen from the right panels of Fig. 8

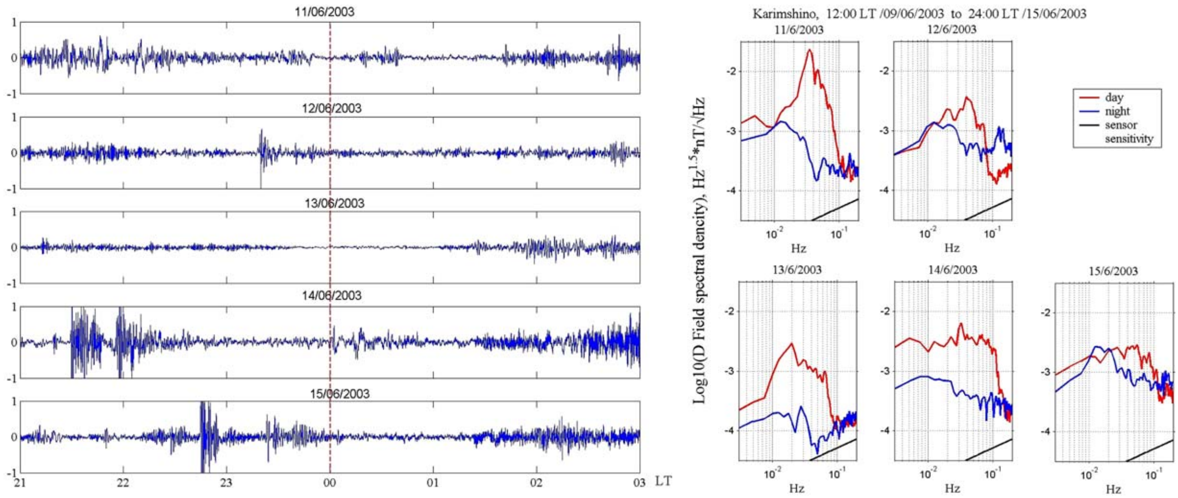

Fig. 6. Left: waveforms of the registered fluctuations of D component of the magnetic field around the local midnights for 1–5 days preceding the EQ. Right: Spectra for one hour vicinity of local noon (red) and for one hour vicinity of local nighttime (blue) of the magnetic field D component for 1–5 days before the EQ, and black line shows the sensitivity of the magnetometer. Day-time spectra are strongest here. (For interpretation of the references in color in this figure legend, the reader is referred to the web version of this article.)

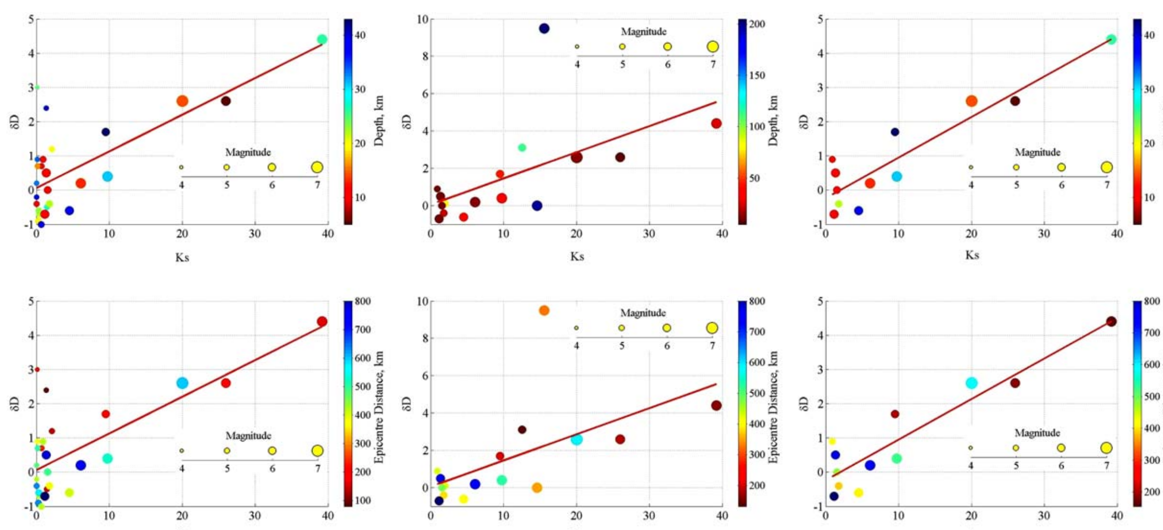

Fig. 7. Depression of δD on K_s for the following few combinations of earthquake parameters: (a) for $M_s > 4$ and depth <50 km, (b) for $M_s > 5.5$ and depth <300 km, and (c) for $M_s > 5.5$ and depth < 50 km. Color of circles indicates the epicenter depth in the upper panels and the epicenter distance in the bottom panels and their size depends on the magnitude M_s.

that the field depression at Karimshino is not related to Japanese EQs and the field depression at Matsukawa does not depend on seismicity at Kamchatka, either.

3. Discussion and conclusions

It seems that suppression of ULF magnetic variation is not taking place inside the ground, but in the lower ionosphere as we supposed in our previous paper (Molchanov et al., 2004).

The following findings have emerged from the present study.

1. The effect of magnetic field depression seems to be maximal especially in the frequency range of 0.02–0.05 Hz.
2. The effect of magnetic field depression is observed during nighttime, and the most pronounced time of occurrence is approximately one hour around the local midnight.
3. The stationarity and local nature of the magnetic field depression effect are clearly demonstrated.
4. The analysis of 4 years of observation at Karimshiro observatory (in Kamchatka) and of 2 years of observations at Matsukawa (Japan) has confirmed the reliability of the magnetic field depression 3–4 days before and EQ.

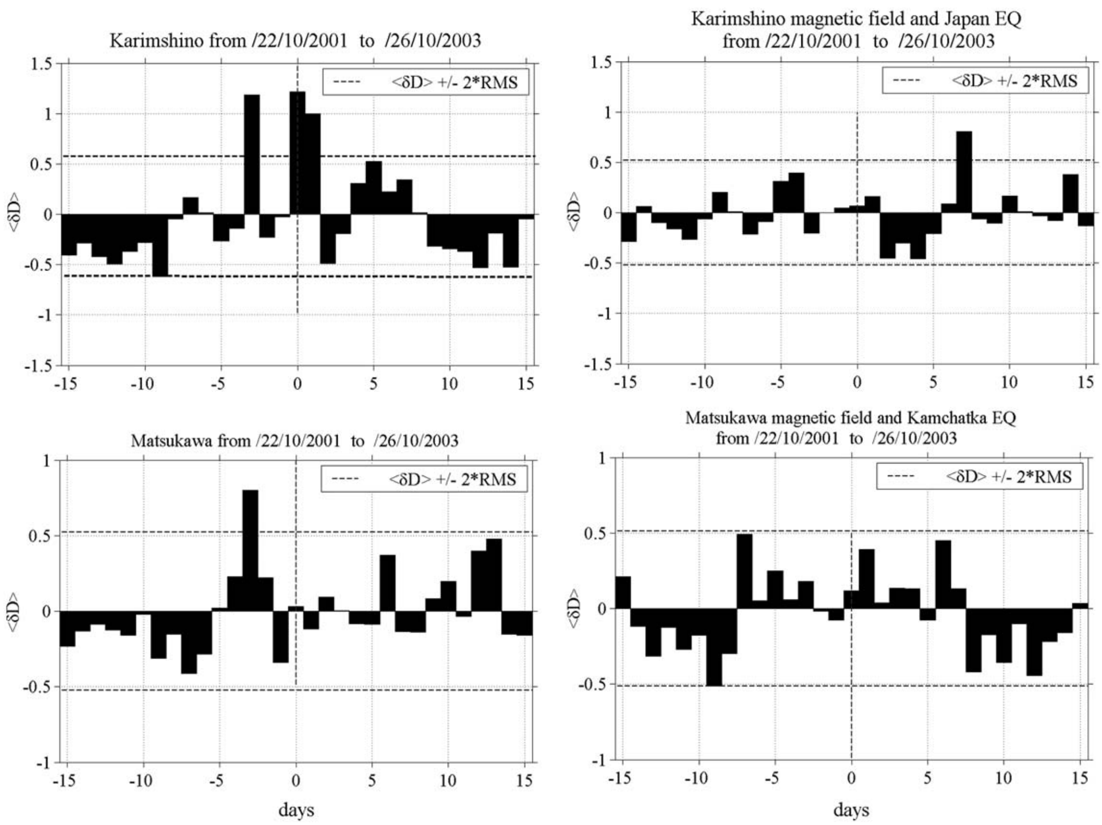

Fig. 8. Left top: Averaged variation of the field depression at Kamchatka; left bottom – for Japan; right top – magnetic field depression at Kamchatka averaged over the dates of the Japanese earthquakes; right bottom – depression at Japan for the earthquake dates at Kamchatka.

Acknowledgements

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