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Determination of hearth position of a forthcoming strong EQ using gradients and phase velocities of ULF geomagnetic disturbances

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Abstract

Behavior of gradient and phase velocity vectors of ULF ($F < 1$ Hz) geomagnetic disturbances was investigated for two earthquake (EQ) events in Japan in 2000 ($M > 6$) and 2003 ($M = 5.8$) years. The gradient and phase velocity vectors were determined using the data of three high-sensitive three-component magnetic stations situated at a distance ~5 km from each other (magnetic gradientometer). Two gradientometers were installed southeast and southwest of Tokyo at a distance ~150 km from each other. It was found that the gradient and phase velocity values had anomaly changes 3–4 months before the strong EQs. New directions of the gradient vectors took place in the same period – the directions just to the forthcoming EQ epicenter. The directions from the forthcoming EQ epicenter arouse for the phase velocity vectors. We propose to use the gradient and phase velocity vectors of the ULF geomagnetic disturbances as important factors of the short-term prediction of strong earthquakes.

Keywords: Seismogenic ULF emissions; Direction finding; Magnetic gradientometer; Short-term earthquake prediction

1. Introduction

Numerous observations and surveys have been conducted in seismic active zones for many years in order to follow the crust movements, seismicity, geomagnetism, ground waters, geochemical changes and so on. However, the problem of the forecasting of strong EQs is still far from its solution. Observations of ULF electromagnetic waves ($F = 10$–0.001 Hz) in seismic active zones have been conducted during the last 15–20 years after high-sensitive magnetometers were elaborated. First anomalous ULF electromagnetic emissions were observed before strong EQ in Spitak (1988) (Kopytenko et al., 1990, 1993) and Loma Prieta (1989) (Bernardi et al., 1991). Increasing of ULF emission intensity was observed several months before the destroying EQ in Guam (1993) (Hayakawa et al., 1996; Kawate et al., 1998). The EQ in Guam took place suddenly without foreshocks and that is why the EQ epicenter could not be beforehand determined by seismic methods.

2. Gradients and phase velocities of the ULF geomagnetic variations

Measurements of parameters of geomagnetic variations at one point on the Earth's surface do not allow reliable determination of a lithosphere source of ULF electromagnetic variations. A reason is that at the Earth's surface we observe the ULF magnetic field variations due to more than one source existing simultaneously (e.g. ionosphere, reflection from the Earth's crust, lithosphere sources). For this purpose we propose a different method using data of three magnetic stations situated at the earth's surface, that is the phase-gradient method firstly suggested in Kopytenko et al. (2000) for investigation of the natural

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ULF geomagnetic variations. This method gives an opportunity to construct gradient and phase velocity vectors of the geomagnetic pulsations along the Earth's surface. The method uses data of three magnetic stations situated at the Earth's surface in a form of a triangle at a distance ~5 km from each other (magnetic gradientometer). We suppose that the distances between the stations are much less than the distance to a source of geomagnetic variations. As a rule, gradient vectors of electromagnetic waves are directed toward the local source of the geomagnetic pulsations, and the phase velocity vectors – from the source. If there are two gradientometers at the distance of 100–150 km, then by intersection of these vector directions one can determine the source location (more exactly, its projection on the Earth's surface) – ULF magnetic location. The gradient and phase velocities of the geomagnetic variations can be expressed through trigonometric functions using coordinates of three stations and magnetic data from these stations (Kopytenko et al., 2000, 2002; Ismaguilov et al., 2002).

3. Experiment and discussion

Recording of the magnetic field variations in Japan on the Izu and Boso peninsulas has been conducted since 1998 by means of six high-sensitive digital three-component magnetic stations MVC-2DS (Hayakawa and Hattori, 2004), and Fig. 1 illustrates the location of the ULF sensors. Each group of three stations represents a magnetic gradientometer. The magnetic stations in each group are located at the distance of 4–7 km from each other. The stars in Fig. 1 show the epicenters of the strongest EQs. The numbers near the epicenters mean the EQ's magnitude determined according to the JMA scale. Black triangles represent three-component magnetic stations (S, M, K – Seikoshi, Mochikoshi and Kamo at Izu peninsula; F, Ki, U – Fudago, Kiyosumi and Uchiura at Boso peninsula).

A seismically active period during which three EQs with magnitude $M > 6$ took place began on June 27, 2000 and lasted for more than 3 months. The strongest seismic shock ($M = 6.4$) occurred on July 1st, 2000. The epicenter of this EQ was located at the depth ~15 km under the sea bottom at the distance of about 85 km to the south-east from the magnetic stations situated on the peninsula Izu as shown in Fig. 1. Seismic activity in the region of peninsula Boso was developing during the whole year 2003. The strongest seismic shock ($M = 5.8$) occurred at the depth ~60 km and its epicenter was located about 15 km from the magnetic stations installed at the Boso peninsula (Fig. 1).

An anomalous behavior of gradient and phase velocities of geomagnetic emissions in the frequency range $F = 0.1$–0.4 Hz in the region of Boso peninsula is shown in Fig. 2. The moment of the strongest seismic shock is marked by a vertical dotted line. In Fig. 2 time evolutions of phase velocities and gradients in total horizontal and vertical components of magnetic field (V_g, V_z, G_g, G_z) are presented.

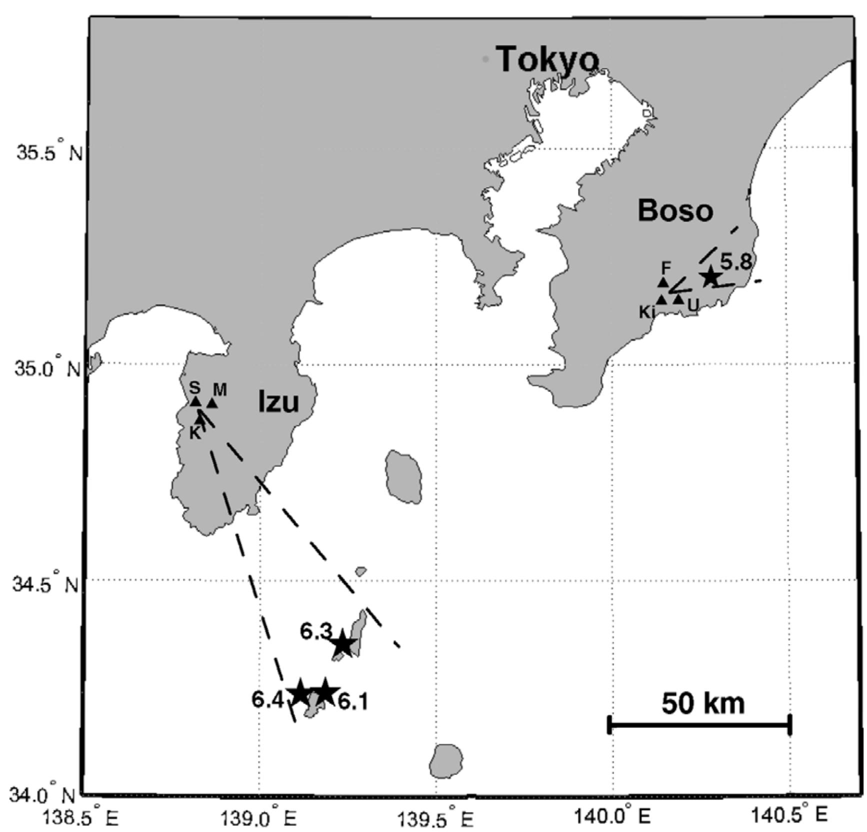

Fig. 1. Position of magnetic stations (triangles) and strong EQ epicenters (stars) in 2000 ($M > 6$) and 2003 ($M = 5.8$) years (Japan). Dotted lines show 30° cones from the magnetic stations to EQ epicenters.

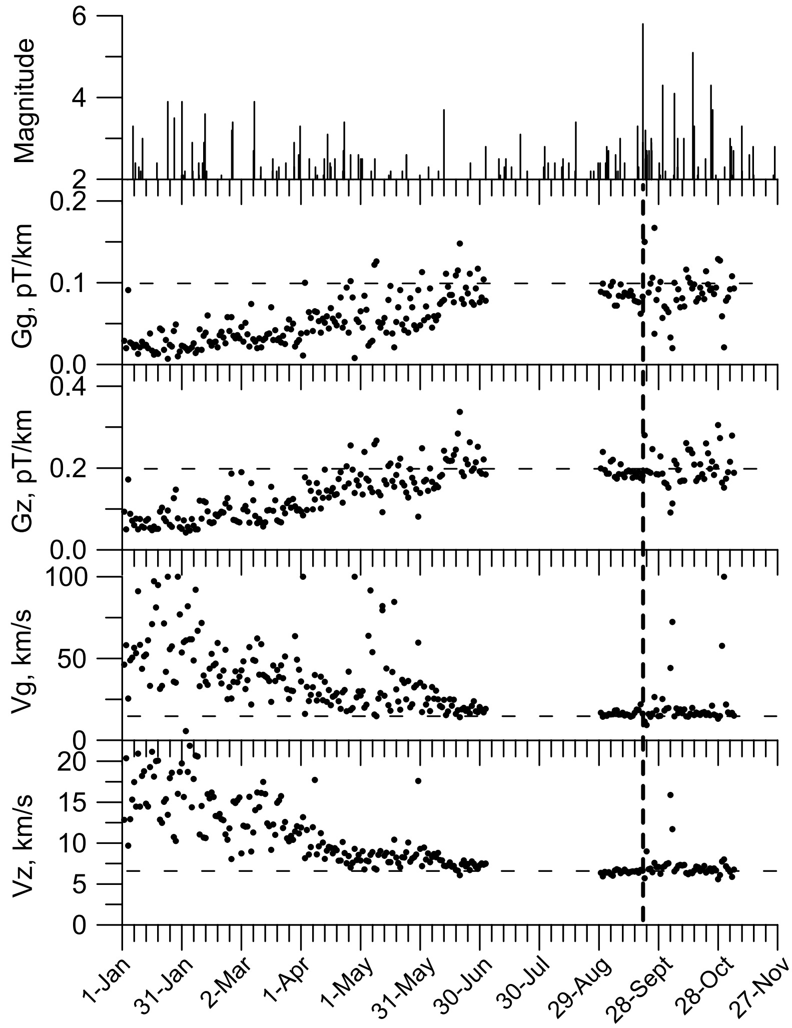

Fig. 2. Time evolution of gradients and phase velocities of geomagnetic emissions ($F = 0.1$–0.4 Hz) before and after EQ $M = 5.8$ at Boso peninsula, Japan, 2003. Dotted vertical line marks the moment of the strongest EQ. V_g, V_z, G_g, G_z – phase velocities and gradients in total horizontal and vertical components of the magnetic field.

Magnitudes of seismic shocks ($M > 2$) are shown at the upper part of the figure. It is seen that in 2003 about half year before the moment of EQ the gradients in the total horizontal component and in the vertical one begin to increase and reach their maximum 2–3 months before the EQ. At the same time the phase velocities decrease and minimal values are observed before the EQ moment. The same but a less pronounced anomalous behavior of the gradients and phase velocities is also observed in the lower-frequency range ($F < 0.1$ Hz) of the ULF geomagnetic disturbances. Unfortunately the data for July and August 2003 are missing.

An anomalous behavior of gradients and phase velocities of the ULF geomagnetic emissions in the same frequency range was also observed before the EQs of 2000 near the Izu peninsula (Fig. 3) and it was earlier studied in Kopytenko et al. (2001), Kopytenko et al. (2002), Ismaguilov et al. (2001) and Ismaguilov et al. (2002). The start of the seismic active period and moments of the strongest seismic shocks ($M > 6$) are marked by vertical dotted lines. During 1–2 months before the beginning of the seismic activity we notice an anomalous behavior of the phase velocities (V_g, V_z) and gradients (G_g, G_z) in the total horizontal and vertical components of magnetic field. Sharp increasings of the gradients are observed 2–5 days before the strongest seismic shocks.

Fig. 4 illustrates the distributions of normalized frequencies of gradient (left part of the figure) and of the phase velocity vector directions (right part) of the ULF variations in the frequency range $F = 0.03$–0.1 Hz (mean-month values) for the period of February–July of 2000. In the figure direction to the north corresponds to 0°, to the east (+90°), to the south (±180°) and to the west (−90°). These histograms were constructed using total horizontal component calculated from the data of magnetic stations situated at the peninsula Izu. As it is seen from Fig. 4, 2–3 months before the beginning in the seismic activity, the distinct maximum appears in the distribution of directions of the gradient vectors – just to the future seismic activity region. A shaded vertical strip marks this direction to the EQ epi-

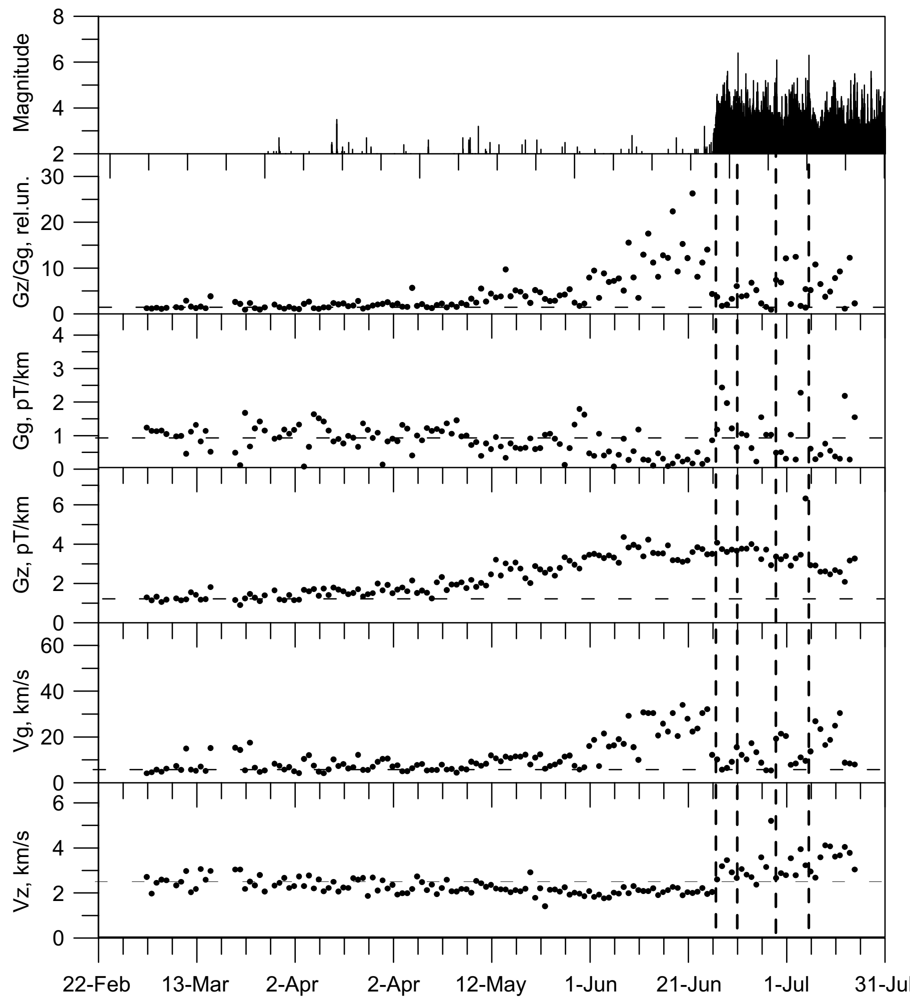

Fig. 3. Time evolution of gradients and phase velocities of geomagnetic emissions ($F = 0.1$–0.4 Hz) before and after EQ $M > 6$ at Izu peninsula, Japan, 2000. Dotted vertical lines mark the moment of the seismic activity start and moments of the strongest EQs. V_g, V_z, G_g, G_z – phase velocities and gradients in total horizontal and vertical components of the magnetic field.

center for the gradient and from the EQ epicenter for the phase velocity vectors. The strip corresponds to 30° cone of location from the magnetic stations on the peninsula Izu, as shown in Fig. 1 by dotted lines. The vectors of the phase velocities are directed in the opposite side (from the future seismic active zone).

Fig. 5 shows histograms of distributions of normalized frequencies of gradient (left part) and the phase velocity vector directions (right part) of the ULF variations in the frequency range $F = 0.03$–0.1 Hz (monthly averaged values) for the period of January–October of 2003. As for Fig. 4, the direction to the north corresponds to 0°, to the east (+90°), to the south (±180°) and to the west (−90°) in Fig. 5. These histograms were constructed using total horizontal component calculated from the data of magnetic stations situated at the peninsula Boso. Fig. 5 indicates that 3–4 months before the strongest seismic shock with magnitude $M = 5.8$ the probability increases at the direction of the future strong EQ epicenter for the gradient vectors of the ULF magnetic disturbances. This direction is marked in Fig. 5 by a shaded vertical strip corresponding to 30° cone of location shown by dotted lines on the peninsula Boso in Fig. 1. As in the previous case, the phase velocity vectors were directed opposite to the gradient vectors (from the future seismic active zone).

In Figs. 2 and 3 moments of the strongest EQs are marked by vertical dotted lines. We can see from the figures that about 4 months before the EQs an anomalous increase in the gradient values began as well as a decrease in the phase velocity values. The works (Kopytenko et al., 2001; Kopytenko et al., 2002; Ismaguilov et al., 2001; Ismaguilov et al., 2002) are devoted to investigation of the gradients and phase velocities of the ULF geomagnetic emissions before the EQs of 2000 near the peninsula Izu using the phase-gradient method. In these works it is suggested that an anomalous behavior of the gradient and phase velocity values before strong EQs is connected with two processes in the region of a future EQ: formation of anomaly of increased conductivity, and arising of wide-band ULF electromagnetic emissions from a region of a future EQ hearth. The anomaly of conductivity appears to be due to tectonic processes or (and) magma rising (Uyeda et al., 2002). Nat-

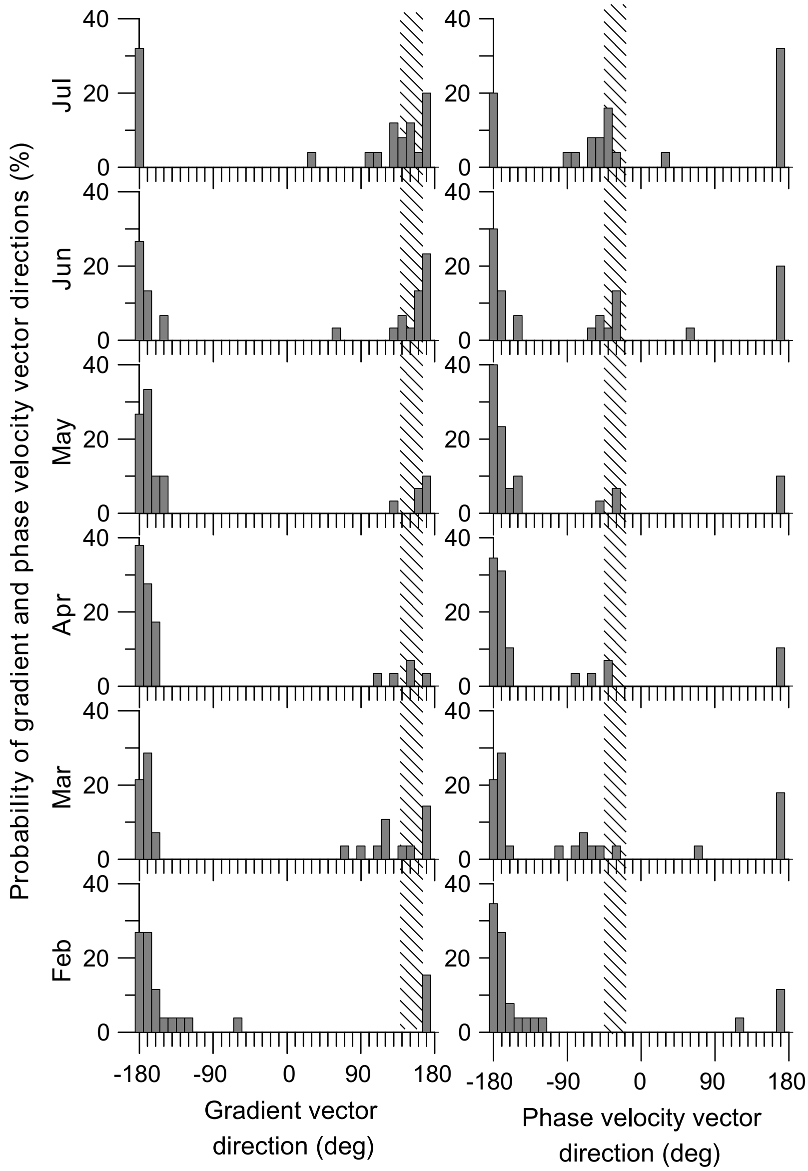

Fig. 4. Normalized frequency distributions (daily mean values) of gradient (left) and phase velocity (right) vector directions of total horizontal component of ULF magnetic disturbances ($F = 0.03$–0.1 Hz) before and after strong EQs ($M > 6$), Izu peninsula, Japan, 2000. Shaded vertical strips correspond to 30° cone including the future EQ epicenters shown by dotted lines in Fig. 1.

ural ULF electromagnetic waves falling down from the ionosphere are reflected from the lithosphere anomaly and we observe increased ULF magnetic field at the Earth's surface. One source of wide-band ULF electromagnetic emissions from the future EQ hearth is a process of formation of microcracks due to tectonic processes (Molchanov and Hayakawa, 1995). Increased magnetic field values lead to increased gradients of the field directed to the future EQ epicenter. The phase velocity vectors will be directed from these sources in this case. Decreasing of the phase velocity values before the seismic active period can be explained by an increase in the conductivity in the region of the future EQ hearth.

The ULF magnetic field amplitudes from lithospheric sources are smaller than those from ionosphere sources. However, the ULF magnetic field gradients from lithospheric source are greater than from ionosphere sources. First, a lithosphere source is usually located closer to the magnetic stations than the ionosphere sources, that are situated at distances of hundreds km. Second, the size of a lithospheric source (kilometers) is much less than the ionospheric source size (tens of kilometers), and so the gradients from the lithosphere sources must be higher. The phase-gradient method uses three-point measurements and allows are to sharply increase the ratio of lithospheric signal/ionospheric signal and a more precise determination of the direction to the future EQ epicenter. Polarization and other methods (Hayakawa et al., 1996; Hobara et al., 2004; Du et al., 2002) use one-point measurements and we suppose that they give good results only when the natural geomag-

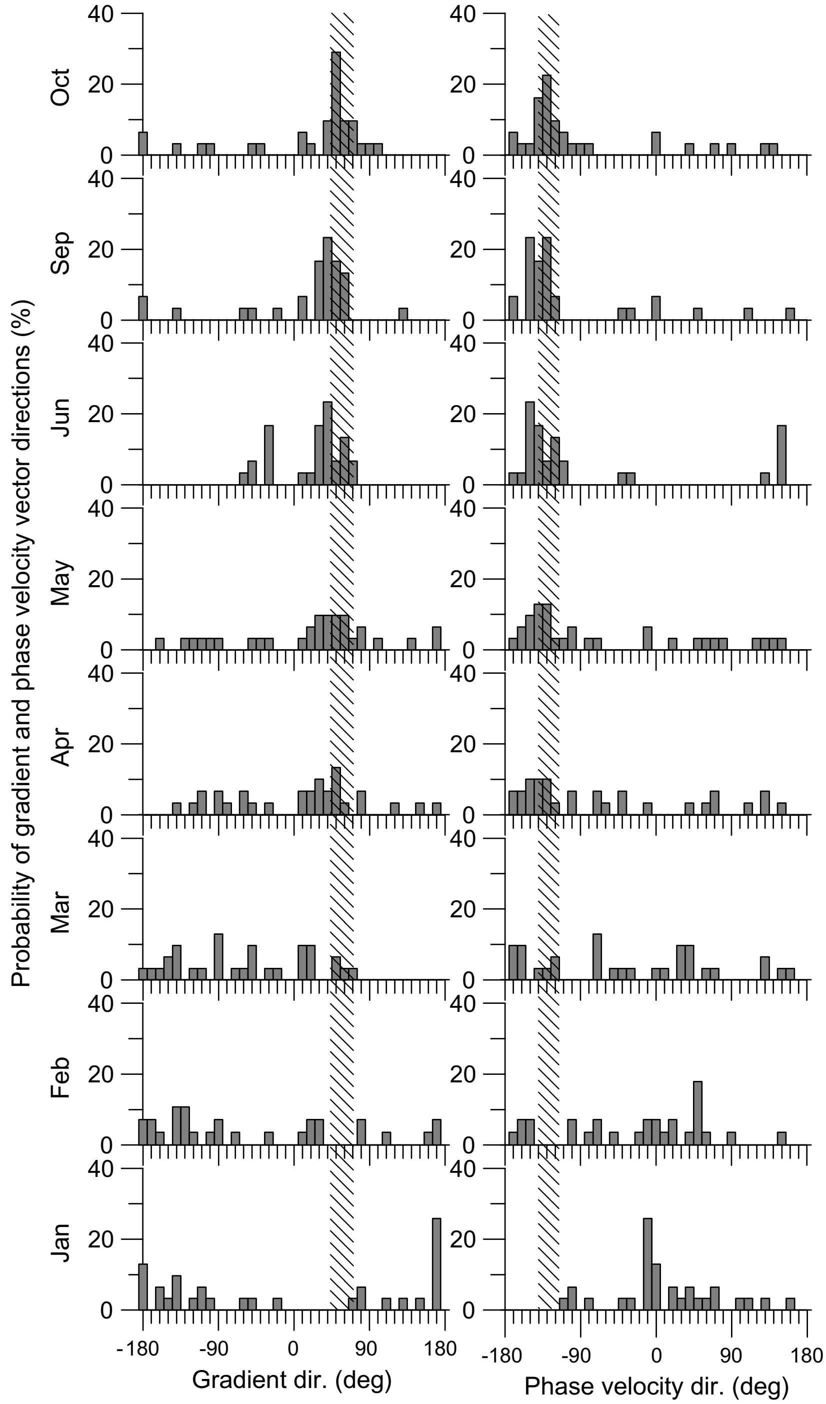

Fig. 5. Normalized frequency distributions (daily mean values) of gradient (left) and phase velocity (right) vector directions of total horizontal component of ULF magnetic disturbances ($F = 0.03$–0.1 Hz) before and after strong EQ ($M = 5.8$), Boso peninsula, Japan, 2003. The shaded vertical strips correspond to 30° cone including the future EQ epicenters shown by dotted lines in Fig. 1.

netic variations of ionospheric origination have amplitudes much less than variations of the lithospheric source.

4. Summary

Anomalous behavior of gradient and phase velocity vectors of ULF ($F < 1$ Hz) geomagnetic disturbances was investigated in this work for two EQ events in Japan in 2000 ($M > 6$) and 2003 ($M = 5.8$) years. It was found that the gradient and phase velocity values had anomalous changes 3–6 months before the strong EQs. New direction of the gradient vectors took place in the same period – the directions just to the forthcoming EQ epicenter. The directions from the forthcoming EQ hearth were observed for the phase velocity vectors. We believe that use of gradient and phase velocity vectors of the ULF geomagnetic disturbances is very important for a short-term prediction of strong EQs.

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