Multi-Point Measurement System and Data Processing for Earthquakes Monitoring

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Abstract: Lithospheric ultra low frequency (ULF) magnetic activity is recently considered as very promising candidate for application to short-time earthquake (EQ) forecasting. However the intensity of the ULF lithospheric magnetic field is very weak and often masked by much stronger ionospheric and magnetospheric signals. The study of pre-EQ magnetic activity before the occurrence of strong EQ is a very hard problem which consists of the identification and localization of weak signal sources in EQ-hazardous areas of the Earth's crust. A new approach is developed to find a source of pre-EQ ULF electromagnetic activity of lithospheric origin. For separation and localization of such sources a new polarization ellipse technique has been used to process data acquired from 3-component magnetometers. The polarization ellipse is formed by the magnetic field components at the measurement station. Calculations based on polarization ellipse parameters from two distant points allow discrimination of seismo-EM signals from natural background ULF signals. The results of experimental verification of this method in Kanto region (Japan), known as one of the most seismoactive, are given which partially confirm its efficiency and give hope, with its further improvement, to the progress in the EQ precursors reliable detection in other regions of the Globe, particularly, in Iceland known by the active seismic activity.

1 INTRODUCTION

Short-term earthquake (EQ) prediction, despite intensive efforts in last half a century, still remains unattainable though numbers of promising leads and directions are indicated (see Uyeda et al., 2009); (Dudkin et al., 2010) for recent review on the subject). The anomalous electromagnetic (EM) emission in ultra low frequency (ULF) band (0.001-10 Hz), believed to be emanating from within the focal zones, have emerged as potential precursor candidates for short-term EQ prediction (Hattori and Hayakawa, 2007); (Hayakawa et al., 1996; 2000; 2007); (Molchanov and Hayakawa, 1995); (Molchanov et al., 1992; 2004). This observational conviction is further reinforced from the suggestions that mechanical deformations or microfracturing in the impending focal zones may give rise to pre- and/or co-seismic EM emission in ULF band due to one or more of the following factors: (1) movement of conductive medium in the Earth's permanent magnetic field (inductive effect) (Fedorov et al., 2001); (Surkov et al., 2003); (2) displacements of boundaries between high and low conductive crustal blocks (Dudkin et al., 2003); (3) electrokinetic effect (Mizutani et al., 1976); (Fitterman, 1979); (4) piezoelectric or piezomagnetic effects (Martin et al, 1978); (Ogawa et al., 1985); (Johnston et al., 1994); (Ogawa and Utada, 2000) and (5) microfracture electrification (Molchanov and Hayakawa, 1995). (All references are given as example). The ULF EM field attenuate rather weakly in crustal material and hence, according to theoretical consideration, associated magnetic field can be detected at large distances up to 100-150 km (Hayakawa et al., 2007).

The practical detection and application of precursory EM signals for real time EQ prediction continue to be challenging due to several problems: (i) intensity of anticipated seismo-EM signals in ULF band is very low (with a few exceptions, e.g., (Fraser-Smith et al., 1990); (Bleier et al., 2009), where magnetometers happened to be in the close proximity to epicenter, critics see in (Campbell, 2009); (Thomas et al., 2009), (ii) difficulty of discrimination of weak seismo-EM signals from the background natural EM fields of ionospheric and magnetospheric origin and (iii) finally the precision limitation of the localization of precursor source or, at least, determination of azimuth direction to the source zone. Very often these problems are

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aggravated by short time (less than 5 minutes) of precursor existence (Bleier et al., 2009). With the availability of very sensitive induction type 3-component magnetometers with high suppression of man-made interference (Pronenko, 2010), the recording of high quality magnetic data in ULF bands has greatly improved (Hayakawa et al., 2007). For the second problem, polarization analysis incorporating the ratio S_Z/S_H (S_Z and S_H are the spectral intensities of vertical and horizontal magnetic field components) is found effective, at least partially, in distinguishing seismo-EM signals from geomagnetic field fluctuations (Hayakawa et al., 1996). The formulations of principal component analysis and fractal approach have been used with some success in discriminating the signals of extra-terrestrial and seismotectonic origin in magnetic field records (see, for example, Hayakawa et al., 1999; 2007); (Serita et al., 2005); Ida and Hayakawa, 2006). With the aim of the identification of source location, the phase difference as well as amplitude difference techniques between pair or more observation points, so-called gradiometric method, was advanced (Ismaguilov et al., 2003; Surkov et al., 2004). However a space derivative of magnetic field is very unstable at low signal-to-noise (S/N) ratio and may give a big error in the estimation of source direction (see remarks about S/N ratio in [Dudkin et al., 2003]). Very promising in the seismo-EM precursors direction finding problem solution is an application of the polarization ellipse (PE) technique, where the PE major axis behavior is investigated (goniometric method) (Du et al., 2002; Schekotov et al., 2007, 2008). This technique allows determination of trends in azimuth angle of anomalous ULF signal and possibly area of EQ epicentre. Taking into account that ULF magnetic source is always in the PE plane the new method of magnetic precursor source location when at least two observation points are available has been proposed by present authors (Dudkin et al., 2010; 2011). In the present paper expanding the steps of this new direction-finding approach, we use the information on magnetic field data from two stations operated simultaneously in Kanto seismoactive region of Japan. The organization of observation site at Iceland to check the method is further proposed.

2 EXPERIMENT, RESULTS AND DISCUSSION

To test the PE method efficiency for locating source region of EM fields produced during EQ preparation process, the same methodology as described in (Dudkin et al, 2010, 2011) was applied to the magnetic data recorded in 2005 in Kanto region, Japan (Figure 1). The Kanto region is heavily populated and EQs can happen close to urban areas. This region is one of the most seismoactive in Japan.

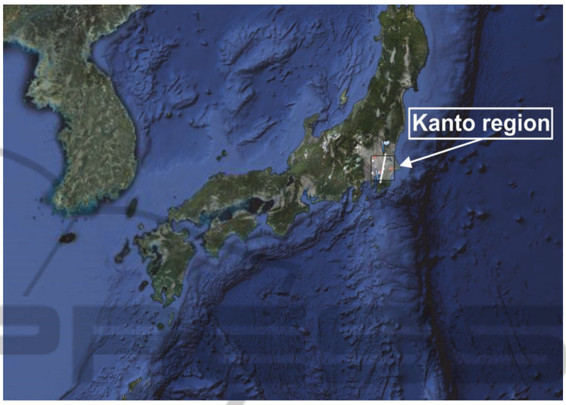


Figure 1: The map of Kanto region.

Seismic activity there occurs due to movement of Pacific and Philippine Sea plates. The plate boundaries underneath the Kanto region are just 10-40 km below the surface of the Earth and have a complex structure. EQs can occur there both due to subducting plates and due to active faults in land. One-year data in frequency range 0.0001-0.5 Hz from two fluxgate magnetometers located in Kakioka and Kanozan geomagnetic observatories (Figure 2) were analyzed.

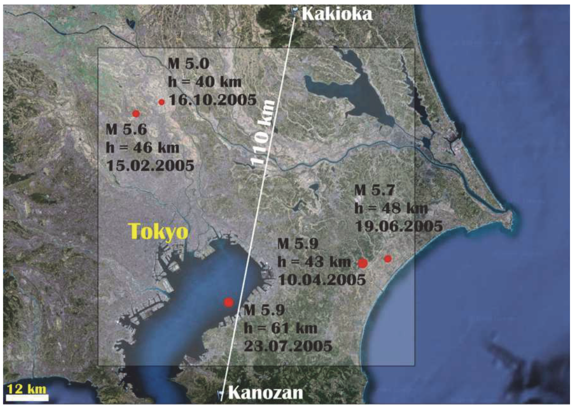


Figure 2: Map of Kakioka-Kanozan area.

The peculiarity of these data is very high man-made electromagnetic interference which complicates much the detection of seismogenic signals.

The monitored area 90x90x90 km was decomposed into 5832 subblocks with dimensions 5x5x5 km, total volume about 730,000km^3 (Figure 3). The data about seismicity in monitored area during the year 2005 were obtained from USGS catalogue. Five EQs with magnitude M_W 5.0 and above occurred there during the year 2005 with depths range from 40 to 61 km.

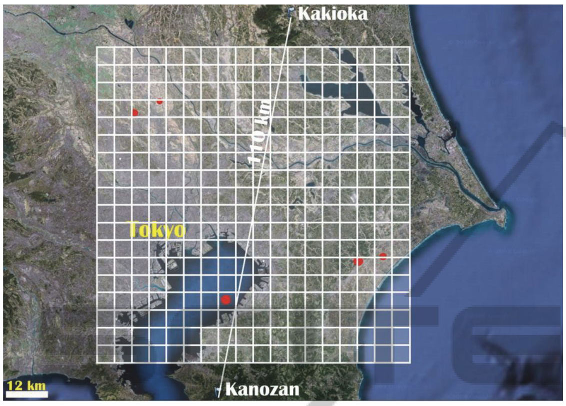


Figure 3: Decomposition of the monitored area.

At the lithospheric magnetic activity detection the same procedure of “blind search”, as for data obtained in China (Dudkin et al, 2011) has been used. The distribution of number of M-lines in time, which are believed to indicate to the magnetic anomalies source (Dudkin et al, 2010) in depth range 0-90 km over the year 2005 and of the signals classified as ionospheric at the background of Kp-index value, is shown in Figure 4.

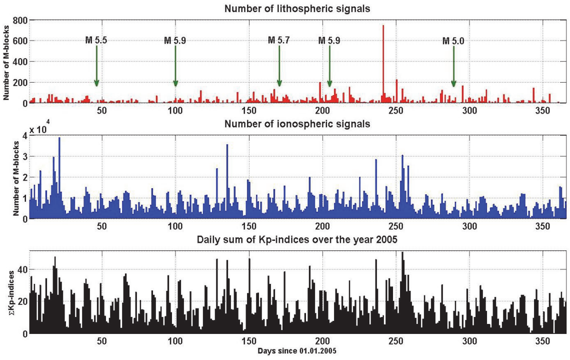
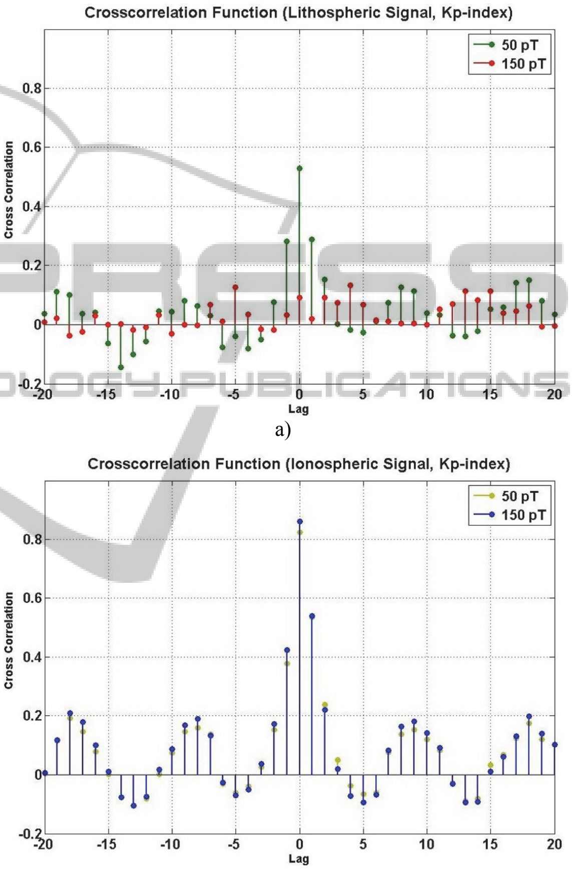


Figure 4: Time distribution of M-lines (red) ionospheric signals (blue) and Kp index (black) numbers in depth range 0-90 km over the year 2005.

We may see that the number of the ionospheric/magnetospheric signals (blue) is in good correlation with diurnal value index of global geomagnetic activity Kp (black). Cross-correlation function of Kp-index value with lithospheric and ionospheric signals at two thresholds (50 pT and 150 pT) is shown in Figure 5 a,b.

We can see very high correlation of ionospheric/magnetospheric M-lines number with Kp-index value almost independently of minimal signal threshold, unlike the lithospheric M-lines. At decreasing of signal threshold the method selectivity also decays, which leads to increasing of correlation between lithospheric M-lines number and Kp-index value.

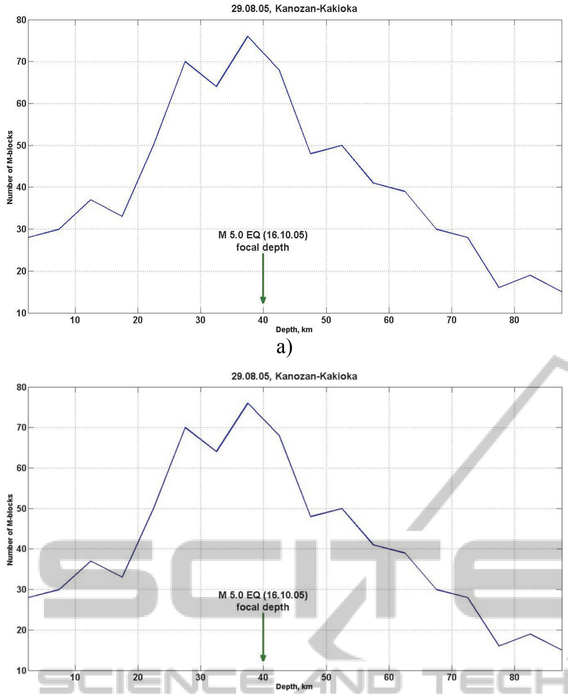


a)

b)

Figure 5: Cross-correlation function of Kp-index value with lithospheric and ionospheric signals at thresholds 50 pT and 150 pT for minor axis of magnetic field polarization ellipse.

The increased lithospheric activity was found only for 3 EQs from 5 under study : 1) on 7 April, 3 days before EQ M_W 5.9; 2) on July, 17 and 21, 6 and 2 days respectively before EQ M_W 5.9; 3) on August, 29, 48 days before EQ M_W 5.0. The depth distribution of blocks with magnetic activity in depth range 52.5-82.5 km on July, 17 and in depth range 17.5-47.5 km on August, 29 are shown in Figure 6 a,b.



a)

b)

Figure 6: Depth distribution of pre-EQ lithospheric magnetic activity a) on on July, 17 b) on August, 29. Red circles denote EQ epicentres.

It is clearly seen that the maximal number of M-lines crosses the slab at the same depth where the EQ occurred, what confirms the validity of the method. For other two cases we did not get clear correspondence with M-lines occurrence. Several causes of these rather poor results may be mentioned.

1. The region is densely populated and the local interference level was very high.
2. The observation network was very sparse and distance between magnetometers was too big.
3. The local tectonic structure is extremely complicated. The crustal block boundaries and rectangular fault model for Kanto region is shown in Fig. 7.

Red lines indicate boundaries of the crustal blocks on the surface. Dashed rectangles indicate rectangular faults with a solid yellow line indicating a fault upper edge. (The block boundaries are drawn with use of article: Nishimura et al., 2007). Red circles denote the studied EQs. Red stars indicate the centres of maximal pre-EQ lithospheric activity.

As it is seen at this figure, the light blue lines show the statistically averaged azimuths for lithospheric M-lines, which in general coincide with direction of local seismogenic fault as for precedent cases. This may be the partial confirmation that the method works here also, but the observation technology has to be improved.

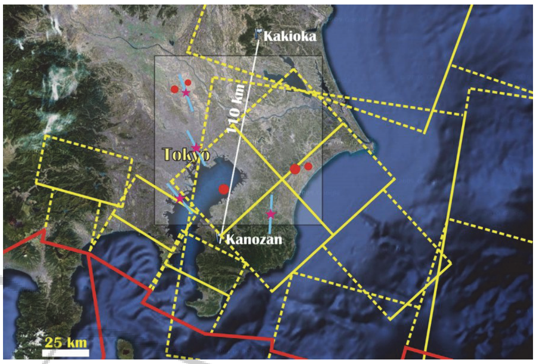


Figure 7: Crustal block boundaries and rectangular fault model. Red lines indicate boundaries of the crustal blocks on surface. Dashed rectangles indicate rectangular faults with a solid yellow line indicating a fault upper edge. Red circles denote the studied EQs. Red stars indicate the centres of maximal pre-EQ lithospheric activity. Light blue lines show the statistically averaged azimuths for lithospheric M-lines.

Very interesting region for EQ magnetic precursor study is Iceland. It is the part of the Mid-Atlantic Ridge which marks the division between the Eurasian and North American tectonic plates, Figure 8.

There the seismic activity near Iceland during years 2010-2013 is shown, where minor white circles denote the epicenters of EQ with M4.0 - 4.9 and major ones – M5.0 - 5.5. The boundary between the tectonic plates is marked by red line. The example of magnetometer sites location for study of pre-EQ lithospheric magnetic activity near Reykjavik, Iceland is marked by green squares.

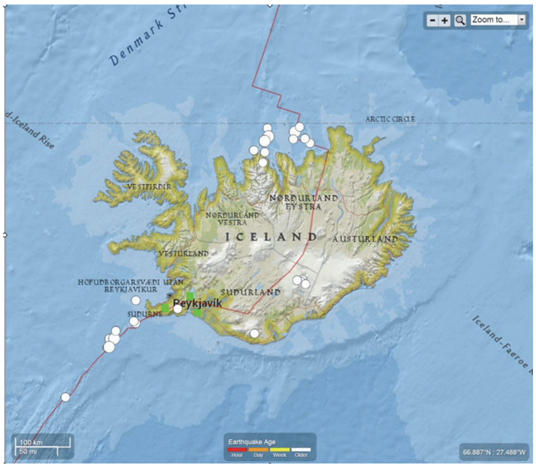


Figure 8: The seismic activity near Iceland during years 2010-2013.

3 CONCLUSIONS

New direction-finding method for study of ULF lithospheric magnetic activity with use of two spaced 3-component magnetometers was tested in seismoactive area of Kanto region (Japan). For analysis of pre-EQ lithospheric ULF magnetic activity there, the area 90x90x90 km was chosen between two measuring sites Kanozan and Kakioka. The data from their magnetometers were analysed during the year 2005 with special attention on magnetic precursor for five main EQs with $M \geq 5.0$.

Because of Kanto region specific peculiarities (zone of the subducting plates with deep EQ hypocentres, high level of industrial interference and very sparse observation network with big distance between magnetometers**)** the ULF magnetic precursors were found only for three EQ.

The pre-EQ magnetic activity was found 48-2 days before EQ in frequency range 0.0007-0.01 Hz at depths close to focal depths of main strikes. The M-lines orientation was well coinciding also with the local fault direction. It is shown that controlled by the orientation of seismogenic faults, resulting seismo-EM field would have definite orientation in comparison to the isotropic direction distribution of highly variable natural signals arising from complex ionospheric-magnetospheric interactions. Based on these physical considerations, the interactions lines defined by the planes of PE, formed by the magnetic fields at minimum two sites, define the azimuth of seismo-EM source.

It may be concluded that in order to raise the reliability of determination of slow crustal nucleation processes preceding EQ (which form pre-EQ ULF lithospheric magnetic activity, i.e. magnetic precursors), it is necessary to cover the monitored area with magnetometer density not less than one magnetometer per 2000 sq. km (the distance between measuring sites less than 50 km). Already available knowledge on the role of high pressure fluids in generating the EQs favours electrokinetic effect to be one of the possible source mechanisms for seismo-EM fields there. Testing the proposed formulation in the other active seismic belts and preferably employing multiple stations would help generalization of the methodology for future EQ precursory studies.

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