Seismogenic ULF magnetic activity – peculiarities of registration

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Abstract

A big number of publications confirm that ultra low frequency (ULF) magnetic precursors were recorded from few weeks up to few hours before earthquakes (EQs). For the detection of magnetic precursors at the background of more powerful sources it is necessary to have magnetic field sensors with wide dynamics and minimum possible spectral noise density. The requirements to a dedicated magnetometer and its main parameters are discussed and the example of such an instrument realization is given. The newly developed technology of EQ-related ULF signals selection is presented. The attempts of this technology application in order to select the candidates for EQ precursors are discussed, basing on the natural ULF signals, collected in India by multi-point synchronized magnetometer network.

1.Introduction

According to present conception, ULF band (0.001-3 Hz) gains in importance at monitoring of lithospheric magnetic activity in seismo-hazardous areas for application to short-time EQ forecasting. A big number of publications confirm that ULF magnetic precursors were recorded from few weeks up to few hours before EQ. The reported there dedicated experiment clearly demonstrates enhancement of the activity in this band few days before the EQ.

The measurement technology of these signals meets serious problems, what often impede their detection. First, the lithospheric ULF EQ magnetic precursors are as a rule very weak and their frequency range is totally overlapping with much more powerful signals of magnetospheric, ionospheric or artificial origin. Second, for the extraction of magnetic precursors at the background of more powerful sources it is necessary to have magnetic field sensors with wide dynamics and minimum possible spectral noise density level in ULF band. Additionally, monitoring of lithospheric activity should be provided in rather close proximity to probable EQ area (no more than ~ 100 km) and almost in real-time regime. Fulfilling last both requirements, there is a chance to register the ULF magnetic precursors, but the problem of their selection at the background of natural or artificial signals of much greater amplitude remains.

The newly developed technology of EQ-related ULF signals selection is shortly presented below. In frames of this technology, the peculiarities of polarization ellipse (PE) parameters formation in frequency range 0.001 - 0.5 Hz at synchronous reception of magnetic field signals from distant points have been analyzed. Then the attempts of the use of this technology in order to select the candidates for EQ precursors are discussed, basing on the natural ULF signals, collected in India.

The wave forms, dynamical Fourier spectra and PE parameters of ULF signals from magnetometers pairs operating during mentioned campaigns have been studied and compared with preseismic activity and natural magnetic field variation data. The main results of the analysis of these multi-point data are presented in the report.

2. Theoretical substantiation

The practical detection of precursory electromagnetic (EM) signals in real time and their applications to EQ prediction continue to be challenging due to several problems: (i) intensity of anticipated seismo-EM signals in ULF band is very low; (ii) difficulty of discrimination of weak seismo-EM signals from the background natural EM fields of ionospheric/magnetospheric origin; and (iii) finally the limitation in the localization of precursor source or, at least, determination of azimuth direction to the source zone.

To extract information about the seismic source from the directional dependence of the ULF magnetic field components, we suggest the following simplifying assumptions:

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(i) in narrow ULF frequency band the magnetic field components can be represented as harmonic (periodic) signals;
(ii) at a given frequency, 3 orthogonal components of magnetic field with specific phases provide estimation of PE parameters, the resultant PE plane in space contains the source of EM field;
(iii) alternating (induction) currents generated by seismo-EM effects can be visualized as small-scale superposition on large-scale telluric current system induced by global induction. These perturbations seen as closed loops at distances several times the dimension of source can be considered to be equivalent to those produced by elementary magnetic dipoles placed in the source region;
(iv) magnetic moment of such a magnetic dipole source is in PE plane formed by its field components at the measurement points.

The main accepted postulate is: as far as the PE plane at any time contains the source of magnetic field, having observations at two distant stations it is possible to find the intersection line of PE planes containing the magnetic dipole moment M, which is aligned along it, and can be calculated from parameters of PE. This line we name as M-line. The calculation of M-lines intersection with studied crustal area (M-area) and use of selection criteria give possibility to discriminate ionospheric and lithospheric signals [1].

3. Experiment: Results and Discussion

The experimental verification of the efficiency of the proposed approach was made at Koyna-Warna region, India. This is a classical example of reservoir triggered seismicity over the past four and a half decades ([2] and references therein). Such features make the area unique for studying peculiarities of magnetic field during EQ preparation process.

To develop and test the PE method for locating source region of EM fields produced during EQ preparation process, two stations to record magnetic variations in ULF bands were established; the first at Koyna, within the limits of focused seismic zone, and other was placed at distant location of ~100 km in Shivaji University, Kolhapur (Fig. 1). Both sites were located in low-noise background and have minimal interference from man-made disturbances.

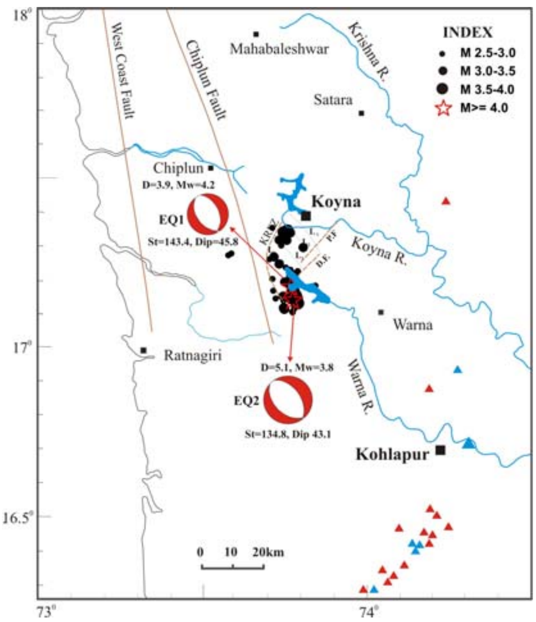


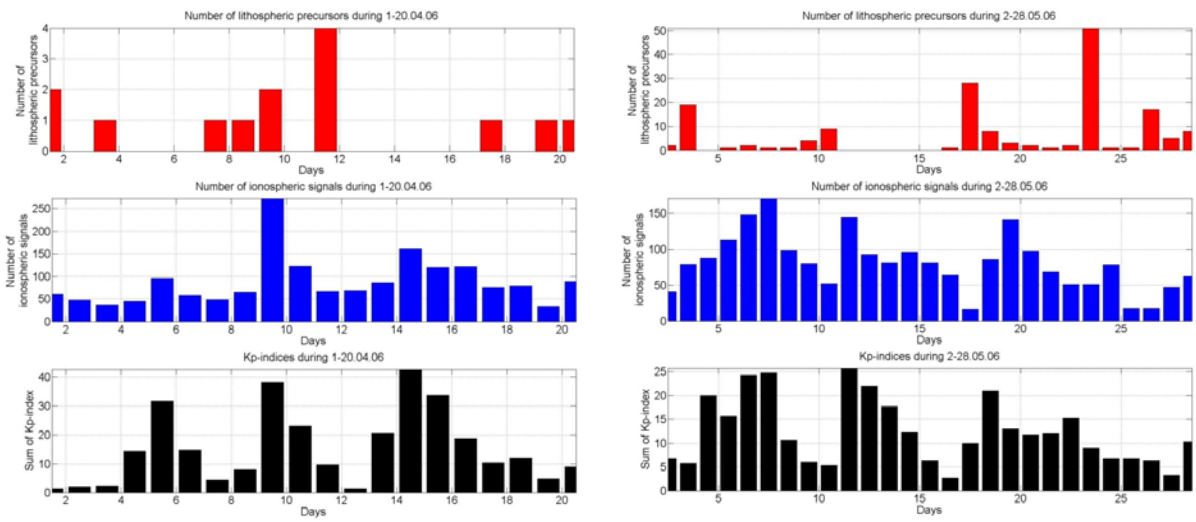
Fig. 1. Map of Koyna-Warna region showing location of ULF magnetometers (black squares) for monitoring EM emission related to reservoir triggered seismicity. Black dots represent epicentres of EQs recorded during the observational campaign period of March-June2006. Fault plane solutions of two moderate earthquakes (Ml>4) are also shown. Surface intersection point of M-Lines (see text) are indicated by triangles.

Extremely low-noise ($S_{B,n}$=0.2pT/Hz$^{0.5}$ at f=1Hz, where $S_{B,n}$ is spectral noise density) with high factor of industrial interference suppression (more than 1000) 3-component LEMI-30 magnetometers, specially designed for EQ EM monitoring by Lviv Centre of Institute for Space Research, Ukraine (http://www.isr.lviv.ua), were deployed at both stations for synchronous recording. LEMI-30 magnetometers operate in frequency range 0.001-32 Hz and ideally suit to record the most promising EQ magnetic precursors in ULF band, which are found dominant below 0.1 Hz [3]. Both stations recorded simultaneous data with 64 samples per second over the entire observational campaign period of March 15 - June 30, 2006. During data processing a re-sampling procedure was applied with averaging every of 64 samples. Thus an upper boundary of signal spectra was decreased to 0.5 Hz. For such data the dynamical Fourier spectra (DFS) for each 24 hours of data recording were calculated. Then for each point of DFS the parameters of PE for each measuring site were calculated, which form the base to execute EQ precursory magnetic analysis.

During observation period 2 largest EQs occurred on 17 April 2006 (Mw=4.2, h=3.9 km, 17.13 N, 73.78 E, UT 16.39.59.4) (EQ1) and on 21 May 2006 (Mw=3.8, h=5.1 km, 17.17 N, 73.77 E, UT 20.29.01.2) (EQ2) and their fault plane solutions as determined by NGRI are shown as inset in Fig. 1. The ULF magnetic activity in relation to these 2 modest magnitude EQs is examined below.

First, for discrimination of M-lines associated with seismo-EM sources from those originating from magnetospheric, ionospheric and far distant man-made ones the following criterion was applied. We calculated the ratio of PE major axes in Koyna and Kolhapur measuring sites against orientation of horizontal magnetic dipole placed in EQ hypocentres. The results of calculation show that the minimal ratio of PE major axes for signals related to EQs is about 2. Naturally, for magnetospheric and ionospheric sources which are much more far from both measuring sites in comparison with EQ hypocentres this ratio is close to unity. So for precursor candidates we selected the M-lines, which cross given M-area, with PE major axes ratio exceeding the threshold value 2.

The detected during the observation campaign interval and classified seismo-EM and ionospheric signals together with Kp-index values are shown in Fig. 2a (for EQ1) and Fig 2,b (for EQ2). The good correlation between the numbers of signals attributed to the ionospheric origin and the values of Kp-index is clearly seen. The number of signals attributed to seismo-EM ones increases before EQ1 (M=4.2) up to 11 April and then approaches to zero level (Fig.1,a). After EQ1 very low seismo-EM activity in region of interest is observed. For EQ2 (M=3.8) the number of magnetic precursors is maximal on May, 17 and then drop rapidly to small value (Fig.2,b). Then on May, 23 the signals classified as seismo-EM origin rise again, which apparently are neither related to any abnormal seismic activity nor marked by intense solar/magnetic disturbances. Given that this time interval is marked by moderate values of Kp, it seems possible that these signals classified as seismo-EM are related to the release of residual mechanical stresses following EQ2.



a) b)

Fig. 2. The number of detected seismo-EM (upper plots) and ionospheric signals (middle plots) with the Kp-index values (lower plots) during time of observation.

Further as an example, the frequency dependences of the seismo-EM and ionospheric/magnetospheric signals against time are shown for 17, 18 and 20 of May (see Fig. 3). The magnetic precursors are confined to narrow frequency range of about 0.01-0.07 Hz and completely overlap with the most dominant frequency range of ionospheric signals.

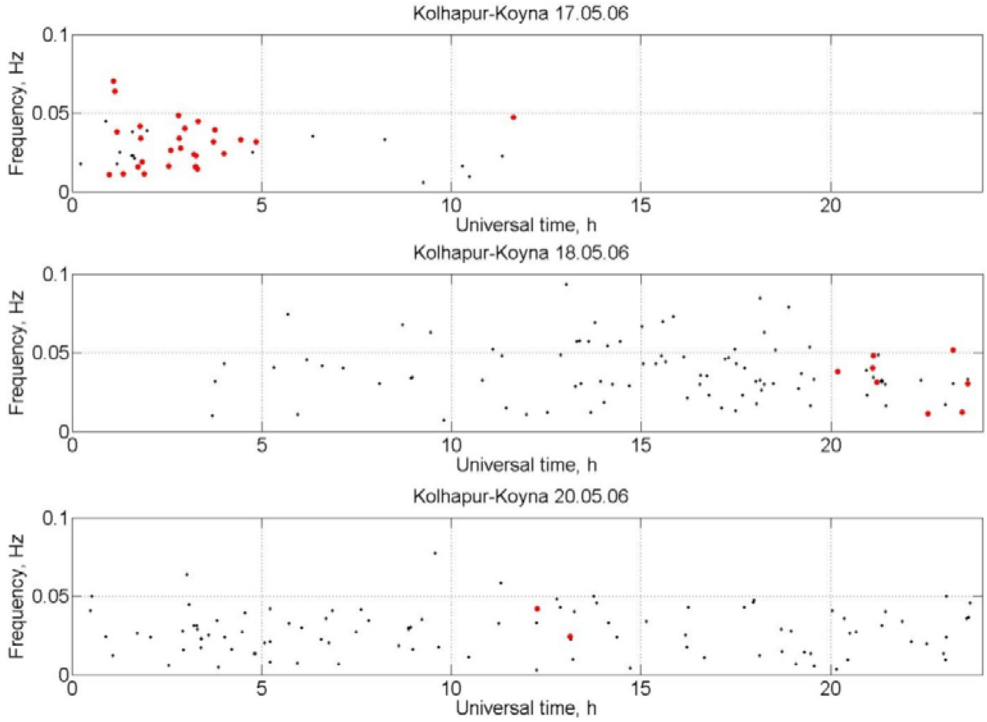


Fig. 3. Distribution of ionospheric (small dots) and seismo-EM (bold dots) M-lines against time and frequency for 17, 18 and 20 May 2006.

4. Summary

The use of highly sensitive and low noise search coil LEMI-30 magnetometers enabled us to resolve ULF magnetic signals in frequency range of 0.001-0.5 Hz with amplitudes as low as of few pT. 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 intersection lines formed by the planes of PE, calculated for the magnetic fields at minimum two sites, define the azimuth of seismo-EM source. Further, ratio of major axes of PEs above certain threshold helps to distinguish ULF signals dominated by seismo-EM origin from those associated with ionospheric origin. In the present case, this threshold is fixed at 2, corresponding to the minimum value of the ratio recorded between Koyna and Kolhapur. Approximating the seismo-EM source as elementary magnetic dipole, the large numbers of spectral lines qualifying this threshold provided statistically averaged azimuth of the seismo-EM field direction. The NNW-SSE orientation of seismogenic ULF signals in the Koyna-Warna corresponds well with causative fault zone inferred from long-term EQ data. The already available knowledge on the role of high pressure fluids in generating the EQs favors electrokinetic effect to be one of the possible source mechanisms for seismo-EM fields. Testing the proposed formulation to the other active seismic areas and preferably employing multiple measuring stations would help generalization of the methodology for future EQ precursory studies, which is under way now.

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5. References

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