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Response function temporal variations of internal origin

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In the geoelectromagnetic studies of electrical conductivity of the Earth's interior [1], the response function (RF) is supposed to be any function (impedance, apparent resistivity, induction vector $\boldsymbol{C}$ and its components A and B, horizontal components anomalous magnetic variation matrix [M]) derived from the Earth's electromagnetic (EM) data that provides us with the possibility to determine the conductivity structure of the Earth. Ideally, RF depends only on the Earth's conductivity and does not depend on the properties of external EM field used. Induction vector $\boldsymbol{C}$ is one of RFs of the Earth widely used for EM monitoring: $\boldsymbol{C} = A\,\boldsymbol{e_x} + B\,\boldsymbol{e_y}$ …(1), where $\boldsymbol{e_x}$ and $\boldsymbol{e_y}$ are unit vectors, x is pointed to North, y – to East, z – downward, A and B form a 1×2 matrix which transforms the horizontal magnetic field (B_x, B_y) observed at a station into the vertical component B_z: $B_z = A\,B_x + B\,B_y$ …(2). In equations (1)–(2) all quantities are complex and depend on period T of geomagnetic field variations, thus we suppose that harmonic analysis was applied to observed time series of magnetic field $\boldsymbol{B}(T)$. The real $\boldsymbol{C}_u = A_u\,\boldsymbol{e}_x + B_u\,\boldsymbol{e}_y$ …(1u) and imaginary $\boldsymbol{C}_v = A_v\,\boldsymbol{e}_x + B_v\,\boldsymbol{e}_y$ …(1v) parts of the vector $\boldsymbol{C}$ are referred to as the real and imaginary Wiese (or Parkinson) induction vectors. Real induction vectors possess an important property: in the notation of Wiese, they are directed away from good conductor, in Parkinson's notation – to good conductor.

Horizontal magnetic tensor [M] is determined from the linear equations system

$B_x(\boldsymbol{r}_1)=M_{xx}B_x(\boldsymbol{r}_0)+M_{xy}B_y(\boldsymbol{r}_0)$

$B_y(\boldsymbol{r}_1)=M_{yx}B_x(\boldsymbol{r}_0)+M_{yy}B_y(\boldsymbol{r}_0)$

where $\boldsymbol{r}_0$ and $\boldsymbol{r}_1$ are base and some other observatory place. Tensor [M] reflects the change in geoelectric cross-section between the base and field point.

Really observed $\boldsymbol{B}(T)$ is composed of

$$\boldsymbol{B}(T) = (\boldsymbol{B}_{en} + \boldsymbol{B}_{in} + \boldsymbol{B}_{ia}) + \boldsymbol{B}_{noise} + \boldsymbol{B}_{LE} \qquad (3)$$

where: $\boldsymbol{B}_{en}$ – normal external primary magnetic field (of period T) of the currents in ionosphere and magnetosphere; $\boldsymbol{B}_{in}$ – normal internal secondary magnetic field of the currents induced in hypothetical horizontally layered (*1D* conductivity) Earth; $\boldsymbol{B}_{ia}$ – anomalous secondary field arising on local/regional conductivity anomalies as result of re-distribution of the currents responsible for $\boldsymbol{B}_{in}$. For commonly used in magnetotellurics idealized model of Tikhonov-Cagniard (plane wave vertically incident on horizontally layered Earth) the normal field in equation (3) has only horizontal components B_x and B_y, B_z in equation (2) is purely anomalous. If two last terms ($\boldsymbol{B}_{LE}$ is the field of lithospheric emission) in equation (3) can be neglected the induction vector carries pure information on conductivity anomaly and if it varies with time one can suppose that conductivity structure changes. In natural environment two last terms in equation (3) can be not small and source can differ from plane wave. So, observed variations of induction vector can be caused also by 1) variation of the properties of external source field, i.e. by its deflection from Tikhonov-Cagniard model, 2) noise, 3) superposition of transient internal EM fields – lithospheric emission (LE). The latter cause together with the change of lithosphere electrical conductivity manifest geodynamic processes including earthquake (EQ) and volcano activity preparation and is of great interest for precursors study.

LE registration is rather difficult and uncertain because it should be separated from continuous external magnetotelluric (MT) field and industrial noise background. There are several cases when LE preceding or accompanying EQ was reliable separated [2 – 4]. In many cases LE observed at one station and its identification was rather uncertain. In this situation, transformation of geomagnetic field time series into RF can give more reliable separation of precursory effects.

The data of permanent geomagnetic observatories in seismically active regions were used for the study of the induction vector changes related with EQ occurrence. Strong and long induction vector variation after very strong Kanto at 1.09.1923 in Japan was reported in [5]. One of early review was presented in [6]. In Surlari observatory (Vrancea zone, Romania) induction vector rose from 0.3 in 1961 to 0.45 in 1967 when shallow strong EQ of magnitude M>5 occurred at the distance of 40 km. Deep (>80 km) stronger EQs in the zone were not preceded by induction vector variation [7]. In China since early 1970s over forty magnetic observatories were deployed in seismically active regions. And anomalous changes of induction vector (T = 10-20 min) with duration from several months to two years were observed before several EQs: Haicheng (M7.3) 1975, Tangshan (M7.8) 1976, Songpan (M7.2) 1976, Heze (M5.9) 1983 [8].

T.A.Klymkovych [9] developed a high temporal resolution program and used it for analysis of magnetic observatory N.Selysche data in Ukrainian Transcarpathians seismic zone and correlations of induction vector changes with small local EQs (M=1.5-3) were found. V.I.Tregubenko used Varentsov's processing program based on multi-windows spectral analysis with three-level selective robust weighting of the local estimates of magnetovariational matrix components. Partial and multiple coherences were applied as the weights for summation. Local estimates with the input coherence more than 0.5 and partial coherences less than 0.7 were excluded from the summation. This program was applied to Ukrainian magnetic observatories network data for 15 years. Aperiodic variations of few months duration before Turkish Izmit EQ 17.08.1999 M7.6 and several Crimean EQs with M=3.5-4.5 were identified. At the same time periodic variations (periods 1 year and 27-29 days and its harmonics) were observed and carefully studied. So the periodic variations of induction vectors are really exist and they carry new information from the Earth interior. V.I.Tregubenko suggested that periodic variations of induction vector are the result of geodynamical processes associated with the position of the Earth and Moon on their orbits.

Recent years our group processed more than dozen geomagnetic observatories data with 1 min temporal reading (Intermagnet) and several with 1 sec reading. Almost at all observatories periodic variations (including diurnal) were found. Moroz et al. [10, 11] also reported on annual variations. Our group [12] studied annual and diurnal variations at 3 geomagnetic observatories of South-Eastern Europe. We study the RF function periodic variations in complex with structural geoelectrical methods MVP and MTS.

After recent catastrophic EQ of 11.03.2011 near Japan we analyzed the data of 7 geomagnetic observatories of South-East Asia collected in Intermagnet. Processing of Japanese observatories MMB and KNY yields very interesting result: At January 1, 2005 induction vector sharply changed, it was 5 days after great Sumatra EQM9.1 at 26.12.2004 and we began to think on the nature of a signal coming from the EQ to Japanese observatories. But to check this result we found the same data in Japanese Data Center, reprocessed them and the change disappeared. Cause was simple: the second source present H, D and Z components, H and Z in nT with precision 0.1 nT and D in minutes with precision 0.01 min, calculation D to Y-component yields satisfactory precision 0.1 nT. Intermagnet after 1.01.2005 gives X,Y and Z with proper precision, before the date gives H, D and Z where D is given with precision 0.1 min that correspond precision in Y component ≈1nT that yields great error when rapid variations with small amplitude are analyzed. This defect of Intermagnet data should be removed. We know some other sources of error under RF determination and pay great attention to error estimation and excluding. More extensive study of Japanese data related to the EQ 11.03.2011 is given in companion abstract [13].

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