The geomagnetic field and TEC anomalies connected with the strong earthquakes

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A lot of scientific articles study correlation of seismic activity with variations of different components of the Earth’s magnetic field. More often this is correlation with a single factor, such as secular variations, Sq-variations, Wolf’s numbers, Kp- and Ap-indices, as well as with the frequency and origin times of geomagnetic storms, etc. However, this analysis does not give a complete pattern of the Earth’s crust processes. To select and estimate the contribution of planetary geomagnetic processes and local responses and calculate the ratio of the external field $T_e$ and telluric variations $\delta T_i$, we have to use data of remote and local stations. Moreover, the ionosphere conditions such as the total electron content (TEC), wind’s velocity, the conductivity and current’s density play the role.

At present, when the network of permanent dual-frequency receivers of the navigation system GPS ($f_1 = 1575.42$ MHz and $f_2 = 1227.60$ MHz) is widely spread, monitoring of the total electron content became much easier. The method of calculating TEC [2] is based on the dependence of the refractive index ($n$) of electromagnetic waves from the free electron concentration ($N_e$) and the wave frequency ($f$):

$$n = \sqrt{1 - \frac{80.8 N_e}{f^2}} \approx 1 - \frac{40.308 N_e}{f^2}.$$

The measured ways at the frequencies $f_1$ and $f_2$ are $S_1 = n_1 S_0 = (1 - 40.308 N_e/f_1^2) S_0$ and $S_2 = n_2 S_0 = (1 - 40.308 N_e/f_2^2) S_0$, respectively, where $S_0$ - a true satellite-receiver distance. Excluding the $S_0$ and integrating, we find the total electron content $TEC_0$:

$$TEC_0 = \frac{1}{40.308 f_1^2 - f_2^2} (L_1 \ast \lambda_1 - L_2 \ast \lambda_2 + S_{const} + \delta S),$$

where $L_1$ and $L_2$ - the numbers of complete turns of phase, $\lambda_1$ and $\lambda_2$ – the wavelengths (m) for frequencies $f_1$ and $f_2$, $S_{const}$ - some unknown initial phase ways (m) and $\delta S$ - error in determining the phase ways (m). To determine $S_{const}$, which is the same as phase ambiguity resolution, code measurements $P_1$ and $P_2$ are used: $\delta S = \delta S_1 + \delta S_2 = (P_1-L_1 \lambda_1)-(P_2-L_2 \lambda_2) = (P_1-P_2)-(L_1 \lambda_1-L_2 \lambda_2)$. Taking into account the ballistics of the navigation satellite, we obtain:

$$TEC = TEC_0 \ast \cos(\arcsin(R_e \cos \theta/(R_e + h_{max}))],$$

where $R_e$ – Earth’s radius, $h_{max}$ – the height of maximum electron density, $\theta$ – the height of satellite
visibility. To construct a continuous series variations of TEC with the least noise (because of the satellite’s location near the horizon), we used only observations with \( \theta \) equal to 57°-90°.

The investigation of this series allows to detect seismic-ionospheric disturbances before and after strong earthquakes [3,4]. Fig. 1a shows the variations of TEC after the Nura’s earthquake, \( K = 13.25 \) (MI = 6.6), which occurred at 15 hours 52 minutes 5 October 2008, the epicenter’s latitude is 39.62 N, longitude is 73.67 E. The level of geomagnetic disturbance was weak: \( Kp = 1 \). There is a sharp increase the amplitude of variations in 5-10 minutes on the nearest \( (126.5 \text{ km}) \) to the epicenter GPS-station OSHK \( (40.53 \text{ N}, 72.78 \text{ E}) \), after \( \sim 1 \) hour oscillations are damped. On the other (more distant) stations such variations are not observed, that indicates the seismo-ionospheric character.

Using data from several GPS-receivers we can determine the velocity of the ionospheric disturbance (ID), and in a combination with the observations of the geomagnetic field \( T \) - to calculate the density the ionospheric current and the conductivity of the ionosphere. Suppose that receivers are located at a distance \( R \) from each other, and the time between the observations of ionospheric disturbances is \( \Delta t \). The distance traveled by ID in the ionosphere is equal \( R_{\text{sw}}=R^*\left(h_{\text{orb}}-h_{\text{max}}\right)h_{\text{orb}} \), where the \( h_{\text{orb}} \) – height of the satellite's orbit, \( h_{\text{max}} \) – the height of maximum electron density. Taking the average values \( h_{\text{orb}}=20000 \text{ km}, h_{\text{max}}=300 \text{ km} \), we have \( R_{\text{sw}}=0.985R \). Then the velocity of the ID is \( v=0.985R/\Delta t \).

The movement of electrons causes the electric current density \( j=\sigma E \) [5], where \( \sigma \) is conductivity (also depends on the TEC) and \( E=\mu_0|v\times H| \) – the intensity of the electric field. The magnetic field is formed by the homogeneous current sheet of density \( j \), must have a value of \( \delta H=j/2 \). Taking into account that the observed field by applying a field-induced currents about 1.5 times greater than the external, then the observed field is \( \delta H=3j/2 \). Therefore, the conductivity of the ionosphere may be calculated as \( \sigma=2\delta H/3\mu_0|v\times H| \).

For example, consider the calculation conductivity of the ionosphere for GPS-stations POL2 \( (42.68 \text{ N}, 74.69 \text{ E}) \) and CHUM \( (42.99 \text{ N}, 74.75 \text{ E}) \). The variation of TEC and the full vector of the geomagnetic field \( T \) are shown in Fig. 1b, long-period trends have been removed. The variations of \( \text{TEC}_{\text{POL2}} \) and \( \text{TEC}_{\text{CHUM}} \) diverge and the time delay \( \Delta t \) is change in time. For \( t_A \) and \( t_B \) \( \Delta t=5.5 \text{ min} \), \( R = 35.7216 \text{ km} \), then \( v=0.985R/\Delta t=106.623 \text{ m/s} \). The observed variation of the geomagnetic field is equal \( \delta H=6 \text{ nT} \), \( H=40 \text{ A/m} \), then \( \sigma=120 \text{ S/m} \).

Thus, the complex analysis of the total variations of the geomagnetic field \( T \) and TEC allows to calculate the parameters of ionospheric disturbances and currents, and can be used to more effectively searching ionospheric oscillations associated with the strong earthquakes.

This work was partially financially supported by the Ministry of Education and Science to implement
the federal program "Scientific and scientific-pedagogical personnel of innovative Russia" (state contract № 02.740.11.0730).

References


Fig. 1a: Variations dTEC during the Nura earthquake.

Fig. 1b: Variations TEC and the total vector of the geomagnetic field T.