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MODELING OF THE TEC DISTURBANCES GENERATED BY SEISMOGENIC ELECTRIC CURRENTS AT DIFFERENT SEASONS

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Abstract

Numerical calculations of the ionosphere Total Electron Content (TEC) disturbances have been performed using global Upper Atmosphere Model (UAM) for the conditions corresponding to the Haiti (January 12, 2010) and Japan (March 11, 2011) earthquakes. The vertical electric currents with the density 10 nA/m^2 and flowing over the area of about 250 by 4500 km have been setup as the sources of the seismogenic impact at the height of 80 km in the UAM electric potential equation. Their action resulted in the relative (%) modeled TEC disturbances with the same key features as the TEC variations observed before both these earthquakes. Both modeled and observed TEC disturbances for both cases appeared at night near the epicenter and magnetically conjugated area; they were 40–60 % by magnitude; and did not move away from the source location during their lifetime. In the Haiti case maximum of both modeled and observed TEC variations was more pronounced in the area magnetically conjugated to the epicenter. In the Japan case both modeled and observed disturbances were more symmetrical relative to the geomagnetic equator. According to the UAM simulations, TEC disturbances that are symmetrical relative to the geomagnetic meridian of the epicenter were obtained by setting up vertical electric currents flowing to the Earth at one side from the epicenter meridian and back currents at the opposite side.

Introduction

Variations of the ionospheric total electron content (TEC) registered before strong seismic events have distinctive features and are considered as ionospheric earthquake precursors. The stable long-living positive and negative disturbances (increase or decrease) with the magnitude of several tens of percents relative to the quiet background values are observed over the epicenter region and often over the magnetically conjugated area. The manifestation zone of these anomalies extends more than 1500 km along the meridian and 3500–4000 km along the parallel, doesn't change its form and doesn't move away unlike the traveling ionospheric disturbances associated with geomagnetic activity. The relative TEC disturbances are observed mostly during night-time, reduce significantly after sunrise up to full disappearance and reappear again after sunset. Modifications of the equatorial anomaly are often registered in case of low-latitude earthquakes (*Liu et al*., 2004; *Pulinets and Boyarchuk*, 2004; *Depueva and Ruzhin*, 1995).

Formation of such TEC disturbances is associated with seismogenic electric fields generated at the ionosphere heights (*Pulinets and Boyarchuk*, 2004) as a result of external electric current flowing above epicenter (*Sorokin et al*., 2007 and references therein). Radon and other radioactive particles emanating from tectonic faults play important role in the process as well as aerosols and soil gases which concentration increases before earthquakes (*Alekseev and Alekseeva*, 1992; *Heincke et al*., 1995; *Omori et al*., 2007). The decay products of radon act as an ionization source of the neutral particles of the near-surface air layer, and aerosols become charged by interacting with newly formed ions and electrons. The electric current is generated by gravitational sedimentation and convectional transport of charged aerosols of different sizes. According to estimations performed by (*Sorokin et al.*, 2007) the density of external electric current may reach 10^{-6}–10^{-7} A/m^2 and corresponding electric field disturbance in the ionosphere amounts to about 10 mV/m. The same electric field intensity was registered by satellite observations over seismic active regions at the area with horizontal scale of several hundred kilometers and more (*Gousheva et al*., 2009; *Zhang et al*., 2013). Electric field generated by charge carriers activated during rock stress and accumulated near the ground surface might act as another or additional ionization source (*Freund et al*., 2009), and electric current with the density of $0.5{\cdot}10^{-6}$ –$1.25{\cdot}10^{-6}$ A/m^2 was registered over 200 cm^2 collector plate in laboratory experiments with stressed rock.

The direct action of the seismogenic electric field on the TEC was proposed in (*Namgaladze et al*., 2009) via the electromagnetic [$\boldsymbol{E} \times \boldsymbol{B}$] plasma drift in crossing electric $\boldsymbol{E}$ and magnetic $\boldsymbol{B}$ fields responsible for increase or decrease of the electron number density and, thus, for the TEC positive or negative disturbances. This physical mechanism was successfully verified in the series of numerical calculations where external electric current of seismic origin was used as an additional input in the electric potential equation. It was shown that sources of electric current with the density of about 1–10 nA/m^2 spread out over the area of 250 by 2000 km create the required electric fields of several mV/m in the ionosphere and generated TEC disturbances are in a good agreement with the anomalies observed before strong earthquakes (*Namgaladze et al*., 2013). All mentioned general features of the ionospheric precursors were reproduced in simulations, but the density of the electric current used in calculations is quite huge. However, the values don't exceed the estimations by (*Sorokin et al.*, 2007) and measurement results by (*Freund et al.*, 2009), but lay in the values range of the electric current density associated with thunderstorm activity (*Blakeslee et al.*, 1989, *Krider and Musser*, 1982; *Le Mouel et al.*, 2010). Since some authors demonstrate skepticism about the anomaly high values of the seismogenic electric current (*Harrison et al.*, 2010; *Denisensko et al.*, 2013], direct measurements of the electric current density over forthcoming earthquake region are highly necessary.

In this we compare TEC disturbances observed before two strong earthquakes occurred in Haiti (January 12, 2010) and Japan (March 11, 2011) at different seasons to reveal common features and differences; we also have performed numerical model calculations of the ionospheric effects for corresponding conditions.

Observational data results

According to the US Geological Survey data, the earthquake with the magnitude *M* 7.0, the focal depth *D*=13 km took place at 16:53 LT on January 12, 2010 at the geomagnetic coordinates of epicenter 35.08 N and 10.29 W. The global 2-hour GPS TEC maps in IONEX format (*Dow et al.*, 2009) were used to calculate the TEC disturbances relative to the quiet background values, which were obtained as a running average for seven days before the day to be studied. The positive 50 % TEC disturbances were discovered for night-time periods on January 9–12 approximately over the epicenter area and the point magnetically conjugated to epicenter with slight shift to the east (fig. 1). The anomalies in the magnetically conjugated area were stronger and occupied bigger area. Weaker negative deviations were registered at the areas to the west from epicenter meridian. Due to the quiet geomagnetic conditions on January 1–12 and revealed characteristics, observed anomalies were considered as typical ionospheric earthquake precursors (*Namgaladze et al*., 2013).

The Great Tohoku earthquake (*M* 9.0, *D* = 30 km) at 14:46 LT on March 11, 2011 was registered at the geomagnetic coordinates of 34.92 N and 144.44 W. Four more earthquakes with the magnitude *M* > 5 occurred within seven days at the distance of several thousand kilometers from epicenter of the main event, i.e. inside the typical manifestation zone of ionospheric precursors, so it was not possible to attribute anomalies for specific event. The analysis of the TEC effects was also attended with great difficulties due to non-stable geomagnetic conditions for the considered period. The TEC analysis showed formation of the strongest and stable positive disturbances with the magnitude of 60 % and more at night on March 8, which were located over the areas to the south from epicenter and to the north from magnetically conjugated point (fig. 2) with shift to the east from the epicenter meridian as in the previous case, but anomalies were more symmetrical relative to the geomagnetic equator. Disturbances moving from high to low latitudes were registered on March 10, but were attributed to the geomagnetic storm had taken place that day (*Namgaladze et al*., 2013).

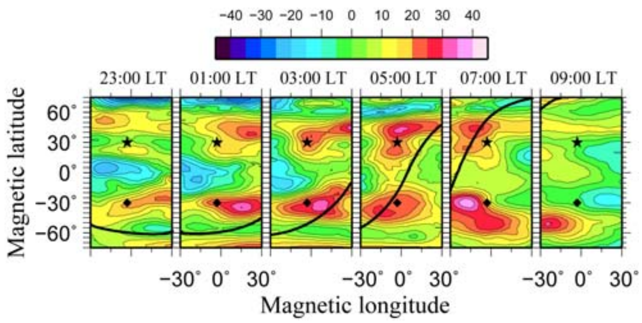

Fig. 1 GPS observed TEC disturbances (%) for January 9, 2010 (Haiti). Star denotes epicenter location, diamond – magnetically conjugated point, black line – terminator.

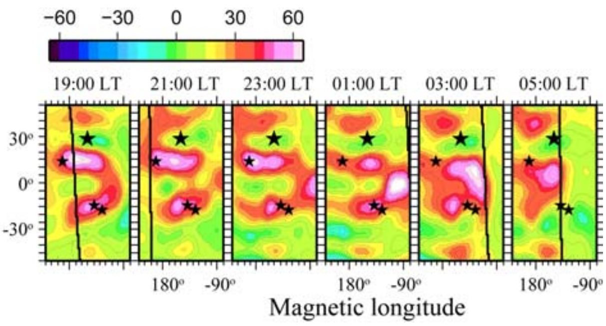

Fig. 2 The TEC disturbances (%) observed on March 8, 2011 (Japan).

Numerical calculations and discussion

Three-dimensional global first-principle model of the Earth's upper atmosphere (UAM) was used to simulate ionospheric effects for the considered events. The model calculates temperatures, velocities and densities of the main neutral and charged components of the near-Earth environment within range from 60-80 km (lower boundary varies depending on task) to the geocentric distance of 15 Earth radii as well as distribution of the electric potential and electric field intensity by solving momentum, heat balance and continuity equations and equation for the electric potential (*Namgaladze et al*., 1988, 1998). Sources of the external electric current flowing to the Earth were used as an additional (to magnetospheric field-aligned electric currents) model input at the lower boundary in the electric potential equation with following parameters: the density $j = 10$ nA/m^2, the acting area with sizes 250 × 4500 km (geomagnetic latitude × longitude). The center of the area with additional sources was located over the epicenter of the corresponding earthquake.

The UAM calculated TEC disturbances relative to the quiet conditions (i.e. without any additional seismogenic electric currents) for the Haiti earthquake are presented in fig. 3. Positive and negative deviations of 40–50 % and 30–40 % were obtained at the areas to the east and to the west from the epicenter meridian respectively; the disturbances' maximum located in the Southern (summer) hemisphere. The effects disappeared at night and reappear after sunrise. The form of the modeled disturbances stretched along the geomagnetic meridian, while observed ones stretched along the parallel. Beside of this, a good agreement between the UAM calculated and GPS observed TEC disturbances was achieved.

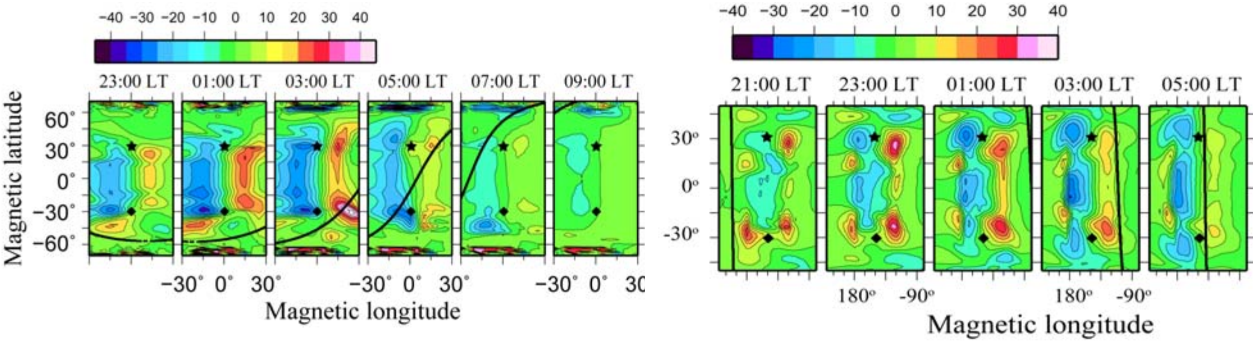

Fig. 3 UAM calculated TEC disturbances (%) for the Haiti (left) and Japan (right) earthquakes.

Fig. 3 shows the calculation results of the TEC disturbances for the conditions corresponding to the Japan earthquake. The calculated positive and negative disturbances had the same positions relatively to each other and the epicenter meridian like in the previous case. The Great Tohoku earthquake took place in conditions close to spring solstice, and symmetry of the modeled effects relative to the geomagnetic equator is clearly visible just like in the observational data. But some differences were found out. First of all, the magnitude of the UAM calculated TEC disturbances is 15–20 % less than the magnitude of the GPS observed deviations; and negative disturbances were not discovered in observations. Secondly, some differences conclude in position of the anomalies relative to the epicenter and magnetically conjugated area: the GPS observed anomalies located closer to the equator. It is natural to assume that deposit from other mentioned earthquakes had place and complicated result picture.

The TEC disturbances symmetrical both the epicenter meridian and the geomagnetic equator were obtained in the UAM simulations by placing two sources of the electric currents of opposite direction (towards the Earth and towards the ionosphere) on the opposite sides from the epicenter meridian (eastern and western) respectively. The result is presented in fig. 4.

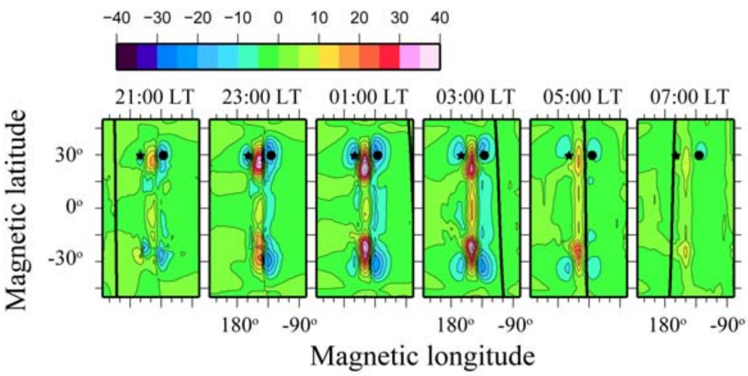

Fig. 4 UAM calculated TEC disturbances (%) for the configuration with external electric currents flowing to the Earth (denoted by star) and to the ionosphere (circle).

Conclusion

GPS observed TEC disturbances prior to the Haiti (January 12, 2010) and Japan (March 11, 2011) earthquakes with the focal zone at the same latitude were briefly described, and typical set of the ionospheric earthquake precursors' features was revealed in both cases in terms of stability, magnetic conjugation and local time dependence of the anomalies. Differences in specific characteristics (position and magnitude) were attributed to the different heliophysical background conditions.

Numerical calculations of the TEC disturbances for considered events were performed with the external electric current as a model input at the height of 80 km in the electric potential equation of the UAM. General characteristics of observed effects were reproduced as well as specific features: more pronounced maximum in the vicinity of the point magnetically conjugated to the epicenter for the Haiti earthquake and symmetry relative to the geomagnetic equator for the Japan case. TEC disturbances symmetrical both the equator and the epicenter meridian were obtained by setting up the external electric currents of opposite directions on the opposite sides from the epicenter meridian.

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