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NUMERICAL MODELING OF THE IONOSPHERIC PRECURSORS OF HIGH-LATITUDE EARTHQUAKES

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Abstract. In this research, we used two mechanisms in numerical experiments for reproduction of observed changes in the ionosphere prior strong high-latitude earthquake on Alaska in 1964. The first mechanism is the disturbances of the zonal electric field in the near-epicentral area. The second mechanism is the propagation and dissipation in the upper atmosphere of the small-scale internal gravity waves (IGW) generated in the epicenter of the future earthquake. The numerical experiments have shown, that the local perturbations of zonal electric fields and the small-scale IGWs generated in the near-epicentral area allow reproducing the morphology of ionospheric disturbances observed in the periods of seismic activity.

Introduction

The large number of scientists from different areas of geophysics tries to construct the theory predicting earthquakes to reduce quantity of victims. Not last place in the list of these researches is occupied the researchers of ionospheric precursors of earthquakes. Among the largest earthquakes of the 20th century is the Alaska Good Friday earthquake of 1964. It occurred on Friday, March 27 (local time). It happened at a point with coordinates 61.1° N and 147.6° W, and had a magnitude M_w=9.2. This earthquake became the first earthquake on which the researchers of the ionosphere have turned a fixed attention (Davies, Baker, 1965; Leonard, Barnes, 1965). In the last twenty years an international intensive research in the new science field of ionospheric precursors of earthquakes has been carried out in many countries (Pulinets, Boyarchuk, 2004; Liperovsky, 2008).

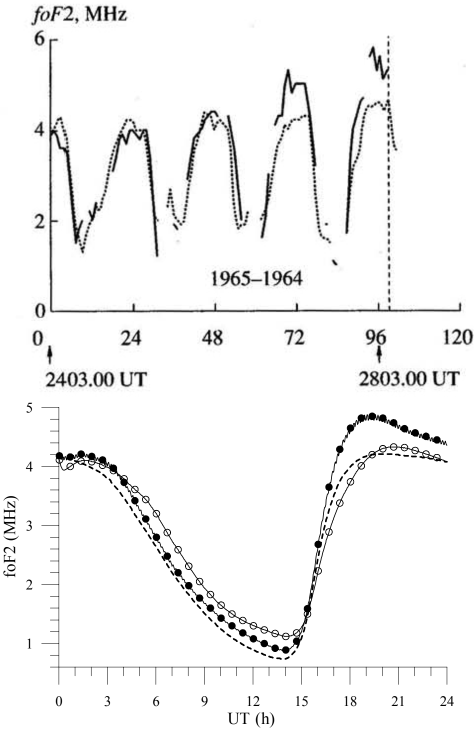

Fig. 1. *foF2* diurnal variation at Anchorage station observed (top) during March 24-28, 1964 (solid line) and March 24-28, 1965 (dotted line) and simulated (bottom) with additional zonal electric field (light circles) and with IGWs (dark circles) and without seismogenic sources (dotted line). Vertical line at the top marks the underground shock instant in the UT axis.

The effects in F2-region maximum electron concentration, N_mF2, for strong middle-latitude earthquakes look like local changes which maxima are located in immediate proximity from epicentral area (Pulinets, Boyarchuk, 2004). Precursory effects of strong near-equatorial earthquakes might be in the form of deepening and widening of electron concentration minimum over the magnetic equator during the daytime and displacement of equatorial ionization anomaly crests (Depueva, Ruzhin, 1995).

Formation mechanism of local large-scale ionospheric precursors of earthquakes

The physical models of lithosphere-atmosphere-ionosphere coupling some days prior to earthquakes are reviewed by Liperovsky et al., 1992; Pulinets, Boyarchuk, 2004; Hayakawa, 2007; Liperovsky, 2008. However, till now there is no common opinion concerning the formation mechanism of local large-scale ionospheric precursors of earthquakes. Some basic hypotheses of lithosphere-atmosphere-ionosphere coupling for an explanation of this mechanism have been offered:

a) the internal gravity waves (IGW) with the period ~1–3 hours generated due to non-stationary inflow of lithospheric gases in the atmosphere prior earthquake (Pertsev, Shalimov, 1996). This mechanism can explain the ionospheric phenomena, occurring on great distances from earthquake epicenter.

b) the IGWs with the period from several minutes up to tens minutes (Mareev et al., 2002), which as supposed, can be excited in the area of preparation of earthquake. The vertical propagation of such waves provides the localization of the effects dissipation above the epicenter of earthquake.

c) the seismogenic electric field with amplitude from units up to tens mV/m (Chmyrev et al., 1989) connected with vertical turbulent transfer of the charged aerosols injected in the atmosphere and isotopes of radon. Grimalsky et al., 2003 considered the mechanism of electric field penetration from lithosphere into ionosphere before earthquake.

d) the abnormal electro-magnetic fields and emissions (Hayakawa, Fujinawa, 1994). This mechanism is found to be insufficient because of the weak intensity of lithosphere radio emissions (Hayakawa, 2007).

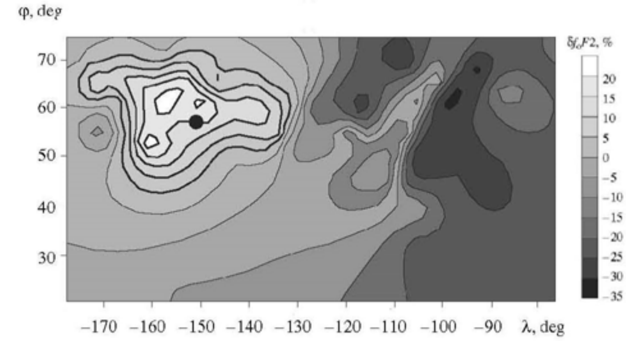

Fig. 2. Map of *foF2* deviations for noon hours of local time 4-6 h prior to earthquake. Black circle marks the epicenter.

Due to local global scale of ionospheric precursor, the two of those mechanisms can consider the small-scale IGWs and/or the seismogenic electric field in the ionosphere (Hayakawa, 2007).

In (Namgaladze et al., 2007) it has been come out with the assumption, that the most probable formation mechanism of areas of disturbed N_mF2 and Total Electron Content (*TEC*), observable prior strong earthquakes, is the vertical transport of *F2*-region ionospheric plasma under action of the zonal electric field, appearing in near-epicentral area some days prior to earthquakes. The geomagnetic conjugacy of the ionospheric precursors of earthquakes (Pulinets et al., 2003) and effects in equatorial anomaly which development is controlled by the zonal electric field (Zakharenkova et al., 2006) are strong arguments in favor of this hypothesis. Besides, the analysis of model calculation results in (Namgaladze et al., 2009) testifies in favor of this hypothesis. There is a question, how such electric fields can arise in the ionosphere prior earthquakes? It is possible two variants:

1) the penetration of seismogenic electric fields into the Earth's ionosphere.
2) the generation of zonal electric field by small-scale IGWs. In (Klimenko et al., 2009), it is carried out the model researches, in which this mechanism was used.

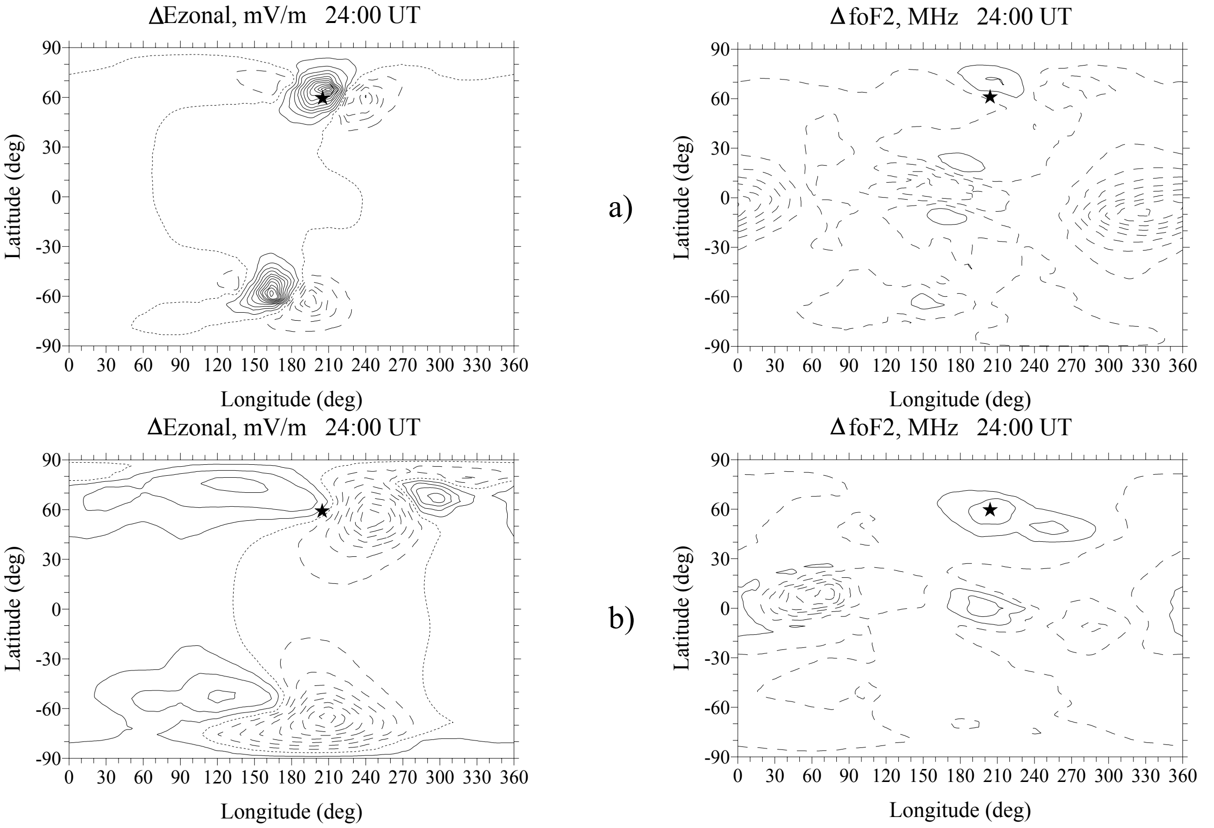

Fig. 3. The global maps of deviations of zonal electric field in the ionosphere (at the left) and *foF2* (on the right) calculated with additional zonal electric field sources (a) and with internal gravity wave (b). Step between isolines in electric field is a) 1 mV/m, b) 0.1 mV/m. Step between isolines in *foF2* is 0.1 MHz.

In this study, we used numerical experiments for reproduction of observed changes in the ionosphere prior strong high-latitude earthquakes on Alaska in 1964.

The statement of a problem and model simulations

The calculations were carried out for quiet geomagnetic conditions of the spring equinox at low solar activity with use of the Global Self-consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP) (Namgaladze et al., 1988; Klimenko et al., 2006). We consider two cases: 1) the additional zonal electric field in the epicentral area of ionosphere; 2) the small-scale IGWs in the epicentral area.

To create zonal electric field over the epicentral area it is necessary to set positive and negative electric charges on the western and eastern boundaries. The sources of additional zonal electric field joined and did not change within 24 hours in the form of additional positive and negative potentials in 10 kV on boundaries of near-epicentral region.

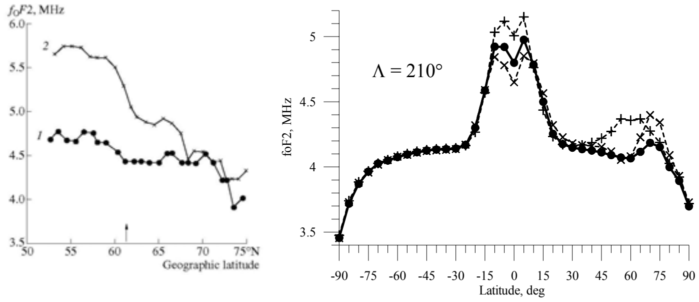

Fig. 4. *foF2* latitudinal profiles. Left – for two neighboring orbits of the Allouette-1 satellite on March 27, 1964: curve 1 on a distance of 20° from epicenter, curve 2 above epicenter. An arrow shows the earthquake latitude. Right – the calculation results without seismogenic sources (●), with IGWs (+) and with electric field (×).

In calculations, the IGWs with the period of 10 min. and amplitude of 10 m/s were set on the bottom boundary of the thermosphere at height of 80 km under following formulas:

$$n(O_2) = n(O_2)_0 \times A \times 10^{-2} \times sin(2\times\pi\times UT/\tau)\ (m^{-3})$$
$$n(N_2) = n(N_2)_0 \times A \times 10^{-2} \times sin(2\times\pi\times UT/\tau)\ (m^{-3})$$
$$n(O) = n(O)_0 \times A \times 10^{-2} \times sin(2\times\pi\times UT/\tau)\ (m^{-3})$$
$$T_n = T_{n0} \times A \times 4 \times 10^{-3} \times sin(2\times\pi\times UT/\tau)\ (K)$$
$$V_{n\Theta} = A \times sin(2\times\pi\times UT/\tau)\ (m/s)$$
$$V_{n\Lambda} = A \times sin(2\times\pi\times UT/\tau)\ (m/s),$$

where A = 10 m/s – amplitude of IGW, UT – Universal Time in s, $n(O_2)_0 = 7.4\times10^{19}$ (m^{-3}), $n(N_2)_0 = 3.0\times10^{20}$ (m^{-3}), $n(O)_0 = 2.4\times10^{16}$ (m^{-3}), T_{n0} = 188 (K) – background values of concentration of molecular oxygen, molecular nitrogen, atomic oxygen and temperatures of neutral gas, accordingly, on the bottom boundary of the thermosphere.

The IGWs were set and did not change within 24 hours per all nearest units of spatial grid the nearest with epicentral point, and in the epicenter of earthquake.

Thus, in both cases it has been considered near-epicentral area in the sizes 10° on latitude and 30° on a longitude.

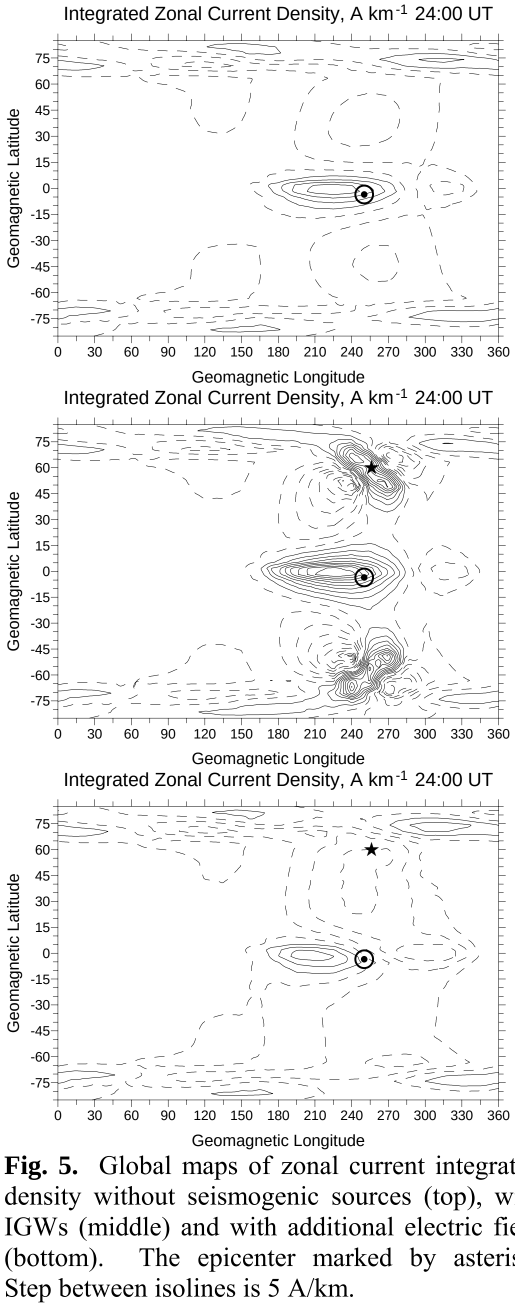

Fig. 5. Global maps of zonal current integrated density without seismogenic sources (top), with IGWs (middle) and with additional electric field (bottom). The epicenter marked by asterisk. Step between isolines is 5 A/km.

Comparisons of simulation results with experimental data

Fig. 1 presents the calculation results of diurnal variation in critical frequency of *F2*-layer, *foF2*, at station Anchorage obtained with additional zonal electric field, with IGW and without seismogenic sources. In addition, it presents the experimental results of diurnal variations in foF2 at Anchorage before earthquake and the same data at the next year. It is visible a good agreement the calculation results and experimental data. Daytime increase in *foF2* is bigger in calculation with use IGW then with additional zonal electric field.

Fig. 2 shows the global foF2 deviations 6 h before earthquake obtained from satellite and ground-base observations (Pulinets, Boyarchuk, 2004).

Fig. 3 presents the global deviations of zonal electric field in the ionosphere and *foF2* calculated in the model with additional zonal electric field sources and with IGWs. In both cases the additional eastward electric field in near epicentral region is formed. Also in both cases, the formation of local cloud-shape increase of *foF2* is visible. The calculation results are in a good agreement with experimental data shown in Fig. 2. It is possible to note the better realistic results in calculation with IGWs.

Fig. 4 presents the calculation results and experimental data from Allouette-1 of latitudinal distributions in foF2. It is visible good agreement of calculation results with experimental data. It is possible to note that in both latitudinal profiles the increase in *foF2* exists in near-epicentral area.

Let us consider the effects of additional sources of seismogenic origins on zonal current integrated density. Fig. 5 shows the calculated global distribution of integrated density of zonal current obtained without seismogenic sources, with IGWs and with additional eastward electric field. It is visible the grater effect in zonal current for the case of additional electric field, but effect for case of IGWs is also exist.

Conclusion

Earlier by means of numerical experiments in (Namgaladze et al., 2009) it has been confirmed, that local disturbances of electric fields allow to reproduce the morphology of ionospheric perturbations observed in seismoactive periods. At the analysis of these numerical results, the generation mechanisms of such electric fields were not discussed. In (Klimenko et al., 2009) the formation mechanism of such zonal electric fields owing to the propagation and dissipation small-scale IGWs in the upper atmosphere is offered.

We have simulated the ionospheric effects of small-scale IGWs and zonal electric field for high-latitude earthquake on Alaska in 1964 with use the model GSM TIP. It is shown, that the effects of these seismogenic sources in *foF2* in near-epicentral area are very similar against each other. The comparison of calculation results at the setting of additional seismogenic sources with observational data has revealed the good agreement. It is possible to note the better realistic results in calculation with IGWs.

Thus, the given research can be considered as the next step to understanding of formation mechanism of ionospheric precursors of strong earthquakes.

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