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NUMERICAL MODELING OF IONOSPHERIC PARAMETERS DURING SEQUENCE OF GEOMAGNETIC STORMS ON SEPTEMBER 9–14, 2005

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Abstract. In the given research it is presented the numerical calculation results of ionospheric parameters during sequence of geomagnetic storms on September 9–14, 2005. The calculations were executed with use of the Global Self-consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP), developed in WD IZMIRAN. The potential difference through polar caps (PDPC) and field-aligned currents of the second region (FAC2) were set as function of *Kp*-index. Thus, the time delay of the FAC2 variations relative to the PDPC variations was considered. The obtained calculation results were analyzed and compared with experimental data obtained at stations Irkutsk, Yakutsk, Arecibo and Millstone Hill.

Introduction

Many researches are devoted to numerical modeling of ionospheric storm effects (Mayr and Hedin, 1977, Namgaladze et al., 1981, Maeda et al., 1989, Sojka et al., 1994, Reddy and Mayr, 1998, Förster et al., 1999, Maruyama et al., 2005, Fuller-Rowell et al., 2007, Lu et al., 2008). They modeled: positive and negative effects of ionospheric storms, caused by thermospheric parameter changes; upper atmosphere heat balance on various phases of ionospheric storm; penetration of magnetospheric convection electric field to lower latitudes and disturbed ionospheric dynamo; external ionosphere and magnetosphere influence on the ionosphere *F*-region behavior during storms. It has been shown, that the basic formation mechanisms of ionospheric disturbances are the electric fields and thermospheric parameter variations. So, according to pioneer work by **(**Mayr and Volland, 1973) the positive ionospheric disturbances in the middle latitudes are formed by meridional component of thermospheric wind, and negative disturbances – by the thermosphere composition variations, that is by changes of the ratio $n(O)/n(N_2)$.

The given research is devoted to numerical modeling ionospheric effects of storm sequence on September 9-14, 2005.

Modeled phenomenon description and problem statement

In Fig. 1 the behavior of geomagnetic activity indexes for the considered time period is shown. The weak geomagnetic storm with Storm Sudden Commencement (SSC) at 14:01 UT was observed on September 9, 2005. The same day there was a solar flare, which was one of 10 most powerful flares registered for all history. It is necessary to note high flash activity (7 flares) during the considered period. The weak geomagnetic storm with SSC nearby 06:00 UT was observed on September 10. It was replaced by very strong geomagnetic storm with SSC at 01:14 UT on September 11, 2005, which proceeded down to September 15, 2005. This geomagnetic storm has caused the auroral activity strengthening, the radio communication infringement and the ionospheric storm. During the considered period index of solar activity level, $F_{10.7}$, changed from 101 up to 120.

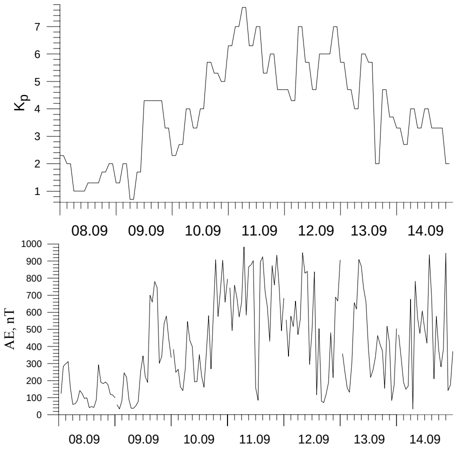

Fig. 1. Behavior of geomagnetic activity *Kp*- and *AE*-indexes on September 9-14, 2005.

In model calculations a potential difference through polar caps (PDPC), auroral particle precipitations (PP) and field-aligned currents of the second region (FAC2) were set as function of *Kp*-index of geomagnetic activity. The PDPC was set according to (Feshchenko, Maltsev, 2003), the PP fluxes and energy according to the model (Zhang, Paxton, 2008), FAC2 based on morphological representations (Iijima and Potemra, 1976, Kikuchi et al., 2008). Thus, FAC2 changed with half-hour delay concerning changes of *Kp*-index and PDPC, which occurred in phase.

It was carried out a large number of numerical experiments with the various setting of input parameters. In Fig. 2 the example of PDPC and FAC2 amplitudes behavior in one of the considered variants of model calculations is shown.

The PDPC is the input parameter in the majority of modeling researches of the ionosphere reaction on magnetospheric storms. Thus, not all researchers use in the calculations the variations of PP fluxes. Moreover, the units from them calculate the ionospheric storm effects with taking into account the FAC2 changes. Therefore, in the given work we have decided to show each of these input parameters contribution.

Calculations have been executed with use of the Global Self-consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP). This model was developed in West Department of IZMIRAN (Namgaladze et al., 1980) and modified (Klimenko et al., 2006) on the electric field calculation.

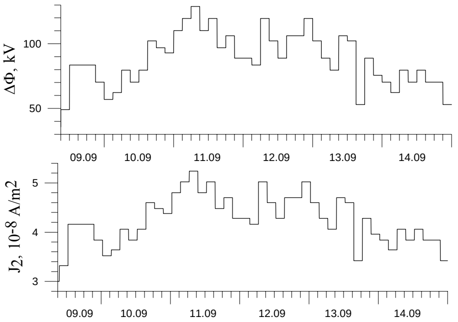

Fig. 2. PDPC and FAC2 amplitudes behavior in one of the considered variants of modeling calculations.

During the simulation of quiet ionospheric parameters only the $F_{10.7}$ changes from day to day were considered. At simulation of the storm-time conditions, the PDPC and FAC2 were set as function from *Kp*. Thus, it was considered the time delay of the FAC2 variations relative to the PDPC variations. The obtained calculation results are analyzed and compared with experimental data obtained at stations Yakutsk (62.0°N, 129.4°E), Irkutsk (52.2°N, 104.2°E), Arecibo (18.5°N, 66.7°W) and Millstone Hill (42.6°N, 71.5°W).

Model calculation results and discussion

In Fig. 3 the calculation results of critical frequency of the ionosphere F2-layer, *foF2*, above stations Yakutsk, Irkutsk and Millstone Hill are shown. In quiet conditions PDPC, $\Delta\Phi$, is set at geomagnetic latitudes ±75° and is equal 35.7, kV. The FAC2, j_2, is set at geomagnetic latitudes ±70° and is equal $3{\cdot}10^{-8}$, A/m^2.

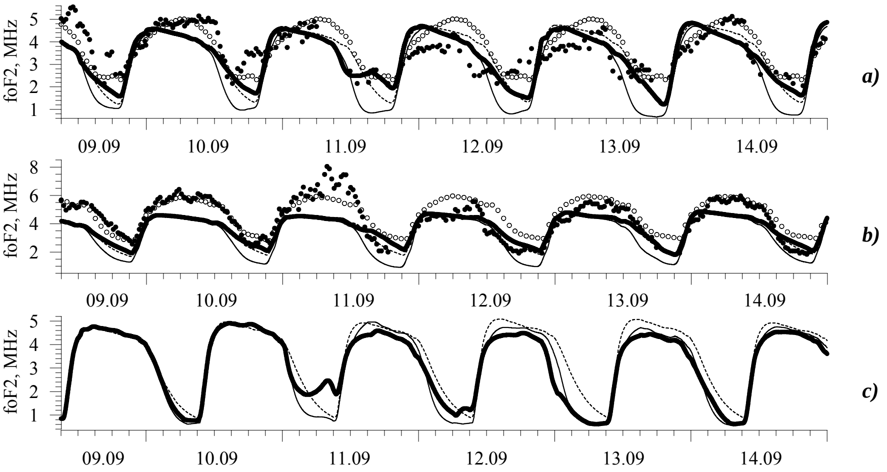

Fig. 3. Effects in *foF2* of magnetospheric convection with additional PP and FAC2 with taking into account the latitudinal shift (thick solid lines) and magnetospheric convection without additional PP and FAC2 (thin solid lines) for stations a) Yakutsk, b) Irkutsk, c) Millstone Hill. Dashed lines show the calculated quiet course. Data of ground sounding for quiet and disturbed conditions in Yakutsk and Irkutsk are shown by light and dark circles.

After carrying out of numerous experiments, we have stopped on the following dependences from Kp-index of PDPC, PP and FAC2 changes in storm-time conditions: $\Delta\Phi$ = 26.4 + 13.3×*Kp*, kV (Feshchenko, Maltsev, 2003) is set at geomagnetic latitudes ±75°, $j_2 = 2.78\times10^{-8} + 0.32\times 10^{-8}\times Kp$, A/m^2 with delay 0.5 h is set at geomagnetic latitudes: 1. ±70° for $Kp\leq3.0$; 2. ±65° for $3.0<Kp\leq 6.0$; 3. ±60° for $6.0<Kp$. The ratio of PP flux during storm, $Flux_{\mathrm{Storm}}$, to PP flux in quiet conditions, $Flux_{\mathrm{Quiet}}$, gets out as follows: $Flux_{\mathrm{Storm}}/Flux_{\mathrm{Quiet}} = 0.55+0.64\times Kp$ (Zhang, Paxton, 2008). Thus, it is set the turn of PP maximum from midnight into the morning sector and the delay is 0.5 h.

We carried out the comparison of model calculation results with experimental data for a storm on September 10, 2005, taken of (Goncharenko et al., 2007) for stations Millstone Hill and Arecibo.

In Fig. 4 it is shown the calculation results and experimental data of electron concentration in the *F2*-layer maximum, height of the *F2*-layer maximum, zonal and meridional components of electric fields and meridional component of thermospheric wind velocity above station Millstone Hill.

The calculation results and observations of zonal and meridional component of electric field, electron concentration and height of *F2*-layer maximum are in a good qualitative agreement. Positive perturbation in electron concentration at heights of the ionosphere *F2*-layer is caused by meridional component of thermospheric wind velocity. Thus the changes of neutral composition above station Millstone Hill, namely, the reduction of the ratio $n(\mathrm{O})/n(\mathrm{N}_2)$, lead to the reduction of electron concentration due to the losses rate growth. The total effect is defined by competing action of thermospheric wind variations and neutral atmosphere composition variations.

Practically all told above about calculation results above Millstone Hill, concerns to the calculation results above Arecibo shown in Fig. 5. Unique difference in this case consists that the counteraction of neutral atmosphere composition changes to a meridional component of thermospheric wind velocity variations is minimal.

From Fig. 6 it is visible the difference between latitudinal courses of the neutral atmosphere composition, calculated in the model and obtained in experiment. The experiment specifies that during storm at northern hemisphere latitudes above 40° the ratio $n(\mathrm{O})/n(\mathrm{N}_2)$ falls relative to the quiet background values, and at latitudes below 40° becomes more, than in quiet conditions. The calculations also give the reduction of this ratio at high latitudes, which disappears at approach equator, remaining, however, less than background values. If the model would reproduced observable latitudinal course of the ratio $n(\mathrm{O})/n(\mathrm{N}_2)$ during storm the positive perturbation in electron concentration above Arecibo would be closer to experiment.

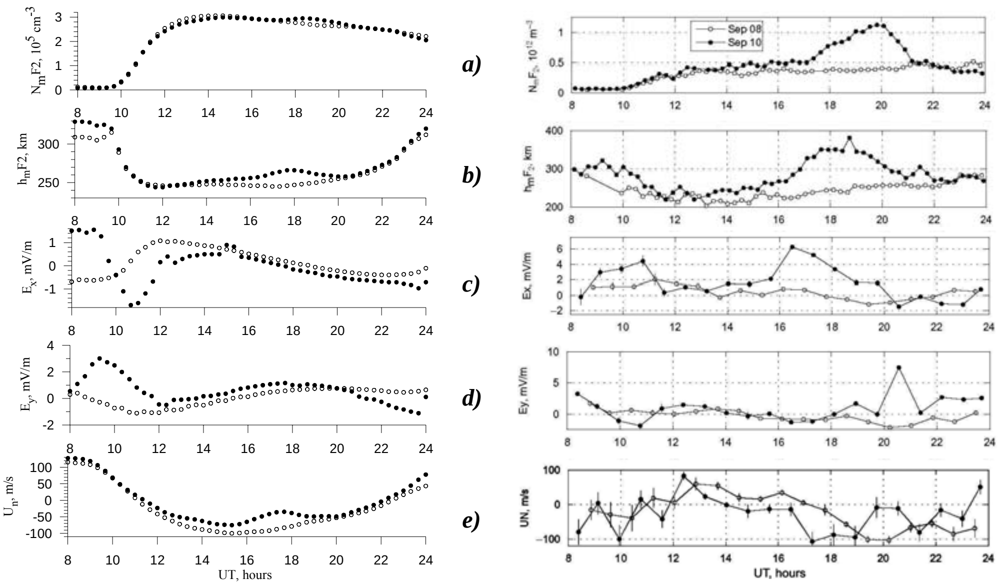

Fig. 4. The behavior above Millstone Hill: a) electron concentration in the *F2*-layer maximum, N_mF2, b) height of the *F2*-layer maximum, h_mF2, c) and d) zonal and meridional components of electric field, E_x and E_y, e) meridional component of thermospheric wind velocity, U_n. At the left – the results of model calculations, on the right – Incoherent Scatter Radar data (Goncharenko et al., 2007). Light circles – quiet conditions, dark circles – storm on September 10, 2005.

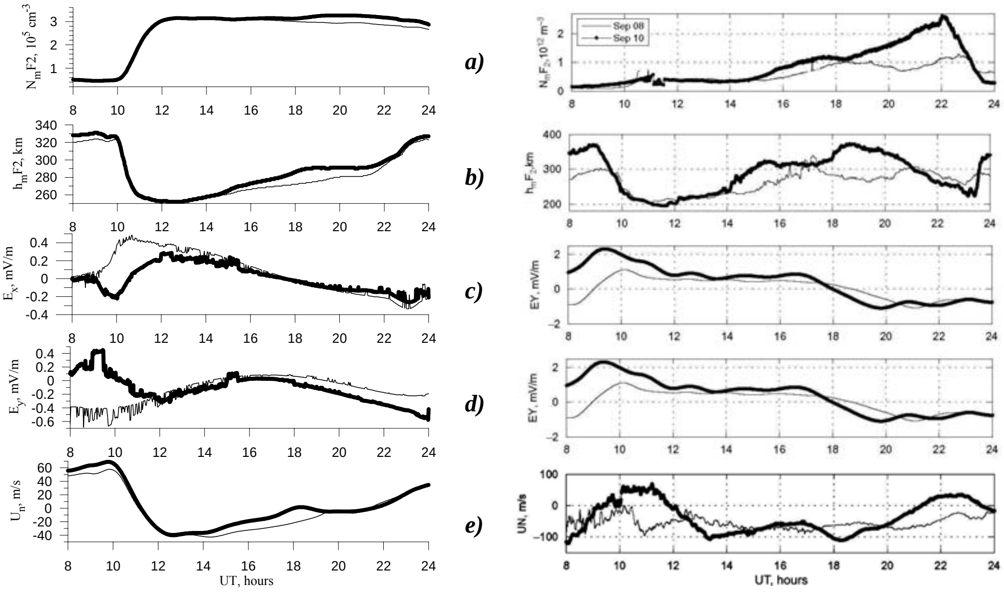

Fig. 5. The same as in Fig. 4 for Arecibo. Thin lines – quiet conditions, thick lines – storm on September 10, 2005.

The reason of quantitative distinctions of calculation results and observations consists in the following. First, changes of PDPC, FAC2 amplitudes and PP intensity were set as function of *Kp*-index, which does not vary within three hours. In the further, it is supposed to use the dependence of input parameters from *AE*-index with time resolution some minutes. In our opinion, it will allow approaching the calculation results to experiment.

Secondly, the use of the dipole approach of geomagnetic field does not allow considering the geomagnetic field distortion really observed during storms (its compression on the dayside magnetosphere and expansion on nightside). By geomagnetic field compression on the dayside it is possible to explain the additional contribution to positive perturbation of electron concentration above Millstone Hill in the afternoon. It is occurred because the volume of plasma tube decreases at compression that should lead to the growth of electron concentration. Unfortunately, now the model GSM TIP does not describe this process. For its account, it is necessary to use the real geomagnetic field instead of dipole approach.

Thirdly, the model calculations of the solar flare ionospheric effects, which we carried out recently, allow approving, that their account during storm sequence will presume to improve the description of *foF2* behavior in the afternoon.

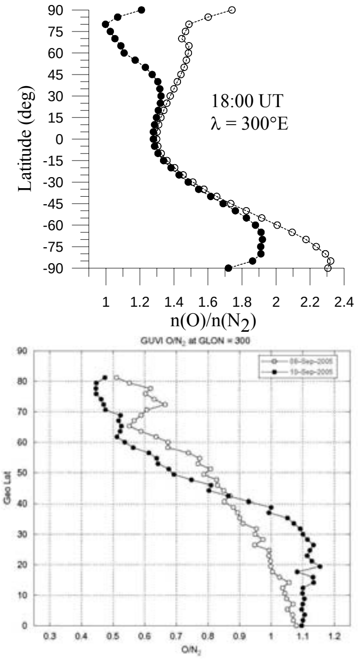

Fig. 6. Latitudinal course of $n(\mathrm{O})/n(\mathrm{N}_2)$. Above – the calculation results, below – experimental data (Goncharenko et al., 2007). Light circles – quiet conditions, dark circles – storm.

Summary

1. In the given research the model calculation results of ionospheric effects of PDPC, PP and FAC2 temporal variations during geomagnetic storms are considered.

2. Comparison of model calculation results with experimental data for different ionospheric stations reveals the satisfactory qualitative agreement.

3. The reasons of quantitative distinctions of calculation results and observations can be: the use of 3 hour *Kp*-indexes at modeling of model input parameters time dependence; the dipole approach of geomagnetic field; the absence in model calculations the effects of the solar flares, which were taken place during the considered period.

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References

Feshchenko E.Yu., Maltsev Yu.P. Relations of the polar cap voltage to the geophysical activity. Physics of Auroral Phenomena: XXVI Annual Seminar (February 25–28, 2003): Proc./PGI KSC RAS. Apatity, 2003, 59–61.

Förster M., Namgaladze A.A., Yurik R.Y. Thermospheric composition changes deduced from geomagnetic storm modeling. Geophys. Res. Lett., 1999, V. 26, No. 16, 2625–2628.

Fuller-Rowell T., Codrescu M., Maruyama N., Fredrizzi M., Araujo-Pradere E., Sazykin S., Bust G. Observed and modeled thermosphere and ionosphere response to superstorms. Radio Sci., 2007, V. 42, RS4S90, doi:10.1029/2005RS003392.

Goncharenko L.P., Foster J.C., Coster A.J., Huang C., Aponte N., Paxton L.J. Observations of a positive storm phase on September 10, 2005. J. Atmos. Solar-Terr. Phys., 2007, V. 69, 1253–1272.

Iijima T., Potemra T.A. Field-Aligned Currents in the Dayside Cusp Observed by Triad. J. Geophys. Res., 1976, V. 81, No. 34, 5971–5979.

Kikuchi T., Hasimoto K.K., Nozaki K. Penetration of magnetospheric electric fields to the equator during a geomagnetic storm. J. Geophys. Res., 2008, V. 113, A06214, doi:10.1029/2007JA012628.

Klimenko M.V., Klimenko V.V., Bryukhanov V.V. Numerical Simulation of the Electric Field and Zonal Current in the Earth's Ionosphere: The Dynamo Field and Equatorial Electrojet. Geomagn. Aeron. 2006, V. 46, No. 4, 457–466.

Lu G., Goncharenko L.P., Richmond A.D., Roble R.G., Aponte N. A dayside ionospheric positive storm phase driven by neutral winds. J. Geophys. Res., 2008, V. 113, A08304, doi:10.1029/2007JA012895.

Maeda S., Fuller-Rowell T.J., Evans D.S. Zonally Averaged Dynamical and Compositional Response of the Thermosphere to Auroral Activity During September 18-24, 1984. J. Geophys. Res., 1989, V. 94, No. A12, 16869–16883.

Maruyama N., Richmond A.D., Fuller-Rowell T.J., Codrescu M.V., Sazykin S., Toffoletto F.R., Spiro R.W., Millward G.H. Interaction between direct penetration and disturbance dynamo electric fields in the storm-time equatorial ionosphere. Geophys. Res. Lett., 2005, V. 32, L17105, doi:10.1029/2005GL023 763.

Mayr H.G., Hedin A.E. Significance of Large-Scale Circulation in Magnetic Storm Characteristics With Application to AE-C Neutral Composition Data. J. Geophys. Res., 1977, V. 82, No. 7, 1227–1234.

Mayr H.G., Volland H. Magnetic Storm Characteristics of the Thermosphere. J. Geophys. Res., 1973, V. 78, No. 13, 2251–2264.

Namgaladze A.A., Zakharov L.P., Namgaladze A.N. Numerical modeling of the ionospheric storms. Geomagn. Aeron., 1981, V. 21, No. 2, 259–265 (in Russian).

Namgaladze A.A., Korenkov Yu.N., Klimenko V.V., Karpov I.V., Bessarab F.S., Surotkin V.A., Glushenko T.A., Naumova N.M. Global model of the thermosphere-ionosphere-protonosphere system. Pure and Applied Geophysics (PAGEOPH), 1988, V. 127, No. 2/3, 219–254.

Reddy C.A., Mayr H.G. Storm-time penetration to low latitudes of magnetospheric-ionospheric convection and convection-driven thermospheric winds. Geophys. Res. Lett., 1998, V. 25, No. 16, 3075–3078.

Sojka J.J., Schunk R.W., Denig W.F. Ionospheric response to the sustained high geomagnetic activity during the March'89 great storm. J. Geophys. Res., 1994, V. 99, No. A11, 21341–21352.

Zhang Y., Paxton L.J. An empirical Kp-dependent global auroral model based on TIMED/GUVI FUV data. J. Atmos. Solar-Terr. Phys., 2008, V. 70, 1231–1242.