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BEHAVIOR OF IONOSPHERIC PARAMETERS AT MID-LATITUDE STATIONS 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 geomagnetic storm sequence on September 9–14, 2005. The calculations were carried out 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 *AE*-index with one-minute time resolution. Thus, the time delay of the FAC2 variations relatively to the PDPC variations was considered. In model calculations, we considered the effects of solar flares, which took place during the considered period. Besides, we realized the empirical model of particle precipitation in the model GSM TIP. The obtained calculation results were analyzed and were compared with experimental data obtained from SPIDR at different mid-latitude stations.

Table 1. Separate intervals for the set of FAC2

Onset	Termination	Conditions
09:00 UT 09.09	14:01 UT 09.09	quiet
14:01 UT 09.09	16:00 UT 09.09	SSC
16:00 UT 09.09	18:00 UT 09.09	main phase
18:00 UT 09.09	06:00 UT 10.09	recovery phase
06:00 UT 10.09	13:00 UT 10.09	SSC
13:00 UT 10.09	20:00 UT 10.09	main phase
20:00 UT 10.09	01:14 UT 11.09	recovery phase
01:14 UT 11.09	05:00 UT 11.09	SSC
05:00 UT 11.09	11:00 UT 11.09	main phase
11:00 UT 11.09	24:00 UT 14.09	recovery phase

Introduction

In the previous researches (Klimenko and Klimenko, 2009; Klimenko et al., 2010) we have presented the results of model calculations of the ionospheric parameters behavior during geomagnetic storm sequence on September 9-14, 2005. These calculations were carried out with use of the Global Self-consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP) developed in West Department of IZMIRAN. Model GSM TIP was described in details in (Namgaladze et al., 1988) and its modification regarding calculations of electric field in (Klimenko et al., 2006). In those 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 basic morphological features of particle precipitations during storms (Hardy and Gussenhoven, 1985) and FAC2 according to the morphological representations (Iijima and Potemra, 1976, Kikuchi et al., 2008). Thus, FAC2 changed with half-hour delay relatively to the changes of *Kp*-index and PDPC, which occurred in phase.

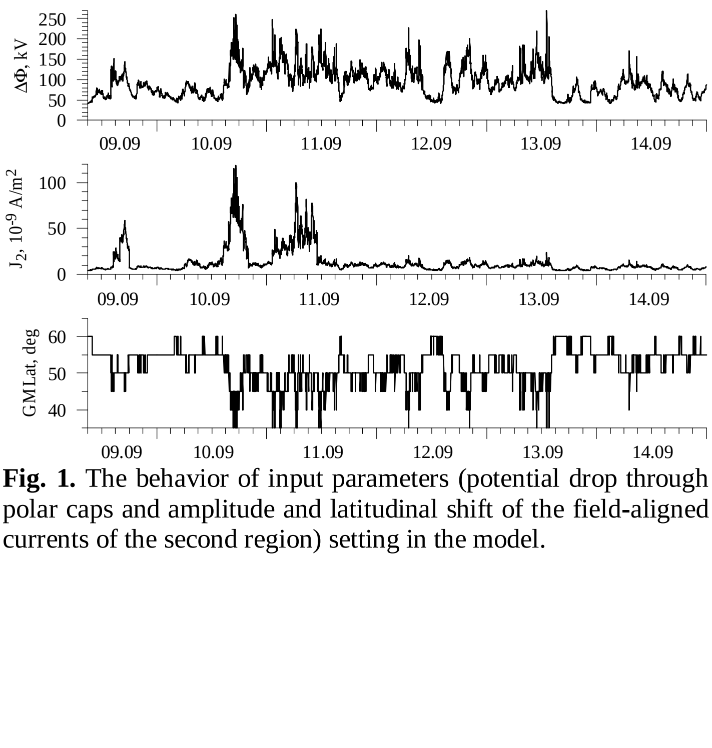

Fig. 1. The behavior of input parameters (potential drop through polar caps and amplitude and latitudinal shift of the field-aligned currents of the second region) setting in the model.

It was carried out a large number of numerical experiments with the various setting of input parameters (Klimenko and Klimenko, 2009). The comparison of model calculation results of the different ionospheric parameters with experimental data of ionosondes and incoherent scatter radars above mid-latitude stations reveals the satisfactory agreement. However, we obtained some distinctions of calculation results and experimental data. The reasons of these distinctions are the following: a) the use of 3-hour *Kp*-index at modeling of temporal dependence of input parameters; b) the dipole approach of geomagnetic field; c) the absence in model calculations the effects of solar flares, which took place during the considered period. At the given stage of our model development, the use of real geomagnetic field is a very difficultly solvable problem.

However, we have tried to remove two other reasons of distinctions. The results of this research are presented in the given paper. As the modeled event has been described in detail in (Klimenko, Klimenko, 2009; Klimenko et al., 2010), we at once shall pass to the description of new statement of the problem.

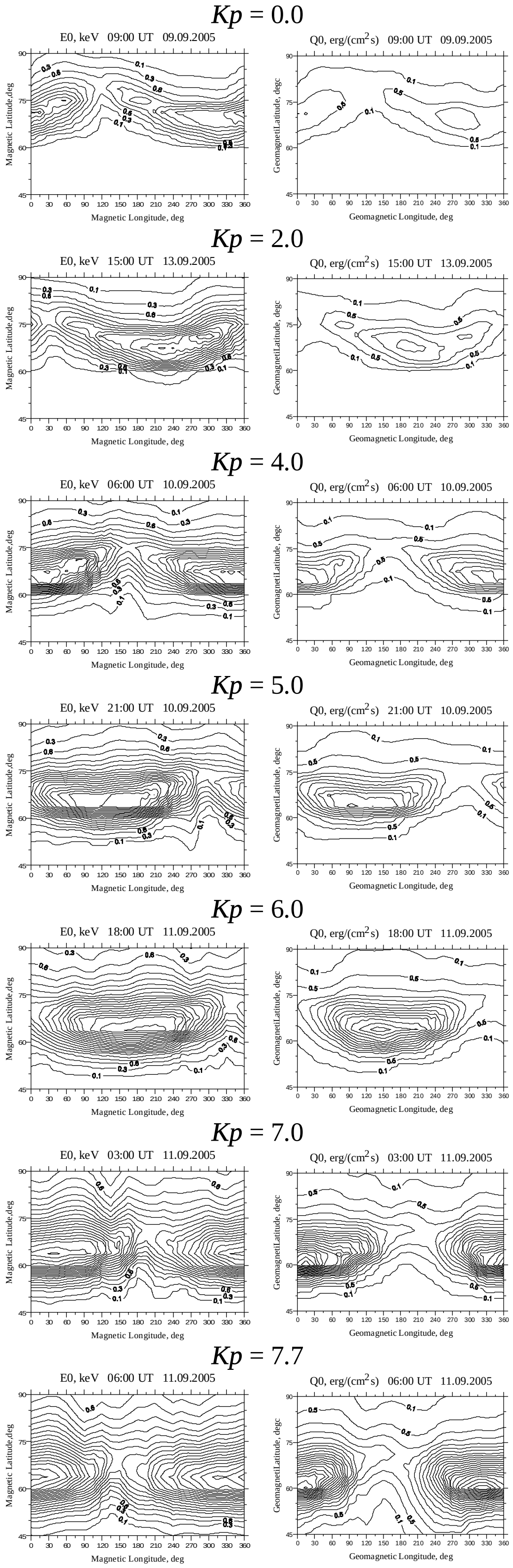

Fig. 2. Calculated particle precipitation energy and energy fluxes for different *Kp*-indices.

The new statement of the problem

The ionospheric parameters in quiet geomagnetic conditions were calculated with taken into account the change of the solar activity index $F_{10.7}$ from day to day within the limits of 101 up to 120. Thus, the PDPC was set equal 38 kV at geomagnetic latitudes ±75°, and FAC2 were set equal 3×10^{-9} A/m^2 at geomagnetic latitudes ±70°.

Instead of functional dependence of model input parameters during storm time only from 3-hour *Kp*-index, we used the dependences both on *Kp*-index and on *AE*-index with the time resolution in one-minute. In Table 1, it is shown how we have divided the considered period into separate intervals for the set of FAC2 depending on storm phases.

The PDPC was set equal $\Delta F = 38 + 0.089\times AE$, kV according to Feshchenko, Maltsev (2003) at geomagnetic latitudes ±75°. FAC2 were set according to Cheng et al. (2008); Snekvik et al. (2007): $j_2 = 3\times10^{-9} + 6\times10^{-12}\times AE$, A/m^2 in quiet conditions and at recovery phase of storm; $j_2 = 3\times10^{-9} + 1.5\times 10^{-11}\times AE$, A/m^2 at SSC with 30 min delay relatively to the PDPC changes; $j_2 = 3\times10^{-9} + 3.6\times 10^{-11}\times AE$, A/m^2 during main phase of storm. The displacement of FAC2 to the lower latitudes was set as by Sojka et al. (1994): ±65° for $\Delta\Phi \le 40$ kV; ±60° for 40 kV < $\Delta F \le 50$ kV; ±55° for 50 kV < $\Delta F \le 88.5$ kV; ±50° for 88.5 kV < $\Delta F \le 127$ kV; ±45° for 127 kV < $\Delta F \le 165.4$ kV; ±40° for 165.4 kV < $\Delta F \le 200$ kV; ±35° for 200 kV < ΔF. Fig. 1 shows the behavior of these input parameters.

Besides, now we realized in the model GSM TIP the empirical model of particle precipitation by Zhang and Paxton, 2008. In this empirical model the energy and the energy flux of precipitating particles depends from *Kp*-index of geomagnetic activity. In Fig. 2, the energy and energy flux of precipitating particles for the different values of *Kp* index are shown. It is visible the increase in the mean energy of precipitating particles and displacement of particle precipitation region to the lower latitudes with growth of geomagnetic activity.

At last, in our calculations we have considered the effects of five solar flares shown in the Table 2 that took place during the examined period.

Model calculation results and discussion

The calculation results obtained with use of the model GSM TIP are analyzed and compared with SPIDR experimental data above stations Millstone Hill (42.6°N, 71.5°W), Ascension Island (8.0°S, 14.0°W), Grahamstown (33.3°S, 26.5°E), Leningrad (60.0°N, 30.7°E) and Tashkent (41.3°N, 69.6°E). In Fig. 3, it is shown the *foF2* behavior above these ionospheric stations during geomagnetic storm sequence on September 9-14, 2005. Above station Millstone Hill, the negative *foF2* disturbances are formed in all days. Exceptions are the positive disturbances on September 9 and 10, obtained in the model GSM TIP and observed in experiment. These positive disturbances in *foF2* obtained in calculation results are a little less, than in experiment. In addition, it is visible the effects of solar flare as thin structure of *foF2* variations during geomagnetic disturbances on September 13. The daytime positive electron density disturbances above Ascension

Island obtained in our calculation results are also observed in experiment. It is visible a good agreement of calculation results and experimental data of *foF2* above Grahamstown: the daytime positive effects and nighttime negative effects. The comparison of *foF2* disturbances, obtained in our calculation results, reveal enough a good agreement with experimental data. In addition, it is visible the solar flare effects in *foF2* on September 14 above stations Ascencion Island, Grahamstown and Tashkent.

Table 2. Solar flares

Day	UT onset	UT peak	UT termination	Ionospheric Effects		
				UT onset	UT peak	UT termination
September 10	19:10	19:36	19:50	19:18	19:44	19:58
September 10	21:30	22:11	22:43	21:38	22:19	22:51
September 11	12:44	13:12	13:53	12:52	13:20	14:01
September 13	19:19	19:27	20:57	19:27	19:35	21:05
September 14	10:05	10:38	10:54	10:13	10:46	11:02

In Fig. 4, it is shown the calculated behavior of vertical profiles of electron concentration above Millstone Hill on September 10, 2005 at different UT moments. During geomagnetic storm it is visible the formation at night time such well-known event as G condition, when *foF2* becomes smaller than *foF1*. In addition, it is possible to note the decrease in electron density in maximum of *F2*-layer and in external ionosphere above Millstone Hill at this time that speaks about the decrease in total electron content above this station.

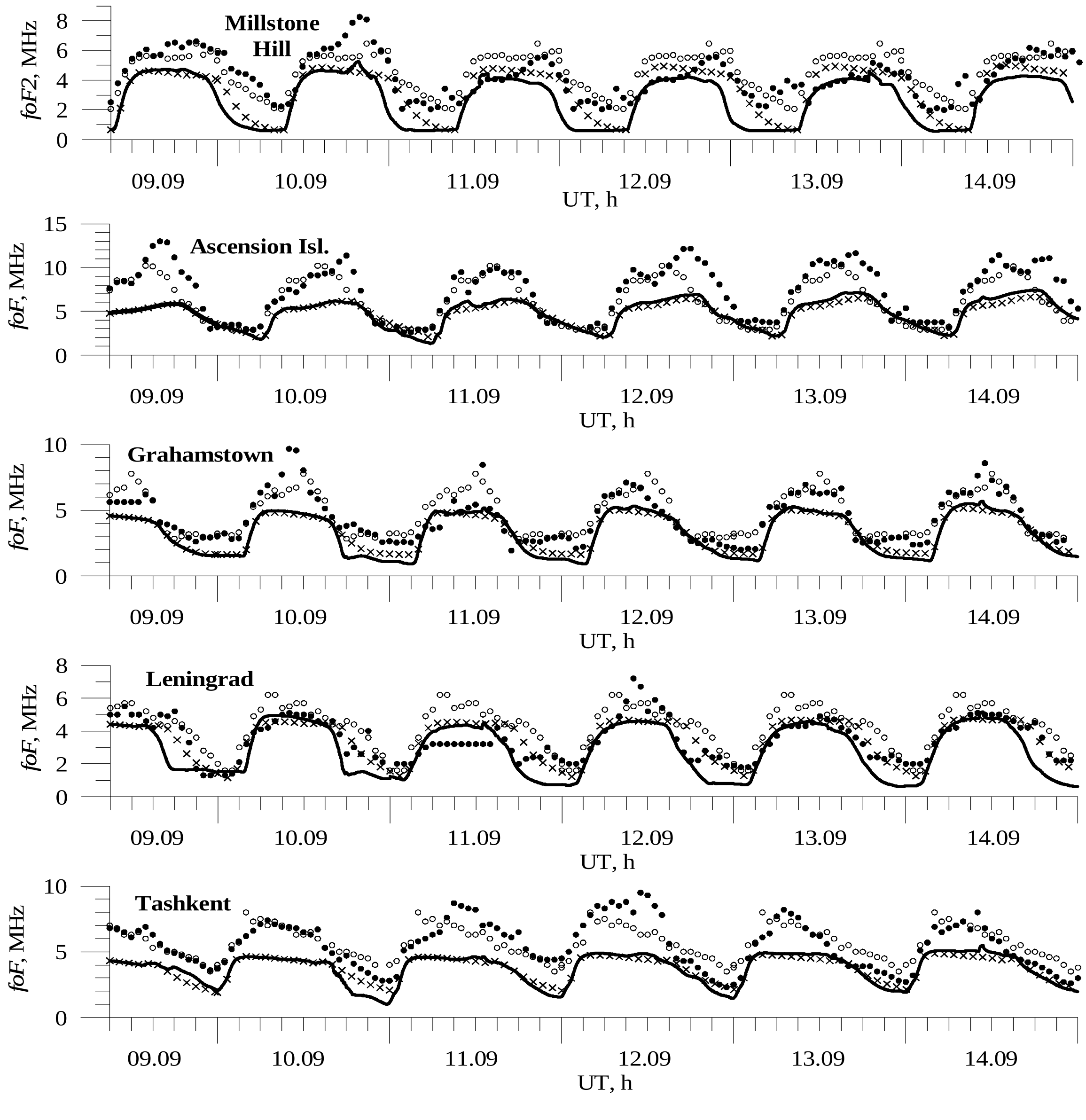

Fig. 3. Behavior of *foF2* above different ionospheric stations. Light and dark circles show the experimental data obtained from SPIDR at quiet and disturbed conditions. Model calculation results for quiet conditions are shown by crosses and for disturbed conditions by solid lines.

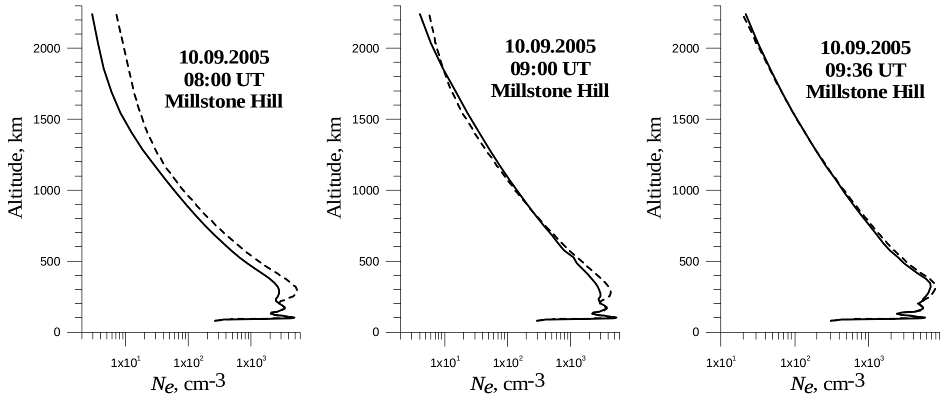

Fig. 4. Calculated in the model GSM TIP the vertical profiles of electron concentration $N_e(h)$ above Millstone Hill on September 10, 2005 in quiet conditions (dashed lines) and during geomagnetic storm (solid lines).

Summary

1. In the given researches it is presented the new approach to modeling of the ionospheric effects of geomagnetic storm sequence:

a) The use of *AE*-index with one-minute time resolution as an independent variable at modeling of the temporal dependence of potential difference through polar caps instead of 3-hour *Kp*-index;

b) The realization of new empirical model of high-energy particle precipitation in the model GSM TIP;

c) The assignment of field-aligned currents of the second region according to the theoretical ideas and experimental data available now;

d) The account in model calculations the effects of solar flares took place during the considered period.

2. The new approach has allowed improving considerably the agreement of the calculation results with experimental data.

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