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NUMERICAL MODELING OF THE IONOSPHERE EFFECTS ON AUGUST 1, 2008 SOLAR ECLIPSE

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Abstract. The model calculation results of the ionospheric effects of solar eclipse on August 1, 2008 are presented. Calculations are executed with use of Global Self-consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP), developed in WD IZMIRAN. It is shown the calculated behavior of critical frequency of the ionospheric *F2*-layer, *foF2,* at various stations during eclipse and after its termination. The physical mechanisms responsible for the obtained *foF2* variations at stations Alert and Beijing are considered. It is carried out the comparison of calculated results of electron concentration in the ionosphere *F*-region and the global maps of total electron content disturbances caused by solar eclipse with observational data of the Kharkov Incoherent Scatter Radar and GPS measurements.

Introduction

Many researches are devoted to the numerical modeling of the ionospheric effects of solar eclipses (Ridley et al., 1984; Roble et al., 1986; Muller-Wodrag et al., 1998; Boitman et al., 1999; Bessarab et al., 2002; Koren'kov et al., 2003). In these works there are presented basically ionospheric effects of solar eclipses in the middle latitudes. It is much less lead the researches of solar eclipse effects in low-latitude, and especially, in high-latitude ionosphere. The given work is devoted to the numerical modeling of effects on August 01, 2008 solar eclipse first of all in high- and low-latitude ionosphere.

August 01, 2008 solar eclipse brief information and formulation of the problem

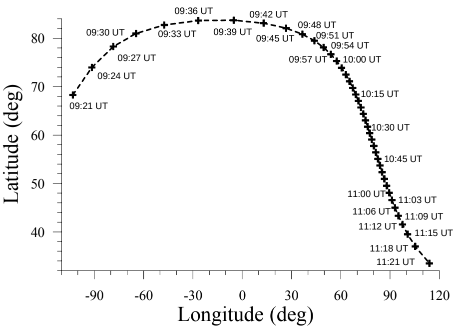

Fig. 1. The path of solar eclipse spot.

On August 01, 2008 has occurred a total solar eclipse, which was visible from within a narrow corridor that traversed half of Earth. The path of the Moon's umbral shadow began in northern Canada and extends across Greenland, the Arctic, central Russia, Mongolia, and China. A partial eclipse was seen within the much broader path of the Moon's penumbral shadow, which included northeastern North America, most of Europe, and Asia. The total eclipse lasted for 2 hours, and covered 0.4% of the Earth's surface in a 10200 km long path. This eclipse has caused the special interest that its way passed through area of high latitudes. Fig. 1 shows the path of solar eclipse spot.

In this study, we present the numerical calculation results of ionosphere effects of this solar eclipse. Calculations are executed for summer conditions in the minimum of solar activity with use of Global Self-consistent Model of the Thermosphere, Ionosphere and Protonosphere (GSM TIP), developed in WD IZMIRAN (Namgaladze et al., 1988; Klimenko et al., 2006). August 01, 2008 solar eclipse has occurred in quiet geomagnetic conditions what is visible from Fig. 2. We obtained the behavior of various parameters of the ionosphere *F*-region and thermosphere during solar eclipse by means of numerical calculations in statement of problem, described in detail by Muller-Wodrag et al., 1998; Bessarab et al., 2002. In addition, we built the global maps of total electron content (*TEC*) disturbances during solar eclipse. We compared the model calculation results with experimental data.

Calculation results and discussion

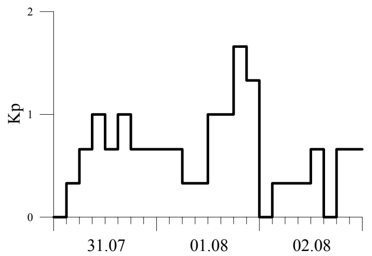

Fig. 2. Geomagnetic situation in the period of solar eclipse on August 1, 2008

Fig. 3 shows the model calculated variations of critical frequency of the ionosphere *F2*-layer, *foF2*, caused by solar eclipse at stations Resolute Bay, Alert, Barentsburg, Loparskaya, Tomsk and Beijing. It is visible the *foF2* decrease at all these stations during passage above them the solar eclipse spot. It is connected with the reduction of solar radiation flux during eclipse and, hence, with the reduction of photoionization rate. This fact is not new and only confirms the results of modeling and experimental researches obtained earlier. Unique difference of the presented calculation results from published earlier, is the presence at high-latitude stations two troughs following one after another in a *foF2* daily course between which the partial return to the background values is observed. It is explained as follows. From Fig. 1 it is visible, that the spot path of solar eclipse passed twice through high-latitude ionosphere, at the initial stage at first came nearer to North Pole, and then left

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from it. Therefore, some high-latitude stations during this solar eclipse appeared twice in the region of the reduced solar flux.

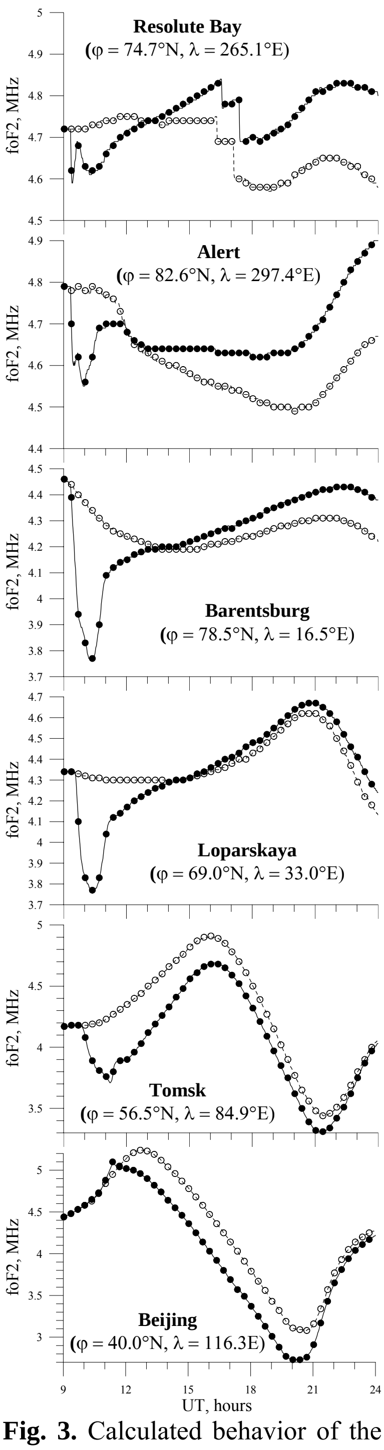

Fig. 3. Calculated behavior of the ionospheric F2-layer critical frequency at various stations. Light circles – quiet conditions, dark circles – during the day of solar eclipse.

The doubtless interest represents the obtained *foF2* behavior after the termination of solar eclipse when the solar radiation flux and, hence, a source of ionosphere ionization is restored. From Fig. 3 it is visible, that at this time the effects in *foF2* at high-, mid- and low-latitude stations are different. At high-latitude stations after the termination of solar eclipse the significant positive perturbations in *foF2* take place. In the middle latitudes the values of these positive perturbations decrease as approaching equator. And at low latitudes the positive perturbations disappear, being replaced by negative perturbations.

For the explanation of the obtained calculation results, in Fig. 4, 5 we show the behavior of the calculated total electron content, zonal and meridional components of the electric field, meridional component of the thermospheric wind, the ratio of atomic oxygen concentration to the molecular nitrogen concentration, $n(O)/n(N_2)$, describing the velocity of chemical losses in the ionosphere, the neutral, ion and electron temperatures, and also the ionization function of atomic oxygen at height of 300 km above high-latitude station Alert and low-latitude station Beijing.

From Fig. 4 it is visible, that at station Alert, unlike *foF2*, in *TEC* it is not visible two decreases following one after another during eclipse. It is explained by the smaller sensitivity of the total electron content on changes of solar radiation flux. It is visible the occurrence of the westward additional electric field during solar eclipse when the meridional component of the electric field practically does not vary. After the termination of solar eclipse above station Alert there are additional eastward and northward components of the electric field. During solar eclipse the additional component of equator ward thermospheric wind appears which disappears after the termination of solar eclipse and the meridional component of thermospheric wind returns to the background values. During solar eclipse there is a growth of the ratio $n(O)/n(N_2)$ which after the termination of solar eclipse amplifies even more, that is connected with the reorganization of thermosphere composition. The solar eclipse causes about identical decrease of neutral and ion temperatures and much more essential decrease of electron temperature which after the termination of solar eclipse are restored, remaining, however, below background values. The reduction of the ionization rate during solar eclipse is well visible from the behavior of the atomic oxygen ionization function.

From Fig. 5 it is visible, that at station Beijing the *foF2* and *TEC* behavior during solar eclipse are very similar. The small positive effect in *foF2* nearby 11:00 UT which is not shown in *TEC*, apparently, is connected with global reorganization of thermosphere and ionosphere parameters, happening in the preceding 1.5 hours from the moment of the solar eclipse beginning which has more affected critical frequency of the *F2*-layer, than on the total electron content. The variations of the electric field during solar eclipse are very weak and appear only after the termination of solar eclipse. In the beginning there is an additional westward electric field which then is replaced by eastward electric field, and also the small northward electric field which is replaced by southward with a little bit greater amplitude. During solar eclipse the additional component of the thermospheric wind to the pole appears which disappears in the course of time. Thus the meridional wind component returns to the background values. During solar eclipse there is a small growth of the ratio $n(O)/n(N_2)$ which slightly amplifies after the termination of solar eclipse, that, as well as in the case of station Alert , is connected with the reorganization of thermosphere composition. The solar eclipse causes about identical decrease of neutral and ion temperatures and a little bit greater decrease of electron temperature which is much less, than at station Alert. It is necessary to note, that if the electron temperature after the solar eclipse termination is quickly restored up to background values, the neutral and ion temperatures being restored after the solar eclipse termination, remain, however, below of background values. The reduction of ionization rate during solar eclipse at station Beijing is well visible from the behavior of ionization function of atomic oxygen.

A long time after the termination of solar eclipse at high-latitude stations, we observe the excess of *foF2* over background values. We connect this excess first of all with the growth of the ratio *n*(O)/*n*(N2) and to a lesser degree with additional eastward electric field and thermospheric wind to the equator. At low-latitude stations, we observe the decrease of *foF2* relative to the background values. We connect this decrease with joint action of the additional electric field, meridional component of thermospheric wind and changes in the neutral atmosphere composition. The westward electric field and pole ward wind cause the reduction of electron concentration. The meridional component of electric field can cause both positive and negative effects in electron concentration depending on a sign of the electric field and longitudinal gradients of electron concentration. The growth of the ratio $n(O)/n(N_2)$ leads to the growth of electron concentration. As a result, it has appeared that the effects of the electric field and thermospheric wind in the middle latitudes prevailed of the effects of change of a neutral atmosphere composition. That has led to the *foF2* reduction.

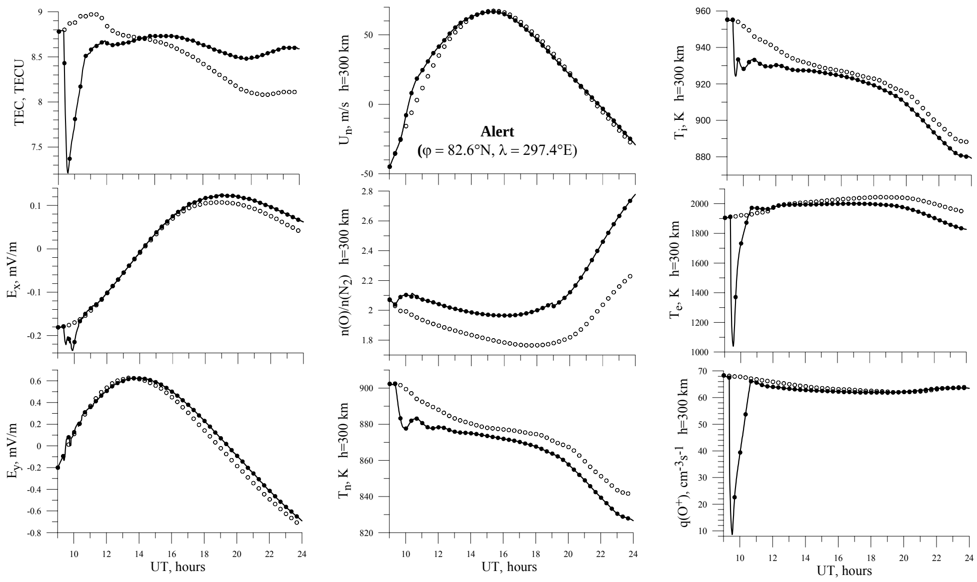

Fig. 4. Calculated behavior of the total electron content *TEC*, zonal E_x and meridional E_y components of electric field, meridional component of thermospheric wind velocity U_n, *n*(O)/*n*(N2), neutral T_n, ion T_i and electron T_e temperatures and O^+ ionization function at height of 300 km under station Alert. Light circles – quiet conditions, dark circles – during the day of solar eclipse.

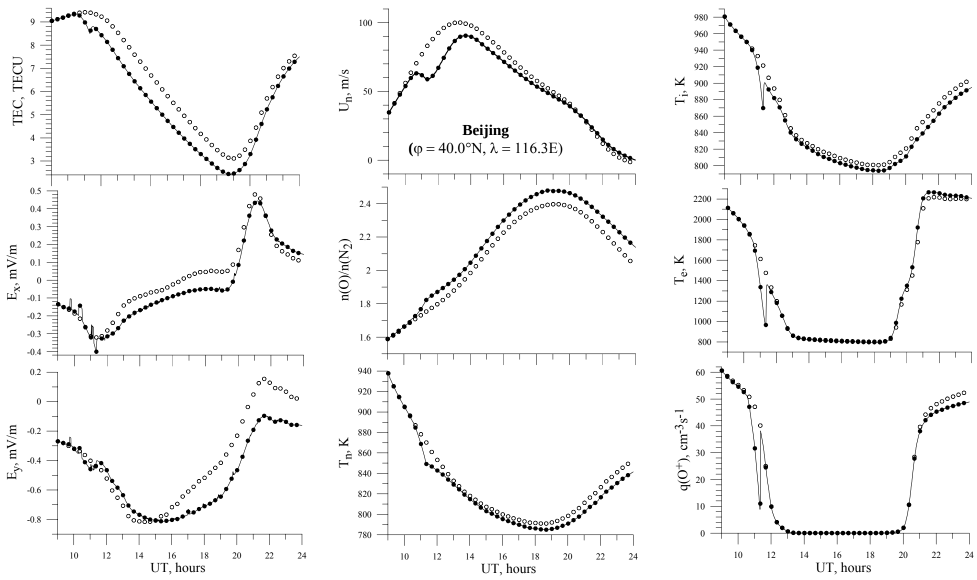

Fig. 5. The same as in **Fig. 4** under station Beijing.

Fig. 6 shows the comparison of calculation results and data observation of Kharkov Incoherent Scatter Radar which was away from a trajectory of solar eclipse maximum. It is visible that the calculated effects of solar eclipse at Kharkov have appeared less, than was observed in experiment. That is in the model calculations we have a little underestimated width of a strip of solar eclipse spot passage.

Fig. 7 shows the global maps of the total electron content disturbances, induced by solar eclipse at 10:00 UT and 12:00 UT on August 1, 2008. The global maps of *TEC* disturbances calculated in the model have been built by the comparison of *TEC* values obtained with take into account solar eclipse and in quiet conditions. Global maps of *GPS TEC* disturbances have been obtained by comparison of *TEC* values in solar eclipse day and on the eve (July 31, 2008). The lead comparison of the global maps of *TEC* disturbances calculated in the model and obtained based on *GPS* measurements has revealed the qualitative agreement of large-scale irregularities appeared in result of solar eclipse. Small-scale irregularities which are visible in experiment, but are absent in the model calculation results, can be caused by internal gravity waves with different spatial scales, thermospheric tides and other mechanisms which are not considered in our calculations.

Summary

1. High-latitude stations during August 01, 2008 solar eclipse appeared twice in the region of the reduced solar flux because the spot of solar eclipse first moves to a pole, and then from it. It has led to occurrence at these stations two troughs in a daily course of critical frequency of the ionosphere *F2*-layer.

2. A long time after the termination of solar eclipse at high-latitudes we have the excess and at low-latitudes the decrease of critical frequencies of the ionosphere *F2*-layer over background values. It is the result of joint action the growth of the ratio *n*(O)/*n*(N2), additional electric field and meridional component of thermospheric wind.

3. The comparison of calculation results and data observation at station Kharkov specifies that in the model calculations we have a little underestimated the width of a strip of solar eclipse spot passage.

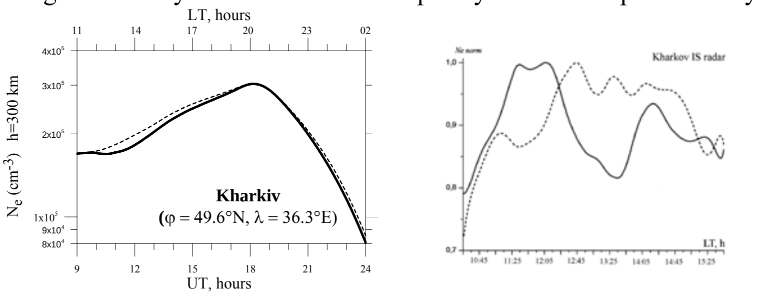

Fig. 6. The electron concentration behavior under station Kharkov at hight of 300 км. Left – calculation results, right – observation data of Incoherent Scatter Radar (Cherniak, Lysenko, 2008) in the form of normalized values of electron concentration. Light circles – quiet conditions, dark circles – during the day of solar eclipse.

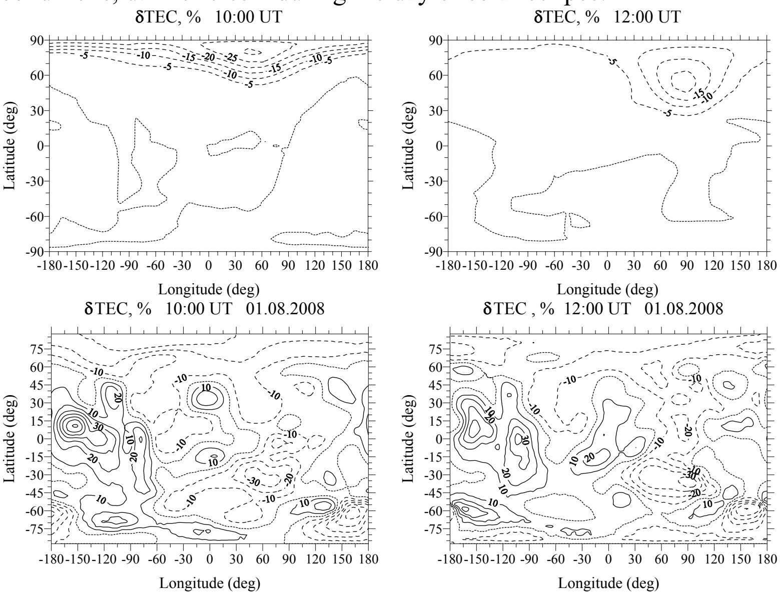

Fig. 7. Global maps of the total electron content *TEC* disturbances, induced by solar eclipse at 10:00 UT and 12:00 UT on August 1, 2005. Above – model calculation results, below – GPS data observations. Dotted lines show the lines where the disturbances are absent.

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