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Modeling of ionospheric parameter variations in East Asia during the moderate geomagnetic disturbances

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Abstract

The results of modeling of ionospheric disturbances observed in the East Asian region during moderate storms are presented. The numerical model for ionosphere–plasmasphere coupling developed at the ISTP SB RAS is used to interpret the data of observations at ionospheric stations located in the longitudinal sector of 90–130°E at latitudes from auroral zone to equator. There is obtained a reasonable agreement between measurements and modeling results for winter and equinox. In the summer ionosphere, at the background of high ionization by the solar EUV radiation in the quiet geomagnetic period the meridional thermospheric wind strongly impacts the electron concentration in the middle and auroral ionosphere. The consistent calculations of the thermospheric wind permit to obtain the model results which are closer to summer observations. The actual information about the space-time variations of thermosphere and magnetosphere parameters should be taken into account during storms.

Keywords: Ionospheric storm; Geomagnetic disturbance; Critical frequencies; F2-layer; Plasmasphere; Photoionization; Recombination; Thermosphere; Magnetosphere; Convection; Neutral wind; Drift

1. Introduction

The ionospheric response to a geomagnetic disturbance is a complex set of events caused by both the upper atmosphere and ionosphere parameters and characteristics of the magnetosphere and solar wind. This response is a subject of many-year studies, the results being presented in numerous reviews (Buonsanto, 1999; Danilov and Lastovicka, 2001; Fuller-Rowell et al., 1996). The theoretical and experimental studies of the ionosphere during magnetic storms made it possible to find the main physical processes determining the electron concentration distribution in the ionosphere at various latitudes and to present the most general picture of an ionospheric storm manifestation. Changes in the neutral composition and system of neutral wind circulation are the most important factors determining ionospheric variations during a geomagnetic storm (Danilov and Belik, 1991; Prolss and Ocko, 2000; Reddy and Mayer, 1988; Rishbeth, 1998). At middle latitudes the negative and positive effects of storms are observed more often in summer and winter, respectively (Rodger et al., 1989; Field and Rishbeth, 1997). Fuller-Rowell et al. (1994) noted that the ionospheric response to a geomagnetic disturbance in a particular place depends on both, local and universal time. A typical storm consists of an initial positive phase later changed to a negative phase. The duration and intensity of these two phases depend on latitude and season.

Disagreement between the geographic and magnetic coordinates complicates the picture of ionospheric disturbances and leads to a longitudinal dependence of the ionospheric effects of geomagnetic storms (Afraimovich et al.,

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2002; Blagoveshchensky et al., 2003; Pirog et al., 2006b; Zherebtsov et al., 2005). In the Eastern Asia, the strongest deviation of geographic coordinates from geomagnetic coordinates is observed. In this sector the formation of the high-latitude large-scale structure of the ionosphere occurs on the background of relatively low electron concentration. The latter fact determines an increased interest to this region. Our investigations of ionosphere manifestations of magnetic storms in the Eastern Asia are continued in three directions: quiet ionosphere, weak and moderate storms, and great storms. In the previously works (Pirog et al., 2006a; Romanova et al., 2006) we presented the results of a morphological analysis and numerical modeling of the ionospheric state during storms observed in different seasons. The morphological analysis has produced the following conclusions. (1) For summer storms, negative disturbances prevail both at high and middle latitudes. At low latitudes, the disturbances mainly have a positive type. (2) In winter the daytime disturbances are positive in the beginning of the storm at all stations involved. During the early recovery phase they are negative at high and positive at middle latitudes. Night disturbances are positive at high latitudes, while being negative at middle latitudes. At low latitudes the disturbances are positive both in daytime and at night during all storms. (3) During an equinox storm positive disturbances are observed in the beginning of the storm, with negative disturbances observed during the main and recovery phases both at high and middle latitudes. At low latitudes they are both positive and negative with high amplitudes. (4) The disturbances change their sign near 30° geomagnetic latitude. Similar effect has been found in the study (Pirog et al., 2001a; Araujo-Pradere and Fuller-Rowell, 2002). It correlates with the change in global circulation (Araujo-Pradere et al., 2004). (5) The results of model simulations and the observed data were obtained by correcting the MSIS-86 thermospheric model which has a different character for summer and winter conditions. It was suggested that this reflects real variation of thermospheric composition during storm depending on the season. Such variations in the neutral composition of the thermosphere can result in the ionospheric storms being negative in summer while positive in winter. The disagreement of the modeled and measured values in the evening hours at high-latitude stations is determined by the variations in the auroral fluxes what are not described by the statistical model and also by the processes related to the motion of the main ionospheric trough.

This paper focuses on modeling the ionospheric effects and processes during moderate storms.

2. Modeling of the vertical sounding data

We have studied variations in the critical frequencies of the F2 and Es layers and also in the heights of the F2-layer maximum during a storm, including the initial and recovery phases. The hourly values of foF2, h′F, and hmaxF2 averaged over several quiet days of the month were used as the quiet level. Table 1 presents the geographic and geomagnetic coordinates of the ionospheric stations from whose data were used in this study.

As indicated earlier there exist differences in the manifestation of the ionospheric response in different seasons particularly during the recovery phase (Pirog et al., 2006b). The local-night storms with closely related intensities (Dst ≈ 80–100 nT) have been selected in this investigation.

2.1. Description of the model

A numerical model for ionosphere–plasmasphere coupling (Krinberg and Tashchilin, 1980; Tashchilin and Romanova, 1995, 2002) is used to interpret the observational data on the ionospheric response to the geomagnetic disturbances. The model is based on numerically solving a system of nonstationary balance equations of atomic (O^+, H^+, N^+, He^+) and molecular ($N_2{}^+$, $O_2{}^+$, NO^+) ions in conjunction with thermal plasma energy equations within closed geomagnetic flux tubes whose foots are at the height $h_0 = 100$ km. Concentrations of all ions, except $N_2{}^+$, are calculated taking into account the processes of photoionization, impact ionization by the magnetospheric electrons and recombination. Apart from ion transport along geomagnetic field lines due to ambipolar diffusion and the horizontal thermospheric wind, we also took into account the drift of plasma across magnetic field lines. The reference spectrum of the EUV radiation from Richards et al. (1994) is used for calculating the photoionization of thermospheric constituents and energetic spectra of the primary photoelectrons.

Electron and ion temperatures are calculated taking into account the heat conduction processes along geomagnetic field lines and of the thermal energy exchange between electrons, ions, and neutral species due to elastic and inelastic collisions. The rate of thermal electron heating is calculated self-consistently by solution of the kinetic equation of photoelectron transport in the conjugated ionospheres. The global empirical thermospheric model MSISE-90 (Hedin, 1991) is used to describe space-time variations of the temperature and concentration of the neutral constituents O, O_2, N_2, H, and N. The velocities of the horizontal thermospheric wind are determined from the HWM-90 model (Hedin et al., 1991).

Table 1
The list of ionospheric stations and their coordinates

Stations	Symbol	Geographic		Geomagnetic	
		Latitude	Longitude	Latitude	Longitude
Norilsk	NO	69.20	88.26	58.71	165.7
Zhigansk	ZH	66.3	123.4	55.2	190.0
Yakutsk	YA	62.0	129.6	50.99	194.1
Irkutsk	IR	52.5	104.0	41.1	174.8
Manzhouli	ML	44.0	117.0	32.0	189.0
Beijing	BP	40.0	116	28.7	188
Chongqing	CQ	29.0	106	18.1	177.8
Guanghou	GU	23	113	11.7	184
Hainan	HA	19.5	109.1	8.1	178.95