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Modeling of the seasonal effects of geomagnetic storms in the eastern Asian ionosphere

E. B. Romanova, A. V. Tashchilin, G. A. Zherebtsov, O. M. Pirog, and N. M. Polekh

Institute of Solar Terrestrial Physics, Irkutsk, Russia

V. F. Smirnov, and A. E. Stepanov

Institute of Space Physics and Aeronomy, Yakutsk, Russia

Shi Shi Jiankui, and Wang Xiao

Center for Space Science and Applied Research, Beijing, China

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[1] The results of studies of ionospheric effects of geomagnetic storms observed in different seasons are presented. A morphological analysis is performed using the data of a network of ionospheric stations located at different latitudes in the longitudinal sector 90°–130°E. Significant differences in the ionospheric response to a geomagnetic storm are obtained depending on latitude and season. At middle latitudes the most interesting is that the positive and negative phases of ionospheric disturbance prevail in winter and summer, respectively. To interpret the observed variations in the ionospheric structure, modeling is performed, using a theoretical ionospheric model. The analysis of the processes governing the response of the midlatitude ionosphere to a geomagnetic storm showed a good agreement between the results of modeling and measurements and made it possible to detect the determining role of the neutral composition in the observed variations in ionospheric parameters. At auroral and subauroral stations the variability of the electron concentration during a storm is much better pronounced. According to the results of the analysis of the trajectories of the ionospheric plasma convection, this variability is caused by the joint action of the convection and energetic electron precipitations. The disturbances in the neutral composition in this latitudinal region influence the background electron concentration level. *INDEX TERMS:* 2441 Ionosphere: Ionospheric storms; 2447 Ionosphere: Modeling and forecasting; 2407 Ionosphere: Auroral ionosphere; *KEYWORDS:* Ionospheric storms; Ionosphere-magnetosphere interactions; Numerical simulations.

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1. Introduction

[2] **Hedin** [1991] ????? XXXXXXXXXXXXXXX ???? 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 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; *Pro-*

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lss and Ocko, 2000; *Reddy and Mayr*, 1988; *Rishbeth*, 1998]. The experimental data and results of modeling [*Forster et al.*, 1995; *Mikhailov and Foster*, 1997] show that during geomagnetic storms the ionosphere is enriched by molecular ions. The variations in the ratio of atomic oxygen concentration to molecular nitrogen concentration [O]/[N2] lead to the changes in the phase of an ionospheric storm. The seasonal variations in the ionospheric effects of storms and their dependence on local time are described with the help of the so-called "AC/DC" effect in the maximum of the $F2$ layer [*Rodger et al.*, 1989; *Wrenn et al.*, 1987]. Using the "disturbance index" determined as the logarithm of the ratio of the electron concentration in the layer maximum in disturbed conditions to the same value in quiet conditions, the authors showed that the seasonal variation or "DC splash" of the disturbance index is caused by the summer-to-winter asymmetry of the thermospheric wind. The "AC" variation during a magnetic storm is caused by the local time changes in the wind. Because of variations in winds and neutral composition, at middle latitudes the negative and positive effects of storms are observed more often in summer and winter, respectively [*Field and Rishbeth*, 1997; *Rodger et al.*, 1989].

[3] *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.*, 2002; *Blagoveshchensky et al.*, 2003; *Pirog et al.*, 2003; *Zherebtsov et al.*, 2003]. In eastern Asia, the strongest deviation of geographic coordinates from geomagnetic coordinates is observed. The formation of the high-latitude large-scale structure of the ionosphere in this sector occurs on the background of relatively low electron concentration. The latter fact determines an increased interest to this region. *Kurkin et al.* [2004] studied the variations in the critical frequencies and index of ionospheric disturbances at the stations of Siberia and Far East during the main phases of geomagnetic storms in various seasons and periods of maxima and minima of solar activity. They found that during the main phase of a storm, negative disturbances of various intensities were observed in summer and fall independently of latitude and local time. In winter at high latitudes, intense positive and negative disturbances were observed at night and in the daytime, respectively. The amplitude of ionospheric disturbances was higher at lower solar activity.

[4] In this paper we present the results of a morphological analysis and numerical modeling of the ionospheric state during storms observed in different seasons at various latitudes of the eastern Asia region.

2. Analysis of the Experimental Data

[5] The data of the network of ionosondes and digisondes located in the longitudinal sector 90–130°E were used for the analysis (see Table 1). We studied variations in the critical frequencies of the $F2$ and E_s layers and also in the heights of the $F2$-layer maximum during a storm, including the preliminary and recovery phases. The hourly values of f_oF2, $h'F$, and $h_{\max}F2$ averaged over several quiet days of the month were used as the quiet level. The storms observed from May 2003 to march 2004 were considered. During this period, 15 storms were detected and split into seasons. The performed morphological analysis showed that there exist differences in the manifestation of the ionospheric response in different seasons.

2.1. Summer Conditions

[6] Figure 1 shows the variations in f_oF2 during a typical summer storm. The illumination conditions determined the weakly pronounced diurnal behavior at high-latitude Norilsk station with a slight decrease before the midnight. At stations from Zhigansk to Manzhouli, the quiet diurnal behavior of f_oF2 had a maximum around the midnight and a minimum in the morning hours of the local time. With a decrease of latitude, the difference between the minimum and maximum values of f_oF2 increased. At more southern stations, a well pronounced diurnal behavior with a maximum and a minimum in the afternoon and morning hours, respectively, was observed. During the storm at latitudes from Norilsk to Yakutsk, the disturbances were negative with the amplitude of 20–50% of the quiet level. The absence of reflections in Norilsk and Zhigansk is caused by the appearance of screening sporadic layers of the r and a types, whereas the negative values of Δf_oF2 in the daytime are related to the G condition when the frequency of the $F2$ layer is close to the frequency of the $F1$ layer. In Irkutsk and Manzhouli in the minimum of Dst in the evening hours of the local time, a sharp depletion of f_oF2 and the following negative disturbance continued the entire recovery period. At Beijing, the disturbance was similar to the one observed at Manzhouli. At low-latitude stations, the disturbances were mainly positive. The transition from positive to negative disturbances takes place southward from Beijing (geomagnetic latitude about 28.7°N).

2.2. Winter Conditions

[7] A winter storm with the initial positive phase in the morning LT hours and minimum values of the index $Dst = -140$ nT is shown in Figure 2. The value of KP in this period did not exceed 7. In the initial and main phase in the daytime on 22 January, positive disturbances were observed at all stations from the auroral zone to the equatorial anomaly. At night at Norilsk, Zhigansk, and Yakutsk anomalous reflections both in the F and E regions were observed. At the recovery phase, the disturbances in the day-

time hours were negative at high and middle latitudes. The higher the station latitude, the longer lasts the recovery of the undisturbed level of foF2 (3 days at Norilsk, 2 days at Zhigansk and Yakutsk, and 1 day at Manzhouli). At Zhigansk, Yakutsk, and Irkutsk after the negative phase, the disturbances again became positive. At night at high latitudes, the disturbances were positive, whereas at middle latitudes they were negative. At low latitudes the disturbances were positive both in the daytime and at night during the entire storm. At Khainan during the main phase of the storm, oscillations of f_oF2 were also observed.

2.3. Equinox Conditions

[8] Figure 3 shows a moderate storm with the minimum value $Dst = -96$ nT on 15 October at 0000 UT. At the development phase of the storm on 14 October at Norilsk and Yakutsk in the afternoon, a sharp decrease in f_oF2 (so called break in the diurnal behavior) was observed. In the evening and nighttime at Norilsk, screening sporadic layers in the E region and auroral absorption prevailed. During the following two days at the recovery phase of the magnetic storm, the ionization in the $F2$ layer stayed very low (4 MHz at noon). Oblique reflections from the poleward wall of the trough were seen in the ionograms at Yakutsk. The auroral ionization zone was located northward from Yakutsk during the entire period. At stations Irkutsk and Manzhouli, a depletion of the daytime values of f_oF2 during the main and recovery phases of the storm was the most pronounced effect of the 14–16 October storm. At low latitudes in the recovery phase, positive disturbances were observed. The reversal of the sign occurred in the vicinity of a geomagnetic latitude of 30°N.

3. Interpretation of the Observational Data

[9] In this section we consider the problem on the correspondence of the observational results obtained to the current concept of formation of the ionosphere response to a magnetic storm. According to this concept, approximately 10–20 min after the onset of the storm, there begins an expansion and shift to lower latitudes of the auroral oval, these events being accompanied by a rapid heating of the high-latitude ionosphere proportionally to the increase in the AE index [*Emery et al.*, 1999]. As a result of this pulse heating, strongly stretched along longitude large-scale gravity waves with a period of 1–3 hours are generated in the atmosphere. Propagating in the thermosphere from high to lower latitudes, they change the relative composition of the thermosphere and parameters of the neutral wind. According to measurements, the meridional velocity of the wind can reach values $U \approx 500 - 800$ m s^{-1} in the periods of magnetic storms, whereas in quiet conditions $U \approx 100 - 200$ m s^{-1} [*Buonsanto et al.*, 1999; *Emery et al.*, 1999; *Hagan*, 1988; *Prolss and Ocko*, 2000]. The intensification of the equatorward wind leads to a lifting of the $F2$ layer and to increase in the charged particle concentration within its maximum. This increase is usually called "positive phase" of a magnetic storm [*Rishbeth*, 1998]. Besides the dynamical impact on the $F2$ layer, there is formed in the meridional plane a disturbed ("storm") circulation cell capable to change considerably the midlatitude thermosphere composition. It happens, first, as a result of the direct transport of the disturbed composition by the wind out of the auroral oval zone, and, second, because of intensification of vertical motions leading to a decrease (upward flows) or to increase (downward flows) of the atomic oxygen concentration in the lower thermosphere [*Buonsanto*, 1999; *Burns et al.*, 1991; *Rishbeth*, 1998]. Within the height interval 200–300 km where the maximum of the $F2$ region is formed, the electron concentration is proportional to the ration of contents of O and neutral molecules, i.e., $N_mF2 \propto R = [O]/[N_2]$. Usually, during the main phase of the storm, the circulation leads to a decrease of R. This leads to a decrease in N_mF2 called the negative phase of an ionospheric storm [*Buonsanto*, 1999]. Studying the ionospheric reaction to a magnetic storm both at middle and high latitudes, one should consider, beside thermospheric disturbances also the effects related to the storm-time variations of magnetospheric sources such as the convection electric field and fluxes of precipitating energetic electrons [*Rodger et al.*, 1992]. It should be noted that the principal difficulty in studying of disturbed ionosphere behavior is related to the limitations in information on spatial-time variations of the thermospheric and magnetospheric parameters during particular magnetic storms. That is why in this paper two sets of model simulations were performed for interpretation of ionospheric observations in the periods of the considered geomagnetic disturbances. In the first set some statistically mean (empirical) models of magnetospheric sources and thermospheric parameters were used. In the second set, a correction of these empirical models was performed in order to obtain the best description of the experimental data.

[10] The theoretical model of ionosphere-plasmasphere interactions (developed in the Institute of Solar-Terrestrial Physics) [*Tashchilin and Romanova*, 2002] was used. This model is based on numerical solution of the system of nonstationary equations of the balance of particles and thermal plasma energy within closed geomagnetic field tubes, their bases being located at a height of 100 km. It assumes that the plasma consists of atomic O^+, H^+, N^+, and He^+ and molecular N_2^+, O_2^+, and NO^+ ions.

[11] Concentrations of all ions, except N_2^+, were calculated taking into account the processes of photoionization, recombination, transport along geomagnetic field lines under the action of the ambipolar diffusion, and drawing of ions by the horizontal neutral wind. The reference spectrum of the EUV radiation from *Richards et al.* [1994] was used for calculations of photoionization of thermospheric constituents and energetic spectra of the primary photoelectrons.

[12] Electron and ion temperatures were determined taking into account the heat conductivity processes along geomagnetic field lines and exchange of thermal energy between electrons, ions, and neutral species due to elastic and inelastic collisions. The rate of the thermal electron heating was calculated self-consistently by solution of the kinetic

equation of photoelectron transport in the conjugated ionospheres taking into account the energy loss while passing through the plasmasphere. The global empirical thermospheric mode MSIS 1986 was used to describe spatial-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 for the high-latitude stations Yakutsk and Norilsk and equatorial station Khainan were determined from the HWM 90 model. For the midlatitude stations Irkutsk and Manzhouli, the velocities were calculated by the approximate method of *Kohl and King* [1967].

[13] The values of the integral flux and mean energy of the precipitating electrons needed to calculate the auroral ionization rates were taken from the global model of electron precipitation by *Hardy et al.* [1987]. The electric field of magnetospheric convection was determined according to the empirical model of the potential distribution [*Sojka et al.*, 1986] and the *Richmond et al.* [1980] model for the high-latitude and equatorial models, respectively.

[14] The reaction of the ionosphere to the considered magnetic storms was reproduced calculating the variations of the plasma parameters within the entire magnetic field tube thee basis of which in the North Hemisphere was located in the points with the geographical coordinates of ionospheric stations shown in Table 1. The general algorithm of model equation solution consisted of three stages. At the first stage, the trajectories of the drift were calculated by integration of the equation of plasma tube motion back in time from the given moment of UT to some initial moment UT_0. Variations of the electric field in time were taken into account via real variations of the hourly values of geomagnetic activity indices (Kp and Ap) and parameters of the interplanetary magnetic field (B_z and B_y). The second stage included calculation of initial distributions of the plasma concentrations and temperatures (at the UT_0 moment) along the field line. At the third stage, the equations of the ionospheric model were integrated in the right direction in time (from UT_0 to UT) along the calculated drift trajectory. The variations in parameters of precipitations, neutral atmosphere, and thermospheric wind were also taken into account using the real variations of the hourly values of geomagnetic activity indices. These calculations were performed for the three above indicated ionospheric storms. In this paper the initial conditions were determined for the moments: 0000 UT on 20 January 2004, 0000 UT on 16 June 2003, and 0000 UT on 12 October 2003. The initial profiles were calculated in the same way by integrating the model equations at the 120-hour time interval beginning from UT_0. Such choice of the calculation interval provides reaching of the degree of filling in the plasmosphere corresponding to quiet magnetic conditions at middle and low latitudes [*Krinberg and Tashchilin,* 1984].

[15] *Tashchilin et al.* [2002] performed a preliminary study of the reaction of the midlatitude ionosphere to an intense geomagnetic storm on the basis of the comparison of the Irkutsk Incoherent Scatter (IS) Radar measurements and the numerical simulation results. It was found that the negative phase of an ionospheric storm (as has been noted earlier (*Danilov and Belik* [1991], *Rishbeth* [1998], and others)) is formed mainly because of variations in the thermosphere composition. Besides this, the preliminary theoretical analysis made it possible to perform a correction of the thermospheric parameters calculated according to the MSIS 86 model to the conditions of the storms in question. Since the changes in the composition (the [O]/[N_2] ratio) obtained from the MSIS 86 model were not able to reproduce the observed behavior of the ionosphere during magnetic storm, these changes were multiplied by a factors of 0.6 and 1.6 for summer and fall, and winter, conditions respectively. These correcting factors were used in the presented below model calculations of the ionosphere reaction to the chosen geomagnetic storms.

[16] The results of the simulation of the ionospheric behavior during the storms are presented in Figures 4–6. Solid curve shows the calculated values of the logarithm of the electron concentration in the $F2$-layer maximum ($\lg N_mF2$) for two high-latitude, two midlatitude and one equatorial stations, circles correspond to the measured values, and dashed curves denote the quiet level calculated over several quiet days. The model reproduce well the variations of the critical frequency during the storms: the values of $|\delta f_oF2|$ calculated by the model vary from 4% to 50%. The peculiarities of the modeling results for particular storms are as follows.

[17] 1. For summer conditions a good agreement between the measured and modeled values of N_mF2 in the daytime both at high and middle latitudes is obtained. The main differences are found in the evening and nighttime periods of local time at high XXXXXXXXX latitudes.

[18] 2. For winter conditions the calculated values of N_mF2 also satisfactorily correspond to the daytime measurements. The simulation results at subauroral station Yakutsk agree with observations better then at other stations both in the daytime and at night. The strongest differences are found in the evening and nighttime LT hours at Irkutsk midlatitude station.

[19] 3. For equinox conditions we succeeded in correcting the calculated and measured variations in the daytime at auroral station Norilsk. In the evening hours when a break in the diurnal behavior was observed, and at night when the ionization at these latitudes is determined by the fluxes of precipitating particles, the model values N_mF2 do not correspond to the observed values. In Yakutsk a satisfactory coincidence between the simulation results and observations is obtained for the entire period except the evening hours on 14 October during the break of the diurnal behavior at the first negative peak in the Dst index. At the midlatitude stations Irkutsk and Manzhouli, the simulated and measured variations in N_mF2 agree well enough. The evening hours on 15 October in the recovery phase, when very low values of f_oF2 were observed, present an exception.

[20] The results of model simulations were obtained because of the correction of the MSIS 86 thermospheric model, the correction being of a different sign for summer (fall) and winter conditions. In the first case the value of R was decreased by a factor of 2, and in the second case it was increased by a factor of about 1.5. Such variations in the neutral composition of the thermosphere are able to lead us to the fact that the ionospheric storms are negative in summer and positive in winter.

[21] The disagreement of the simulation results and measurements in the evening and night hours at high-latitude stations shows that a correction to the conditions of the considered magnetic storms is needed not only of thermospheric parameters, but the empirical models of magnetospheric sources as well. The effects of the correction of the models of precipitation and convection electric field were considered analyzing the situation of formation of the main ionospheric trough (MIT) on 14 October 2003 according to the data of Yakutsk and Norilsk stations. To do this, calculations of two versions of global distributions of the electron concentration for the moments 0800, 1000, and 1200 UT, the results being presented in Figure 7. Version I corresponds to the calculations without corrections of empirical models of magnetospheric sources, whereas version II show the results of the following corrections for disturbed conditions: the zone of the auroral precipitations and magnetospheric convection was widened equatorward by 5°, the electric potential was increased by 30% of the value obtained from the empirical model. The correctness of these changes was discussed by *Fuller-Rowell et al.* [1994]. Figures 7a and 7e show the values of $\lg N_e$ at a height of 300 km in the coordinates: geomagnetic colatitude–MLT for versions I and II of the calculations, respectively. Figures 7b and 7d show isolines of the electric potential of convection (taking into account the corotation) and the energy flux of the precipitating electrons also for versions I and II. The positions of Norilsk and Yakutsk stations are shown by circles. One can see in Figures 7a and 7e that the main ionospheric trough (MIT) in version II of calculations is better pronounced: the trough depth is a factor of 2.8 and 3.8 for 0800 and 1200 UT, respectively, the length in MLT is from 16 to 4 hours, whereas in version I the depth of MIT is a factor of 1.8–3.1 and the length in MLT is 18–5 hours. Stations Yakutsk and Norilsk are located at the edge of the trough at 1000 UT and 1200 UT (see Figure 7e) for version II of the calculations. Figure 8 shows the diurnal behavior of the logarithm of the electron concentration in the $F2$-layer maximum ($\lg N_mF2$) calculated using versions I and II (curves 1 and 2, respectively). The circles show the measured values of f_oF2. One can see that according to the diurnal behavior of f_oF2 at Norilsk station, the equatorial wall of the trough was observed at 0800 UT, whereas according to the simulation results it appeared at $\sim$ 1100 UT and $\sim$ 1200 UT for versions II and I, respectively. Therefore the correction performed brought the calculation results closer to the observational data, but appeared to be insufficient to provide their complete agreement. The calculations for Yakutsk subauroral station showed the absence of MIT in version I and its presence in version II. However, the calculated time of the MIT equatorward wall appearance poorly agree with the observational data. Thus at high latitudes where magnetospheric convection and precipitation of energetic electrons play an important role, the use of empirical models for calculation of the auroral ionization and electromagnetic drift velocity does not make it possible to simulate the real structure of MIT. A simple correction of empirical models of magnetospheric sources provide no significant improvement, this fact indicating to a need of development of methods of adaptation of empirical models to real geomagnetic disturbances.

[22] The strongest differences between the calculations and measurements are seen for the winter storm at middle latitudes (Irkutsk) in the evening and nighttime. One can see from Figure 5 that for the winter storm at midlatitude station Irkutsk in the evening and nighttime, the calculated values of the electron concentration exceed considerably the measured values of. This can happen because of two causes. It is known that the ionization level in the vicinity of the $F2$-layer maximum after sunset is controlled, first, by the plasma input from the outer ionosphere and, second, by the change in the $F2$-layer height caused by the meridional component of the thermospheric wind. In order to estimate the input of each of these factors into the deviation of calculations from the observations, we first performed calculations without the wind. As a result, the agreement of calculations and observations was considerably improved. This fact shows that the wind velocities are overestimated both in the calculations and in the empirical model HWM 90. Then we considered an assumption that the disagreement is caused by the input of ions from the plasmasphere, the input value depending on plasmasphere filling in. The calculation results presented in Figure 5 correspond to the situation when the plasmasphere over Irkutsk is almost full and is able to support high values of N_e after sunset during the storm, whereas in real conditions the ionosphere is not completely full. In order to check these assumptions, two versions of calculations were performed for Irkutsk station without any correction of the thermosphere (Figure 9). Version III corresponds to the conditions of filled plasmasphere (curve 1). Version IV corresponds to the conditions of unfilled plasmasphere when the model equations were integrated at the time interval of 24 hours (curve 2). In the case of filled plasmasphere, in the evening and nighttime the ion fluxes from the plasmasphere to ionosphere (from -0.7×10^7 cm^{-2} s^{-1} to -1.6×10^7 cm^{-2} s^{-1}) are observed even during the storm (Figure 9 (bottom), curve 1). At the same time in the case of unfilled plasmasphere, the fluxes are much weaker (from -0.2×10^7 cm^{-2} s^{-1} to -0.5×10^7 cm^{-2} s^{-1}, Figure 9, curve 2). During the storm on 22 January, the flux is directed from the ionosphere into plasmasphere (0.2×10^7 cm^{-2} s^{-1}) what is close to the real conditions. This fact explains the better coincidence of the calculated values of the electron concentration with observations in the evening and night hours obtained for version IV at the recovery phase of the storm (from 22 to 26 January 2004). On quiet day 21 January the best agreement between the calculated and observed values of N_e is obtained for version III. This is due to the fact that in the period 18–21 January 2004 (4 days) corresponds to quiet geomagnetic conditions (when the total value of the Kp index did not exceed 22) and the plasmasphere was filled, because the characteristic time of filling in of a plasma tube with $L \leq 2$ is three days (for Irkutsk $L = 1.74$) [*Krinberg and Tashchilin*, 1984]. Thus one can conclude that modeling the response of the midlatitude ionosphere to geomagnetic storms, one has to take into account the time variations of the degree of filling in of the plasmasphere, that is, to consider the ionosphere and plasmasphere as a united system.

4. Conclusions

[23] As a result of morphological and theoretical analysis of the seasonal features of ionospheric storm manifestations at various latitudes of the east Asian region, the following regularities are found:

[24] 1. For the summer storm, an appearance of negative disturbances in the electron concentration is typical both at high and middle latitudes. At low latitudes the disturbances are mainly positive. The sign of the disturbance changes in the vicinity of 30°of geomagnetic latitude.

[25] 2. During the winter storm, positive disturbances were observed in the daytime during the main phase at all the stations considered. At the recovery phase in the daytime, the disturbances are of the negative character at high and middle latitudes. At low latitudes, the disturbances are positive both in the daytime and at night during the entire storm.

[26] 3. In the equinoxes during the main phase of the storm and in the beginning of the recovery period at middle and high latitudes, negative ionospheric disturbances were observed. At low latitudes, both types of disturbances were observed.

[27] 4. The results of model calculations with correction of the MSIS 86 thermospheric model showed that the observed at middle latitudes negative character of an ionospheric storm in summer and positive type in winter can be explained by the corresponding variations in the thermospheric composition.

[28] 5. The available empirical models of auroral precipitations and magnetospheric convection do not make it possible to describe adequately in the scope of a theoretical model of a storm the real structure of the disturbed high-latitude ionosphere. A correction of empirical models of magnetospheric sources provides no significant improvement.

[29] 6. It is shown that at modeling of the response of the midlatitude ionosphere to a geomagnetic storm, one should take into account variations during the storm of the degree of plasmapause filling in, that is, to consider the ionosphere and plasmasphere as a united system.

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O. M. Pirog, N. M. Polekh, E. B. Romanova, A. V. Tashchilin, and G. A. Zherebtsov, Institute of Solar Terrestrial Physics, P. O. Box 4026, Lermontov str. 126, RU-664033 Irkutsk, Russia. ()

V. F. Smirnov, and A. E. Stepanov, Institute of Space Physics and Aeronomy, RU-677891 Yakutsk, Russia. (pir@iszf.irk.ru)

Jiankui Shi Shi, and Xiao Wang, Center for Space Science and Applied Research, P. O. Box 8701, Beijing 100080, China. ()

Table 1. List and Locations of Ionospheric Stations

Stations	Symbol	Geographic Coordinates		Geomagnetic Coordinates	
		Latitude	Longitude	Latitude	Longitude [31]
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

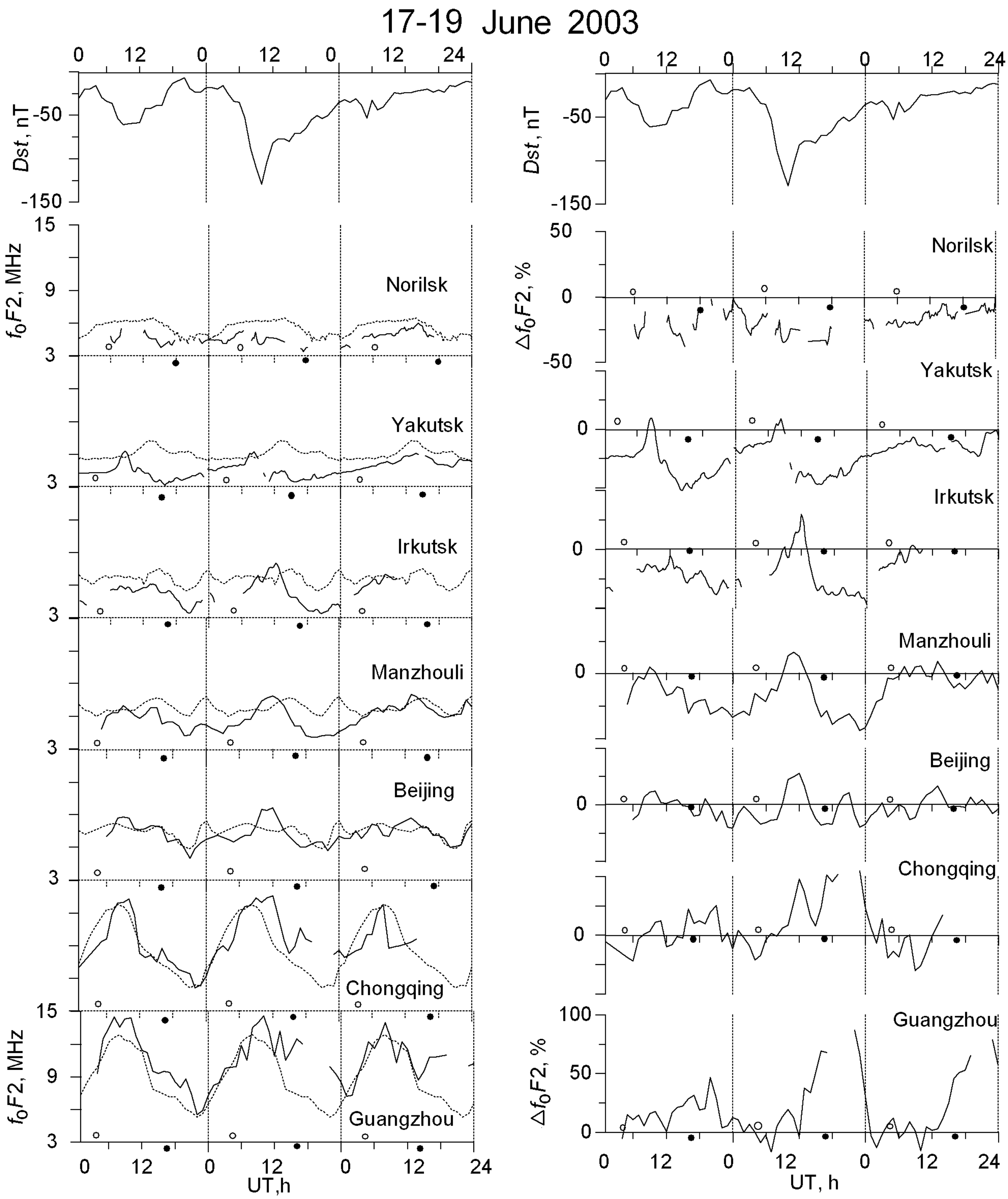

Figure 1. Variations in the Dst index, critical frequencies of the $F2$ layer, and Δf_oF2 during the storm on 17–19 June 2003. Dashed and solid curves show the diurnal behavior of f_oF2 in undisturbed time and its current values, respectively. Open and solid circles on the time axis show the local noon and midnight, respectively.

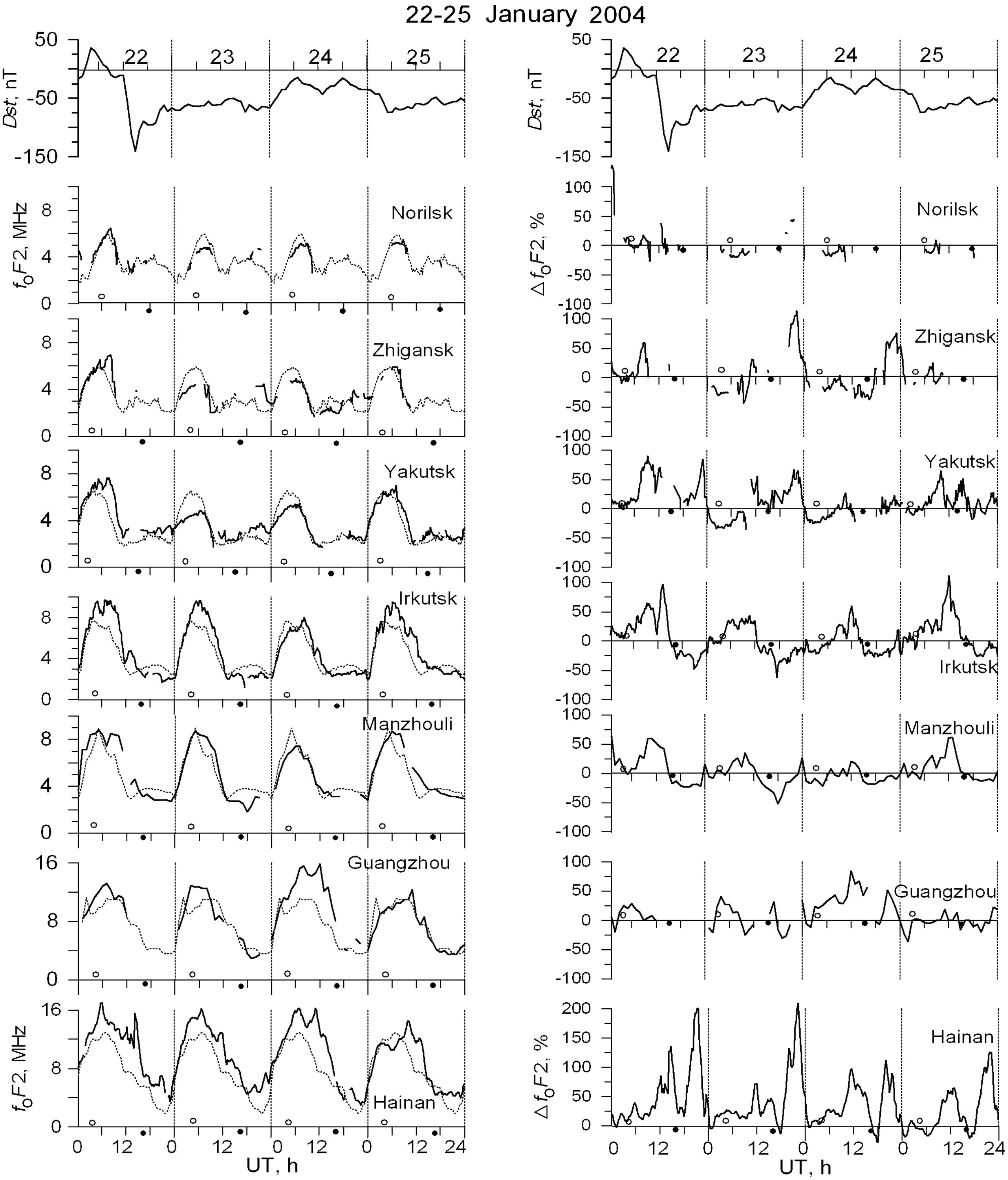

Figure 2. Variations in the *Dst* index and critical frequencies of the *F*2 layer during the storm on 22–25 January 2004.

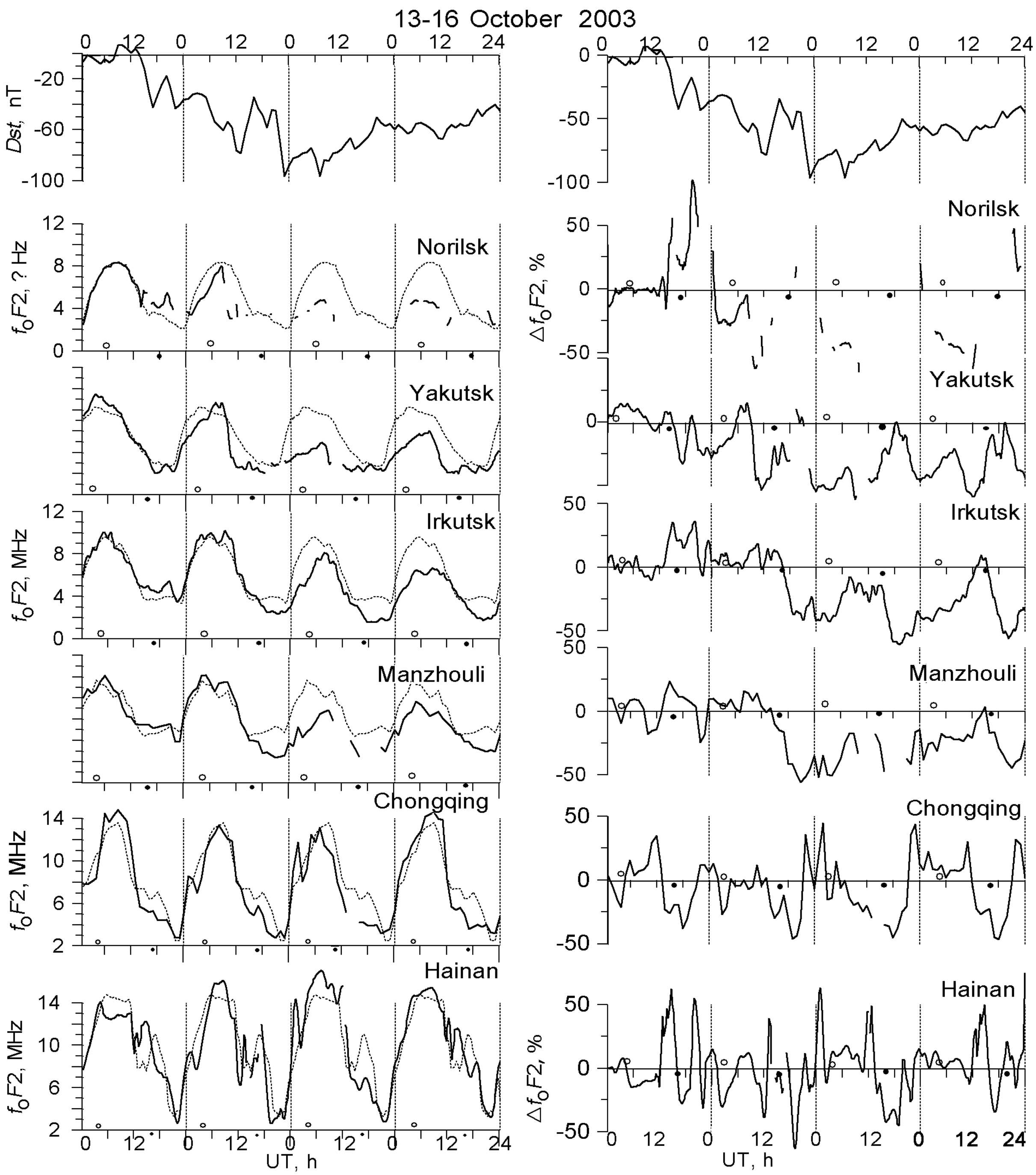

Figure 3. Variations in the *Dst* index and critical frequencies of the *F*2 layer during the storm on 13–16 October 2003.

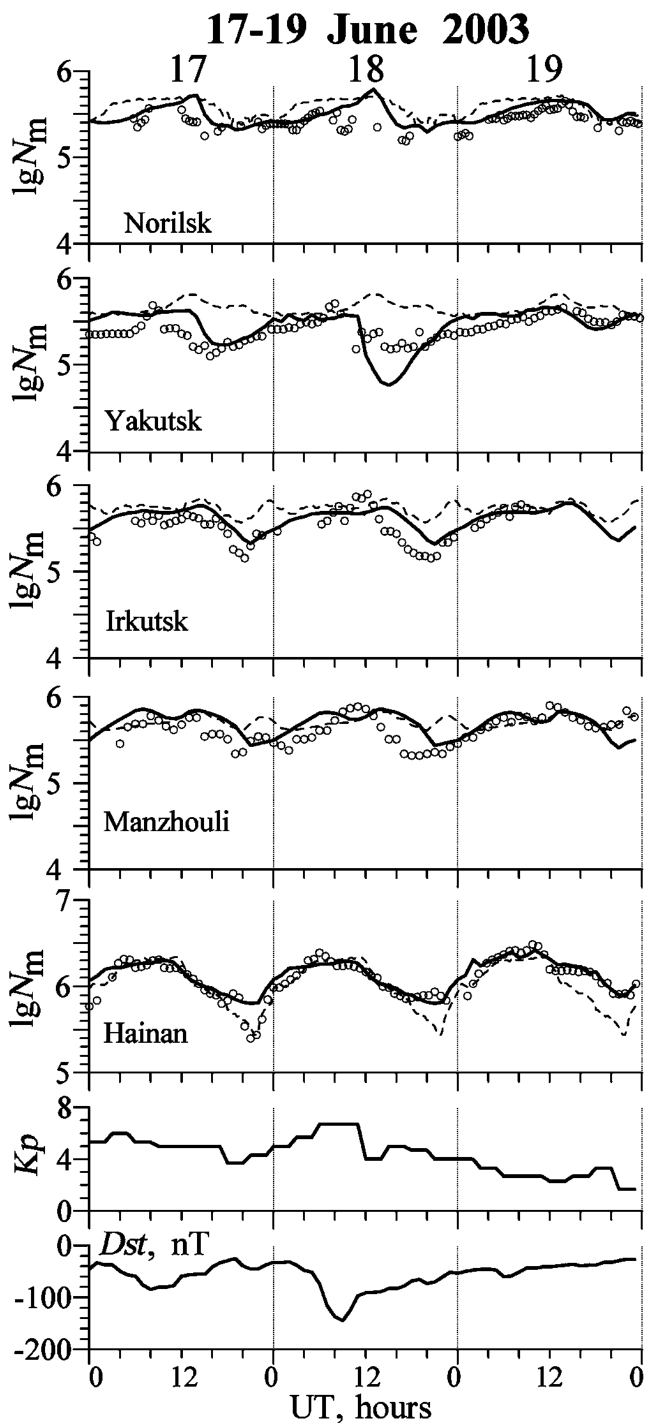

Figure 4. Variations in the Kp and Dst indices and the electron concentration in the $F2$-layer maximum during the storm on 17–19 June 2003. Circles show the N_mF2 values calculated on the basis of measurements of f_oF2; dashed curves show the quiet level calculated on the basis of the measurements of f_oF2 on quiet days; solid curves show N_mF2 calculated by the model.

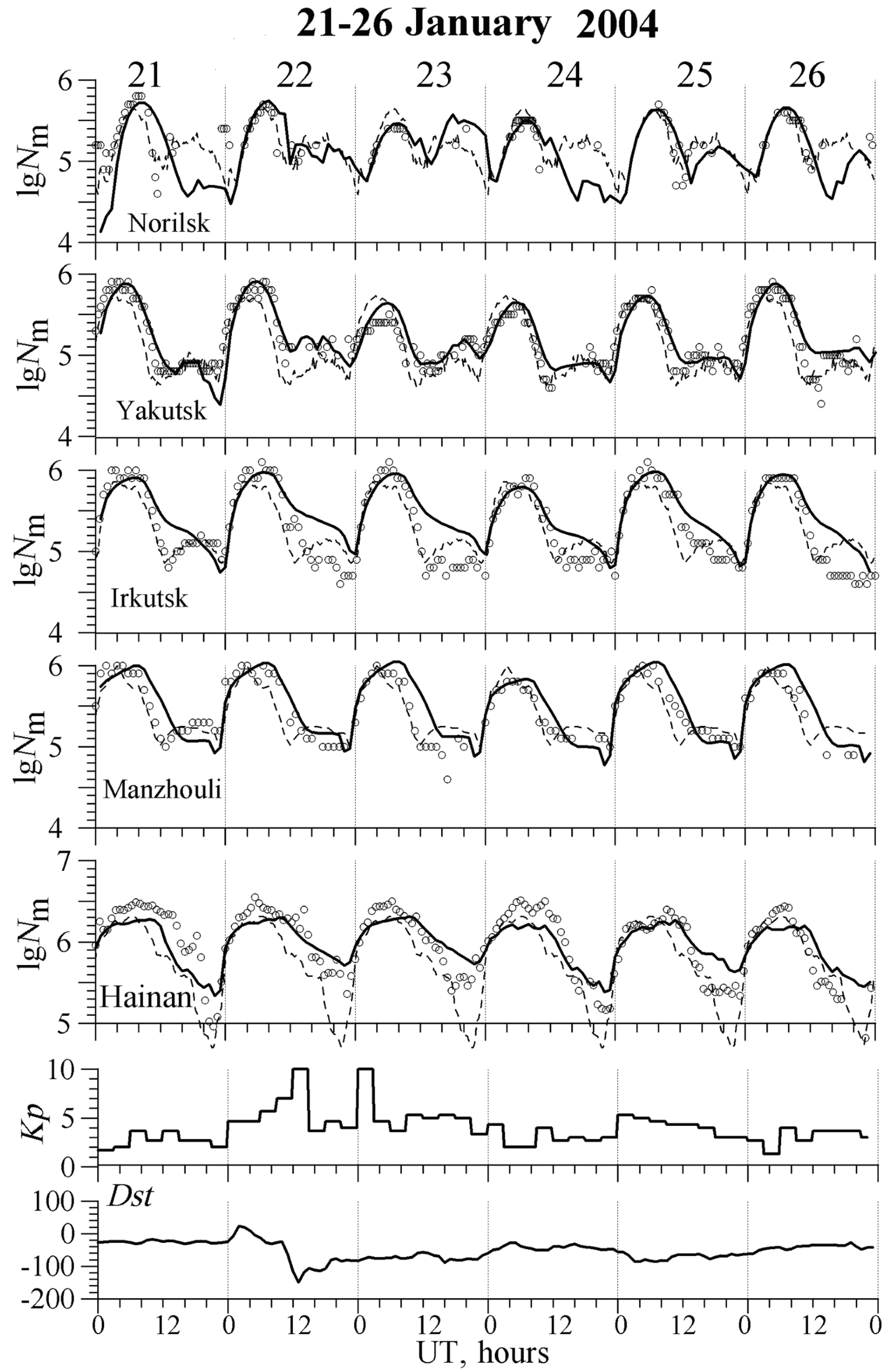

Figure 5. Same as in Figure 4, but for 21–26 January 2004.

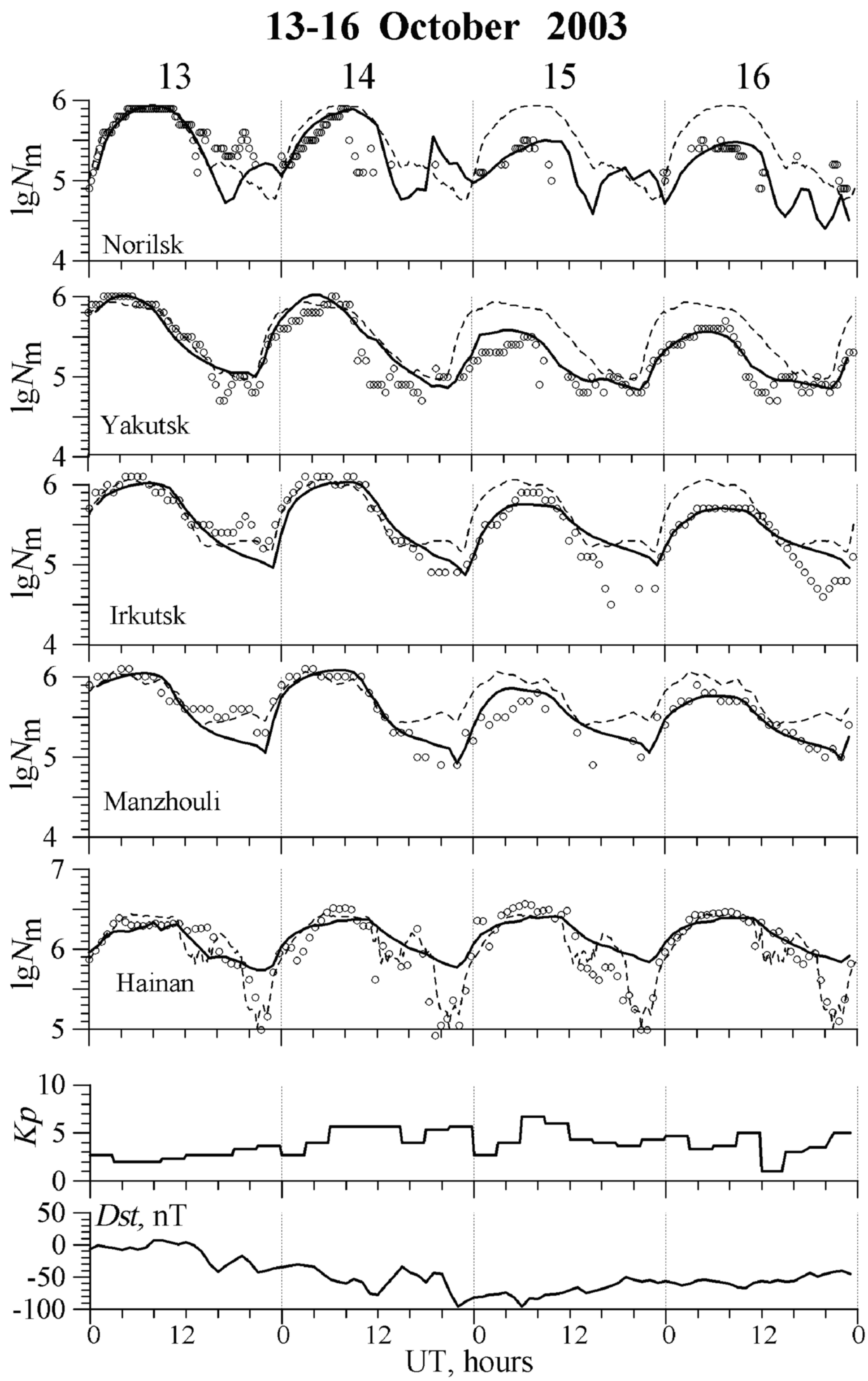

Figure 6. Same as in Figure 4, but for 13–16 October 2003.

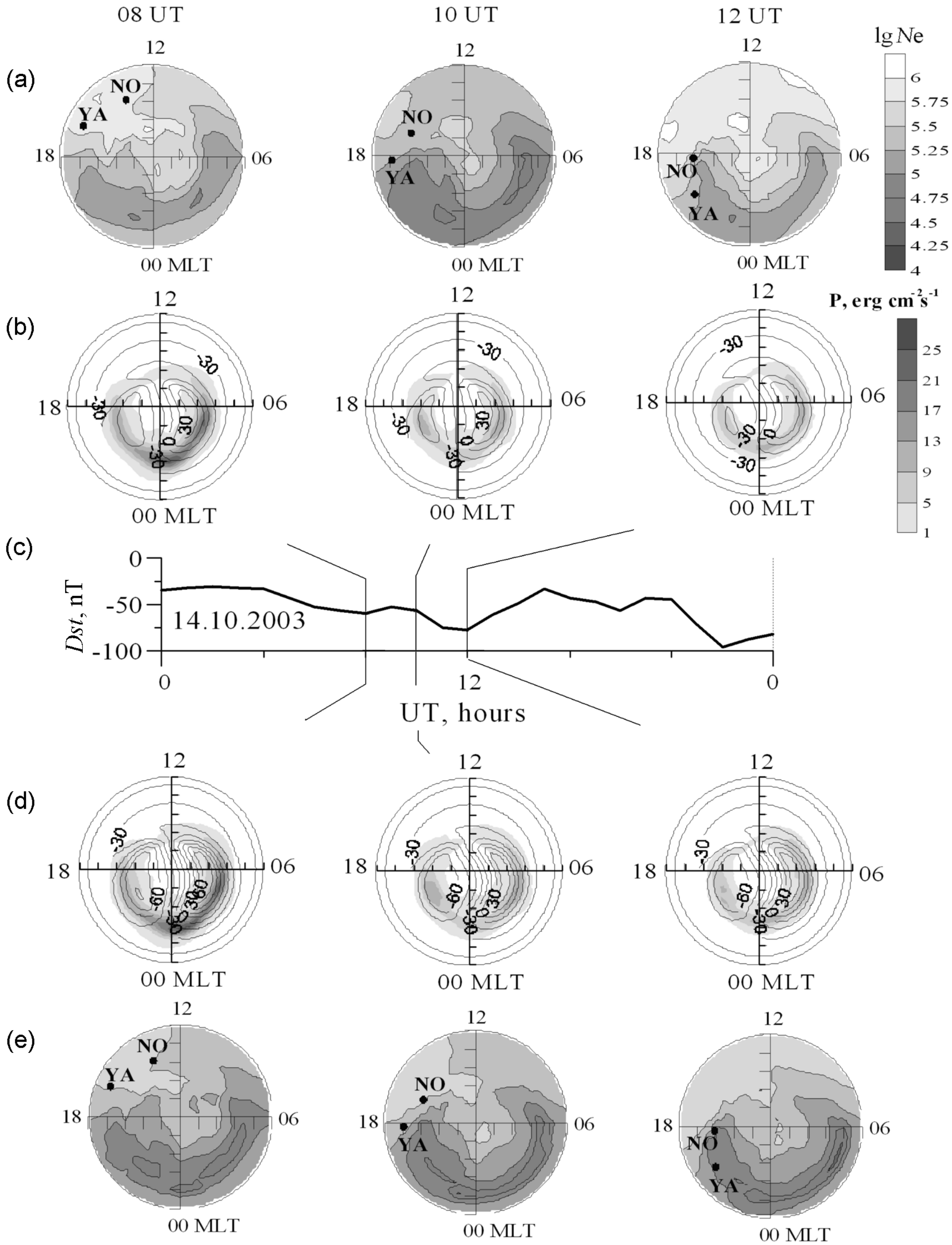

Figure 7. Electron concentration at a height of 300 km in the coordinates geomagnetic colatitude–MLT at 0800, 1000, and 1200 UT on 14 October 2003 (version I (Figure 7a) and version II (Figure 7e)); isolines of the electric potential of the convection with allowance for the corotation and the precipitating electron flux (version I (Figure 7b) and version II (Figure 7d)); the *Dst* index (Figure 7c). The positions of Norilsk and Yakutsk stations are shown by circles.

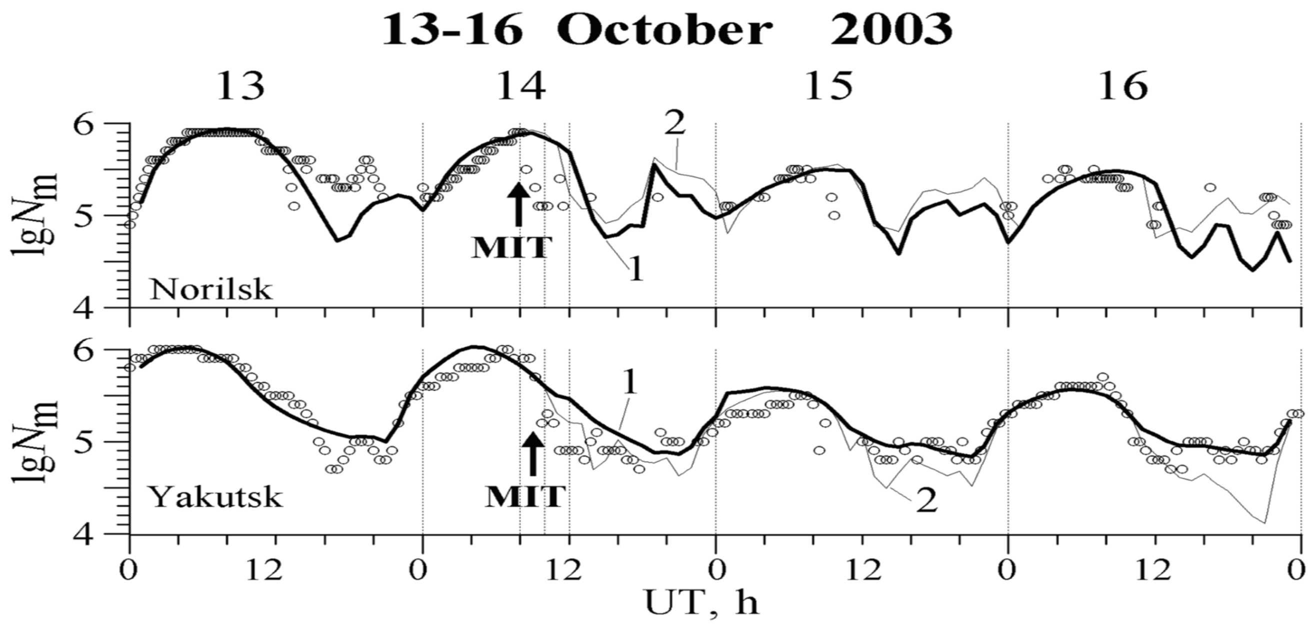

Figure 8. Variations in the electron concentration in the maximum of the $F2$ layer at stations Norilsk and Yakutsk in the period 13–16 October 2003. Points show N_mF2 calculated on the basis of f_oF2 measurements. Curve 1, N_mF2 calculated using the model with the use of the empirical models of electron precipitation and convection electric potential without corrections (version I); curve 2, the same with the corrections of these models (version II). MIT, main ionospheric trough.

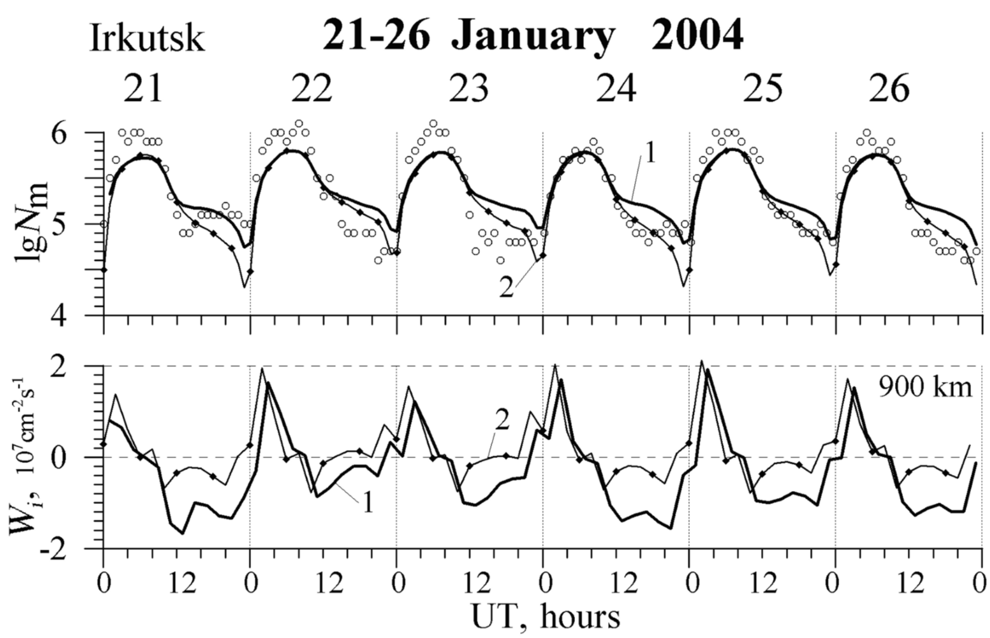

Figure 9. Variations in the electron concentration in the $F2$-layer maximum and ion fluxes at a height of 900 km for midlatitude station Irkutsk during the period 21–26 January 2004 calculated without thermospheric correction: curve 1, version III; curve 2, version IV.