COMPLEX OBSERVATIONS OF IONOSPHERIC DISTURBANCES IN THE NORTH-EASTERN REGION OF ASIA

D.G. Baishev¹, A.E. Stepanov¹, S.E. Kobyakova¹, S.N. Samsonov¹, V.I. Kurkin², O.M. Pirog², I.N. Poddelsky³, A.I. Poddelsky³

¹Yu.G.Shafer Institute of Cosmophysical Research and Aeronomy SB RAS, Yakutsk, 677981, Russia; ²Institute of Solar-Terrestrial Physics SB RAS, Irkutsk, 664033, Russia; ³Institute of Cosmophysical Research and Radio Wave Propagation FEB RAS, Paratunka, Russia

Abstract. Variations of ionospheric parameters, cosmic noise absorption and geomagnetic field at subauroral and mid-latitude stations (L~3-4) in the north-eastern region of Asia in December 2006 are analyzed. 3 intervals, 6-9 December 2006 (minor magnetic storm with minimum Dst=-47 nT), 14-17 December 2006 (major magnetic storm with minimum Dst=-146 nT), and time period of 19-23 December 2006 which is characterized by long-lasting continuous magnetic activity in the auroral zone (HILDCAA event) are selected. Some features of a development of ionospheric disturbances caused by magnetospheric processes under different conditions in the solar wind and interplanetary magnetic field.

INTRODUCTION

Study of the influence of solar and interplanetary phenomena on the near-Earth space has been the most important problem of the solar-terrestrial physics. The Earth’s plasmasphere is the region of the inner magnetosphere located up to 4-6 radius of the Earth and refilled by cold corotating plasma. As a matter of fact, plasmasphere is an extension of the ionosphere (Lemaire and Gringauz, 1998). A number of critical problems of plasmasphere physics to understand a processes occurring in the ionosphere and atmosphere of the Earth such as a formation of plasmapause, filling and emptying of plasmasphere remain yet to be solved (Kotova, 2007). Filling and emptying of plasmasphere depends on geomagnetic activity level determined by parameters of solar wind and interplanetary magnetic field (IMF). Plasmapause during the storms corresponds to the equatorial wall of the main ionospheric trough (Benkova et al., 1980; Holt et al., 1984; Besprozvannaya et al., 1986; Whalen, 1987).

Ionospheric disturbances caused by a development of magnetic storm is a complex of events depending on various factors (Prößl et al., 1991; Buonsanto, 1999). In spite of the fact that a vast volume of experimental and theoretical data has been accumulated, some difficulties exist to forecast the effects of solar activity on the ionosphere. A difference between the geomagnetic and geographic coordinates complicates the picture of ionospheric disturbances and leads to a longitudinal dependence (Afraimovich et al., 2002; Blagoveshchensky et al., 2003; Pirog et al., 2006).

Kurkin et al. (2008) present the results of studies of the subauroral and mid-latitude ionosphere variations in the north-eastern region of Asia during magnetic storms under low solar activity (SA). They found that large daytime negative disturbances are observed during the main and recovery phases at the high latitudes, whereas the positive disturbances observed during the main phase at the mid latitudes. The disturbances changed their sign between Yakutsk and Irkutsk. During the main and recovery storm phases the fall of foF2 associated with a displacement of the equatorial wall of the main ionospheric trough (Galperin et al., 1986) to the equator is observed in the afternoon and evening. Besides, large-scale ionospheric disturbance similar to disturbances registered within the same region on 8 and 10 November 2004 (Pirog et al., 2007) is observed on 15 December 2006.

The geomagnetic activity associated with sporadic and continuous magnetic field reconnection under southward IMF component can last for days to weeks and has been called high-intensity long-duration continuous AE activity (HILDCAA) events (Tsurutani and Gonzalez, 1987). It is believed that some feature of these continuous (sporadic) plasma injections/HILDCAAs are the cause of the acceleration of magnetospheric energetic electrons to high energies.
In this paper, study of ionospheric, cosmic noise absorption and magnetic disturbances caused by variations of IMF and solar wind parameters is conducted to show a possibility of plasmapause position determination and its dynamics by ground-based radio physical complex.

**EXPERIMENTAL DATA AND OBSERVATIONAL RESULTS**

We analyze the results of complex observations of ionospheric disturbances in the north-eastern region of Asia. There are used the data of vertical sounding stations located at different latitudes along 190° magnetic meridian and at Irkutsk, oblique-incidence sounding on the radio paths Magadan–Irkutsk and Norilsk–Irkutsk by the chirp sounder (frequency-modulated continuous wave ionosonde) of own construction, riometers and magnetometers and OmniWeb database. Coordinates of stations used in analysis are presented in Table.

<table>
<thead>
<tr>
<th>Stations</th>
<th>Symbol</th>
<th>Geographic latitude</th>
<th>Geographic longitude</th>
<th>Geomagnetic* latitude</th>
<th>Geomagnetic* longitude</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kystatyam</td>
<td>KYS</td>
<td>67.2</td>
<td>123.2</td>
<td>61.9</td>
<td>194.4</td>
</tr>
<tr>
<td>Zhigansk</td>
<td>ZGN</td>
<td>66.8</td>
<td>123.4</td>
<td>61.5</td>
<td>194.7</td>
</tr>
<tr>
<td>Zyryanka</td>
<td>ZYK</td>
<td>65.8</td>
<td>150.8</td>
<td>60.0</td>
<td>217.7</td>
</tr>
<tr>
<td>Yakutsk</td>
<td>YAK</td>
<td>62.0</td>
<td>129.8</td>
<td>56.4</td>
<td>201.3</td>
</tr>
<tr>
<td>Irkutsk</td>
<td>IRK</td>
<td>52.5</td>
<td>104.0</td>
<td>48.3</td>
<td>176.2</td>
</tr>
<tr>
<td>Norilsk</td>
<td>NOK</td>
<td>69.2</td>
<td>88.3</td>
<td>58.7</td>
<td>165.7</td>
</tr>
<tr>
<td>Magadan</td>
<td>MGD</td>
<td>60.1</td>
<td>151.0</td>
<td>50.8</td>
<td>210.8</td>
</tr>
</tbody>
</table>

*Coordinate transformation: GEO-->CGM, Year= 2006, height= 110 km
http://omniweb.gsfc.nasa.gov/vitmo/cgm_vitmo.html

After long-lasting quiet SA level characteristic for a solar minimum a series of M and X class bursts were observed in December 2006. It is most powerful (X5 class) with the subsequent sharp increase of solar radio emission intensity was registered on 6 December 2006 from 1829 to 1900 UT. However, active region on Sun was at this time interval out of a geoeffective zone. More effective one was X class burst observing on 13 December 2006 after that the magnetic storm with minimum Dst=-146 nT at 07 UT on 15 December 2006 was followed. In present paper variations of ionospheric parameters during two successive magnetic storms on 6-9 December 2006 and 14-17 December 2006, and HILDCAA event (19-23 December 2006) are considered.

The main phase of minor magnetic storm with minimum Dst = -48 nT at 12 UT on 6 December 2006 started at 07 UT on 6 December 2006 and the recovery phase continued till 00 UT on 9 December 2006. Fig. 1 presents the variations of foF2 on the chain of vertical sounding stations at Zhigansk, Yakutsk and Irkutsk, cosmic noise absorption at Kystatyam located about 50 km northern of Zhigansk and magnetic field at Zyryanka located at similar latitude as ZGN but about 2 hour eastern from one. During the main phase an increase of the F2 layer critical frequency and an occurrence of the sporadic E layer (Esr) were observed at Zhigansk (Fig. 1a). In the night hours reflections form F2 layer at Zhigansk was absent due to blanketing of Esr layer the critical frequency of which reached ~6 MHz on 6 December 2006 and smoothly decreased during 7-9 December 2006. At Irkutsk in day hours short-time fluctuations of foF2 with amplitude of 1 MHz were observed. Also in the course of the first magnetic storm both intensifications of AE index (up to 800 nT) and spikes in the cosmic noise absorption up to 4 dB at Kystatyam were occurred. Magnetic field variation at subauroral station Zyryanka most pronounced during a maximal development of ring current in the magnetosphere.

The geomagnetic storm with minimum Dst = -146 nT at 07 UT on 15 December 2006 started at 20 UT on 14 December 2006. During the initial stage of magnetic storm at Zhigansk in the night hours of LT there were observed the sporadic retarding Es layers (Esr) with critical frequencies of ~6 MHz blanketing the F2 layer (Fig. 1b). It shows that at this time Zhigansk was situated in the auroral zone. During the main phase of magnetic storm on 15 December 2006, the reflections from the F2 layer at Zhigansk were absent due to the total absorption and blanketing by sporadic-E layers. During the recovery phase of magnetic storm
Fig. 1. Magnetic activity, ionospheric and riometric parameters during the magnetic storm on 6-9 December 2006 (a), the magnetic storm on 14-17 December 2006 (b), and during the HILDCAA event on 20-23 December 2006. Thin lines show the median of foF2 and blue circles correspond to their current values at Zhigansk and Yakutsk. Red stars show the critical frequency of Esr echoes at Zhigansk.
on 15 December 2006 at Zhigansk blanketing Esr reflections with critical frequencies of \(~6\) MHz were registered in the evening-night hours. F2 layer was appeared on 16 December 2006 and its frequencies were recovered to the quiet level. At Yakutsk during the initial magnetic storm phase in the night hours on 14 December 2006 the anomalous echoes of F2 layer (F2s) with frequencies up to 5 MHz were registered. It testifies an intensification of diffuse aurora precipitation intensity near Yakutsk, i.e. plasmapause has moved to low latitudes till \(L\sim3\) and Yakutsk was located on the poleward wall of main ionospheric trough (Collis and Haggstrom, 1988). During the main phase of magnetic storm on 15 December 2006 at Yakutsk short-term reflections showing that observed frequencies in the noon were smaller by a factor of \(~2\) than one in the quiet period were appeared. After the noon critical frequency \(f_0F2\) increased sharply (up to \(~7\) MHz), then also sharply fell and was remained at level of \(~2.5\) MHz. During the recovery phase of magnetic storm and following days the ionospheric parameters recovered smoothly to the quiet level. At Irkutsk on 14 December 2006 F2s reflections were also registered which were defined as the reflections from the polar wall of main ionospheric trough. During the main phase of magnetic storm fluctuations of critical frequencies of F2 layer about the quiet level were observed. It is necessary to pay attention to a peak of \(f_0F2\) in the evening hours during the recovery phase of magnetic storm. It corresponds to a peak of \(f_0F2\) at Yakutsk, i.e. in this case there is an ionospheric disturbance arising in the auroral zone and propagating to low latitudes. Large bays in the cosmic noise absorption (more than 4 dB) at Kystatyam and magnetic variations at Zyryanka were observed on 14-15 December 2006.

Fig. 2 presents the variations of maximum observed frequencies (MOF) on the paths Magadan-Irkutsk and Norilsk-Irkutsk on 14-16 December 2006. It is seen that ionospheric parameter variations (see Fig. 1b) caused by significant change of characteristics of high frequency radio wave propagation. On the path Magadan-Irkutsk in the day time on 15 December 2006 the low MOF not exceeding 10-12 MHz were registered. In the afternoon (5-7 UT) these MOF values increased by a factor of 2 and then quickly decreased. On the path Norilsk-Irkutsk such increase of MOF not observed. The radio wave propagation through sporadic Es layer was the general phenomenon for both paths. Only the reflections from Es with MOF close to the daytime MOF from F2 layer were recorded on the paths Magadan-Irkutsk and Norilsk-Irkutsk in the night.

![Fig. 2. Variations in MOF on the paths Magadan – Irkutsk and Norilsk – Irkutsk on 14-16 December, 2006. Solid lines show the values of MOF; stars indicate the MOF from Es.](image)

During the HILDCAA event on 19-23 December 2006 the critical frequency of F2 layer at Zhigansk and Yakutsk were remained constant with slight fluctuations near the quiet level (\(~5\) MHz) except the day hours on 23 December 2006 when the \(f_0F2\) decreased up to \(~4\) MHz (see Fig. 1c). At Zhigansk in the night hours Esr with critical frequencies of \(~3\) MHz were registered during whole period. The enhancements of the auroral activity (AE index) were accompanied by bursts in the cosmic noise absorption and magnetic field variations at subauroral latitudes.
Variations of ionospheric parameters during two consecutive magnetic storms on 6-9 and 14-17 December 2006 and HILDCAA event (19-23 December 2006) are presented. In the main phase of the first magnetic storm an increase of critical frequencies of F2 layer and an occurrence of sporadic reflections in the E layer (Esr) at Zhigansk and Yakutsk at night was observed. During the main phase of the second magnetic storm at Zhigansk and Yakutsk there were no reflections from F2 layer due to the total absorption and blanketing by sporadic-E layers. It is noticed that at Zhigansk critical frequency of Esr reflections in the evening-midnight hours smoothly fell down about 6 MHz to 2 MHz on 6-9 December 2006 (the first magnetic storm) while for a strong magnetic storm on 14-17 December 2006 such reflections with foEs~6 MHz was basically registered on 14 and 15 December 2006. In the night hours on 14 December 2006 at Yakutsk there were abnormal reflections of F2 layer (F2s) with frequencies to 5 MHz testifying to displacement of plasmapause to low latitudes to L~3. Large bays in the cosmic noise absorption (more than 4 dB) at Kystatya and magnetic variations at Zyryanka were observed on 6-8 and 14-15 December 2006. On the path Magadan - Irkutsk on 15 December 2006 low MOF not exceeding 10-12 MHz in the afternoon was registered. In the afternoon (5-7 UT) these values have increased in 2 times and then have quickly decreased. On the path Norilsk-Irkutsk such MOF increase was not observed. It confirms occurrence of abnormal increase foF2 in the longitudinal sector of Yakutsk.

During HILDCAA event daytime critical frequency of F2 layer kept a constant (~5 MHz), except an interval of 23 December 2006 when foF2 has gone down to ~4 MHz. At Zhigansk Esr reflections with foEs~3 MHz were also registered.

On the basis of experimental data analysis it is possible to separate some types of the ionospheric disturbances registered at high-latitude stations.

The first type of ionospheric disturbances is connected with a response of the ionosphere to the magnetic storm showing decrease of critical frequencies in the day time during the main phase of a storm. These are typical negative disturbances which lead to considerable decrease of the maximum observed frequencies on the paths of oblique-incidence sounding.

The second type of ionospheric disturbances are the sporadic "thick" retarding E layers (Esr) and cosmic noise absorption (riometer). Their appearance is caused by a precipitation of electron fluxes with different energies (Besprozvannaya et al., 1991a).

The third type represents the anomalous reflections in the F2 region (F2s) in the night hours associated with a formation of the polar wall of main ionospheric trough and correspond to bordary of the diffuse aurora precipitation (Khalipov et al., 1977; Besprozvannaya et al., 1991b).

The fourth type is the peak of foF2 appearing in the auroral zone and moving to middle latitudes. It represents large-scale ionospheric disturbance (Pirog et al., 2007, 2010).

On middle latitudes (Irkutsk) fluctuations of foF2 in the day hours were observed during all chosen periods. Variations of MOF on the path Magadan-Irkutsk also show all noted above disturbances.

Thus, the obtained experimental data on a network of digital ionosondes of vertical and oblique-incidence sounding have shown that ground-based radio physical complex can be used for diagnostics of dynamics of large-scale ionospheric structures and corresponding to them the plasmapause and zones of diffuse and discrete aurora precipitation.

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