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REACTION OF THE LOWER POLAR IONOSPHERE TO X-CLASS SOLAR FLARES IN JANUARY 2005

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Abstract. The data of observations of the lower ionosphere above the settlement of Tumanny of the Murmansk region (69.0ºN, 35.7ºE) obtained by the method of partial reflections during strong solar flares on 15-20 January 2005 are provided. The relationship between splashes in X-ray and corpuscular radiations of the Sun and the effects, caused in the D region of the polar ionosphere under the influence of this radiation, is established.

Introduction

Investigations of influences of solar flares on the ionosphere of the Earth have been carried out for a long time [Mitra, 1977]. However, solar flares are not predicted yet, regular observations over conditions of the lower ionosphere are not conducted, and each solar flare represents a unique event. From this point of view registrations of ionospheric effects of new flares give additional information in the understanding of processes of electron concentration increase and a sudden change of ion chemical processes which takes place, mainly, in the lower ionosphere of the Earth. One of the ground methods of quantitative study of flares effects in the lower ionosphere is the method of partial reflections (PRM) [Mitra, 1977]. The purpose of the paper is to investigate the response of the D region of the polar ionosphere to strong solar flares of the class Xn ($n\times10^{-4}$ W/m^2) on 15-20 January 2005.

The means of observations and the method of investigation

The radar of partial reflections is near the settlement of Tumanny. The description of the radar and regimes of its operation are provided in the paper by Tereshchenko et al. [2003]. Observations were conducted on frequencies 2.65 ÷ 2.78 MHz at the pulse capacity of the transmitter of about 60 kW and 15-μs duration of pulse. Reception of scattered signals was carried out by the transceiving antenna with width of the direction diagram 19°×22° on the level of half power. Two circular polarizations, which were amplified by the receiver with a 40-kHz band, were radiated and accepted in turn. Registration of amplitudes of signals was carried out in the interval of heights of 50-146 km. A data reading step was 1.5 km. The receiving equipment is fitted with a multi-channel high-speed analog-digital converter and a computer for reception, processing and analysis of the data. The amplitudes of ordinary and unordinary components of the reflected signal were averaged for every minute from all registered heights. Using the average data, profiles of electron concentration $N_e(h)$ were calculated by the method of differential absorption of radiowaves as it was described in the works [Belikovich et al., 2003, 2004]. During these measurements additional geophysical equipment was used. It was a facility for measurements of ionospheric drifts, which used spaced reception of scattered signals, a magnetometer, and a riometer at the frequency of 32 MHz.

Results of observations

During the implementation of measurements by the PRM during the period from 15 to 20 January 2005 there were some large chromospheric flares taking place on the Sun. The strongest of them, flares of class Xn ($n\times10^{-4}$ W/m^2), were observed on 15 January at 0:43 and 22:58 UT - flares X1.3 and X2.7, respectively; on 17 January at 09:52 UT - the flare X3.9; on 19 January at 08:22 UT - the flare X1.4; and on 20 January at 07:01 UT - the flare X7.1. The data of satellites GOES-10 and GOES-12 about fluxes of X-ray radiation of the Sun in the ranges of 0.5-3 Å and 1-8 Å and about protons of high energy during these events are presented on the site [http://goes.ngdc.noaa.gov/data/avg/2005/]. The prominent feature of the observable phenomena was very high background of X-ray radiation which fluxes, before the strongest flares, were, respectively, $(0.6\text{-}1)\cdot10^{-6}$ W/m^2 in the range 1-8 Å and $(0.2\text{-}1)\cdot10^{-7}$ W/m^2 in the range 0.5-3 Å. For comparison we should note, that fluxes of X-ray radiation before the flare of the same class on 1 January 2005 were an order less.

In Figure 1 the height-temporal dependence of amplitude of the reflected ordinary wave A_0, averaged for a minute, during the considered period of observations is shown. In the same Figure the temporal profile of X-ray radiation of the Sun in the range of 1-8 Å is presented (according to satellite GOES-12 data) by a continuous curve.

At the registration of disturbances during the period from 6 to 13 UT on 15-20 January 2005 the solar zenith angle at heights of 50-80 km above Tumanny reached the values of χ = 81º-89º, i.e. the lower part of the D region of the ionosphere was shining with the Sun light. Therefore the increase in intensity of the X-ray radiation, observable during the strong flare of the class M8.7 on 15 January at 06:38 UT, has caused at once growth of electron concentration in the ionosphere and decrease of a reflecting layer height. Strong flares of X-ray radiation of the class X1.3, M8.5, M3.3 and X2.7, occurred in the dark ionosphere which was not lighted by the Sun at 0:43, 04:31, 14:22 and 22:58 UT respectively, for the obvious reason, did not change the position of the reflecting layer which was taking its place at heights from 80 till 95 km.

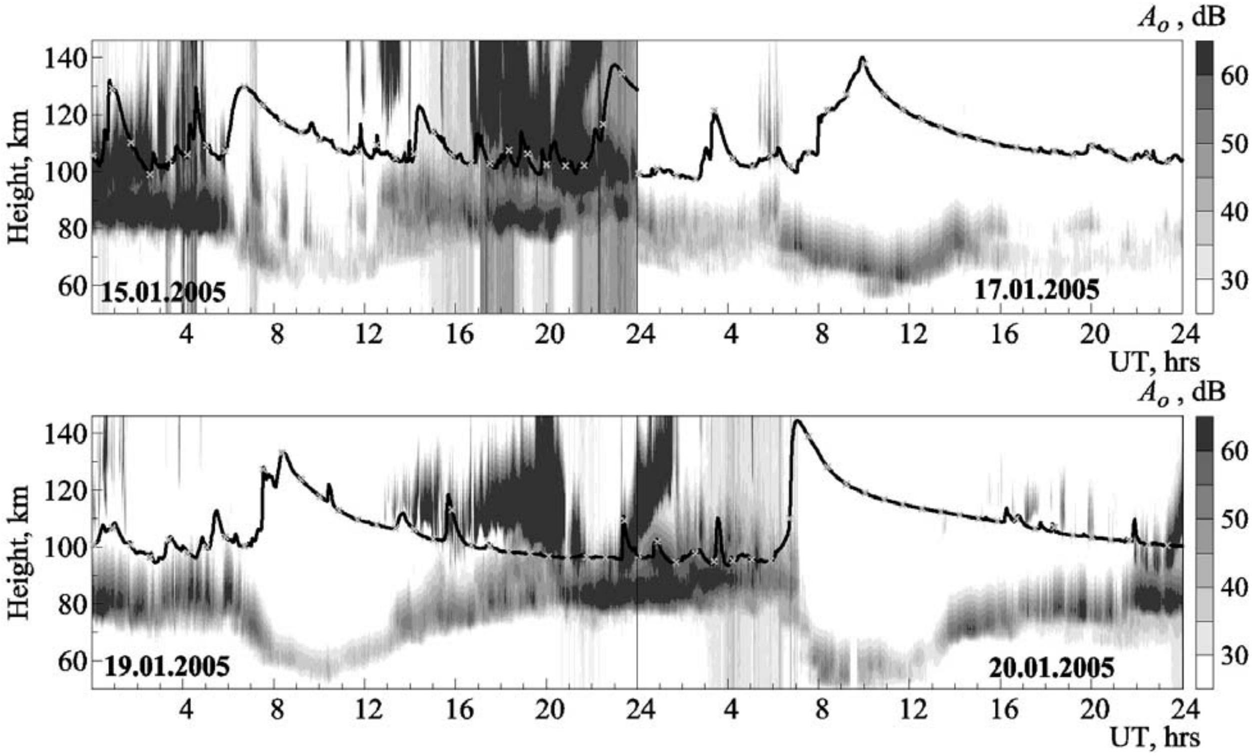

Figure 1. Radioecho amplitude of an ordinary wave depending on time and heights and a flux of X-ray radiation.

Similar variations of heights of the layer were observed on 17, 19 and 20 January (see Figure 1). It was noted that the higher the intensity of a flux of X-ray radiation was, the lower the layer of reflections fell. The absence of appreciable reflections from the heights of the E-region and from the upper D-region can be caused by strong absorption of radiowaves, and at lower heights (approximately 50-60 km) it can be caused by low electron concentration. We should note, that the method of PR has a threshold sensitivity of about 50-80 el/cm^3. From the comparison of satellite and ground data presented in Figure 1, one can see, that the temporal structure of solar flares is appreciably narrower than the corresponding structure of the reflection region.

Therefore, in the lighted conditions at heights of 50-70 km in the ionosphere the essential contribution to the formation of free electrons provids not only X-ray radiation of flares, but also the penetration of energetic particles. From Figure 1 it is seen, that during the period from 7 to 8 UT the basic contribution to ionization of the D region gives X-ray radiation of the Sun. Theoretical calculations showed, that at big zenith angles ($\chi \geq 87°$), the speed of ionization by solar protons with energies 2-60 MeV is an order higher, than the speed of ionization by strong X-ray radiation. At zenith angles of the Sun $\chi < 87°$ the effect from flares of X-ray radiation at heights of 55-60 km is comparable with that from proton penetration, and at smaller heights it can exceed it.

As a consequence of the strong solar flares (the class X) there were a significant modification of ionosphere structures and displacement of auroral processes to middle latitudes. The following phenomena can serve as an illustration of it: the full absorption of radiowaves in the E region on 20 January 2005 and partial absorption in the D region (Figure 1), the displacement of the auroral zone in the direction of lower latitudes (Figure 2), and also behaviour of electron concentration and riometric records of absorption in the polar cap (PCA), presented in Figure 3.

In Figure 3 it is seen, that at heights of 50-70 km the consequences of solar flares showed a substantial increase of electron concentration and its gradients in comparison with corresponding values at quiet and moderate solar activity. At these heights the electron concentration reached the values of 10^3 cm^{-3}, i.e. it increased approximately by an order of quantity and more. The reason of N_e increase at this time can be the change of conditions in the environment, destruction of ion clusters and photodetachment of electrons due to amplification of electromagnetic and corpuscular radiations of the Sun.

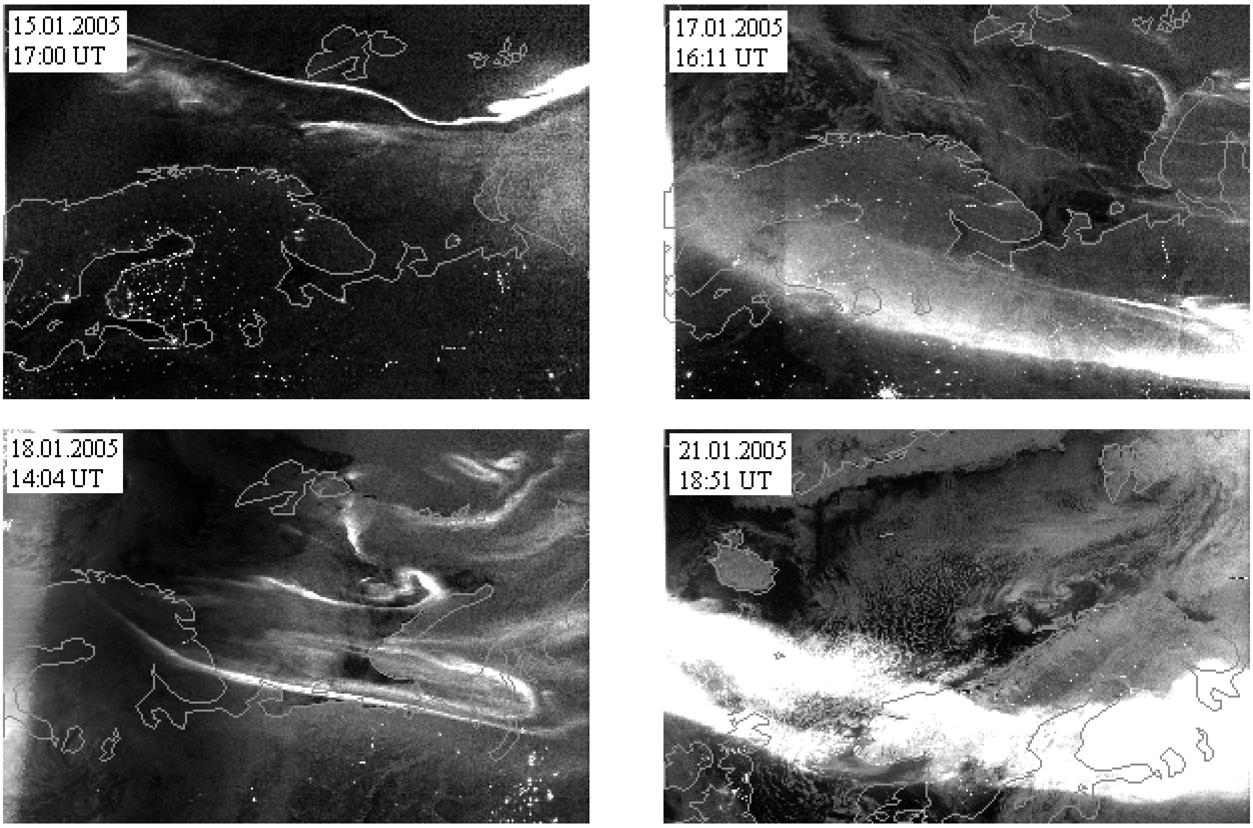

Figure 2. Aurora photos from satellites DMSP [http://spidr.ngdc.noaa.gov/spidr/index.jsp]

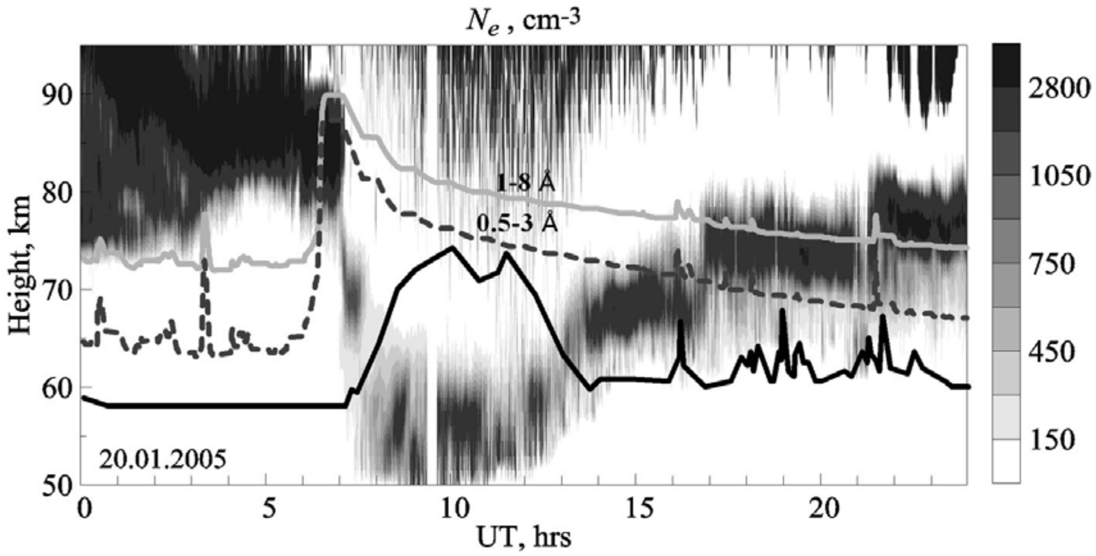

Figure 3. Daily course of electron concentration in the D region of the polar ionosphere, a flux of X-ray radiation (grey and dashed curves) and vertical riometric absorption (a black curve) on the frequency 32 MHz.

The analysis of the following measurements results has shown, that 3 days after the strongest flare on 20 January the disturbed ionosphere returned to the initial condition.

Discussion

The consideration of the radioreflection amplitude behaviour during the flares it is noted that the region of reflection has a small size at heights. The size depends on tool opportunities of the PRM and conditions in the environment. Apparently, the presence of high electron concentration and, hence, the strong absorption of radiowaves leads to the absence of partial reflections at heights exceeding 70 km, and zero concentration of electrons during the flares has no physical sense. Therefore, for data acquisition by the PRM in the big range of heights it is necessary to use a number of frequencies [Belrose, 1970].

For estimation of degree of disturbance of the geomagnetic field in January 2005 time dependence of the sum of three-hour K-indexes for every day has been considered. In result it has been established, that during the period from 17 till 19 January the level of the general geomagnetic disturbance was maximal ($\sum K \geq 50$). High values of fluxes of the hard X-ray radiation (0.5-3 Å) on 17 and 20 January, registered by satellites GOES, were accompanied by generation of solar protons right at the beginning of each strong flare. It is confirmed also with results of investigation of cosmic rays. Neutron monitors at the ground level during the considered period have shown Forbush-decrease of cosmic rays intensity up to 20 % [PGI Geophysical Data, 2005; <http://pgi.kolasc.net.ru>]. The effect happens very seldom and is connected to fluxes of high-energetic particles, erupted from the areas of the solar flares.

At present time we have good enough understanding of the physical mechanisms responsible for the basic displays of solar flares in the ionosphere, however, till now it is not managed to construct the full scheme of processes determining behaviour of charged particles which could be taken for a basis for construction of a dynamic model of the D region [Danilov, 1989]. Therefore there are required new experimental data which can be obtained by various ground radiophysical methods, and also by direct methods of local measurements with satellites and rockets.

Conclusions

In the given paper the influence of powerful solar flares, which took place on 15-20 January 2005, on conditions of the D region of the polar ionosphere was considered. With the help of the method of partial reflections abnormal values of electron concentration in the lower part of the D region and unusually low values of heights of the lower part of the ionosphere were detected.

It is shown, that the behaviour of electron concentration at heights of 50-70 km is controlled by X-ray radiation of solar flares and action of the solar protons penetrating to these heights. At the same time, variations of electron concentration coordinate well qualitatively with changes of vertical absorption of cosmic radio emission. In the lighted conditions ($81^\circ \leq \chi \leq 89^\circ$) efficiency of an X-ray source of ionization very strongly depends on a zenith angle of the Sun.

It is established, that 3 days after the strongest flare on 20 January the disturbed ionosphere returned to the initial condition.

The detected features in the behaviour of electron concentration during solar flares require further experimental investigations and theoretical understanding.

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