"Physics of Auroral Phenomena", Proc. XXVIII Annual Seminar, Apatity, pp. 182 - 185 , 2005

Polar Geophysical Institute

OBSERVATIONS OF THE IONOSPHERIC EFFECTS IN THE HIGH LATITUDE D-REGION DURING SOLAR FLARES IN APRIL, 2004

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Abstract. Observations of the polar lower ionosphere by the partial reflection technique during medium solar flares in April 2004 are presented. The electron concentration profiles in the D-region of the ionosphere and the effects of X-ray flares in the profile structure under both quiet and disturbed conditions are considered.

Introduction

Up to now the lower ionosphere (the range of heights of 50-90 km) remains insufficiently studied both experimentally and theoretically [Danilov et. al., 2001: Belikovich et. al., 2003]. The development of theory is prevented by complex ion composition, the absence of information on the rate constants of some reactions and poor knowledge of the altitude distribution of small components. These difficulties aggravate in the polar ionosphere, where most of time there are corpuscular sources of ionization due to precipitating energetic particles. Therefore, a simulation of the D-region still remains an urgent task.

To construct a dynamical model of the lower ionosphere, detail investigations of spatial and temporal changes of the D-region caused by perturbations of different nature are needed. The chromospheric solar flares are one of the most important natural sources of disturbances [Mitra, 1977]. In the ground observations, solar flares manifest in impulse ionizing effect on the Earth's atmosphere of X-ray and ultra-violet radiation, fluxes of cosmic rays, subrelativistic protons of the polar cap and electrons of auroras. Their interaction with the Earth's atmosphere causes a number of effects: a sudden growth of electron concentration in the lower ionosphere, modification of the D-region structure, increase of absorption of medium and short radiowaves, etc. [Mitra, 1977; Alpert, 1972; Belikovich et. al., 1975; Garmash et. al., 1999].

The purpose of the present paper is to investigate the reaction of the polar lower ionosphere to the solar flares of class M, using the data of the partial reflection facility of the Polar Geophysical Institute.

Characteristics of the facility and research technique

One of basic tools for quantitative study of flare effects in the lower ionosphere is the technique of partial reflections [Mitra, 1977]. The characteristics and pattern of the measuring complex of partial reflections of the PGI are described in the paper [Tereshchenko et. al., 2003]. The registration of the scattered signals by this facility is carried on continuously in the altitude range of 45-140 km during all periods of observations. The amplitudes of ordinary and extraordinary components of the signal are averaged over one minute at all heights from the range of interest. These data are used for a common assessment of observation results and then are also averaged over the intervals of 5-15 minutes. Using the averaged data, the profile of electron concentration $N_e(h)$ is calculated by the method of differential absorption of radiowaves, as described in [Belikovich et. al., 2004]. As a result, the effect of four solar flares in the D-region of the polar ionosphere during April, 2004, has been revealed.

Results of measurements and analysis

The flares were observed at the times given below and were characterized by corresponding integral fluxes of X-ray radiation in the wavebands of 0.05-0.3 nm and 0.1-0.8 nm (the data of GOES-10 satellite [ftp://ftp.ngdc.gov/STP/SOLAR.DATA]):

1) start – April 5 at 05:05 UT, max – 05:55, end – 06:14, flux – $0.028\ \mathrm{erg/(cm^2 \cdot s)}$;

2) start – April 6 at 12:30 UT, max – 13:28, end – 13:44, flux – $0.032\ \mathrm{erg/(cm^2 \cdot s)}$;

3) start – April 8 at 09:53 UT, max – 10:19, end – 10:47, flux – $0.015\ \mathrm{erg/(cm^2 \cdot s)}$;

4) start – April 11 at 03:54 UT, max – 04:19, end – 04:35, flux – $0.013\ \mathrm{erg/(cm^2 \cdot s)}$.

The fluxes of X-ray radiation before the flares made, respectively: $3.1 \cdot 10^{-7}$, $1.4 \cdot 10^{-7}$, $1.4 \cdot 10^{-7}$ and $9 \cdot 10^{-8}\ \mathrm{erg/(cm^2 \cdot s)}$.

The altitude-temporary behavior of the amplitude of an extraordinary wave A_x and electron concentration N_e in the D-region of the ionosphere, averaged every 15 minutes, during a flare on April 5, 2004, is shown in Fig. 1. One can see that under such conditions, at the heights of the D- and E-regions, there is a decrease in radioecho intensity of extraordinary polarization. At the same time, the electron concentration in the lower ionosphere grows.

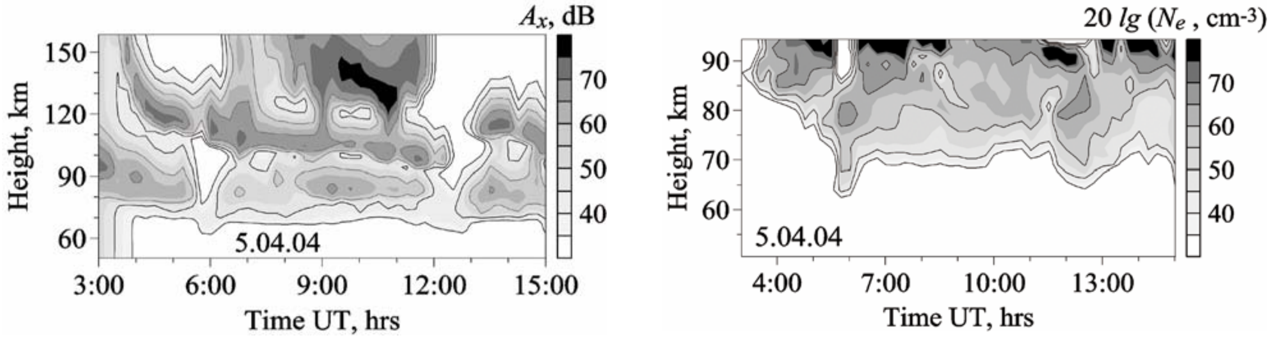

Fig. 1. The amplitudes of radioecho and electron concentration as functions of time and height.

The riometric records at the frequency of 32 MHz during the flare (Fig. 2) showed an impulse of solar radio emission with the duration of about 10 – 15 min (05:40-05:50 UT April 5, 12:30 – 12:45 and 13:10 – 13:25 UT April 6).

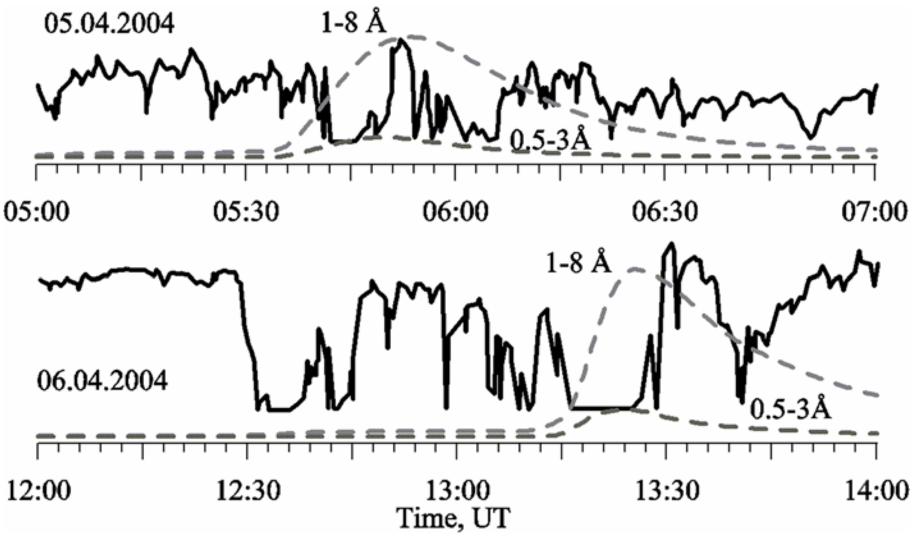

Fig. 2. Riometric records (solid curves) and X-ray fluxes according to GOES-10 measurements (dashed curves).

In Fig. 3 the altitude profiles of electron concentration with the time of averaging of 10 minutes in quiet conditions on April 2 (dashed curves), and during flare maximum on April 5, 6 and 8 (solid curves) are presented. The growth of electron concentration was accompanied by modification of D-region structure. It was seen a formation of additional ionospheric layers at the heights below 70 km. At maximum intensity of solar X-ray radiation, the electron concentration in the additional layers reached $(1.5-2.7)\cdot 10^3$ cm^{-3}. Under disturbed conditions, the additional ionization occurred at lower heights. The increase of ionization at the heights lower or close to 70 km is in a good qualitative agreement with a known effect of increase in the amplitude of long radiowaves [Mitra, 1977; Alpert, 1972; Belikovich et. al., 1975]. The occurrence of additional ionization in the lower D-region during flares can be explained by peculiarities of solar X-ray spectrum and altitude dependence of the recombination coefficient.

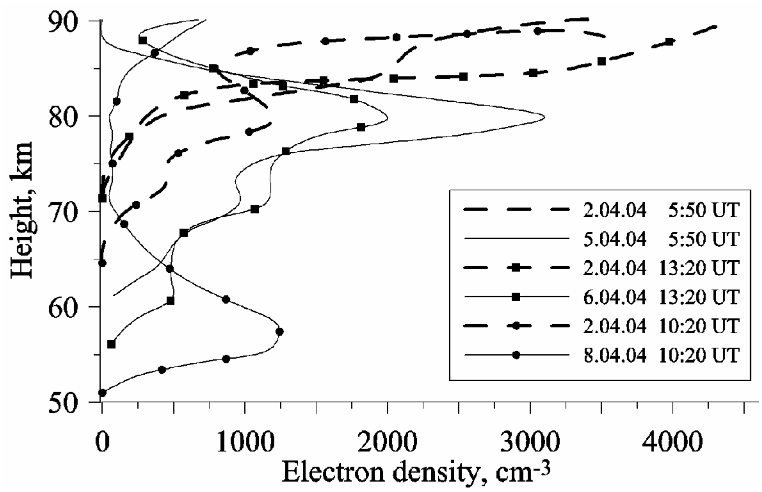

Fig. 3. Altitude profiles of electron concentration under quiet (April 2) and perturbed conditions (April 5, 6 and 8).

In Fig. 4, the altitude-temporal distribution and amplitude of the power spectrum of fluctuations of electron concentration during the solar flare on April 05, 2004, are presented. The appearance of wavelike variations can be seen in the isolines of electron concentration in Fig. 4. The temporary variations of electron concentration during a flare indicate the presence of wavelike perturbations of ionospheric plasma with a period longer than 3 minutes.

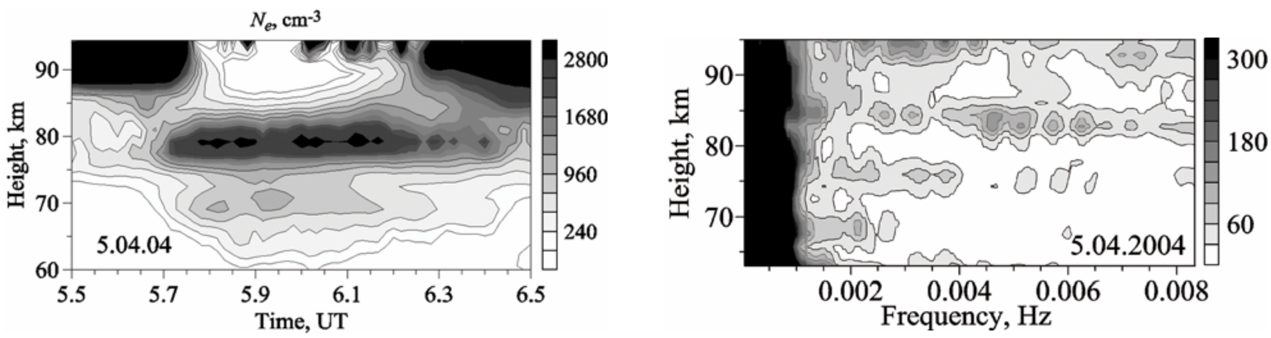

Fig. 4. Altitude-temporal distribution and amplitude of the power spectrum of the fluctuations in the electron concentration.

It is interesting to follow the variations of electron concentration N_e versus X-ray flare intensity *I* and the square root of intensity $I^{0.5}$. To find the relations at the fixed altitudes in the D-region, we used 5-min data of X-ray fluxes and electron concentration. As an example, in Fig. 5, such relations for an X-ray flux in the range 1 – 8 Å are given for April 5, 2004 at the altitudes of 62 – 80 km.

The calculations show that at altitudes below 74 km, the determination coefficient for the dependence $N_e(I)$ is higher that for the dependence $N_e(I^{0.5})$, suggesting a linear relation between the intensity of X-ray emission, which is proportional to the ionization rate, and electron concentration in the considered region. At the altitudes from 75 to 81 km, the determination coefficient is larger for the dependence $N_e(I^{0.5})$, i.e. we have a square-law recombination. Consequently, in the low part of the D-region we have a linear law of recombination, while at higher altitudes there is a square-law recombination. It should be noted that a conclusion about linear relation between ionization rate and daytime variation of electron concentration was also revealed in the paper [Belikovich et al., 2003].

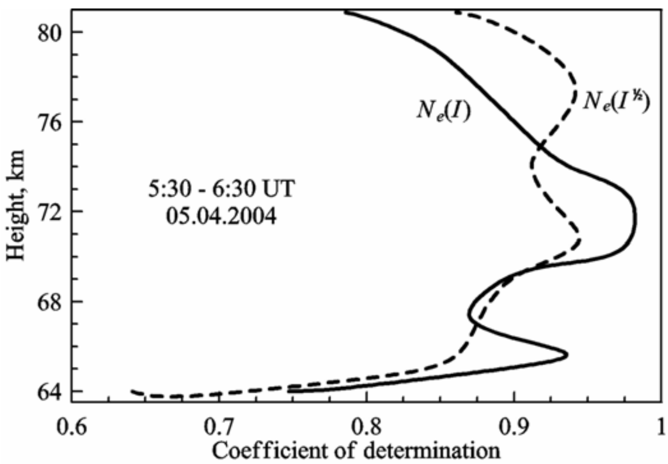

Fig. 5. The determination coefficients for rectilinear regress of electron density on the intensity of X-ray flare as function of height.

Conclusions

Thus, in association with medium solar flares, a two-layer region of additional ionization with the peak electron concentration of $2.7 \cdot 10^3$ cm^{-3} at altitudes lower than 85 km was detected in the polar ionosphere. The ionospheric effects of solar X-ray flares were accompanied by strengthening of absorption of middle radiowaves, splashes of cosmic meter radioemission and generation of infrasonic waves with a period of about 3 minutes and longer. The effects of solar flares depend on geophysical conditions in the ionosphere. They are most pronounced when there are no disturbances. It is shown that at the altitudes lower than 75 km, the electron concentration is proportional to the intensity of X-ray emission. This testifies the linear law of recombination at these altitudes. The above features in electron concentration behavior during solar X-ray flares require further experimental and theoretical exploring.

Acknowledgments. This study was partially supported by the grant № 05-05-64304 of Russian Foundation for Basic Research. This study is performed as a part of the basic research program №30 of the Presidium of RAS "Solar Activity and Physical Processes in the Sun-Earth system".

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