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THE STUDY OF THE IONOSPHERIC D-LAYER BY PARTIAL-REFLECTION TECHNIQUE AT MIDDLE AND HIGH LATITUDES IN THE SPRING OF 2004

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Abstract. Results of observations by the method of partial reflections of ionospheric effects of two solar flares in April 2004 are given. Investigations were implemented by measuring complex located at different latitudinal zones: Vasil'sursk (Nishegorodsky region) and Tumanny (Murmansk region). Quantitative estimates of electron concentration values in the polar and middle-latitude *D*-region during quiet conditions and the solar flares are obtained. Correlation of prompt variations of electron concentration at heights about 80 km at the observational points are found and it is shown that during the solar flares electron concentration at the heights of 60-70 km is followed by the intensity of X-ray flux in the range of 0.5-3.0 Å. The effect demonstrates functioning of a linear law of recombination in the D-region of the ionosphere.

Introduction

Registration and study of the ionospheric effects of solar flares permit to obtain interesting information about the processes in the low ionosphere [Mitra, 1977]. In particular, the measurements of electron concentration and fluxes of solar X-rays by spacecraft permit to find out an effective coefficient of recombination. [Benediktov, 1968; Belikovich et. al., 1971]. Interesting results were obtained in the investigations with the partial reflection technique conducted in March 2004 at Vasil'sursk (Nishegorodsk region, 56.1° N, 46.1° E) and Tumanny (Murmansk region, 69.0° N, 35.7° E). The present work is a result of common investigations, which were conducted by the NIRFI and PGI in accordance with a preliminary arranged program. The results of summer cycles of measurements, the parameters of the equipment and treatment techniques can be found in the papers [Belikovich et. al., 1973, 2003].

Results of observation

A spring cycle of simultaneous observations was conducted from March 31 to April 8 in Vasil'sursk and Tumanny. The period was characterized by rather high solar and geomagnetic activity. Therefore, in Tumanny, most of days were accompanied by the disturbances of auroral types and it was hard to compare the observations in Vasil'sursk and in Tumanny. However, the day of April 2 was quiet, which permitted to make a comparison of altitude profiles of electron concentration for this day. In Fig. 1, noon profiles $N(h)$ for Tumanny and Vasil'sursk are shown.

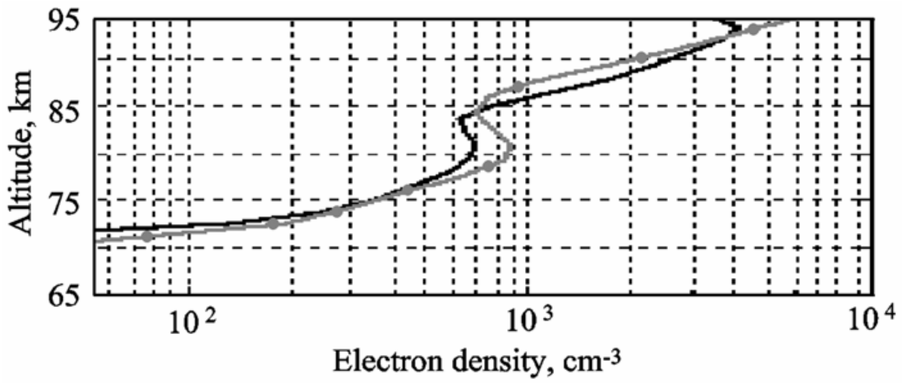

Fig.1. Midday electron density profiles for Tumanny (grey line with circles) and Vasil'sursk (black line) for 02 April 2004.

In Fig. 2 the behavior of electron concentration in the daytime at the heights of 72, 75 and 82 km for Tumanny and Vasil'sursk is shown. One can see a high correlation of concentration variations at the height of 82 km (upper lines) and, on the average, a good agreement at other heights.

As clearly seen from Fig. 1 and 2, for quiet conditions the electron concentration over Tumanny and Vasil'sursk agree well, with taking into account that at local noon a cosine of the solar zenith angle in Tumanny is 1.3 times smaller than in Vasil'sursk. The excess of high-latitude electron concentration over that in middle latitudes is not larger than 30 %. It should also be noted that there is a high correlation of electron concentration variations at the height of 82 km at these points, which are separated by more than 1400 km.

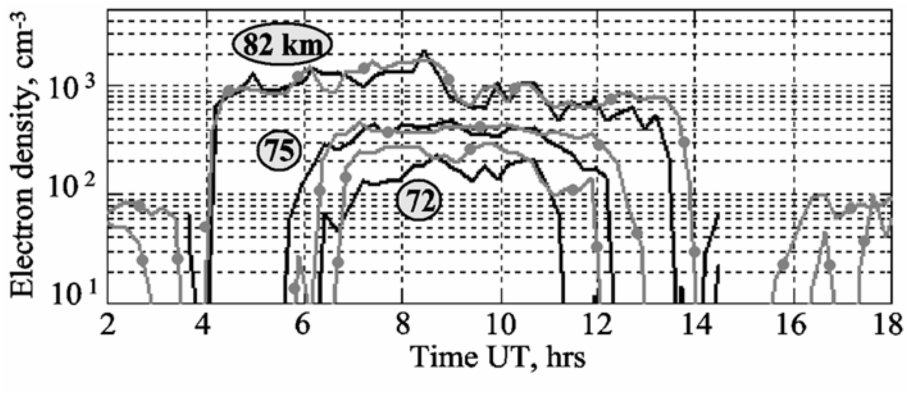

Fig. 2. Time variation of electron density at the altitudes of 72, 75 and 82 km for Tumanny (grey line with circles) and Vasil'sursk (black line).

In the period of measurements, there were several chromospheric flares on the Sun. Two of them, with the peak flux of X-ray emission exceeding 10^{-6} W/m^2, produced a considerable increase in the electron concentration, which was registered by means of partial reflections. The flare of the greatest interest was observed on 6 April 2004 at 13:48 UT with the peak flux of X-ray emission of $2.49 \cdot 10^{-5}$ W/m^2 in the waveband 1-8 Å and $4.23 \cdot 10^{-6}$ W/m^2 in the waveband 0.5-3 Å. At that time, in Tumanny a rather weak auroral disturbance was observed. An additional ionization, caused by an X-ray flare, was clearly seen against the background,.

Fig. 3 shows the behavior of electron concentration in Tumanny and Vasil'sursk at the two heights of 64 and 70 km. It should be noted that at high altitudes the amplitude of extraordinary component of the scattered signal becomes negligible and it reduces the accuracy of measurements. Besides, the values of concentration smaller than 10^{-3} cm^{-3} are not distinguished by the present equipment and technique of treatment.

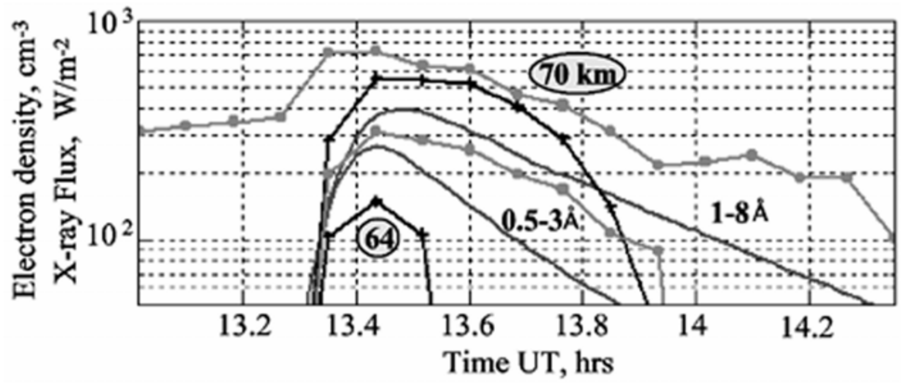

Fig. 3. Electron density at the altitudes of 64 and 70 km and temporary profiles of X-ray radiation during solar flare (solid black line) for Tumanny (grey line with circles) and Vasil'sursk (black line with crosses) 06.04.2004.

The values of concentration in Fig. 3 were obtained by 5-minute averaging, the time given in fractions of an hour. In this Figure the minute values of X-ray emission fluxes (solid curves) from the data of spacecraft GOES-10 [http://goes.ngdc.noaa.gov/avg/2004/G1010404.txt] are also given. It should be noted that at this time the solar zenith angle in Tumanny and Vasil'sursk was the same and equal to 73°.

From Figure 3 it follows:

1) temporal evolution of electron concentration is similar to that of the flux of X-ray emission in the range 1-8 Å or X-ray emission in the range 0.5-3 Å;

2) at the time of the flare, the electron concentration over Tumanny was approximately twice as high as that over Vasil'sursk.

The second flare occurred on April 8, 2004, at 10:23 UT with the peak flux of X-ray emission $7.8 \cdot 10^{-6}$ and $9.3 \cdot 10^{-7}$ W/м^2 in ranges 1-8 Å and 0.5-3 Å, respectively. At this time, an auroral disturbance was observed in Tumanny. An additional ionization caused by the X-ray flare was not practically seen against the background of the disturbance.

In Fig. 4, the behavior of electron concentration in Vasil'sursk at three heights 63, 67 and 77 km is shown.

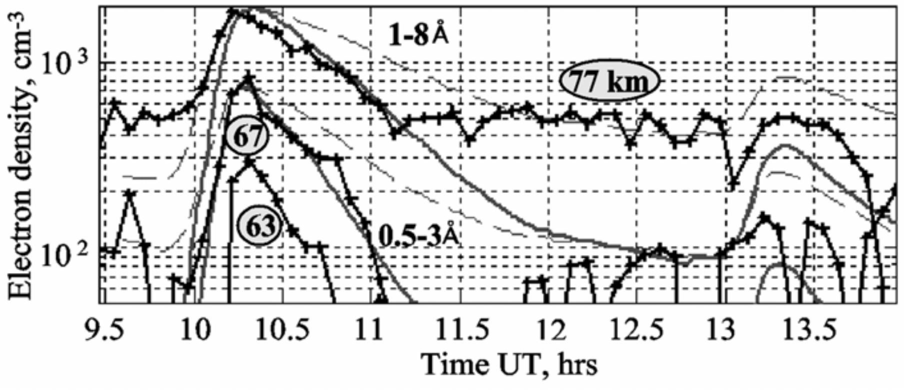

Fig. 4. Time variations of electron density at the altitudes of 63, 67 and 77 km during a solar flare for Vasil'sursk (line with crosses) on 08 April 2004. The solid lines are minute values of fluxes in the ranges 1-8 Å and 0.5-3 Å, multiplied by $10^{8.4}$ and $10^{8.9}$, respectively. The dotted lines are square root of the flux.

The values of concentration were obtained with 5-minute averaging, the time given in fractions of an hour. At 13:20 UT there was a repeated flare. As can be seen from the Figure, the small flare with the peak flux of X-ray emission of $1.4 \cdot 10^{-6}$ and $1.02 \cdot 10^{-7}$ W/m^2 does not lead to a noticeable increase in electron concentration. The most important conclusion from Fig. 4 is that the electron concentration strictly follows X-ray emission flux and not square root of the flux.

Discussion

A conclusion that the electron concentration during solar flares follows the intensity of radiation rather than the square root of intensity could be made long time ago. However, the authors were tending to the conclusion of the photochemical theory $N = (Q/\psi)^{0.5}$, where Q is the rate of electron production, ψ is the effective coefficient of recombination. Still, in the paper [Mitra, 1977], when analyzing the ionospheric effects of solar flares and cases of absorption in the polar cap, it was found that the value of ψ should decrease with the growth of Q for this equality to be satisfied. In the review [Itkina, 1978a], a conclusion was made that the effective rates of disappearance decrease with the growth of ion production function. Having analyzed about 300 solar flares with P being the flux of X-ray radiation within the range of 1-8 Å and A, the absorption of radiowaves at the frequency of 13 MHz, Itkina [1978b] found that $A \approx P^{0.8}$. This result is very close to the direct proportionality. We note that the proportionality of the daytime variation of electron concentration to the cosine of solar zenith angle is found in the paper [Belikovich et. al., 2003]. Thus there are plenty of facts suggesting the linearity of recombination law in the D region which now should be physically explained.

In our view, the explanation can be found in terms of dust or cluster. In this case, it should be adopted that the recombination of positive and negative charges basically occurs on dust particles. It is known that due to higher mobility of electrons compared to that of positive ions, the neutral particles gain a negative charge. On these negatively charged dust particles there occurs the recombination of positive ions. The number of dust particles in a unit volume is limited and not connected with the value of electron concentration. For the linear recombination law to hold, the dominance of the term containing dust particle concentration in the equation of ionization balance should be the case. A change in the concentration of dust particles will modulate the coefficient of electron losses. In this way, the seasonal and daily fluctuations of electron concentration can be easily explained. We note that the influence of meteoric dust on the effective recombination coefficient was considered as early as in 1966 [Parthasarathy and Rai, 1966]. The recombination on dust particles was also examined in a number of other papers (see, for example [Hodges, 1969]). In the recent years, the concept of dust plasma has been applied to the explanation of polar mesosphere echo [Havnes, 2004].

Above 80 km in the atmosphere, the atomic oxygen is present, which interferes in the formation of cluster. The fluctuations of this level will result in electron concentration changes. If such fluctuations cover a large area, this can explain the synchronous changes of electron concentration at the heights of ≈80 km.

Conclusions

1. In spring, the electron concentrations above Tumanny and Vasil'sursk are practically coincident under quiet conditions. The excess of electron concentration in the high-latitude D region as compared to middle latitudes is not more than 30 %. At the heights of ≈ 80 km, a high correlation of variations in the electron concentration in the sites, which are more than 1400 km apart, can sometimes be observed.
2. The X-ray radiation of solar flares with radiation intensity greater than $3 \cdot 10^{-6}$ and $3 \cdot 10^{-7}$ W/m^2 in the ranges 1-8 Å and 0.5-3 Å, respectively, causes an appreciable ionization at the heights of 60-70 km, easily determined by partial reflection technique. The electron concentration is proportional to the intensity of X-ray radiation, which testifies to the linear recombination law. It is possible to explain the linear law in terms of electron recombination on dust particles.
3. The above results are obtained based on a small amount of measurements and, therefore, require further studying. The hypothesis, relating the linear character of recombination law to the presence of dust plasma, requires a quantitative verification.

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