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Peculiarities of the Middle Latitude Ionospheric D-Region Dynamics, Caused by the Solar Terminator

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Using a partial reflection technique, there are carried out experimental investigations of electron density variations in the middle latitude D-region of the ionosphere, characteristics of partial reflection signals and radionoises during the morning and evening solar terminator passage. The electron density was found to increase by about 50-150% both during the terminator passage and after it. In order to explain such events, a hypothesis of electrons precipitating from the magnetosphere, which is caused by the solar terminator, was suggested. The main characteristic features during evening terminator passage are discussed.

1. Introduction

The morning solar terminator (henceforward the terminator) is a moving with the Earth velocity region of sharp changes in atmospheric equilibrium; therefore it is reasonable to expect that the terminator is a powerful natural source of various spatial-temporal disturbances in the Earth's ionosphere and atmosphere. A number of papers deal with investigating such phenomena (see, e.g. Antonova et al. (1988); Beley et al. (1983a, 1983b); Bezrodny et al. (1977); Belikovich and Benediktov (1986); Gokov and Gritchin (1994); Gokov and Tyrnov (2002); and Somsikov (1983, 1991, 1992)). Those of the first papers, in which there were experimentally found effects caused by the terminator, are papers Bezrodny et al. (1977) and Beley et al. (1983a, 1983b). On the basis of analyzing data on the Doppler frequency shift of a low frequency transmitter during the terminator passage across a radio wave path, it has been found in these papers that the terminator causes a quasi-periodic electron-density structure in the ionosphere, which moves in the wake of the terminator. The later papers deal mainly with studying parameters of the wave disturbances in the E- and F- regions of the ionosphere and investigating the atmosphere turbulence generation (see reviews in Somsikov (1991, 1992)). The terminator influence on the lower ionosphere D-region parameters is the least studied one, which is explained by difficulty in conducting long-time continuous (hours-days) systematic measurements. Along with other effects, we demonstrated increase in the electron density N in the D-region for the terminator passage (Gokov and Gritchin (1994), Gokov and Tyrnov (2002)).

This paper gives results of experimental investigations of the electron density changes in the middle latitude ionospheric D-region during the morning and evening terminator passage; these results being obtained by means of a partial reflection (PR) technique (Belrose and Burke (1964) and Belrose (1970)). A possibility of electrons precipitating from the magnetosphere, which is caused by the terminator, has been considered.

2. General information on the terminator

It should be noted that the optical terminator width determined by a time interval of the full solar disk appearing above the horizon in an optical range, is about 100 km, therefore a characteristic period of

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the optical terminator passage is ~ 5 min. Transient in the terminator range, setting changes in the atmospheric temperature, have a larger period, which is determined by a height distribution character of the atmospheric components absorbing solar energy, and therefore the terminator range width, L, will be significantly larger (L ~1000 km), a characteristic time of the passage being Δt ~30 min in the near-equator region (Somsikov (1992)). During the morning time, the terminator passage is accompanied by a number of physical processes in the atmosphere due to rapid increasing in the solar radiation flow. Their energy is rather high. In a similar way as it is done in Gokov and Chernogor (2000) for the solar eclipse, we estimate changes in internal energy of atmospheric gas having the volume V and mass m:

$$\Delta E = Cm\Delta T = C\rho V\Delta T = \frac{\pi}{4}C\rho d^2\Delta z\Delta T,$$

where ρ is the air density, Δz is the thickness of a heated air layer, C is the specific heat of air. Assuming that near the Earth $\rho \approx 1.3$ kg/m^3, $d \approx 1000$ km, $C \approx 10^3$ J/(kg·K), $\Delta z \approx H \approx 8$ km (H being the scale height), $\Delta T \approx 5$ K, we obtain $\Delta E \approx 4.1 \cdot 10^{18}$ J. We are going to believe that temperature increasing occurs within Δt not less than 30 min. At the same time, the average power, $P = \Delta E / \Delta t$, is about $2.3 \cdot 10^{15}$ W. The estimated ΔE exceeds the energy of a 200-megaton super-atomic bomb, the estimation of P being more than an order of magnitude larger than the power used by the mankind in 2000. As seen from these comparisons, the energy and power of a heat source of disturbances, caused by the morning terminator, are rather considerable.

Therefore it should be expect a number of characteristic changes in the ionospheric plasma (wave disturbances with various periods and duration, changes in a wind mode, and dynamics of the electron density, etc.) in the period of the morning terminator passage and after, which (depending on conditions in the Earth ionosphere, atmosphere and magnetosphere) will be repeated from day to day, demonstrating new characteristic features caused by other factors (for example, cyclic and sporadic changes in geomagnetic and solar activities, solar flares, magnetic storms, etc.).

Evaluations of changes in the specific internal energy, $\Delta\varepsilon$, and the specific power, p, of this source give $\Delta\varepsilon = \Delta E / V \approx 4.5 \cdot 10^3$ J/m^3 and $p = P / V \approx 2.5$ V/m^3. Powerful squalls and hurricanes (typhoons) have approximately the same specific characteristics but their energy release is connected with air mass motions.

The evaluations given are related to a near-equator region. At the middle latitudes, a size of the region disturbed by the terminator is larger (Somsikov (1992)) due to an inclination of the Earth rotation axis. Moreover, there exists dependence of the terminator parameters on the season. Thus, according to Somsikov (1983), at a certain latitude the terminator region width changes approximately by 10% from summer to winter. As there are different temperatures on the both sides of the terminator surfaces, i.e. in the illuminated and darkened regions, which also depend on the season, the amplitude of the disturbance and its other characteristics should also change during a year.

Taking into account that the duration, Δt, of the air temperature increase is about 30-60 min, a longitudinal size of the disturbed atmospheric region is $L \approx V_t\,\Delta t$. Assuming that at the middle latitudes the terminator velocity is $V_t \approx 350$ m/sec, we obtain $L \approx 1300$ km. Let a transverse size of this region be of the same order. Then, a change in the internal energy in the atmospheric region with the radius of $L/2 \approx 700$ km, under the average value of $\Delta T \approx 5$ K, is $2 \cdot 10^{19}$ J. The average power of $6 \cdot 10^{15}$ W corresponds to it. The largest cyclone (Chernogor (1998)) has approximately the same energy, and its power is about $3 \cdot 10^{14}$ W, which is more than an order less than the power given above.

With increasing the height z, energy characteristics decrease proportionally to the gas density, $\rho \propto \exp(-z/H)$. Thus, for instance, in the ozonosphere (the average height being 45 km) ρ decreases by three orders. For the same ΔT and H, the energy characteristics of the process connected with the terminator also decrease by three orders.

Thus, the energy, power and their specific values of the atmospheric processes caused by the morning terminator have large values. Therefore, there are strong grounds to believe that the terminator may cause disturbances in the atmosphere not only in the shadow or light shadow but far beyond their boundaries. As in the latitude region of $\pm 45^{\circ}$, the terminator velocity is larger than the acoustic velocity, then in this case a shock density wave is generated. Moreover, for the passing terminator, one should expect displaying (or enhancing) of atmospheric-ionospheric-plasmospheric relationships.

A not less interesting picture takes place during the evening terminator passage. In the evening the terminator passage is accompanied by a number of physical processes in the atmosphere due to the fast decrease of the solar radiation flux. Their power is high enough, it is comparable to the power of the processes during the morning terminator passage. The decrease of the internal energy in the atmosphere and the average power of a source will be approximately identical in magnitude you those in the morning (taking into account that the air temperature decrease duration Δt - as well as in the morning - is about 30-60 min). Thus, it should be expect an increasing or depresion of the atmosphere-ionosphere-plasmosphere interactions during the evening terminator passage and after it.

3. Equipment, methods of data measuring and processing

The probing of the ionospheric D-region during the terminator passage was performed with the MF radar (Tyrnov et al. 1994) located at the Radio-physical observatory of Kharkov V. Karazin National University (Ukraine) (see Table 1).

Table 1

Coordinates of Radio-physical Observatory of the Kharkov National University (Ukraine)

	Geographic		Geomagnetic				
Elevation (m)	Latitude (N)	Longitude (E)	Latitude (N)	Longitude (E)	Inclination	Declination (W)	L
156	49° 38'	36° 20'	45.37°	118.7°	66° 36.8'	6° 19.6'	~2.0

The main parameters of the facility are as follows: the operating frequencies being f = 2-4 MHz, the duration of sounding pulses being τ=25 mcs with the repetition frequency F = 1-5 Hz, the radiated pulse power being P_l = 150 kw, the antenna gain coefficient being G = 40-150. Amplitudes of mixing PR signals and noise of the ordinary and extraordinary polarizations, A_{mo}, A_{mx} (indices o,x), were recorded on a magnetic carrier after digitizing with the frequency of 1 Hz. In order to separate signal amplitudes A_o, A_x, on the noise background before radiating each sounding pulse, there were carried out 2-6 noise samples of A_{no} A_{nx}.

The measurements of A_{mo}, A_{mx} and A_{no} A_{nx} noise were carried out within a height range of 60-111 km for different seasons in the middle latitude near Kharkiv City (its geographic coordinates: φ = 49.5°N, λ = 36.3°E) over 1990-2003. The duration of continuous measurements was not less than 5-8 hours (both 2-4 hours before and after the terminator passage). The total number of observations is about 200 (approximately fifty-fifty for morning and evening conditions).

Estimating of the average intensities of the PR signal $<A^2_{o,x}>$ and noise $<A^2_{no,nx}>$ was made using 60 realizations over the 60 sec period. The statistical error of estimations obtained did not exceed than 10%. Using data on $<A^2_{o,x}>$ values, there was calculated their ratio, $R = <A^2_x> / <A^2_o>$, used further to obtain height-time electron density profiles, $N(z,t)$ (z is the height in km over the Earth surface, t is the time), in accordance with the differential absorption technique (Belrose (1970)) using the regularization algorithm (Garmash and Chernogor (1996)) according to Tikhonov et al. (1990). The $N(z)$ profiles were calculated for the average intervals of 10 min over the whole observation period with an error not more than 30%. The height-time $<A^2_{o,x}>(z,t)$, $<A^2_{no,nx}>(z,t)$ and $N(z,t)$ variations were analyzed.

For estimating slow variations of $<A^2_{o,x}>$ or $N(z,t)$, there was used an algorithm of the rapid Fourier transformation over the time interval of 64 or 128 min.

4. Experimental results

4.1. Morning Terminator

The analysis of the experimental $<A^2_{o,x}>(z,t)$ and $<A^2_{no,nx}>(z,t)$ -height-time dependences has shown that during the morning solar terminator passage in about 30-50 % of the cases the partial reflection signals from the ionospheric D-region irregularities were observed (Gokov and Gritchin (1994),Gokov et al. (1993), Gokov and Tyrnov (1998), Tyrnov and Gokov (1999, 2002a,b), Garmash et al (1998, 1999)). These signals occur, as a rule, for 10-50 min, then they disappear and are recorded again as coming from the same heights 1-2,5 hours after the morning terminator passage (in summer usually about 1 earlier hour than in winter). In about 70-75% of the cases the $<A^2_{o,x}>(z,t)$ and $<A^2_{no,nx}>(z,t)$ values at the fixed heights have a quasiharmonic character (the parameters of such quasiharmonic processes for various seasons on the whole are the same as those obtained by us earlier and analyzed in (Gokov and Gritchin (1994),Gokov et al. (1993), Gokov and Tyrnov (1998), Tyrnov and Gokov (1999, 2002a,b), Garmash et al (1998, 1999)); the lower boundary of the partial reflections becomes as to their height some kilometers (~5-8 km) lower the height range, Δz, of the partial reflections is usually ~ 10-15 km (rarely $\Delta z > 15$ km). Essential distinctions in the partial reflection signal behavior conditioned by the ionospheric D-region irregularities were not experimentally observed during the morning terminator passage in various seasons.

Our analysis of the $N(z,t)$ value has shown that approximately in ~ 25% of the cases during the terminator passage or soon after it (in ~30-60 min), increasing in the electron density in the ionospheric D-region by 50-150% takes place.

As a typical example, we consider two experiments where we observed unusual behaviour of characteristics both of PR signals and noise and the electron density in the upper part of the ionospheric D-region.

Figs.1a,b show time changes in $<A^2_{o,x}>$, Figs.2a,b show $R(t)$ dependences corresponding to them, and Fig.3 shows examples of height-time changes in N (the moment of the terminator passage is marked with a vertical line).

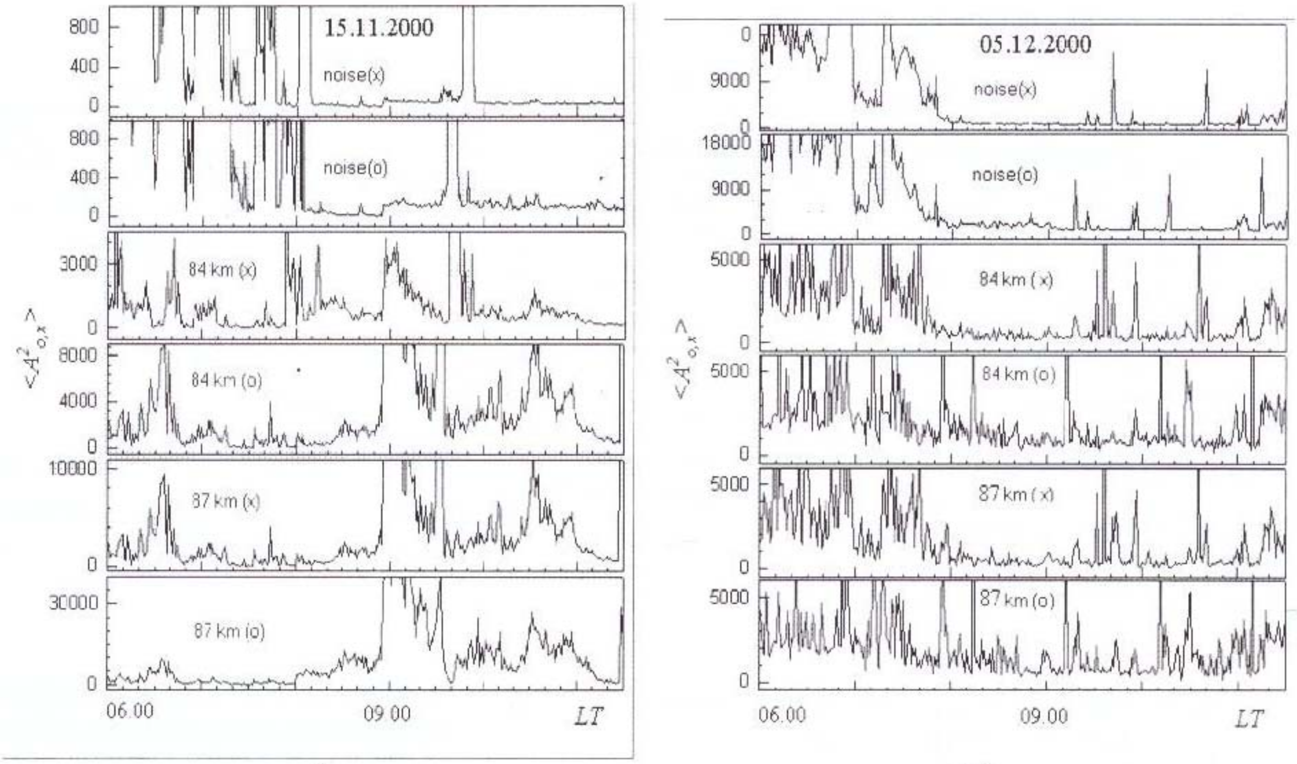
Note the main special features characteristic of other experiments as well.

1. Intensity of noise and their dispersion being several times smaller. This process starts just after the beginning of the terminator passage or some time before it (~30 min).

2. Increasing in the average intensities of a PR signal and its dispersion just after (sometimes in 10-30 min) or approximately 20-30 min before the terminator passage of ~ 30-90 min.

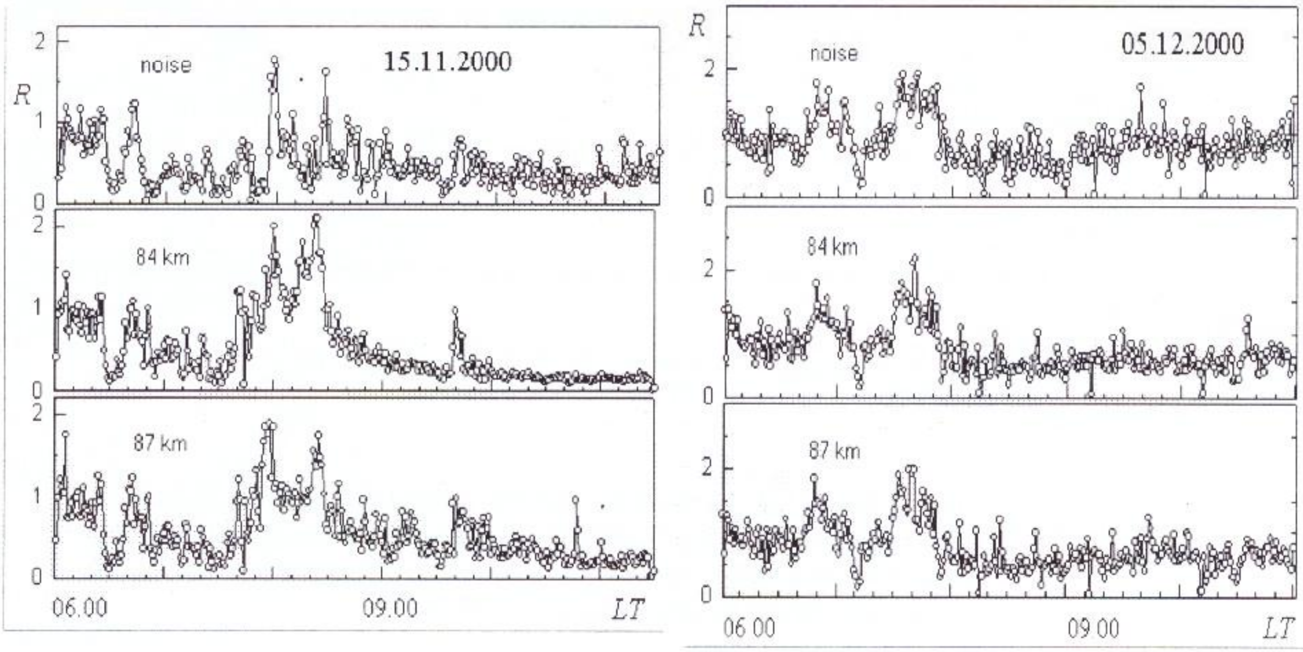
3. The R ratio being 1.5-2 times smaller after the moment of the terminator passage, and the presence of quasi-periods in the $R(t)$ dependences before this moment.

4. The N increasing during the terminator passage (in the experiment on 15.11.2000, the N increasing is observed near the moment of the terminator passage, and on 05.12.2000 40 min after it). The duration of such events is ~ 30-90 min.



a) b)

Fig. 1. Temporal dependences of radio noise and partial reflection signal intensities at the morning terminator passage.



a) b)

Fig.2. Temporal dependences of radio noise and partial reflection signal intensities ratio, $R = <A^2_x> / <A^2_o>$, at the morning terminator passage.

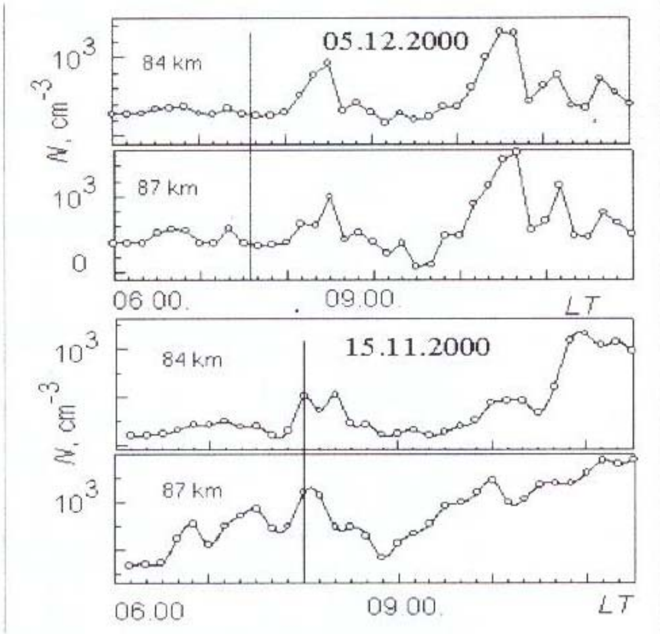


Fig. 3. Temporal variations of electron density at the morning terminator passage.

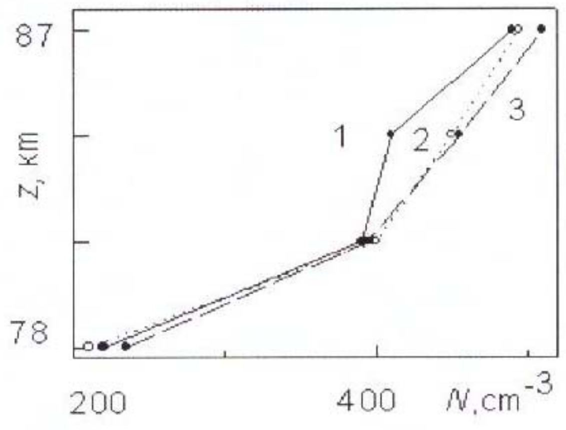


Fig. 4. Sample of *N(z)* profiles obtained on 22.03.89 after the terminator passage.

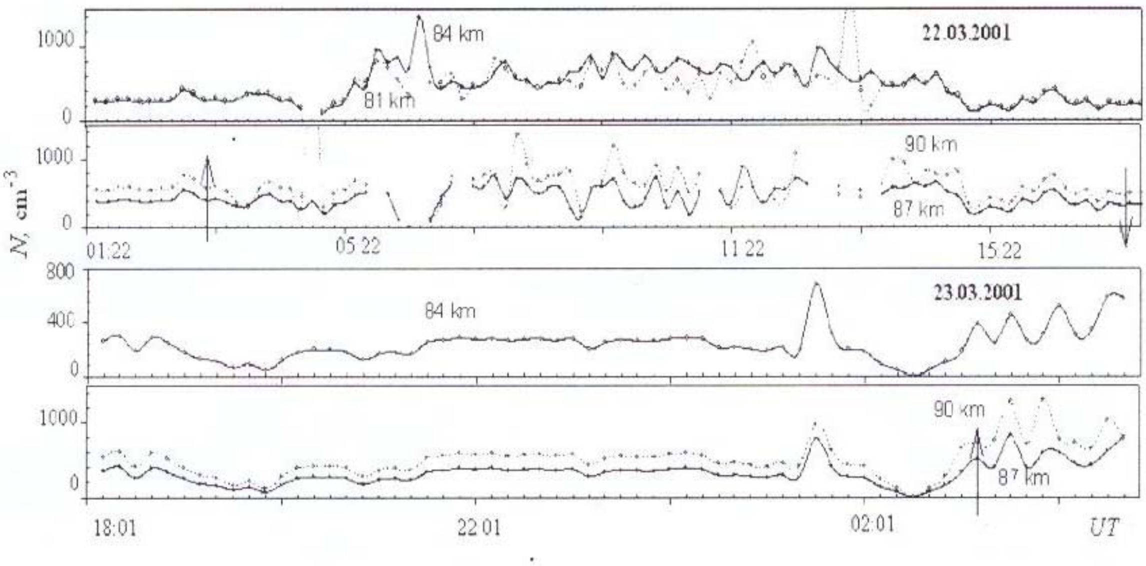


Fig.5 An example of the typical electron density in the middle-latitude ionospheric D-region variations including the morning and evening terminator passage periods (the terminator passage moments (for 85 km) are marked by arrows) on22-23.03.2001.

Fig.4 shows *N(z)* profiles obtained on 22.03.1989 after the terminator passage (curves 1-3 were obtained in succession within 30 min). It is seen from the figure that over this time interval, the *N(z)* profiles did not sufficiently change.

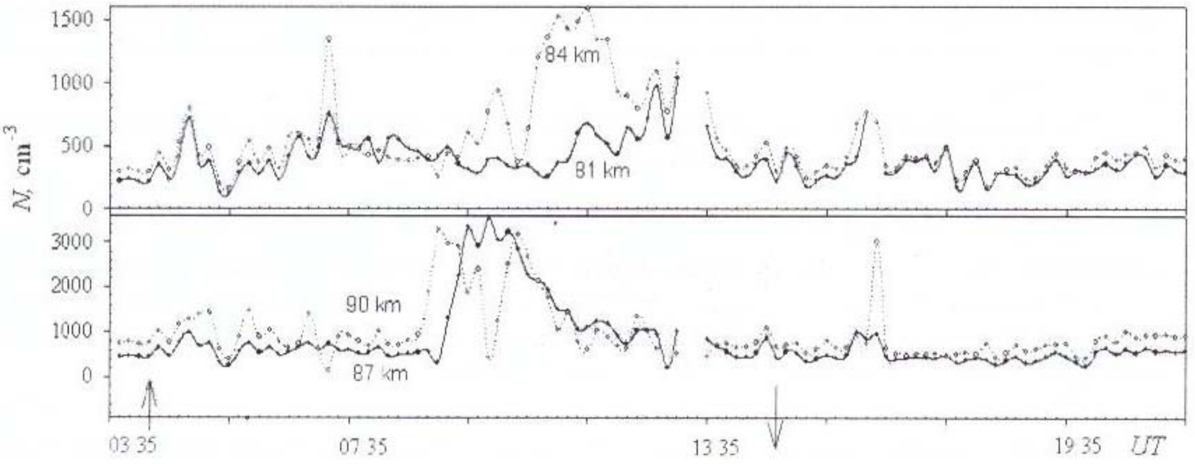


Fig.6. An example of typical electron density in the middle-latitude ionospheric D-region variations including the morning and evening terminator passage periods (the terminator passage moments (for 85 km) are marked by arrows) on 14.12.2000.

Fig.5 (the experiment was carried out on 22-23.03.2001) shows an example of the typical middle-latitude ionospheric D-region electron density behavior under the quiet conditions (under the quit geomagnetic conditions and without the charged particles precipitations, etc.). A diurnal variation of *N(z,t)* is clearly seen. A rather smooth increase in the electron density 70-80 min after the morning terminator passage (22.03.2001) and a smooth decrease in *N (z,t)* are clearly seen during the evening terminator passage (it is characteristic - as was marked in Gokov and Gritchin (1994) - that decreasing in the *N (z,t)* value begins 60-90 min before to the evening terminator passage). It is clearly seen here that on 23.03.2001, at once after the morning terminator passage, the electron density increasing in the ionospheric D-region by more than 50-100 % was observed (the terminator passage moments (for 85 km) are marked by arrows).

4.2. Evening terminator

In the evening the reconstruction in the ionospheric D-region begins approximately 1 to 1.5 hours before to the terminator passage. Intensity of PR signals decreases and during 30-60 min after the sunset a lower boundary of recorded partial reflections becomes higher by 10-15 km (an upper boundary rises by 8-12 km). The height-time changes in the PR signal characteristics, radionoise and parameters of the ionosphere have frequently quasi-harmonic characters. The analysis of the Kharkiv National University experimental data bank has shown, that the parameters of such quasi-harmonic processes for various seasons are on the whole the same as those obtained earlier and analyzed by us (Gokov and Gritchin (1994),Gokov et al. (1993), Gokov and Tyrnov (1998), Tyrnov and Gokov (1999, 2002a,b), Garmash et al. (1998, 1999)).

A represantative example of the electron density variation during the evening terminator passage is given in Fig.5. In this experiment during the evening terminator passage the *N (z, t)*-values in the D-region varied rather smoothly. In a number of other experiments (in about 20-25 % of the cases) during the evening terminator passage or soon after it (in 30-60 min) in the ionospheric D-region, a short-time (~20-50 min) increase in the electron density by more than 50-100 % takes place. Such changes in the electron density have frequently a quasi-harmonic character (with a process duration of 2-3 hours). Fig.6 shows a characteristic example of such height-time variations of the *N (z, t)* –value in the middle-latitude ionospherc D-region. It is well seen, that after the evening terminator passage distinct electron density increases by more than 50-100 % with a duration of 20-40 min were observed in this experiment within about 2.5 hours.

The feature in the electron density variations under consideration is observed approximately with equal repetition during all seasons as regular ones.

Based on the experimental data bank analysis we shall note the kay features of the height-time variations in the PR signal characteristics, radionoise and parameters of the ionosphere which are characteristic for the experiments which have been carried out during the evening terminator passage:

1. Becoming of the noise intensity and their dispersion some times larger. This process begins, as a rule, approximately 1 to 1.5 hours before the terminator passage commencement and proceeds within 1-2 hours after it (the noise intensity increase is about 10-100).

2. Becoming of the PR signals intensity and their dispersion some times smaller 1-1.5 hours before the terminator passage beginning and their full loss almost in all the height range in the D-region 30-120 min after the terminator passage.

3. Becoming of the R-values 1.5-4 times larger during and after the evening terminator passage and presence of the quasi-periods in the $R(z,t)$-dependences.

4. Short-time (about 20-50 min) increase in the electron density in the ionospheric D-region by 50-150 % within 1-2.5 hours during the evening terminator passage.

5. Calculation results. Discussion.

Let us discuss processes in the ionospheric D-region, accompanying the terminator passage.

Decreasing in the average intensities of noise and its dispersion may be explained as follows. The noise within ~2-3 MHz is a superimposition of signals from radio facilities operating in this range. The morning terminator passage is accompanied by increasing in both the electron density and radio signal absorption in the ionosphere over large areas having the characteristics size, L, of several thousand kilometers. Increasing in the absorption leads to weakening noise received by both the main lobe and lateral ones of the antenna pattern of the PR radar system consisting of the orthogonal vertical rhombs. An opposite effect occurs before the evening and during the evening terminator passage.

In order to explain the increasing in the average intensity of the PR signal and its dispersion, we take into account that (see, for instance, Chernogor (1985))

$$< A^2_{x,o} > \propto \frac{\overline{\Delta N^2}}{\Omega^2_{\pm} + \nu^2} \exp\left\{-4K_{x,o}\right\},$$

where $\overline{\Delta N^2}$ is the intensity of N fluctuations, $\Omega_{\pm} = \omega \pm \omega_L$, $\omega_L = 2\pi f_L$, $f_L = f_B \cos\alpha \approx 1.3$ MHz, f_B is the electron gyrofrequency, α is the angle between the vertical and the vector of the geomagnetic field induction, ν is the frequency of electron/neutral collision, $K_{x,o}$ is the integral coefficient of absorbing the PR signal by the x- and o- polarizations.

The morning terminator passage causes the following processes: 1) increasing in N and hence in $K_{x,o}$; 2) increasing in gas temperature and hence in ν; 3) considerable increasing in $\overline{\Delta N^2}$ (see Chernogor (1985)). All these three factors cannot fully explain the observed increasing in $<A^2_{o,x}>$. To do this requires to have the contribution of the latter to be more than those of the first two. It is only possible for a strong turbulization of the medium, which may be caused, for instance, by the flows of precipitating charged particles. Increasing in the dispersion of signal intensities does bear witness to a rate of change in the processes and also to incomplete subtracting of the noise. The noise dispersion over the same intervals increased as well.

The third effect is decreasing (during and after the morning terminator passage) and increasing (during and after the evening terminator passage) in the ratio of intensities, R, and of its dispersion, σ_R. In view of the fact that

$$R = \frac{< A_x^2 >}{< A_o^2 >} = \frac{\Omega_+^2 + \nu^2}{\Omega_-^2 + \nu^2} \exp\{-4(K_x - K_o)\}$$

and $\Omega_+^2 >> \nu^2$, $\Omega_-^2 >> \nu^2$ in the larger part of the ionospheric D-region ($z \approx 75 - 90$ km), the ratio of the intensities can be write as follows

$$R \approx \frac{\Omega_+^2}{\Omega_-^2} \exp\{-4(K_x - K_o)\}.$$

When the morning terminator passes, N and $K_{x,o}$ are increased. This leads to decreasing the R value. Besides, the R value becoming 2 times smaller during the terminator passage bears witness to increasing in N on the average by 30 % at 70 – 80 km. An opposite effect occurs before the evening and during the evening terminator passage. The σ_R increase is connected with increasing of nonstationarity of the medium.

The N increase observed during the and after terminator passage may be caused by the following causes:

1) ionization of NO molecules by means of scattered radiation in the Lyman-α (at the morning); at the same time, $\Delta N \leq 10^7$-10^8 m^{-3}, which cannot explain the N increase observed;

2) ionization of $O_2(^1\Delta_g)$ molecules by means of scattered solar radiation at the wave length of 102.7-11.8 nm (at the morning); at the same time, $\Delta N \leq 10^7$ m^{-3}, which is also small;

3) motions of the region of strong gradients of the atmospheric parameters at the morning and evening;

4) the terminator interaction with atmospheric irregularities;

5) radiation instability caused by the large gradient of the radiation flow;

6) increasing in the Railey-Taylor instability in the terminator region;

7) the presence of the magnetically-conjugated terminator causing a strong photoelectron flow from the magnetically-conjugated region;

8) ionization by means of energetic electron flows.

Out of the given sources, a flow of electrons from the radiation belt seems to be the most possible. Importance of the middle latitude particle precipitation was repeatedly discussed (see, for instance, Chernogor (1997); Chernogor et al. (1998); Garmash et al (1999); Gokov and Chernogor (2000); Gokov and Gritchin (1996); Gokov and Tyrnov (2000); Lyatsky and Maltsev (1983); Lastovicka and Fedorova (1976); Knut and Fedorova (1977); Knut and Vurzburger (1976); Hargreaves (1982)). The precipitation may arise as a result of pitch angle redistribution of the radiation belt particles; this may be caused either by configuration distortion of the field lines (geomagnetic traps) or by decreasing in the "transverse" energy, $\varepsilon_\perp$,of moving charged particles. Moreover, in the process of forming and relaxing disturbances of the conductivity tensor of the ionospheric plasma, the polarization field, E_p, has a vortical component, E_r, as well. The latter mechanism is considered in Garmash et al. (1988); Garmash and Chernogor

(1989); Garmash and Chernogor (1995); Garmash and Chernogor (1998). Under the terminator passage considerable changes in the ionospheric plasma conductivity tensor and variations of the electric field components E_φ and E_r are possible and hence the $\varepsilon_\perp$ components are possible as well.

On the basis of the suggested mechanism of high energy electrons precipitating from the radiation belt, we shall estimate the flow parameters as it is done in Chernogor et al. (1998); Gokov and Tyrnov (2000); Chernogor (1997) for ionospheric disturbance sources of another nature: rocket launches, magnetic storms, heating of the ionosphere by means of powerful radio-frequency radiation. From the experimental electron density values under the undisturbed N_0 and disturbed N conditions, we shall estimate the ionization rate, $q_0 = \alpha_0 N_0^2$ and $q = \alpha N^2$ ("o" corresponding to the undisturbed conditions). At $z > 75$ km in the D-region, the recombination of electrons with ions NO^+ and O_2^+ (which is proved to be correct by Danilov (1989)) is considered main, α changes approximately from 10^{-11} to $2\ 10^{-13}$ m^{3}sec^{-1} (further, we take $\alpha \approx \alpha_0$, i.e. neglecting the atmosphere heating under precipitating electrons). The flow density, P_1, of the power, P, of a particle having the ε energy will be taken as (see, for instance, Lyatsky and Maltsev (1983), Chernogor et al. (1998)) $P_1 \approx 2\varepsilon_i \Delta z \Delta q = \varepsilon p$, where $\Delta q = q - q_0$, $\varepsilon_i \approx 35$ eV is the energy of one ionization act, Δz is the height range of effective absorption of the p flow of electrons with the given ε energy (this expression is valid if one neglects the energy distribution of precipitating electrons). The P power and the E energy of electrons precipitating upon the S area for the precipitating durations, Δt, may be estimated for the relationships of $P = P_1 S$ and $E = P\Delta t$. In calculations on the basis of analyzing PR signals and $N(z,t)$, there was used $\Delta t = 1.2\ 10^3$ sec.

Calculation results of the given values for the experiments discussed are presented in Table 2.

Table 2.

The electron flow parameters.

Date	05.12.00		15.11.00	
z, km	84	87	84	87
N_0, m^{-3}	$3.5\cdot10^8$	$4.2\cdot10^8$	$2.5\cdot10^8$	$3.5\cdot10^8$
N, m^{-3}	$7.5\cdot10^8$	$8.0\cdot10^8$	$4.8\cdot10^8$	$8.0\cdot10^8$
q_0, m^{-3}sec^{-1}	$0.7\cdot10^6$	$1.8\cdot10^6$	$0.4\cdot10^6$	$1.3\cdot10^6$
q, m^{-3}sec^{-1}	$3.4\cdot10^6$	$6.4\cdot10^6$	$1.5\cdot10^6$	$6.4\cdot10^6$
P_1, J m^{-2}sec^{-1}	$1.9\cdot10^{-7}$	$5.1\cdot10^{-7}$	$4.1\cdot10^{-7}$	$1.4\cdot10^{-7}$
p, J m^{-2}sec^{-1}	$1.8\cdot10^7$	$3.4\cdot10^8$	$2.8\cdot10^7$	$9.4\cdot10^7$
ε, MeV	0.1	0.04	0.1	0.04
S, m^2	10^{14}	10^{14}	10^{14}	10^{14}
P, w	$2.9\cdot10^8$	$5.1\cdot10^7$	$4.1\cdot10^7$	$1.4\cdot10^7$
E, J	$3.1\cdot10^{11}$	$6.1\cdot10^{10}$	$4.9\cdot10^{10}$	$1.7\cdot10^{10}$
Δt, sec	$1.2\cdot10^3$	$1.2\cdot10^3$	$1.2\cdot10^3$	$1.2\cdot10^3$

For convenience of the calculations, we took $\Delta z = 10$ km, it was also assumed that the energy of precipitating electrons was $\varepsilon > 40$ keV, which was rather correct (see, for instance, data for solar flares and magnetic storms and other sources in Chernogor (1997); Chernogor et al (1998); Garmash et al.

(1988)). The calculation results presented correlate well with the known data on electron flows, experimentally obtained (or estimated) for disturbances of different natures. The densities of the electron flows and their energy characteristics are in accordance with the theoretical calculations from Chernogor (1997); Chernogor et al. (1998); they may fully provide increasing in the electron density, N, observed at 81-87 km. Estimations of E_p and E_r using method from Garmash et al. (1988); Garmash and Chernogor (1998), with account of the calculations conducted, showed that the mechanism discussed might be used for explaining the observed N changes.

6. Conclusion

1. An increase in the electron density in the middle latitude ionospheric D-region by approximately 50 to 150% was experimentally found both during the morning solar terminator passage and after it.

2. An short-time increase (~20-50 min) in the electron density in the middle latitude ionospheric D-region by about 50-150% during 1-2.5 hours was experimentally found after the evening solar terminator passage.

3. Within the hypothesis of electrons precipitating from the magnetosphere, calculations were carried out, and the possibility of electron precipitation caused by the solar terminator was shown.

4. The densities of the electron flows with energies of 40-80 keV have been estimated, the values of which were 10^7-$10^8 m^{-2}sec^{-1}$.

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References

1. Антонова В.П., Гусейнов Ш.Ш., Дробжев В.И. и др. Комплексное экспериментальное исследование волн в атмосфере, генерируемых солнечным терминатором (Complex experimental investigation of waves in the atmosphere, generated by the solar terminator) // Изв. АН СССР. Физика атмосферы и океана. - 1988. - Т. 26, № 5. - С. 837-841
2. Белей В.С., Галушко В.Т., Ямпольский Ю.М. Экспериментальные исследования перемещающихся ионосферных возмущений на параметры КВ радиосигнала (Experimental investigations of moving ionospheric disturbances affecting SW radio signal parameters): Препринт № 231. Харьков: ИРЭ АН УССР, 1983. - 16 с.
3. Белей В.С., Галушко В.Т., Ямпольский Ю.М. и др. Распространение радиоволн в ионосфере (Propagation of radio waves in the ionosphere). - М.: Наука, 1983. - 82 с.
4. Беликович В. В., Бенедиктов Е. А. Искусственные периодические неоднородности в нижней части Е-области на восходе и заходе Солнца (Artificial periodical irregularities in the lower part of the E-region at sunrise and sunset) // Геомагнетизм и аэрономия. - 1986. - Т. 26, №5. - С. 837-841.
5. Belrose J.S. Burke M.J. Study of the lower ionosphere using partial reflection. 1. Experimental technique and method of analysis // J. Geophys. Res. – 1964. – Vol. 69, No 13. - P.2799-2818.
6. Belrose J.S. Radio wave probing of the ionosphere by the partial reflection of radio waves (from heigths below 100 km) // J. Atmos. Terr. Phys. - 1970. - Vol. 32, - P.567-597.
7. Безродный В.Г., Блиох П. В., Салькович И.С. и др. О неоднородностях нижней ионосферы, движущихся за терминатором (On irregularities of the lower ionosphere, moving in the wake of

the terminator) // Тез. Докл. Семинара КАПГ по физике страто-мезосферы и нижней ионосферы. Ростов-на-Дону. М.: Наука, 1977. – 52 с.

8. Черногор Л.Ф. Современная наука о природе. Интегрирующий курс естествознания. Учебное пособие (Contemporary natural science. An integrating course. Textbook). - Харьков, 1998. - 240 с.
9. Черногор Л.Ф. Инфразвуковое воздействие землетрясений и их предвестников на параметры околоземного пространства (Infra-acoustic influence of the earthquakes and their precursors on the parameters of near-Earth space) // Радиофизика и радиоастрономия. - 1997. - Т. 2, №4. - С. 463-472.
10. Черногор Л.Ф. Возмущение неоднородной структуры в нижней ионосфере под действием мощного радиоизлучения (Disturbing of the irregular structure in the lower ionosphere influenced by powerful radiofrequency radiation) // Известия вузов. Радиофизика. - 1985. - Т.28, №12. - С. 17-
11. Chernogor L.F., Garmash K.P.,. Rozumenko V.T. Flux Parameters of Energetic Particles Affecting the Middle Latitude Lower Ionosphere. Radiofizika I Radioasronomiya. - 1998. - Vol. 3, No2. - P. 191-197,
12. Данилов А.Д. Популярная аэрономия (Popular aeronomy). - Л.: Гидрометеоиздат, 1989. - 230 с.
13. Гармаш К. П., Костров Л. С., Розуменко В. Т. и др. Глобальные возмущения ионосферы, вызванные стартом ракеты, на фоне магнитной бури (Global ionospheric disturbances caused the rocket lanch on the magnetic storm background) // Геомагнетизм и аэрономия. - 1999. - Т. 39, № 1. - С. 72-78.
14. Гармаш К.П., Черногор Л.Ф. Профили электронной концентрации D-области ионосферы в спокойных и возмущенных условиях по данным частичных отражений (Profiles of the ionospheric D-region electron density under quiet and disturbed conditions from data on partial reflections) // Геомагнетизм и аэрономия. - 1996. - Т. 36, №2. - С. 75-79.
15. Гармаш К.П., Шварцбург А.Б., Черногор Л.Ф. Возникновение крупномасштабных возмущений в ионосфере, инициируемых мощным нестационарным радиоизлучением (Appearing of large scale disturbances in the ionosphere, initiated by powerful non-stationary radio frequency radiation) // Компьютерная оптика. - 1988. - №6. - С. 62-71.
16. Гармаш К.П., Черногор Л.Ф. Эффекты в околоземной космической плазме, стимулированные воздействием мощного радиоизлучения (Effects in the near Earth plasma, initiated by powerful radiation) // Зарубежная радиоэлектроника. Успехи современной радиоэлектроники. - 1998. - №6. - С.17–40.
17. Гармаш К.П., Черногор Л.Ф. Влияние вихревой компоненты низкочастотного электрического поля, генерируемого при нагреве ионосферы мощным радиоизлучением, на параметры взаимодействия волна-частица (Influence of the vortex component of the low frequency electric field, generated under heating the ionosphere by powerful radio frequency radiation, on the parameters of wave-particle interaction) // Международный симпозиум "Спутниковые исследования ионосферных и магнитосферных процессов". Москва. ИЗМИРАН. 11-13 декабря 1995. Тезисы докладов. - 1995. - С.30-31.
18. Гармаш К.П., Черногор Л.Ф. Генерация и распространение электромагнитных волн, связанных с вариациями проводимости (Generation and propagation of the electromagnetic waves related to conductivity variations) // Всесоюзный семинар "Распространение радиоволн в ионосфере". Тезисы докладов. М.: Радио и связь, 1989. - С.70.
19. Гармаш К.П., Гоков А.М., Костров Л.С., Розуменко В.Т., Тырнов О.Ф., Федоренко Ю.П., Цымбал А.М., Черногор Л.Ф. Радиофизические исследования и моделирование процессов в ионосфере, возмущенной источниками различной природы. 1.Экспериментальная база и процессы в естественно возмущенной ионосфере (Radiophysical Investigations and Modeling of Ionospheric Processes Generated by Sources of Various Nature. 1. Experimental Technical

Precipitation of energy particles during a bay-like disturbance of the midlatitudinal D-region of the ionosphere) // Геомагнетизм и аэрономия. - 1977. - Т. 17, №5. - С. 854-861.

32. Кнут Р., Вюрцбергер И. Ионосферные возмущения на средних широтах, вызванные частицами высоких энергий (Ionospheric disturbances at middle latitudes, caused by high-energy particles) // Геомагнетизм и аэрономия. - 1976. - Т. 16, №4. - С.666-673.
33. Лаштовичка Я., Фёдорова Н.И. Международные координированные измерения геофизических эффектов солнечной активности в верхней ионосфере. 3.Необычное среднеширотное ионосферное возмущение корпускулярного происхождения (International coordinated measurements of geophysical solar-activity effects in the upper ionosphere. III. Extraordinary midlatitudinal ionospheric disturbances of corpuscular origin) // Геомагнетизм и аэрономия. - 1976. - Т. 16, №6. - С.1018-1025.
34. Ляцкий В.Б., Мальцев Ю.П. Магнитосферно-ионосферное взаимодействие (Magnetospheric-ionospheric interaction). - М.: Наука, 1983. - 192 с.
35. Сомсиков В.М. Солнечный терминатор и динамика атмосферы (Solar terminator and atmosphere dynamics). - Алма-Ата: Наука, 1983. - 192 с.
36. Сомсиков В.М. Волны в атмосфере, обусловленные солнечным терминатором (обзор) (Waves in the atmosphere, caused by the solar terminator (review)) // Геомагнетизм и аэрономия. - 1991. - Т. 31, №1. - С. 1-12.
37. Сомсиков В.М. О генерации турбулентности атмосферы солнечным терминатором (On the generation of atmosphere turbulence by means of solar terminator) // Геомагнетизм и аэрономия. - 1992. - Т. 32, №3. - С. 55-59.
38. Тихонов А.Н., Гончаровский А.В., Степанов В.В. и др. Численные методы решения некорректных задач (Numerical methods of the decision of incorrect problems).- М.: Наука, 1990. - 229 с.
39. Tyrnov O.F., K.P. Garmash, A.M Gokov, A.I. Gritchin, V.L. Dorokhov, L.G. Kontzevaya, L.S. Kostrov, S.G. Leus, S.I. Martynenko, V.A. Misyura, V.A. Podnos, S.N. Pokhilko, V.T. Rozumenko, V.G. Somov, A.M. Tsymbal, L.F. Chernogor and A.S. Shemet. The radiphysical observatory for remote sounding of the ionosphere // Turkish J. of Physics. – 1994. - Vol.18. - P.1260-1265.
40. Tyrnov O. F., Gokov A. M. Peculiarities of variations in ionospheric parameters of the lower D-region during natural disturbances // XXVIth General Assembly of the URSI (Toronto. Canada. August 13–21, 1999). Abstracts. Toronto: University of Toronto, 1999. - P.466.