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Middle Latitude Ionospheric D-Region Responses to Distant Launchings and Flights of Space Vehicles Investigated Experimentally by Means of a Partial Reflection Technique

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ABSTRACT. Possible changes in the electron density, N, in the middle latitude ionospheric D-region were investigated experimentally by a partial reflection technique over periods of launchings and flights of the variously typed rockets for different distances from launching sites. Rockets of medium and great powers were found to be able to produce short-time pulsed disturbances in the lower ionosphere electron density over distances up to several thousands of kilometers. It seems likely that these effects have been caused by stimulated pulsed electron flows coming from the magnetosphere into the lower ionosphere of the Earth, with their energy of $\sim 10^2 - 10$ KeV and flux density values of $p \sim 10^8 - 10^9 \mathrm{m}^2\mathrm{s}^{-1}$.

INTRODUCTION

Launchings and flights of space vehicles (SVs) with running engines and falls of SVs cause a number of processes in the ionosphere (see, e.g., [1 – 35]). Phenomena accompanying the rocket launchings, are remarkable for their variety, spatial-temporal, energetic, and other characteristics. They depend on the distance to a trajectory of the SV, its height, fuel type, engine powers and conditions of the ionosphere both over a launching site and a place of the flying SV, and at the observation station.

A classification of the ionospheric plasma disturbances occurring over the SV launchings and flights is usually made using their spatial scales. Disturbances with horizontal scales of $L_1 \leq 100$ km, $L_2 \sim 100 - 1000$ km and $L_3 \sim 1000 - 10000$ km are called the localized, large-scale and global, respectively.

The localized disturbances are closely adjacent to the rocket body, depending on its velocity, V, and engine thrust, F; they move with the rocket along the flight trajectory. Such disturbances were observed by many investigators after first launchings of the high-altitude rockets (in the late 1940s and early 1950s).

H.G. Booker was the first to record the large-scale disturbances in 1959 when the Vanguard – II, an artificial satellite of the Earth, was launched [1]. Blowouts of many tons of water and molecular hydrogen at the moment of the rocket launching were found to lead to decreasing the electron density, N, in the

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ionospheric plasma. This phenomenon bears a name of an ionospheric hole. Its size in the ionospheric F-region is $\sim 100 - 1000$ km, N becoming $2 - 3$ times smaller about $30 - 40$ min after a rocket launching. The hole lifetime is several hours. A horizontal size of the lower density increases, being $\sim 10 - 1000$ km for $z \sim 100 - 300$ km, respectively (z being the height above the Earth surface). Forming of the lower density is accompanied to produce the density waves with the effective velocity of $V \sim 0.1 - 1$ km/s and the periods of $T \sim 10 - 100$ min. Such disturbances are reviewed in [15].

The global disturbances in the ionosphere seem to have been discussed in [14, 20, 21] using the measurements by the techniques of the incoherent scattering and vertical sounding. Then the observations of such disturbances became complex [10 – 13, 18, 19, 22 – 28, 30 – 34]. Considerable attention is paid to seeking effects in the E- and F-region of the ionosphere, caused by influencing it with launchings and flights of the rockets and space vehicles. Owing to efforts of a number of investigators [10 – 13, 18, 19, 22 – 28, 30 – 34], at present there have been rather well (but far from a complete manner) studied main types, magnitudes and characters of the plasma disturbances in the ionospheric E- and F-regions, mechanisms of the disturbances transported over the global disturbances and their propagation velocity having been found out. The ionospheric plasma disturbances appear as a result of generating acoustic shock waves and waves having an electromagnetic nature (magneto-hydrodinamic waves of various types) (see, e.g., [24 – 26, 34]). This generation is caused by supersonic motions of a SV and its jet stream (fuel combustion) in the atmosphere and ionosphere, and a supersonic expansion of ionized matter of the stream in the Earth magnetic field. At the same time in the vicinity of the SV there appear quasi-periodic disturbances of the electron density, N, of the magnetic, ΔB, and electric, ΔE, fields with the amplitudes of $\sim 100\%$, $5 - 50$ nTesla and ~ 5 mkV/m $- 5$ mV/m, respectively. These disturbances propagate at the heights of the ionospheric E- and F-regions in quasi-horizontal directions, weakening mainly due to the wave divergence of no more than 1 or 2 orders of the magnitude. At the same time, the ionospheric plasma disturbances develop at the observation site, having the amplitude of $\Delta N / N \approx 10^{-2}$, which are experimentally recorded [24 – 26, 34].

Quite another thing is going at present with investigations of the lower ionosphere (the D-region) reaction to launchings and flights of SVs. The publications show only sporadic experimental investigations [18, 28–29, 31–32]. In the first place it is explained by intricacy of the composition and physicochemical processes occurring in the D-region, and also by difficulties in conducting prolonged experimental investigations. Therefore up to nowadays, investigators have an incomplete information on the characters and disturbance types of the ionospheric plasma parameters, mechanisms of the disturbances (if those are present) transported over the global distances, their propagation velocities, values of disturbances in the ionospheric D-region.

The paper presented shows experimental investigation results obtained by a partial reflection (PR) technique, concerning possible variations in the electron density of the middle latitude ionospheric D-region at the moments of distant launchings of various types rockets.

EQUIPMENT AND METHODS OF EXPERIMENTAL INVESTIGATIONS

For a number of years, experimental investigations were carried out at the V. Karazin Kharkiv National University Radiophysical Observatory situated in the vicinity of Kharkiv City by the facility for investigating the lower ionosphere by the PR technique [36] (see Table 1).

Table 1: Coordinates of V. Karazin Kharkiv National University Radiophysical Observatory

	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 PR technique facility when carrying out the investigations were as follows: the sounding frequencies being $f = 2.1$ and 2.31 MHz, the pulse duration being $\tau = 25$ mcsec with the repetition frequency of $F = 1$ Hz, the pulse power being $P \approx 150$ kW, the antenna gain coefficient being $G \approx 40$.

In the experiment height-time amplitude dependences of the mixture of the partially reflected signals and radio noise, $A_{so,x}(z,t)$, (where t is the time, "o" and "x" correspond to the ordinary and extraordinary polarizations, respectively) were recorded from 14 or 22 height levels, beginning from 45 or 60 km every $\Delta z = 3$ km. In order to select the amplitudes of partially reflected signals, $A_{o,x}(z,t)$, there were also recorded those of only radio noise, $A_{no,x}(z,t)$, (2-6 samples within the 50 kHz frequency band) at the moments preceding the radiation of a sounding pulse. The measurements of $A_{so,x}(z,t)$ and $A_{no,x}(z,t)$ were conducted in the course of the continuous observations lasting units-tens of hours.

Estimating of the mean values of PR signal intensities, $< A_{o,x}^2 >$, and of the noise, $< A_{no,x}^2 >$, was made by means of 60 realizations over a time interval of 60 sec. A statistical error in the estimating was not more than 10%. The height-time dependences of $< A_{o,x}^2 > (z,t)$ and $< A_{no,x}^2 > (t)$ were calculated.

Using the $< A_{o,x}^2 >$ data obtained, their ratio, $R(z) = < A_x^2 > / < A_o^2 >$ was calculated. The height profiles $R(z)$ were calculated over the averaging intervals of $\Delta t = 5$ and 10 min at the fixed heights with a step of $\Delta z = 3$ km. Thereupon by means of the differential absorption technique [37, 38] this ratio was used to obtain height profiles of the electron density, $N(z)$. Calculating of the $N(z)$ profiles was carried out by means of the methods from [39, 40] using a regularization algorithm.

When obtaining the $N(z)$ profiles, there was used a model profile of the electron-neutral molecule collision frequencies, $\nu(z)$, [41]. The errors in the $N(z)$ profile calculation over the averaging intervals of 10 or 5 min did not exceed 30% or 50%, respectively.

In order to estimate periods of rather slow variations in $< A_{o,x}^2 > (z,t)$ and the electron density, $N(z)$, a quick Fourier transformation algorithm over the time intervals of 32, 64 and 128 min was used. At the same time, the time series was formed out of the every-second values of $A_{no,x}(z,t)$, $A_{o,x}(z,t)$ and $A_{no,x}(t)$. Height-time variations in the $< A_{o,x}^2 > (z,t)$, $< A_{no,x}^2 > (t)$ and $< A_{no,x}^2 > (z,t)$ values obtained were analyzed.

The distance between the launching rocket site and the observation site was $R_1 \approx 700 - 10000$ km. 200 experiments were analyzed. About 150 experiments out of them were made during the night SV launchings and over the periods of morning and evening solar terminator passes. The analysis of these mass data has shown that in these experiments we cannot unambiguously relate changes in characteristics of the PR signals and radio noise, and also of the ionospheric parameters to the ionospheric disturbances caused by the SV launchings and flights. Therefore we separately analyzed the data obtained during the daytime when possible changes in characteristics in the PR signals, radio noise and ionospheric parameters might be identified with the disturbances considered.

Table 2 shows the main information on the experiments conducted during the daytime; the SV information has been taken from URL: http//www.space.com.

Table 2: Information on experiments for rocket launchings

Data	Vehile type	Launching site (Cosmodrome)	Geographycal latitude, longitude, *degree*	Distance, *km.*	Min. and max. orbit inclination, *degree*	Launching time, UT
15.05.1997	Soyuz	Baikonur (Russia, Kazachstan)	45.36 N 63.26 E	2050	49 99	12:10
13.08.1998	– / –	– / –	– / –	– / –	– / –	09:43:11
26.02.2001	– / –	– / –	– / –	– / –	– / –	08:09

28.04.2001	–/–	–/–	–/–	–/–	–/–	07:37
25.04.2002	–/–	–/–	–/–	–/–	–/–	06:26
26.06.2002	–/–	–/–	–/–	–/–	–/–	05:36:02
02.02.2003	–/–	–/–	–/–	–/–	–/–	12:59:40
15.05.1997	Atlantis	Cape Canaveral, (USA)	28.45 N 80.53 E	9330	28 57	08:07:48
24.05.1997	–/–	–/–	–/–	–/–	–/–	12:33
07.10.2002	–/–	–/–	–/–	–/–	–/–	18:45:41
12.07.2000	Proton	Baikonur (Russia, Kazachstan)	45.36 N 63.26 E	2050	49 99	04:56:36
20.11.1998	–/–	–/–	–/–	–/–	–/–	06:40
17.10.2002	–/–	–/–	–/–	–/–	–/–	04:41
21.10.2000	Zenit	Launched from sea level (Ukraine, USA)				05:52
17.07.1999	–/–	–/–	–/–	–/–	–/–	06:38
25.08.1997	Delta-2	Cape Canaveral, (USA)	28.45 N 80.53 E	9330	28 57	14:39
24.10.1998	–/–	–/–	–/–	–/–	–/–	12:08
10.06.1999	–/–	–/–	–/–	–/–	–/–	13:48:43
30.01.2001	–/–	–/–	–/–	–/–	–/–	07:55
18.10.2001	–/–	–/–	–/–	–/–	–/–	18:51
04.05.2002	–/–	–/–	–/–	–/–	–/–	09:54:58
03.07.2002	–/–	–/–	–/–	–/–	–/–	06:47:41
20.11.2002	–/–	–/–	–/–	–/–	–/–	22:39
20.12.2000	Ariane	Kourou (France)	5.2 N 52.73 E	9500	5 100	12:26
09.06.2001	–/–	–/–	–/–	–/–	–/–	05:45
05.06.2002	–/–	–/–	–/–	–/–	–/–	06:44
14.07.2000	Atlas	Cape Canaveral, (USA)	28.45 N 80.53 E	9330	28 57	05:21
21.02.2002	–/–	–/–	–/–	–/–	–/–	14:43
23.07.1999	Columbia					04:28
16.01.2003	–/–	–/–	–/–	–/–	–/–	15:39
07.08.1997	Discovery					14:41
19.08.1997	–/–	–/–	–/–	–/–	–/–	11:08
17.03.2002	Rokot	Baikonur (Russia, Kazachstan)	45.36 N 63.26 E	2050	49 99	09:21
30.06.2003	–/–	–/–	–/–	–/–	–/–	14:15
06.08.2001	Titane	Cape	28.45 N	9330	28	07:28

heavy weight SVs, their engine powers being ~10^{10} – 10^{11}W, and their released energy being not less than 10^{13} J.

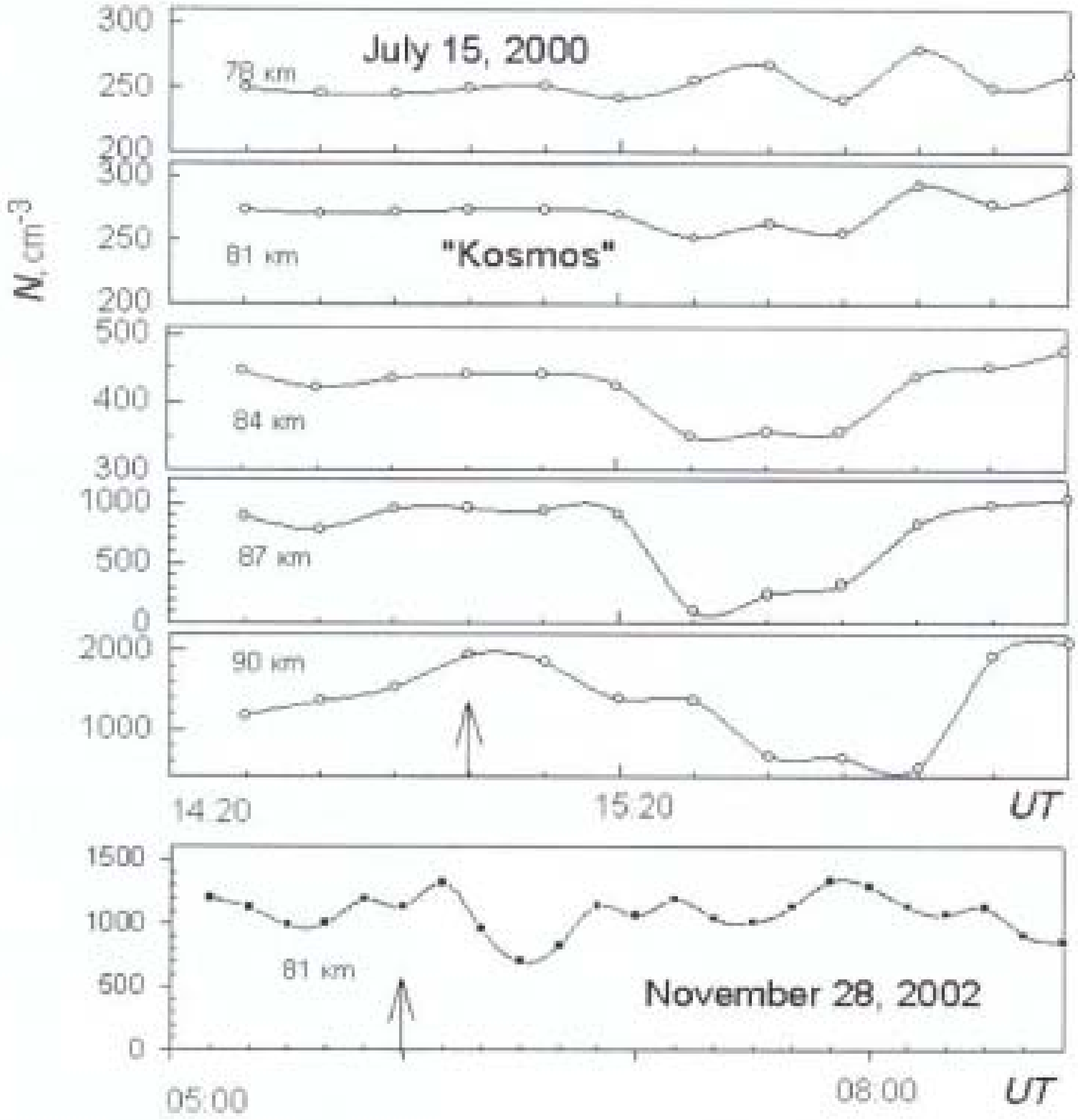

FIGURE 1. Height-time electron density variations in the middle latitude ionospheric D-region over the launching period of SV "Kosmos" (the time of SV launching is marked by arrow).

Over the launching period of "Zenit" on 17.07.1998 at 87 – 90 km 10 – 15 min after the launching, the *N* value decreased by ~50% for about 30 min, then (about 45 – 55 min after the launching) throughout the D-region, quasi-periodic *N* changes with the ~50 – 100% amplitude were observed for about 3 hours (see an example of Fig. 2b). The total weight of this type rockets was about 480 tons, the starting thrust being about 770 000 kgf. The burning time of the first and second stages was 150 and 315 sec, respectively. The "Zenit" rockets belong to the heavy weight SVs, their engine powers being ~10^{10} – 10^{11}W and their released energy being not less than 10^{13} J.

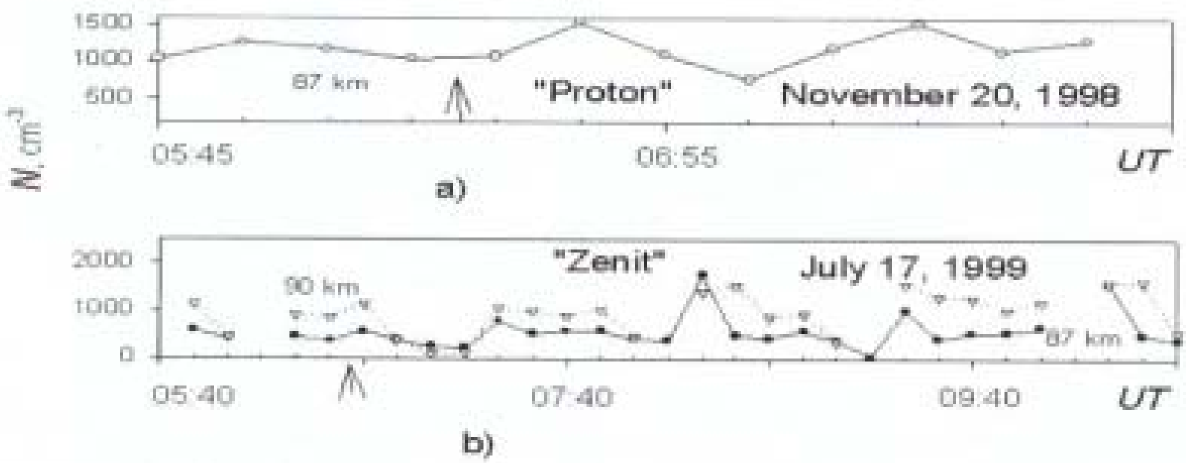

FIGURE 2. Height-time electron density variations in the middle latitude ionospheric D-region over the launching period of SVs "Proton" (a) and "Zenit" (b).

For the launching "Soyuz" SV there were found the following main special features in the N changes (the total weight of this type rockets was about 300 tons, the starting thrust being about 410 000 kgf, the burning time of the first and second stages was 150 and 315 sec, respectively. The "Soyuz" rockets belong rather to the heavy weight SVs, their engine powers being $\sim 10^{10} - 10^{11}$W, and their released energy being not less than 10^{13} J.):

– 26.02.2001: quasi-periodic N changes at 81 – 84 km with the ~50 min amplitude 40 – 50 min after the launching for about 3 hours;

– 02.02.2003: quasi-periodic N changes throughout the D-region with the $\geq 50\%$ amplitude and the ~50 min period 40 – 50 min after the launching for 2 – 2.5 hours;

– 13.08.1998: quasi-periodic N changes at $z \geq 93$ km with the ~50 – 100% amplitude and the ~ 30 – 40 min period 10 min after the launching. An example of such $N(z,t)$ variations is shown in Fig 3.

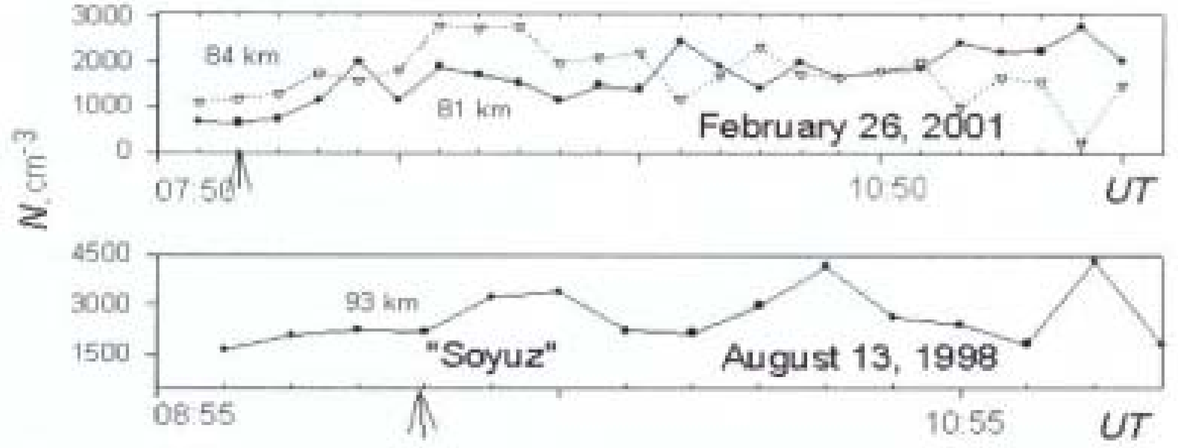

FIGURE 3. Height-time electron density variations in the middle latitude ionospheric D-region over the launching period of SV "Soyuz".

For the launching "Delta-II" SV, the following characteristic of the special features in the N changes were found: quasi-periodic N changes at $z \geq 84$ km with the ~50 – 100% amplitude and the ~ 30 – 40 min period 10 after the launching. An example of such variations is shown in Fig. 4. The total weight of this type rockets was about 230 tons, the starting thrust being about 360 000 kgf. The burning time of the zeroth, first, second and third stages was 64, 265, 444 and 880 sec, respectively. The "Delta-II" rockets belong rather to the medium weight SVs, their engine powers being $\sim 10^9 - 10^{10}$W, and their released energy being no less than 10^{12} J.

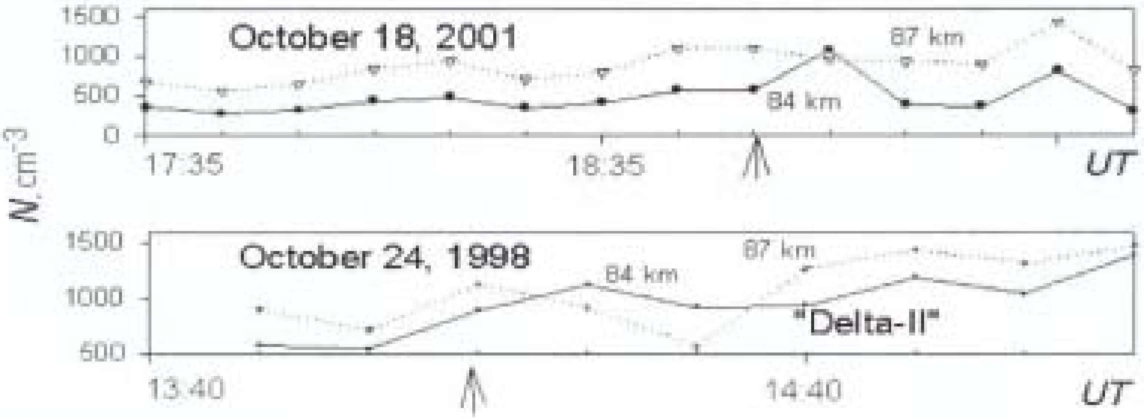

FIGURE 4. Height-time electron density variations in the middle latitude ionospheric D-region over the launching period of SV "Delta-II".

For the launching "Atlas" SV on 21.02.2002, the electron density at 84 km 10 – 15 min after the launching increased by about 80% within 25 – 30 min with a subsequent typical diurnal variation. The total weight of this type rockets was 234 tons, the starting thrust being about 362000 kgf. The burning time of the zeroth, first, second and third stages was 56, 172, 283 and 393 sec, respectively. The "Atlas" rockets belong to the medium weight SVs, their engine powers being $\sim 10^9 - 10^{10}$W, and their released energy being no less than 10^{12} J.

For the launching "Ariane" SV on 05.06.2002, the electron density at 84 km 35 – 45 min after the launching increased by about 100% within 25 – 30 min with a subsequent quasi-periodic changes having an amplitude of ~50 – 100% (see an example of Fig. 5). The total weight of this type rockets was 470 tons, the starting thrust being about 550 000 kgf. The burning time of the zeroth, first, second and third stages was 142, 205, 325 and 759 sec, respectively. The "Ariane" rockets belong to the heavy weight SVs, their engine powers being $\sim 10^{10} - 10^{11}$W, and their released energy being no less than 10^{13} J.

Over the launching periods of the "Columbia" and "Atlantis" SVs, the clear-cut N changes related to the launchings were missed as the launchings occurred near the period of the terminator passing over the observation station, and therefore it was not possible to identify unambiguously the observed N changes.

Searching for effects caused by a launching heavy weight rocket (400 tons) GSVL is of great interest. The rockets of this type were launched from a launching site in India, the distance to the observation site being about 5600 km. For the launching SV on 18.04.2001, the following characteristic features were found in the N changes: quasi-periodic N changes at $z \geq 84$ km with an ~50 – 100% amplitude and ~30 – 40 min period are about 10 min after the launching. An example of such variations is shown in Fig. 5.

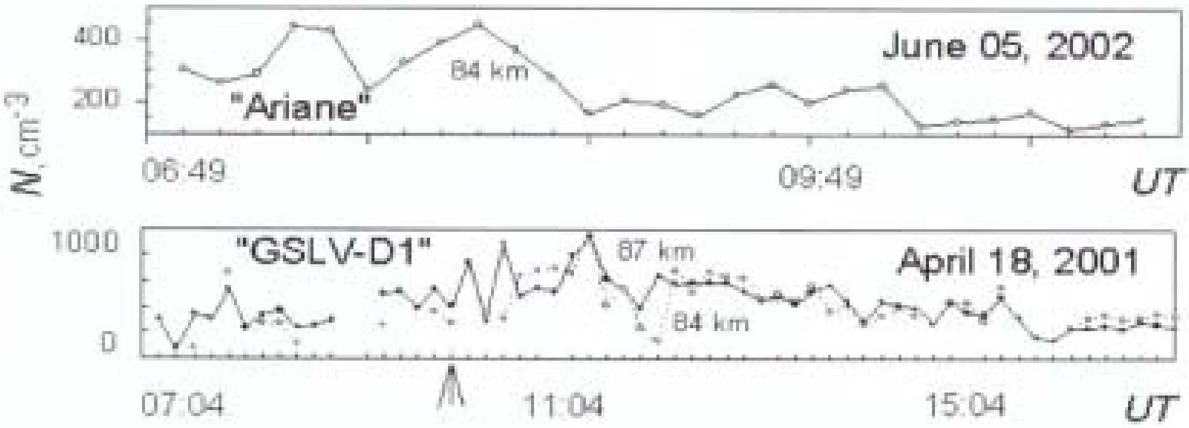

FIGURE 5. Height-time electron density variations in the middle latitude ionospheric D-region over the launching period of SVs "Ariane" and "GSLV".

Over the launching periods of the light weight rockets "Rokot" (the total weight of this type rockets was 97 tons, the starting thrust being about 160 000 kgf), "Titane" (the total weight of this type rockets was about 150 tons, the starting thrust being about 194 000 kgf) and "Discovery", N changes related to the launchings were not found.

Thus, it was established that some special features for the electron density changing in the ionospheric D-region occur over the periods of distant launchings and flights of the rockets belonging to various types. Nevertheless, in order to have details and clear the matter up, one should conduct additional investigations, store larger mass data, and carry out a statistical analysis.

DISCUSSION

Over the periods of distant launchings of the SVs, the following special features in the height-time changes in the ionospheric D-region electron density were experimentally established:

1) quasi-periodic N changes at $z \geq 81$ km with an ~50 – 100% amplitude and an ~30 – 40 min period about 10 min after the launchings;

2) quasi-periodic N changes at 81 – 90 km with an ~50% amplitude and an ~30 – 50 min period 40 – 50 min after the launching during about 2 – 3 hours;

3) for the launching "Kosmos" SV, 45 – 50 min after the launching, the N value at $z \geq 84$ km decreased by 50 – 100% within 40 – 50 min with a subsequent recovery to the diurnal variation.

On the whole, behaviour of the electron density (the response) is ambiguous, which seems to have been caused by a whole number of the factors mentioned above.

It is experimentally shown in [24 – 26, 34] that the VS launchings are accompanied by the large-scale and global disturbances in the ionosphere. In the near-Earth atmosphere ($z < 90 - 100$ km), operating rocket engines and SV flights with a supersonic velocity lead to generating and intensifying of shock-acoustic waves (SAWs). The power of such SAWs is $P_A \approx 10^8 - 10^9$ W for heavy and superheavy rockets (about a $10^{-3} - 10^{-2}$ fraction of the jet stream power). A height range in the lower ionosphere E-region (100 – 130 km) provides most favourable conditions under which SAWs are generated, since this ionospheric plasma region is situated above the mesosphere wave guide which effectively captures and canalyzes acoustic waves over great distances. The atmosphere at these heights is still rather dense, causing a SV to move with a supersonic velocity, which completely satisfies the conditions of generating SAWs. According to the experimental investigations [42], an SAW, in a place of its generation, gives rise to relative changes in the electron density within ~10 – 100%. The shock wave is a source of the acoustic-gravitational waves (AGWs) propagating at heights of the ionospheric E- and F-regions over distances of not less than 2000 km.

Supersonic plasma expanding of a jet stream of the rocket engine and supersonic plasma moving under the influence of an SV in the gyrotropic ionosphere give rise to generating electromagnetic and magneto-hydrodynamic (MHD) waves belonging to various types [43 – 48].

The disturbances experimentally founded in the electron density in the middle latitude D-region of the ionosphere 10 – 15 min after the SV launching may be related to generating MHD disturbances in the ionospheric plasma, which - under certain conditions - having effects on the Earth radiation belts may cause pulsing precipitating electrons of high energies. Such pulsing precipitating electrons, in their turn, may cause the experimentally observed changes in the electron density over great distances from the SV launching site. Earlier a similar mechanism was proposed to explain the experimental results obtained at the time of distant powerful earthquakes and strong thunderstorms (see [49 – 52]).

The electron density disturbances 45 – 50 min after the SV launching seem to be related to the correcting rocket engines. It is little likelihood that such considerable disturbances are related to the waves (in particular, AGWs) propagating in the lower ionosphere. It is more probable that these electron density disturbances were caused by the pulsing particle fluxes from the magnetosphere. These precipitation processes may be caused by the correcting rocket engines being turned on.

As in the case of the earthquakes in [50, 51] using the methods from [35] on the basis of a mechanism for precipitating high-energy particles (electrons, protons), we shall estimate parameters of the electron flows for the experiments discussed.

Using the electron density values under the undisturbed (N_0) and disturbed (N) conditions, there were estimated ionization rates of $q_0 = \alpha_0 N_0^2$, $q = \alpha N^2$, where α_0 and α are the corresponding recombination coefficients. For the simplicity of the procedure, we shall neglect the atmosphere heating at the moment of precipitating particles and assume that $\alpha \approx \alpha_0$. It is also assumed that at the lower heights there predominates a recombination of electrons with ion-bonds, for which $\alpha \approx 10^{11}$m^{3}sec^{-1}. This is valid at $z \leq 75$-90 km under conditions of a weakly disturbed ionosphere for the day- and night- time, respectively [35]. At the higher heights, the α -value decreases from 10^{-11} down to $2 \cdot 10^{-13}$ m^{3}sec^{-1} . The latter value is characteristic of the recombination of electrons with ions NO^+ and O_2^+ . If we neglect the precipitating particle distribution in energy, which is unknown for the ground observations, the power particle flux density is $P_1 \approx 2\varepsilon_i \Delta z \Delta q$, where $\Delta q = q - q_o$, $\varepsilon_i \approx 35$ eV is the energy lost in one ionization act, Δz is the height range where the flow of the particles of the given energy ε is absorbed. Further we assume that $\Delta z = 10$ km. On the other hand, the P_1 parameter is connected with the particle flow p: $P = \varepsilon p$. When having P_1 , one can estimate the power and energy of the particles precipitating over the area S: $P = P_1 S$, $E = P\Delta T$ where ΔT is the precipitation duration. The methods of estimating the particle flow parameters consist in calculating first the Δq value and then P_1 , p , P and E values.

The calculation results are given in Table 3. In the calculations we assumed that $S = 10^{14}$m^2. There was also assumed that the flows of electrons with $\varepsilon > 40$ KeV have the most effect on the D-region plasma, which was quite reasonable (see, e.g., [35]).

Table 3: Parameters of electron flows

Date	05.06.2000	20.11.1998	26.02.2001	13.08.1998	24.10.1998	18.04.2001
z, km	84	87	81	93	84	84
N_o, m^{-3}	2.0×10^8	10×10^8	8.5×10^8	20×10^8	5.0×10^8	3.6×10^8
N, m^{-3}	4.2×10^8	16×10^8	1.9×10^9	35×10^8	11.5×10^8	9.0×10^8
q_o, m^{-3}sec^{-1}	2.8×10^5	2.0×10^6	7.2×10^6	8.5×10^5	1.8×10^6	7.2×10^5
q, m^{-3}sec^{-1}	12.3×10^5	5.2×10^6	3.4×10^7	24.4×10^5	10.5×10^6	5.7×10^6
Δq, m^{-3}sec^{-1}	9.5×10^5	3.2×10^6	2.7×10^7	1.6×10^6	8.7×10^6	5.0×10^6
P_1,J m^{-2}sec^{-1}	3.2×10^{-6}	1.1×10^{-5}	9.2×10^{-5}	5.4×10^{-6}	3.0×10^{-5}	1.7×10^{-5}
p, m^{-2}sec^{-1}	2.1×10^8	9.2×10^8	2.1×10^9	4.5×10^8	2.1×10^9	1.1×10^9
ε, MeV	0.1	0.08	0.15	0.08	0.1	0.1
P, w	3.2×10^8	1.1×10^9	9.2×10^9	5.4×10^8	3.0×10^9	1.7×10^9
E, J	7.7×10^{11}	13×10^{12}	2.8×10^{13}	6.5×10^{11}	5.4×10^{12}	3.1×10^{12}
ΔT, sec	2.4×10^3	1.2×10^3	3.0×10^3	1.2×10^3	1.8×10^3	1.8×10^3

It appears that the quasi-periodic $N(z)$ variations observed in the lower ionosphere may be caused by the pulsing electron flows with

$p \sim 10^8$–10^9 m^{-2}sec^{-1} with the energy of 10^2 – 10 keV. Such electron density values are similar as to their magnitude to the flows over the periods of different natures (see, e.g., [35, 50 – 51, 53 – 57]), being not large under the middle latitude ionosphere conditions. In the high latitudes, the p values are known to be larger by several magnitude orders [58].

CONCLUSION

Thus, the rockets of medium and high powers are capable of causing short-time pulsing disturbances in the lower ionosphere electron density over distances up to several thousand kilometers or even more. These effects seem to have been stimulated by the pulsing electron flows coming from the magnetosphere into the Earth ionosphere with about 10^2 – 10 keV with the flow values of $p \sim 10^8$ – 10^9 m^{-2}sec^{-1}. These precipitation processes might be caused by correcting rocket engines turned on.

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