

UPPER ATMOSPHERE IONIZATION BY THE REPs IN 1985-86 AND VLF INVERSE PROBLEM

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A year ago it was reported at the 20th Apatity seminar [Beloglazov and Remenets, 1997] that among experimental data for the two year period on the radio trace Aldra-Apatity with three frequencies it had been found two cases for 1985 and five cases for 1986 of relativistic electron precipitations. In the present work a quantitative analysis is performed for these events by the method of inverse VLF problem.

The purpose of the analysis is to prove the suggestion that during the REPs ionization of the stratosphere is taking place. A clue to the proof is the fact that it is possible to solve the inverse problems only for a set of unmonotonous effective electron concentration functions $N_e(z)$ [Remenets, 1994, 1997]:

$$\begin{aligned}
 N_e(z) &= A(z_0) \exp \left[b(z_1 - z_0) \right] \exp [b(z - 58)], & z < z_1 \\
 N_e(z) &= A(z_0) \exp [b(z - z_0)], & z_1 \leq z \leq z_0 \\
 N_e(z) &= A(z_0) \exp \left[\left(0,407 + 0,134 \frac{|z_0 - 58|}{35} \right) (z - z_0) \right], & z > z_0 \\
 A(z_0) &= 80 \left(1 + \frac{19}{8} (z_0 - 40) / 43 \right) \exp [b(z_0 - 58)], & \text{electron/cm}^3, \text{ where } b = -0.14 \text{ 1/km.}
 \end{aligned} \tag{1}$$

The events considered took place in the following time intervals:

20.10.85, 10.50-11.04-12.10 UT;	23.10.85, 08.48-09.10-11.30 UT;
25.03.86, 09.30-10.40-17.00 UT;	27.03.86, 12.35-13.50-19.30 UT;
22.04.86, 12.15-19.00-22.00 UT;	23.04.86, 18.20-19.10-20.20 UT;
05.05.86, 07.30-08.22-09.40 UT.	

The intermediate moments correspond to the VLF disturbance maxima. The corresponding geophysical situation is moderate. Three of these events are presented in Fig. 1 and Fig. 2. The curve numbers in the first figure and indexes of amplitudes A_i and phases ϕ_i in Fig. 2 are the numbers of working radio frequencies from Aldra (10.2, 12.1, 13.6 kHz) and from England (16 kHz) in the pointed sequence. A distance to the receiver point (in Apatity) is equal to 883 km for the first case and 2497 km for the second one.

All above mentioned VLF events are united by qualitative similarity of the amplitude and phase variations for the three Aldra frequencies with the minima of these magnitudes (a maximum of the VLF disturbance).

The VLF inverse problems have been solved for some moments of these events including the disturbance maxima. The input data of the problems are the experimental amplitude and phase variations of the radio signals for the trace Aldra-Apatity which is completely located in the auroral zone. To solve the VLF inverse problem we performed minimization of a functional containing the differences of the experimental and calculated values which were radio signal relative amplitude and phase changes for the first three frequencies. Minimization of the functional has been accomplished for the set of unmonotonous electron concentration profiles (1) which approximated an additional ionization process in the upper atmosphere due to the relativistic electrons below the ionospheric D-region. Two minimization parameters z_1 and β determine the electron concentration profile $N_e(z)$ with the homogeneous electric conductivity between the heights z_0 and z_1 . The upper part of the profile (higher than z_0) is identical to the undisturbed auroral daytime profile [4] with $z_0=62$ km. The parameter β is an increment of the bottom part of the profile below the height z_1 . If β becomes negative the corresponding profile $N_e(z)$ becomes essentially unmonotonous.

The parameters of the effective profiles obtained due to minimization and corresponding effective radio wave guide heights h [Beloglazov and Remenets, 1982] are given in Tables 1 and 2. In the first table the cases are presented for which all the amplitudes are above the noise level (an effective range of the amplitude channel is 20 Hz [Beloglazov and Remenets, 1982]). In the upper part of the table the experimental amplitudes A_i and phases ϕ_i as input data are given. The indexes "q" and "d" mean the quiet and disturbed conditions on the radio trace. The values in brackets are the

calculated ones resulting from the inverse problem solution. The parameters h' and h'' are the effective heights of the model wave guides which have been obtained using the amplitude data only and phase data only, respectively. The construction of Table 2 is just the same but the profile parameters obtained are not strict. They are rather of estimation character. At the moments presented in the table the amplitudes for some of the frequencies are comparable with the noise level. So, in the calculations such A_i were setting equal to this level. The anomalous attenuation of the radio signals (up to 8-10 times) during the REPs on 20.10.85, 25.03.86, 22.04.86, 23.04.86 resulted in the effective height h lying in the range 30-35 km.

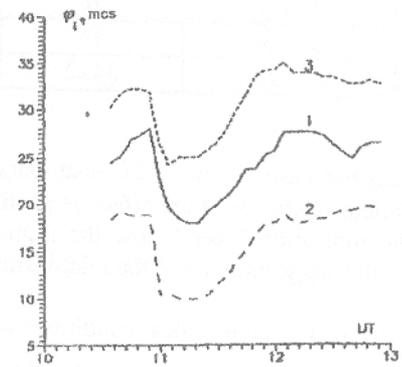
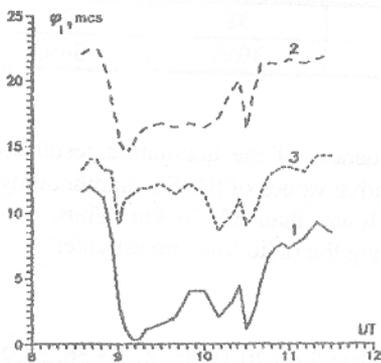
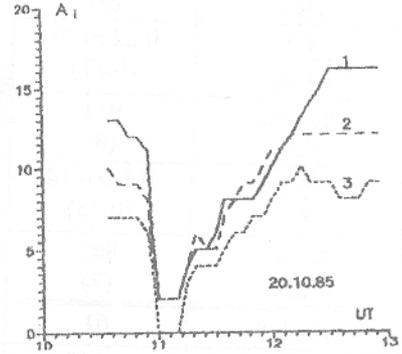
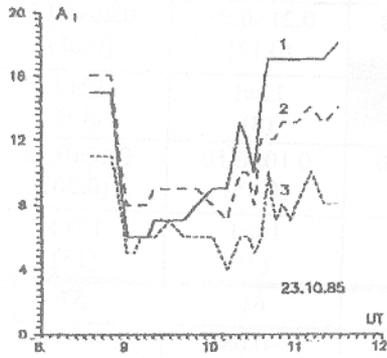


Fig.1.

Fig.2.

Table 1

	23.10.85	27.03.86	27.03.86	05.05.86
UT	09.10	13.03	17.10	08.22
$(A_1)_d$	0.38 ± 0.07	0.40 ± 0.07	0.27 ± 0.07	0.37 ± 0.06
$(A_1)_q$	(0.43)	(0.43)	(0.32)	(0.32)
$\varphi_{1q} - \varphi_{1d}$	12 ± 1	10 ± 1	10 ± 1	10 ± 1
mcs	(11)	(11)	(12)	(12)
$(A_2)_d$	0.50 ± 0.07	0.54 ± 0.09	0.46 ± 0.08	0.43 ± 0.08
$(A_2)_q$	(0.55)	(0.55)	(0.42)	(0.42)
$\varphi_{2q} - \varphi_{2d}$	6 ± 1	6 ± 1	10 ± 1	10 ± 1
mcs	(7)	(7)	(12)	(8)
$(A_3)_d$	0.55 ± 0.11	0.30 ± 0.20	0.30 ± 0.20	0.40 ± 0.10
$(A_3)_q$	(48)	(0.48)	(0.39)	(0.39)
$\varphi_{3q} - \varphi_{3d}$	5 ± 1	5 ± 1	7 ± 1	7 ± 1
mcs	(5)	(5)	(6)	(6)
Z_1 , km	62 ± 2	62 ± 3	61 ± 3	61 ± 1
β , 1/km	-0.05 ± 0.01	-0.05 ± 0.02	-0.06 ± 0.02	-0.06 ± 0.01
h , km	48 ± 2	48 ± 3	44 ± 3	44 ± 1
h' , km	44 ± 1	42 ± 2	44 ± 3	41 ± 2
h'' , km	51 ± 1	49 ± 3	37 ± 1	38 ± 1

Table 2

	20.10.85	25.03.86	27.03.86	22.04.86	23.04.86
UT	11.05	10.40	13.50	17.00	19.10
$\frac{(A_1)_d}{(A_1)_q}$	0.17±0.09 (0.13)	0.11±0.06 (0.13)	0.20±0.07 (0.22)	0.13±0.07 (0.13)	0.14±0.07 (0.15)
$\varphi_{1q} - \varphi_{1d}$ mcs	8±1 (9)	9±1 (9)	17±1 (16)	11±1 (9)	15±1 (17)
$\frac{(A_2)_d}{(A_2)_q}$	0.22±0.11 (0.17)	0.19±0.06 (0.17)	0.23±0.08 (0.31)	0.21±0.07 (0.17)	0.20±0.07 (0.21)
$\varphi_{2q} - \varphi_{2d}$ mcs	9±1 (8)	10±1 (8)	12±1 (12)	12±1 (8)	12±1 (14)
$\frac{(A_3)_d}{(A_3)_q}$	0.14±0.14 (0.15)	0.10±0.10 (0.15)	0.20±0.20 (0.29)	0.10±0.10 (0.15)	0.10±0.10 (0.20)
$\varphi_{3q} - \varphi_{3d}$ mcs	8±1 (7)	7±1 (7)	10±1 (10)	10±1 (7)	13±1 (13)
Z_1 , km	61	60	60	61	57
β , 1/km	-0.08	-0.08	-0.08	-0.08	-0.08
h_s , km	38	38	38	38	34
h' , km	33	38	35	38	33
h'' , km	34±2	38±1	37±2	39±2	34±3

In the analyzed cases of the VLF disturbances we can state the uniqueness of the qualitative result concerning the unmonotonous character of the effective profiles obtained (with the negative values of β). The unmonotony is caused by a sporadic ionization layer below the regular ionospheric D-region, lower than 55–50 km. Thus, the analysis has confirmed the suggestion about the relativistic electron precipitations along the radio trace investigated.

COMMENTS. The geophysical conditions were the following.

- Kp indices were never greater than 4 on 23.03.85, 25.03.85, 22.04.86, than 3 on 20.10.85, 27.03.86, 23.04.86 and than 2 on 05.05.86.
- Cosmic ray indices were constant in all the events except the one on 05.05.86 when before 02-03.05.86 and later on the same day there were solar proton precipitations.
- The X-ray flares on the Sun were absent except the period 23.04.85, 10.35-10.51 UT. The SID effect is distinctly seen in Fig.1 as synchronous dropping down of the amplitudes and phases.
- According to the noise cosmic ray absorption data in Apatity there were «bays» of absorption on 20.10.85, 08.00-11.00 UT, on 23.03.86, 08.00-08.40-17.00 UT, on 27.03.86, 12.50-13.30-17.00 UT, on 23.04.86, 18.50-19.05-19.30 UT, there was a «bay» above a «slope» of the absorption function on 22.04.86, 18.20-18.40-19.50 UT and a bottom of the «bay» on 05.05.86.
- According to the Apatity magnetometer data there was a variation synchronous with the REP on 23.04.86, 18.50-19.25-20.30 UT (max(E) = 100 nT, max(H)=60 nT, max(D)=90 nT).

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