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A REVIEW OF ALL POWERFUL VLF DISTURBANCES INITIATED BY THE ULTRARELATIVISTIC ELECTRON PRECIPITATION DURING 1974-1992

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The VLF monitoring of some radiostations was performed at the Polar Geophysical Institute of RAS (Apatity, 67.5° N, 33.3° E) during 1974-1992. The registration was continuous except the summer vacations (1-1.5 months) and some induced technical interruptions. So the total time of registration per year was equal to 85-90%. The quality of registration prior to and after these years is different.

During the first period of registration, the 10.2 and 13.6 kHz of OMEGA station in Aldra (66.5° N, 13.2° E) and 16.4 kHz of YXZ station (66.4° N, 13.2° E) were accepted by the device with 200 Hz range of the amplitude channels and with the quartz base generator in the phase channels. During the second period of registration all three signals from OMEGA (including 12.1 kHz) and GBR signal (16 kHz, 52.3° N, 1.15° W, 1982-1989 years) were monitored by 20 Hz amplitude channels and with the highly stable base signal in the phase channels [1]. The first period refers to the 20-21-st solar activity cycle and the second period of observations refers to the 21-22-d cycle. It is important to note that before the 1981 the VLF disturbances which might pretend to have been caused by relativistic electron precipitations (REP) did not exceed 30-50 events and only five of them may pretend to be the strong disturbances (StD). There was one definite StD on 29.10.77, 16.20-16.35-17.00 UT and there had been existing a non powerful disturbance (PwD) for 5.5 years. For the second period of registration (after 1981 y.) there were more than 250 quite reliable disturbances [2-4] (connected with relativistic electron precipitations).

Uncertainty of the statements for the first period is caused by relatively broad intervals between the frequencies used (near 3 kHz), by the relatively low quality of the registration device indicated above and by the discrete character of work of the JXZ station.

During the classification of the VLF disturbances caused by REPs we used four gradations (weak, moderate, strong and powerful) [2-4]. A disturbance is called powerful if an amplitude of one or the amplitudes of more than one radiosignals (the signals with the frequencies 10.2, 12.1, 13.6 kHz) become equal to the device zero in the conditions of linear amplification with 20 Hz effective frequency range. Such realization for the trace 885 km long is possible only in conditions when the atmosphere along the radio trace is intensively ionized at the height interval of 20-40 km. The cause of anomalous ionization are the ultrarelativistic electron precipitations (UrEP) [2-4]. The first trustworthy StD and PwD were registered in 1982 [5] and 1983 respectively. Below, we present the results of quantitative analysis for all PwDs except those which were published by us (a mark * at the conclusions below) before.

The quantitative analysis in our case is the solving of the inverse VLF problem in the set of the unmonotonous electron concentration profiles [2,3,6] which are the rough approximations to two layers of ionized atmosphere: the top layer is the normal ionosphere and the bottom layer is due to the anomalous ionization. The note of all PwDs is the following:

06.04.83, 01.30-05.50-10.30 UT;
16.04.84, 17.30-18.10-19.40 UT;
*20.10.85, 10.50-11.05-12.20 UT;
25.03.86, 09.30-10.40-17.00 UT; 27.03.86, 12.35-13.50-19.30 UT;
22.04.86, 12.15-17.00-22.00 UT; 23.04.86, 18.20-19.10-20.20 UT;
27.03.88, 09.30-11.00-19.00 UT; 01.04.88, 07.40-08.00-09.00 UT;
01.04.88, 10.50-12.00-13.30 UT; 02.04.88, 18.50-20.15-21.30 UT;
03.04.91, 12.05-13.00-14.30 UT; 03.04.91, 15.00-16.12-18.50 UT;
*21.01.92, 22.00-22.50-24.00 UT; 22.01.92, 06.15-07.40-10.00 UT.

The most prolonged of these disturbances 27.03.88 is represented in Fig.1. The letters A_i and $_i$ are the indicators of amplitude and phase curves with a number i = 1,2,3,4 of the frequency f = 10.2, 12.1, 13.6, 16.0 kHz respectively.

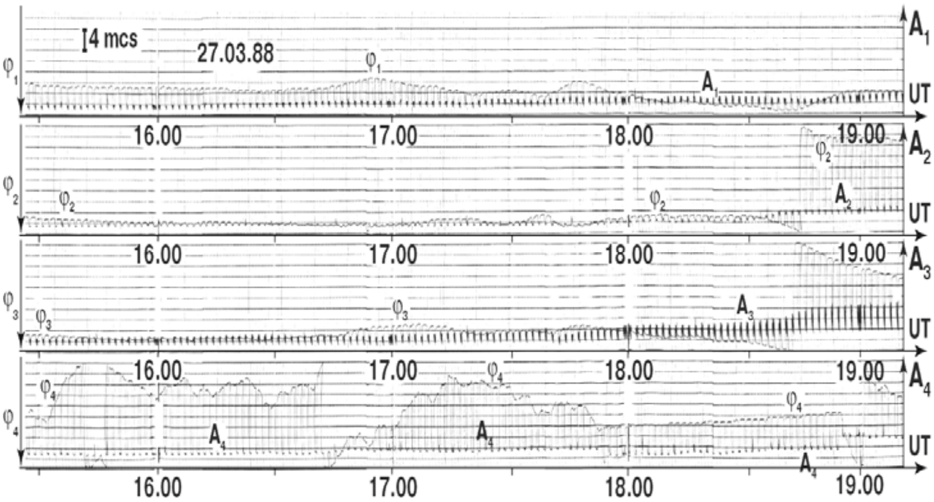

Fig.1. The example of the VLF variation during UrEP.

The results of the VLF inverse problem solutions are represented in two parts of Table 1 for 9 powerful VLF disturbances at the time period of their maximum amplitude and phase variation for all three radio signals (i = 1,2,3 for the f = 10.2, 12.1, 13.6 kHz respectively). Three events were analyzed for two "undisturbed" initial monotonous profiles N_e(z) [6] with z_0=55, 62 km (columns No 2.1 and 2.2) for a day and z_0 =70, 75 km (columns 8.1, 8.2 and 9.1, 9.2) for a night.

Table 1

No.of.col.	1	2.1	2.2	3	4	5
Time of Disturb.	16.04.84 18.10 UT	27.03.88 11.00 UT	27.03.88 11.00 UT	01.04.88 08.00 UT	01.04.88 12.00 UT	02.04.88 20.15 UT
z_0, km	62	55	62	62	55	62
$\frac{(A_1)_d}{(A_1)_c}$	0.20±0.08 (0.22)	0.05±0.05 (0.06)	0.05±0.05 (0.23)	0.32±0.11 (0.21)	0.07±0.07 (0.13)	0.13±0.07 (0.06)
$\varphi_{1c}-\varphi_{1d}$ mcs	13±1 (12)	12±1 (13)	12±1 (14)	6±1 (9)	9±1 (11)	21±1 (21)
$\frac{(A_2)_d}{(A_2)_c}$	0.29±0.06 (0.30)	0.10±0.10 (0.07)	0.10±0.10 (0.31)	0.29±0.15 (0.28)	0.11±0.11 (0.16)	0.21±0.07 (0.11)
$\varphi_{2c}-\varphi_{2d}$ mcs	8±1 (9)	12±1 (14)	12±1 (11)	5±1 (7)	14±1 (12)	19±1 (18)
$\frac{(A_3)_d}{(A_3)_c}$	0.42±0.09 (28)	0.07±0.07 (12)	0.07±0.07 (0.29)	0.32±0.11 (0.26)	0.13±0.13 (0.20)	0.18±0.06 (0.10)
$\varphi_{3c}-\varphi_{3d}$ mcs	8±1 (8)	8±1 (9)	10±1 (9)	4±1 (6)	11±1 (11)	14±1 (16)
z_1, km	60	51	59	62	53	56
β, 1/km	-0.07	-0.09	-0.07	-0.07	-0.08	-0.09
h', km	38	28	39	38	33	28

In the Table, z_1 and β are the parameters of an effective unmonotonous electron concentration profile N_e(z) which has been found by the minimization of a functional [6] containing the differences between the experimental and theoretical values, relative amplitude and phase of which change the radio signal for three frequencies. The parameter z_1 is the bottom level of the layer with homogeneous electric conductivity at the range z_0 - z_1 km. The parameter β is the height increment of the bottom part of the effective profile [2,3]. If it becomes negative the corresponding profile N_e(z) becomes essentially unmonotonous. By the set of such unmonotonous electron concentration profiles we approximate an additional ionization process in the middle atmosphere due to the REP.

The parameter h' is the effective height of a waveguide formed by the Earth and the ionized middle atmosphere [1,6]. The calculation of the parameter h' is not necessary for solving the inverse problem but it is methodologically useful because, as it is shown in the scientific literature, this effective height is located inside the so called essential region of electric conductivity layer relative to the radiowave reflection.

The experimental amplitude A_i and phase $_i$ data in comparison with the calculated ones (the values in the brackets) are given in Table 1. The calculated data are obtained on the basis of the inverse problem solution results. The indice "c" and "d" mean the "calm" (before a disturbance) and "disturbed" conditions at the radio trace.

In Table 1 for two cases (27.03.88 and 01.04.88) for which all amplitudes are comparable with the noise level, the profile parameters obtained are not strict and are of an estimation character. In the minimization of the functional G the "experimental" amplitudes A_i were set equal to the noise level. For the same cases it has been seen from the experimental values of amplitudes before a UrEP that the ionosphere was not quiet, that it was disturbed by the auroral particles. So it was necessary to realize the calculations with a model of initial ("calm") ionosphere (β=0.05 1/km) for which the effective height (z_0 =55 km) is by some km lower than for initial undisturbed ionosphere (z_0 =62 km). The result turned to be positive in the sense that a value of the functional G (z_0) had diminished by 3.5 and 4.5 times for 27.03.88 data and for 01.04.88, 12.00 UT data respectively.

In Table 1 (continuation) the columns 8 and 9 correspond to the night ionosphere conditions. According to our estimation [7] the auroral night effective height h in quiet and moderately disturbed conditions is equal to 75 and 70 km respectively. The ratio of functional values G(z_0=70 km)/G(z_0 =75 km) was equal to 2.0 and 0.45 for 21.01.92 and 22.01.92 respectively. The calculations were fulfilled with β=0.39 1/km for the bottom part of the initial ("calm") monotonous profile N_e(z).

Table 1 (continuation)

No.of.col.	6	7	8.1	8.2	9.1	9.2
Time of Disturb.	03.04.91 13.00 UT	03.04.91 16.12 UT	21.01.92 22.50 UT	21.01.92 22.50 UT	22.01.92 07.40 UT	22.01.92 07.40 UT
z_0, km	62	62	70	75	70	75
$\frac{(A_1)_d}{(A_1)_c}$	0.08±0.05 (0.15)	0.12±0.06 (0.21)	0.04±0.04 (0.09)	0.04±0.04 (0.14)	0.08±0.04 (0.09)	0.08±0.04 (0.15)
$\varphi_{1c}-\varphi_{1d}$ mcs	17±1 (17)	11±1 (11)	12±1 (15)	12±1 (13)	13±1 (15)	13±1 (13)
$\frac{(A_2)_d}{(A_2)_c}$	0.12±0.06 (0.21)	0.27±0.07 (0.28)	0.10±0.03 (0.07)	0.10±0.03 (0.12)	0.09±0.03 (0.07)	0.09±0.03 (0.13)
$\varphi_{2c}-\varphi_{2d}$ mcs	14±1 (14)	9±1 (8)	20±1 (18)	20±1 (19)	18±1 (18)	18±1 (19)
$\frac{(A_3)_d}{(A_3)_c}$	0.14±0.07 (0.20)	0.23±0.08 (0.26)	0.17±0.07 (0.07)	0.17±0.07 (0.19)	0.11±0.04 (0.07)	0.11±0.04 (0.20)
$\varphi_{3c}-\varphi_{3d}$ mcs	12±1 (13)	9±1 (7)	23±1 (21)	23±1 (24)	22±1 (21)	22±1 (23)
z_1, km	57	61	66	67	66	68
β, 1/km	-0.08	-0.07	-0.09	-0.07	-0.09	-0.07
h', km	34	38	30	36	30	37

As a result of the work we may state that during 1974-1980 there was no PwD and the UrEP activity was much lesser than in 1982-1992. The analysis of PwDs confirmed our statement of previous publications that in case of UrEP the middle atmosphere is abnormally ionized at the altitudes of 20-40 km. The above estimation of an effective height of electric conductivity layer is equal to 28-38 km.

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