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SOUTHERN BOUNDARY OF THE ULTRA RELATIVISTIC ELECTRON PRECIPITATION ON MAY 13, 1987

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Introduction

The phenomenon of the ultra-relativistic electron precipitation (UREP) into the polar atmosphere from the near-Earth was analyzed in a cycle of publications [1-6]. The analysis was based on the very low frequency (VLF) data in the cases of abnormal disturbances. It was shown that the phenomenon was accompanied with the effect of the geomagnetic cutoff. It was observed that energy of the precipitating electrons was such (about 100 MeV) that they could generate bremsstrahlung X- rays, which were capable to create an electric conductivity sporadic D-layer at the altitudes 10 – 40 km. Such sporadic layer formed the reflected signals (due to the partial reflections from the altitude intervals where the conductivity gradient differed from zero) from the on ground monochromatic VLF radio sources (10 – 16 kHz). The effective height h of radio wave reflection is changing during a disturbance from the undisturbed value $h \approx 60$ km to $h \approx 30$ km in the maximum of powerful disturbance (PwD's) at daytime. In addition to these results the same VLF data can be used for estimation of the latitude of southern boundary of a disturbance. This capability is realized in this paper for the UREP on May 13, 1987.

Amplitude and phase experimental data on May 13, 1987 [6]

The amplitudes of the on ground signals as functions of time for 4 frequencies 10.2, 12.1, 13.6 and 16 kHz are represented on Fig. 1 (*left*). The signals with first three frequencies were gotten for a shorter radio pass Aldra (North Norway) - Apatity (Russia), its length S_1 being equal to 885 km. The radio pass was completely in auroral zone and directed W - E. The 4th signal came to Apatity from Great Britain (GBR station, its length S_2 = 2497 km). This radio pass was partly auroral due to its northern part. Intensity of this abnormal disturbance was comparable with the ones caused by the proton precipitations but the disturbance was qualitatively different due to the absence in the received Aldra - Apatity signals of the rays with two reflections from above.

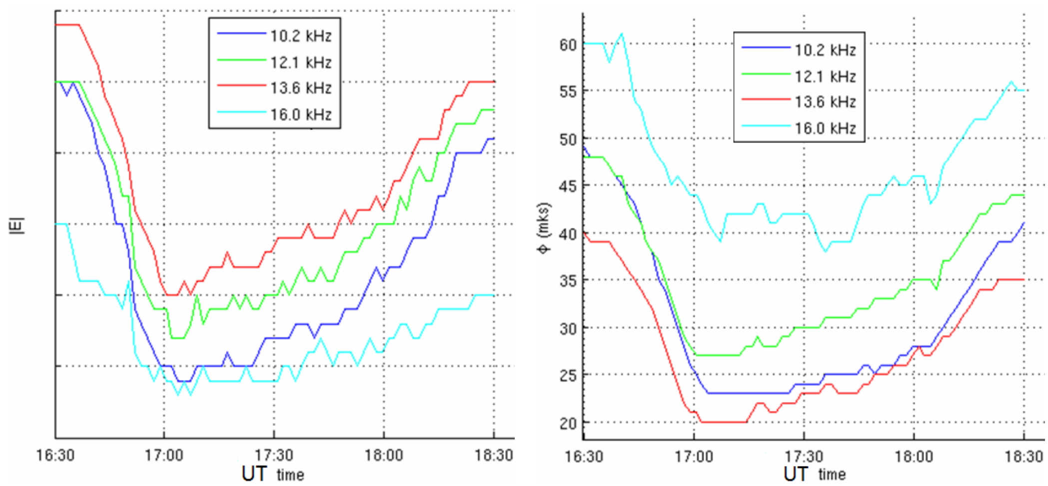

Fig. 1 Qualitative similarity of the amplitude (left) and phase (right) variations for shorter and long radio-passes. The amplitudes are given in relative units. The ratios of amplitudes for different frequencies are unknown.

The phases of the on ground signals as functions of time for the same 4 frequencies are represented on Fig. 1, *right*. These data were gotten by Beloglazov M.I., a member of the Polar Geophysical Institute in Apatity, RAS. The qualitative similarity of the amplitude and phase data represented on Fig. 1 for both radio-passes indicates on a mutual physical cause of the disturbance, which had place at the northern auroral end of the long radio- pass.

The problem named in the Introduction was solved in two stages. The first stage is finding of a solution of the VLF problem of first kind according to the data for the auroral shorter radio-pass only. In frames of this problem we found the reflection coefficient of the first ray from the ionized middle atmosphere and the effective height of the radio-pass, the near Earth waveguide being considered homogeneous at every moment of the disturbance. The solution of the problem was begun in [7]. Here we finished it more accurately. The latitude position of a boundary between perturbed and non-perturbed parts of the long radio- pass (16 kHz) is an object of determination by the help of the inverse problem of second kind. This problem is solved in the final part of the report.

Solution of the VLF inverse problem of first kind

The results of the solution of the VLF inverse problem of first kind for the event on May 13, 1987 are presented at Fig.2. It was gotten by the self-consistent VLF method [1-5], in which were used a diffraction ray (Watson-Fock wave) and two rays reflecting from the ionized middle atmosphere [8].

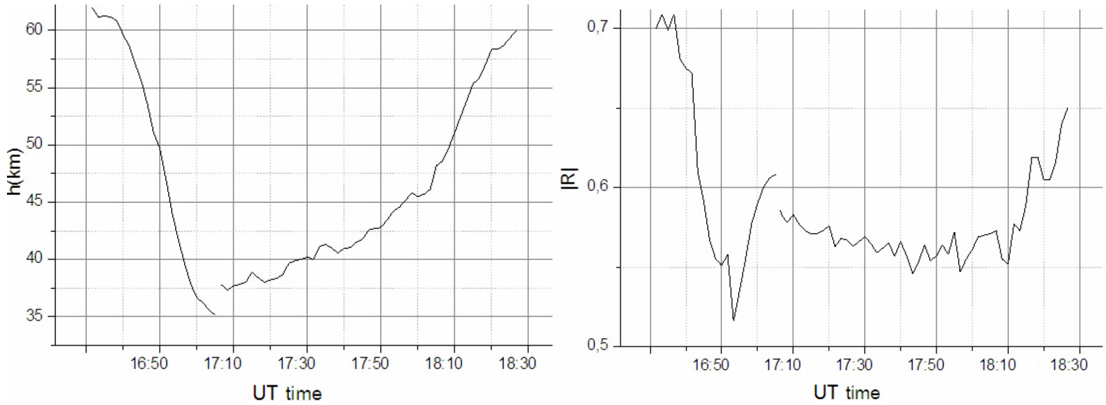

Fig. 2 Variations of the effective height h(t) (left) and the reflection coefficient modular R(t) (right) of a wave-guide, as functions of universal time (UT) for the auroral radio-pass Aldra- Apatity.

The first part of the disturbance (before 17:00) was gotten by an analysis at positive direction of time and with the determination of the initial values $h(t_0)$ and $R(t_0)$, where t_0 = 16:30 UT. The second part of the disturbance (after 17:00) was gotten by an analysis at negative direction of time and with the determination of the initial values for analysis $h(t_m)$ and $R(t_m)$, where t_m = 18:30 UT. The values of breaks of the continuous curves in 17.00 UT on Fig. 2 indicate on the error order of the method of analysis used. For the effective height it is about 3 km, maximum variation being 27 km. For the reflection coefficient the estimation is about 0.04, maximum variation being 0.18. These results are quite satisfactory, if to consider that at the maximum of disturbance (UT = 17:00) the signal/noise ratio was about several units for the amplitudes. The error of the phases measurements was ± 0.5 mks).

Solution of the VLF inverse problem of second kind

Let us imagine a model of a wave-guide with length S_2, which consists of two parts. The southern part of the wave-guide with length S_2 - D_{avr} was modeled with the help of the middle latitude ionosphere and the northern part with length D_{avr} which did not depend on time. The latitude of the pointed boundary was chosen equal to 62^0 N. To this undisturbed model a third section with variable length D (D = 0 ÷ S_2) was introduced in the vicinity of the receiver. This North terminal part of the wave-guide homogeneous at every time moment was characterized by the changes in time of the electric properties of the sporadic D-layer of conductivity, which the VLF inverse problem of first kind had given, Fig 2. The calculations of the relative amplitude and phase variation (-φ_{calc}) were fulfilled according to the following approximate formulas for:

$$E_{calc}(t_n, D) = E * \exp\left[-\frac{Im(v)(S_2 - D_{avr})}{R}\right] * \exp\left[-\frac{Im(v_{avr})(D_{avr} - D)}{R}\right] * \exp\left[-\frac{Im(v_{dist}(t_n))(D)}{R}\right]$$

$$\varphi_{calc}(t_n, D) = \left[\frac{Re(v)(S_2 - D_{avr})}{R}\right] + \left[\frac{Re(v_{avr})(D_{avr} - D)}{R}\right] + \left[\frac{Re(v_{dist}(t_n))(D)}{R}\right]$$

$$GII(D) = \sum_{n=0}^{n=m} \frac{[\tilde{E}_4(t_n) - E_{calc}(t_n)]^2}{\tilde{E}_4(t_0)^2} + \sum_{n=0}^{n=m} \frac{[\tilde{\varphi}_4(t_n) - \varphi_{calc}(t_n)]^2}{(\Delta_{max}\tilde{\varphi}_4(t_0))^2}$$

E_{calc} and (- φ_{calc}) are the amplitude and the phase calculated of a signal with frequency f_4 (long radio- pass) for a moment of disturbance t_n and a fixed length D; v -is an eigenvalue with zero number for a model of undisturbed middle latitude wave-guide; v_{avr} -is analogous one for an undisturbed part of auroral wave-guide; $v_{dist}(t_n)$ -is an eigenvalue for a disturbed part of the wave-guide at a moment t_n of the disturbance; R -is the Earth radius. The last eigenvalues were calculated according to the generalized Schumann's method [9]. $GII(D)$ is a discrepancy function of parameter D, which was minimized relative to the value of D. The minimum was achieved at the relative distance D / S_2 = (45 ± 5) % and for the latitudes $(62 \pm 1)^0$ N correspondingly, Fig. 3, *right*. A discrepancy- function $GII(D)$, which contained only phase data, was minimized too, and the corresponding result was practically the same: D / S_2 = (46 ± 5)%; $(61.7 \pm 0.8)^0$ N. Continuation of the calculations for a function-discrepancy $GII(D)$, which contained only the amplitude data (Fig. 3, *left*), gave the following result: D / S_2 = (42 ± 6)%; $(62 \pm 1)^0$ N. It concludes, that our approximate calculations indicate on the fact that on 13 May 1987 the southern boundary of UREP did not become lower than 62^0 of North latitude for the radio-pass Ragby- Apatity.

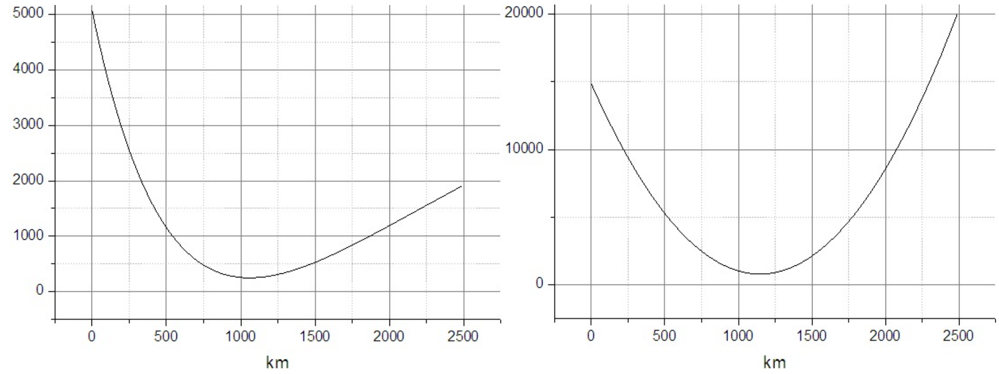

Fig. 3 The discrepancy function GII(D) of parameter D.

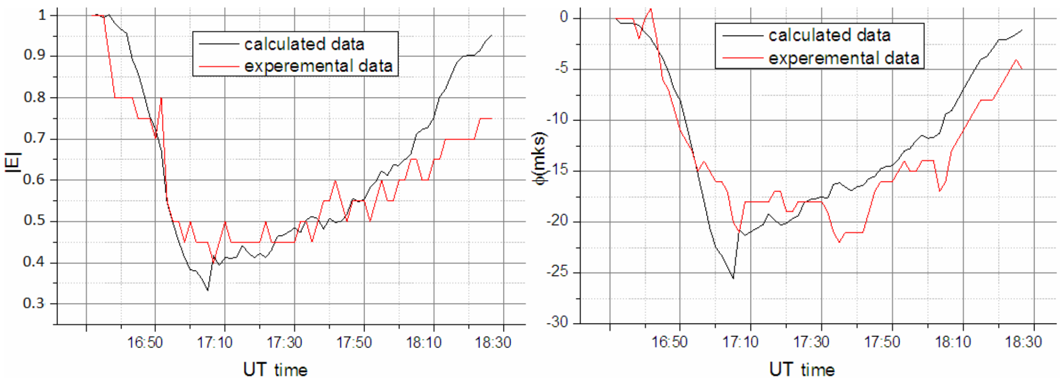

Fig. 4 Estimation of the accuracy of the inverse VLF problem of second kind by comparison of the experimental and calculated data. Black line - experimental data; red line - calculated data with optimal value of D = 1050 km.

Conclusion

The discrepancy function $GII(D)$ gets its minimal value when (45 ± 5)% of the long radio pass is disturbed by the ultra-relativistic electron precipitation (on May 13, 1987). To this minimum a value of North latitude, being equal to $(62 \pm 1)^0$, corresponds.

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