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A STUDY OF PARTIAL RADIOREFLECTIONS IN THE HIGH-LATITUDE D-REGION BY A MEASURING FACILITY OF POLAR GEOPHISICAL INSTITUTE

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Abstract. A specific facility for measuring electron density and ionospherical drift velocity by the partial reflection technique is described. The characteristics of the station, the methods analysis and interpretation of partial reflection are considered. A few figures illustrate the measured parameters of the lower ionosphere. Finally, an attempt is made of evaluating the full potential of the probing technique.

Introduction

During a few year period, Polar Geophysical Institute has been studying the lower ionosphere using the partial reflection technique [Vlaskov and Bogolubov, 1998]. The measuring station is located on the Kola peninsula near Tumanny (69.0° N, 35.7° E). This station was repaired and improved in the spring of 1999. The radar transmitter has a peak power of 100 kW at the frequency 2.7 MHz, the pulse length of 15 μs, the ordinary wave repetition rate of 1 Hz and a delay between the extraordinary and ordinary pulses of 275 ms. The receiver has sensitivity of less 0.5 μV, passband of 50 – 60 kHz, the heights rate — 30 – 240 km, the range of registration is something within the limits of survey, and the height resolution — 0.5n (where n = 1, 2, 3 …).The antenna array consists of 32 (4×8) extended range cross-vibrators with a rotating field polarization and it is available for transmission and reception. Therefore it occupies an area of $5.5 \cdot 10^4$ m^2, and has a gain of 12.5 – 18.7 dB, beam width — 19° (north-east) and 30° (north-west) as well as the side lobe label 12%.

The ionospheric vertical sounding facility contains a drift measurement device. The device consists of three spaced receiver points, which are located at peaks of an isosceles triangle. The receiver point is an antenna element, which is isolated from the antenna array and is operated in the receiver regime only. One peak of the antenna system triangle is directed to the south and the altitude of the triangle is arranged along the geographical meridian, as shown in Fig. 1. The goal of this paper is to demonstrate the potentialities of the facility for the investigation of structure and processes in the lower ionosphere.

Partial radioreflection technique

Irregularities in the electron density or in the collision frequency give rise to partial reflections of radio waves [Belrose, and Burke, 1964]. The ratio, A_x/A_o of the amplitudes of the extraordinary and ordinary components of the weakly scattered signals is given by

$$A_x/A_o = \left|R_x/R_o\right| \exp\left[-2\int_0^h \left(K_x - K_o\right) \mathrm{d}\,h\right],$$

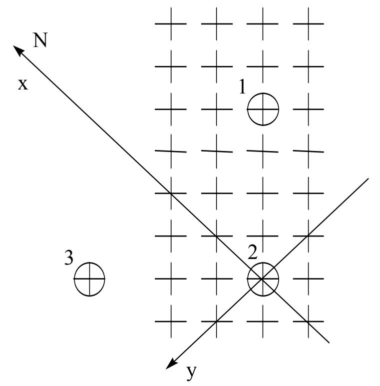

Fig.1. Antenna system configuration.

where $R_{x,o}$ is the reflection wave and $K_{x,o}$ the corresponding absorption index. The exponential term gives differential absorption of the magneto-ionic components scattered from a height *h* and depends on the electron density and collision frequency below this height. The coefficient $R_{x,o}$ for a very weak scattering is given by the Fresnel formula $R_{x,o} = \Delta n/2n$, where *n* is the complex refractive index of the medium, which is near unity. The ratio R_x/R_o determined by the wave frequency, the gyrofrequency, and electron collision frequency, but is independent of the actual electron density. When A_x/A_o is observed, as a function of height, and collision frequency is known, the electron density may be determined by differentiation of above equation. At low heights where the differential absorption is small $A_x/A_o \cong R_x/R_o$ and therefore the measured amplitude ratios can provide a measure of collision frequency.

In Fig.2 the average A_o amplitude, the average A_x/A_o ratio, the calculated R_x/R_o values (for an assumed collision frequency model), and the electron density profile are shown for a disturbed day, December, 27, 1999. Note that at low height A_x/A_o is not exactly equal to the calculated values of R_x/R_o, and this difference is assumed to be due to incorrect choice of the value of the collision frequency.

In Fig.3 the time-altitude picture of the O-mode echo amplitude is shown for the August, 7, 1999. According to the theory employed, which assumes that reflection is due to ionization irregularities $\Delta N/N$, these experimental measurements provide a study of the fine D-region structure.

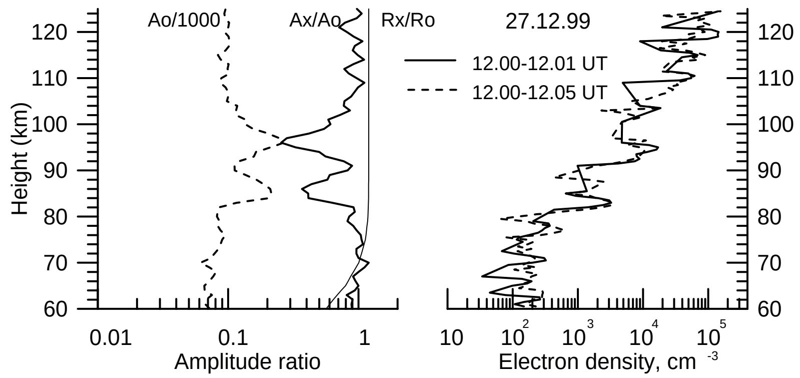

Fig.2. Profile of *Ao*/1000, *Ax*/*Ao* and Rx/Ro for 2.7 MHz, and electron density *N* derived from these results.

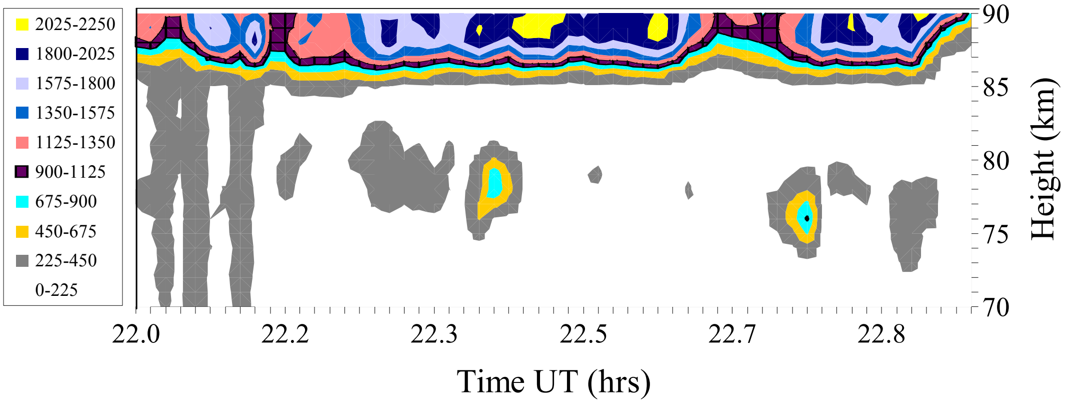

Fig.3. Time – altitude picture of the echo amplitude of O-mode 07.08.99.

Fig.4 shows the diurnal variations of the O-mode amplitude and the electron density at heights 70-90 km for a particular day in July and December 1999. As can be seen from Fig.4 the electron density is higher in summer (the middle panel) than in winter (the bottom panel). There is a clear diurnal change in July, but a small diurnal change in December. A characteristic feature of summer data is a minimum in the electron density in the height range around 85 km. A minimum in the electron density near the mesopause is always accompanied by an increase of the O-mode amplitude A_o observed at the same heights (see the top panel in Fig.4). Such minimum of N_e and maximum of A_o could be explained by the attachment of free electrons to neutral particles and formation of negative ions that are present in the lower ionosphere.

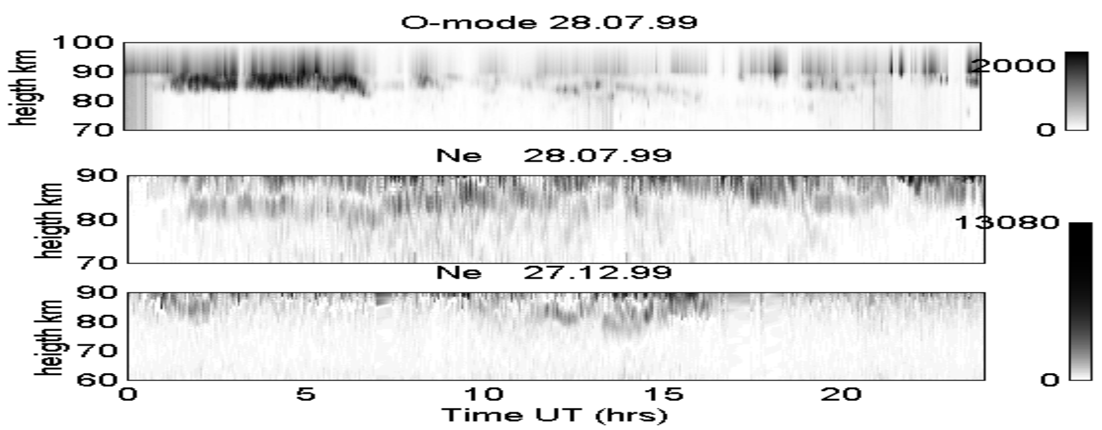

Fig.4. Time – altitude picture of the electron density in July and December, 1999.

Since the partial reflections refer to the neutral atmosphere parameters, it is obvious that variation periods of the atmosphere can be investigated by spectra research of partial reflection intensity (Fig.5). Furthermore the phenomena of PMSE involves periodical variations of the neutral atmosphere and especially the temperature variations. Consequently it is necessary to collect a continuous volume of data for a long period of time. There was developed a method of combination of the separate data volumes. This method uses Fourier analysis and provides a filling interruption between the data volumes taking into accounts the phase and amplitude of the signal

Drift measurements

The principles of the device operation was described by many authors in details [Mirkotan, Kushnerevsky, 1964; Galkin et al., 1971]. Therefore we don't consider this question in minor detail in the paper. However it is necessary to note the basis of the spaced receiver technique. When the radio sensing is in progress the ionospheric irregularities generate a diffraction pattern at the ground level. The movement of the diffraction pattern is registered with the spaced sensors and as a result we obtain similar records which are displaced relative to each other.

There are many methods of the spaced receivers data processing but only two are well known; they are the similar fading technique and the correlation analysis. The similar fading technique is not suitable for obtaining reliable information about the drifting irregularities because this method is employed in the case of the isotropic diffraction pattern and it only gives so-called apparent drift velocity. In the real circumstances the diffraction pattern is anisotropic, and changes are formed during its motion. Hence it is necessary to apply the statistical approach, e.g. the correlation analysis.

The analysis of the ionospheric drift records can be carried out using various ways of the correlation functions application. These ways are well known as full correlation analysis, which was developed by Briggs [Briggs, 1984] and the generalized correlation analysis [Khudukon et al., 1994]. The example of the drift velocity behavior deduced by full correlation analysis is presented in Fig.6.

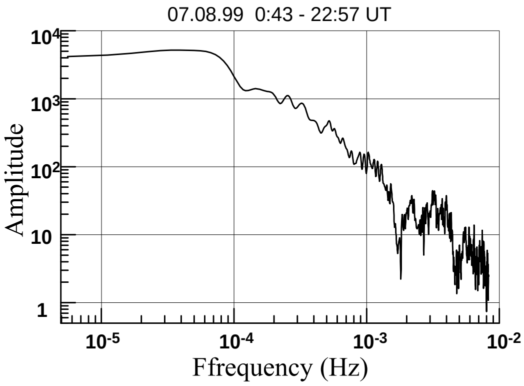

Fig.5. Spectrum of twenty two-hour data sequences at the height of 82 km.

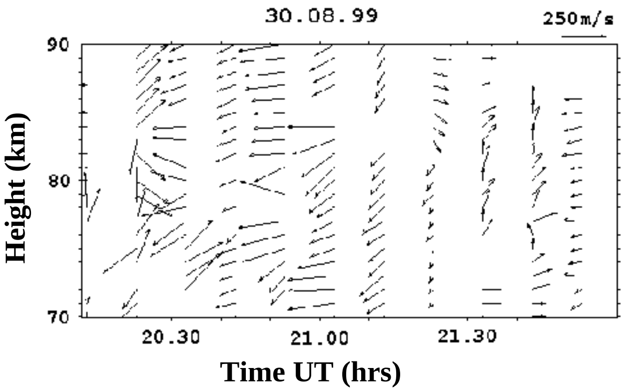

Fig.6. Time – altitude picture of the irregularity speed measurements.

The distinctions between these methods consist, predominantly, in the approach of extracting the information from correlation functions. The full correlation analysis uses mutual intersections of auto- and cross-correlation functions as well as maximum of the functions for the determination of drift velocity and anisotropy of the irregularities. And the total quantity of the characteristic points for this method is not large. On the other hand, the improved technique of Khudukon et al. applies the definition of the correlation level and the employing of the correlation levels for the extraction of time lag values, which gives a big quantity of the characteristic points for the parameters of the irregularities determination. This is a feature of generalized correlation analysis, which increases the statistical accuracy of the technique at the expense of the more complete utilization of the information, which is extracted from correlation functions.

The processing of the fading records of the reflected signal which is received by spaced sensors using the generalized correlation analysis has been carried out for the first time. Furthermore the derived values of the parameters correspond to the real geophysical situation. The estimations of the drift velocity varies from 30 m/s to 130 m/s. The velocity vectors keep general direction to the east and fluctuate at different heights within the limits of 45°. However, it is possible that in some cases the velocity vector direction varies within 180°. The correlation analysis gives us an opportunity to estimate the transversal anisotropy parameters of the ionospheric irregularities such as the axes ratio and orientation angle. The conception of the anisotropy parameters virtually proceeds from the assumption that contours of the diffraction pattern can be approximated with ellipses. From this it follows that the transversal anisotropy can be defined as the ratio of semi-major and semi-minor ellipse axes and the orientation angle indicates the orientation of the semi-major axis. Thus, the computed values of the axis ratio vary from 1.1 to 1.5 and the orientation angle has fractional fluctuations approximately nearby 10° within the limits of 20°. Therefore, it is necessary to note that the phenomena of the character signal fading is very rare and so we had no opportunity to form a certain complete pattern of the drift velocity and anisotropy parameters alteration.

Application of the cross-correlation function for the altitude sorting of the irregularities scales

During the determination of the drift velocity and anisotropy parameters it was revealed that values of the main maximum of the cross-correlation functions depend on the height. For the investigation of the dependence there were estimated the cross-correlation functions for the three pairs of sensors and the time-altitude picture of the evaluations of the cross-correlation functions maximum was plotted. The estimation of the cross-correlation functions was carried out in 100-s time interval of the spaced-received records. The choice of the time interval quantity is found with a character-fading period. The average value of the period for the processed data varies from 1.5 to 4 sec. Fig. 7 shows the time-altitude picture of the evaluation of the cross-correlation functions maximum for the 30 August 1999. The top panel of

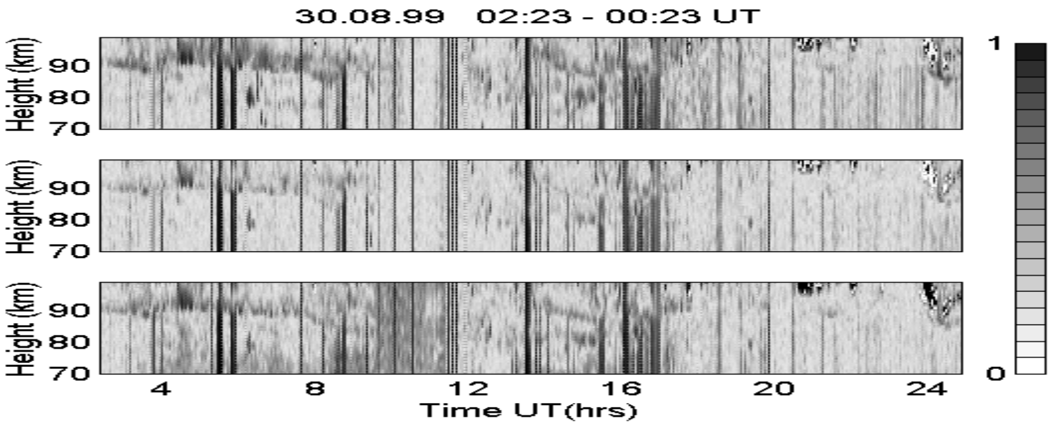

Fig.7. Time-altitude picture of the normalized cross-correlation function maximum.

the picture refers to the first pair of the spaced sensors (1-2), the middle panel is intended for the second pair of sensors (1-3) and the last panel for the third pair (2-3). Furthermore, the correlation level of the normalized correlation function maximum is depicted with the color intensity. As shown in fig. 7, some regions with high correlation level appear during time intervals from 02:30 to 10:00 UT and from 13:00 to 17:00 UT. The period 02:30 – 10:00 is characterized with one layer at the altitudes 87 – 100 km and two layers appear in the next interval 13:00 – 17:00. These layers can be interpreted as a region where irregularities with a scale more than 150 m are grouped. This quantity depends on the size of the antenna system. Therefore, vertical lines with the highest intensity correspond bad to the data. It is necessary to note that the comparison of the same picture for the following days showed that other days were characterized by the similar stratified structure. Therefore, it is possible to draw a conclusion that such method provides the data of the altitude scales irregularities sorting.

Conclusions

The measuring facility of the Polar Geophysical Institute enables one to investigate the structure and behavior dynamics of the lower ionosphere irregularities. This fact is confirmed byy the figures, presented in this paper. Therefore, the application of new methods of data processing allows us to evaluate other parameters of the irregularities for a more thorough knowledge about processes of the lower ionosphere. The method of the partial radioreflections permits to determine regions of the D-layer with stratified and thin structures and as well as to employ it for research some phenomena such as PMSE and noctilucent clouds.

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