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Spectra of Tides and Planetary Waves from the Data of Ionosonde Measurements near Saint Petersburg

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ABSTRACT

Spectra of the critical frequency of the F2 ionospheric layer in the range of periods 0.5 – 40 days are analyzed using the data of measurements with the ionosonde DPS-4 at the Peterhof scientific station of Saint Petersburg State University (60°N, 30°E). Spectral analysis is executed using the Lomb –Skargle method for 60-day running intervals. Spectra show maxima at periods of 1 day and 0.5 day corresponding to diurnal and semidiurnal changes, and maxima in the range of periods 2 – 40 days. These waves have frequently maximum amplitudes in spring and summer, which is opposite to the PW amplitudes observed in the lower and middle atmosphere. This may be caused by different mechanisms including possible PW propagation from the middle atmosphere of the winter hemisphere to the summer thermosphere along the waveguides crossing the equator at altitudes above 60 km.

Keywords: upper atmosphere, ionosphere, ionospheric disturbances, planetary waves, tides, spectral analysis

1 INTRODUCTION

Planetary waves (PWs), generated in the lower atmosphere can propagate upwards into the thermosphere and create fluctuations of ionospheric parameters with periods of several days. Wave sources in the thermosphere itself, for example, changing solar and geomagnetic activity, could be other reasons for planetary wave-like oscillations. Numerous studies revealed oscillations of ionospheric parameters, particularly, the critical frequency of the F2 layer, f_0F2, having periods longer than 2 days [1-3]. This allows suggestions that PWs propagating from the lower atmosphere can influence the ionospheric electron density. However, atmospheric modeling showed that PWs with observed periods might not directly propagate to altitudes above 110 km [4-6].

Several mechanisms were proposed to explain how lower atmosphere PWs can influence the ionospheric plasma. They include PW modulation of tidal and gravity waves, which then transfer this modulation to the F-region of the ionosphere. Another mechanism could be modulation of O/N_2 density ratio in the region of the mesosphere-lower thermosphere (MLT), which then is transferred to high altitudes. However, recently, these mechanisms are not yet adequately studied and further observations of planetary wave-like ionospheric oscillations is requires.

Since 2018, regular observations of ionospheric parameters with the DPS-4 ionosonde are performed at the Peterhof Scientific Station of Saint Petersburg State University (60° N, 30° E). In this study, we present the first results for spectra of oscillations of ionospheric parameters in the range of periods 0.5 – 40 days according to these measurements.

2. METHOD OF DATA ANALYSIS

Measurements are made with the standard ionosonde DPS-4 in the “Geomodel” Resource Center of SPbSU. Digital ionosonde DPS-4 consists of two-channel transmitter and four receiving antennas. It is characterized by a comparatively low power of the transmitter (300 W), which is achieved by the use of phase coding, digital pulse compression and Doppler integration. Control, data collection, signal processing and standard data analysis is accomplished by a multiprocessor computer system. The synchronization of time is achieved through the Global Positioning System (GPS). At present, there is a worldwide network, which includes more than 70 DPS-4 ionosondes in different countries. Regular continuous measurements with the ionosonde DPS-4 in SPbSU are conducted starting from the year 2018.

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Usually, standard measurements are made twenty-four hours a day with the time spacing 7.5 min. Ionosonde gives information about a large variety of ionospheric parameters. For the wave analysis, we use the critical frequency of ionospheric F2 layer, f_0F2. Spectral analysis in the present study is executed using the standard method of Lomb - Skargle [7,8]. This method is based on the approximation of non-equidistant measured values of the analyzed quantity by sinusoidal functions with different frequencies ν. In comparison with the standard computer program realized the Lomb –Skargle method [9], the algorithm, used in the present study makes it possible to determine also amplitudes and phases of all spectral components. PW spectra were calculated using 60-day intervals. This makes it possible to determine wave components with periods up to 40 day. To study seasonal changes of PW amplitudes we used running 60-day intervals with the time shift of 6 days.

3. RESULTS OF THE ANALYSIS.

The dependence of obtained spectra on time in months starting from the beginning of 2018 is shown in Figure 1.

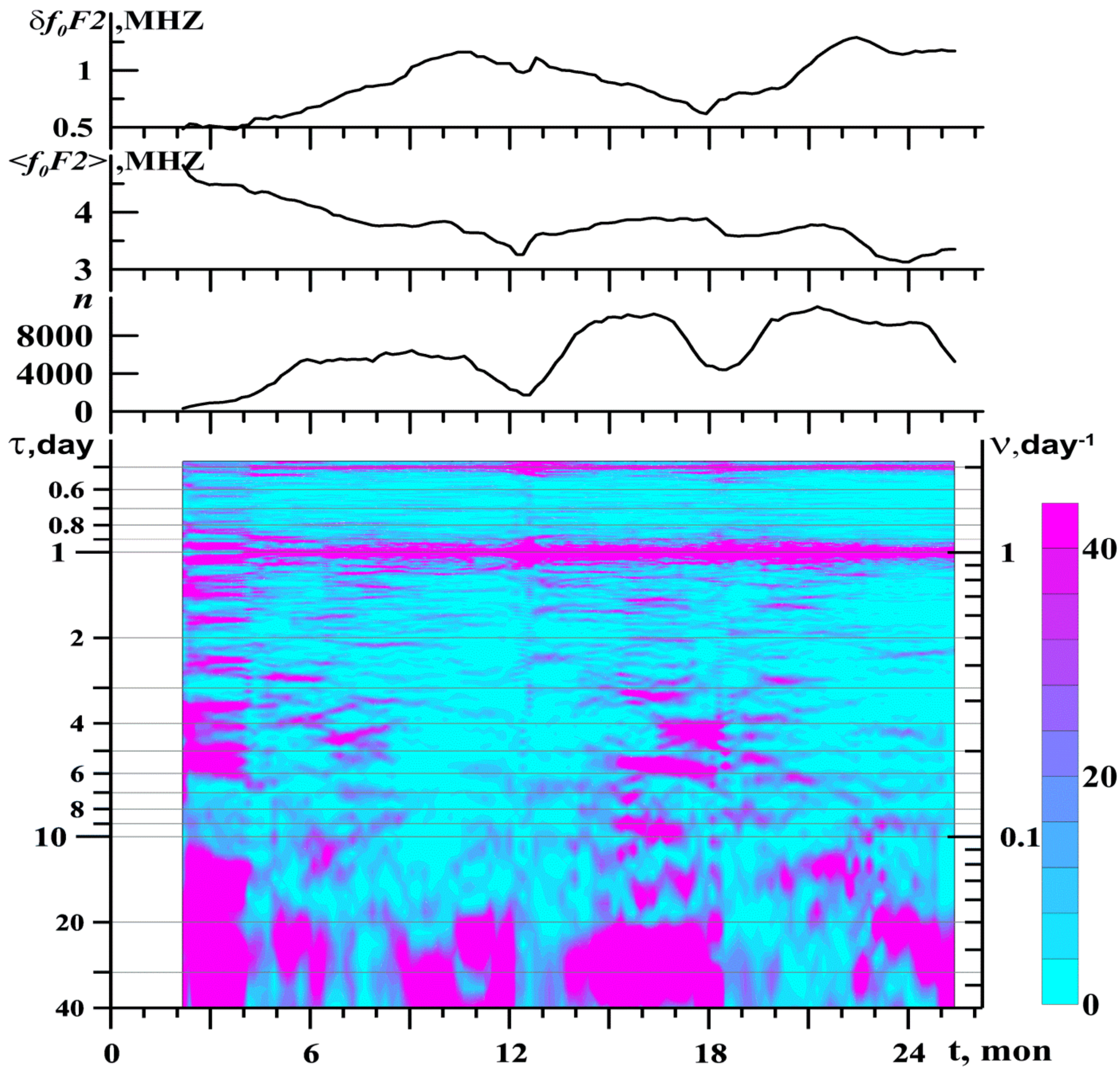

Figure 1. Time variations of the f_0F2 spectral density (in relative units) during years 2018 – 2019 at Saint Petersburg. Shown also are the numbers of measurements within 60-day intervals, n, the average value $<f_0F2>$ and the standard deviation δf_0F2 of the critical frequency of ionospheric F2-layer.

In Figure 1 one can see spectral maxima at periods $\tau = 1/\nu = 1$ d and $\tau = 0.5$ d, which are connected with diurnal and semidiurnal changes in ionospheric parameters. They may be connected with changes of solar radiation during a day and with atmospheric tides. Figure 1 shows constant presence of the diurnal and semidiurnal spectral maxima during the entire interval of observations. In addition, Figure 1 shows presence of spectral maxima in the range of periods $\tau \sim 2$ – 40 d, which could be connected with planetary wave-like oscillations in the F2 ionospheric layer. Amplitudes and periods of these spectral maxima are variable in Figure 1. Examples of individual spectra for 60-day intervals corresponding to high wave activity in Figure 1 are shown in Figure 2.

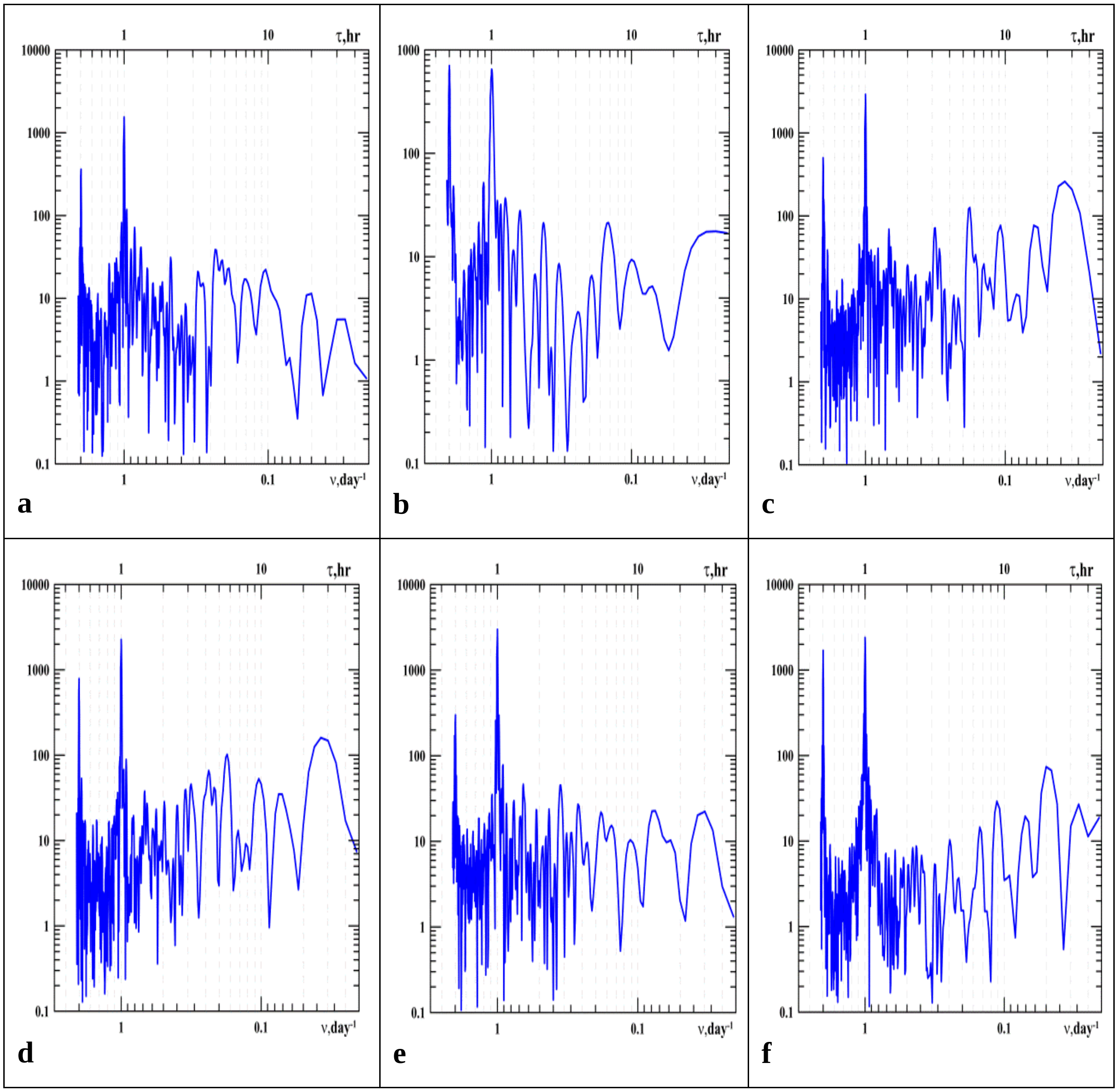

Figure 2. Spectra of critical frequency f_0F2 in Saint Petersburg for the 60-day intervals, centered around the following dates: 2018.08.16 (a), 2019.02.02 (b), 2019.05.01 (c), 2019.05.31 (d), 2019.09.04 (e) and 2019.12.03 (f).

Figure 2 represents spectra for the measurements in years 2018 and 2019, when sufficiently large numbers of f_0F2 experimental values were registered during respective 60-day intervals. In all panels of Figure 2 the largest maxima are located at the diurnal period $\tau = 1$ d. The second maximum is visible at $\tau = 0.5$ d, which correspons to the 12-hour component of daily variations (semidiurnal tide). Other spectral maxima are located in the period range $\tau \sim 2$ – 40 d.

Table 1. Periods τ_i in days and amplitudes S_i in relative units for 10 main maximums (i = 1, 2,..., 10) of spectra, depicted in Figure 2. Other presented parameters: n is the number of *f0F2* registrations during respective 60-day intervals; $<f_0F2>$ and δf_0F2 are the average value and standard deviation of the critical frequency of the F2 layer.

Date	2018.08.16	2019.05.01	2019.05.31	2019.09.04	2019.12.03
n	5470	9940	9440	9600	9420
$<f_0F_2>$,MHz	3.8	3.9	3.9	3.6	3.2
δf_0F_2, MHz	0.83	0.85	0.74	0.84	1.2
τ_1(day) / S_1	34 / 5.6	27 / 260	27 / 160	30 / 22	20 / 74
τ_2(day) / S_2	20 / 11	16 / 77	13 / 35	13 / 23	14 / 20
τ_3(day) / S_3	9.6 / 22	9.2 / 77	9.6 / 53	8.9 / 10	8.9 / 30
τ_4(day) / S_4	6.9 / 17	7.1 / 26	6.9 / 13	6.5 / 15	6.7 / 14
τ_5(day) / S_5	5.3 / 23	5.6 / 130	5.7 / 102	5.4 / 22	4.7 / 3.7
τ_6(day) / S_6	3.9 / 30	4.3 / 5.6	4.2 / 66	3.8 / 27	4.1 / 10
τ_7(day) / S_7	3.2 / 21	3.1 / 71	3.2 / 46	2.8 / 45	2.6 / 6.8
τ_8(day) / S_8	2.5 / 6.1	2.0 / 26	2.5 / 26	2.3 / 23	2.3 / 8.7
τ_9(day) / S_9	1.0 / 1500	1.0 / 2920	1 / 2260	1.0 / 2990	1.0 / 2400
τ_{10}(day) / S_{10}	0.5 / 140	0.5 / 500	0.5 / 790	0.5 / 120	0.5 / 1690

Table 1 depicts periods and amplitudes (in relative units) for 10 spectral maximums for respective dates depicted in Figure 2. One can see frequently repeated maximums around periods τ ~ 30, 20, 16, 13, 9, 7, 5, 4, 3, 2.3 d. These periods correspond to PW modes, which are observed in the lower and middle atmosphere. Maximum amplitudes in table 1 correspond to periods of diurnal and semidiurnal oscillations. In the region of PW periods, amplitudes $S_i > 50$ in table 1 are noted at periods τ ~ 27, 20, 16, 9.4, 5.6, 4.2, 3.1 d. Table 1 also shows that at a fixed PW period, wave amplitudes vary considerably depending on the date of measurements. This variability can be connected with changes in the amplitudes of PWs, which can propagate into the ionosphere from the lower layers of the atmosphere. In the literature, different mechanisms of the penetration of PW modes from the MLT region to the heights of F2 layer were discussed. One of the mechanisms assumes changes in the concentration of atomic oxygen near the turbopause under PW actions, which then may extend to the F2 altitudes [1,10]. Possible coupling of planetary wave-like oscillations in the MLT region and in the ionosphere were confirmed, for example, by observed simultaneous changes in the wind speed in these regions [10].

Figure 1 shows that maximum amplitudes of oscillations with periods τ ~ 2 – 40 d are frequently observed in the northern spring and summer months, when westward stratospheric winds prevent PW propagation from the lower to the upper atmosphere. However, the analysis of PW waveguides by [11,12] showed that they can cross the equator above altitues of 60 km. Therefore, PWs observed in summer ionosphere can, in prinsiple, propagate from the lower wave sources located in the winter hemisphere.

For more complete understanding of the mechanisms of connections between planetary wave-like structures in the ionosphere and PWs in the underlying regions of the atmosphere, additional studies with the use of more years of observations are required. In particular, straight comparisons of frequencies and amplitudes of PWs observed in the lower and middle atmosphere with respective parameters of ionospheric oscillations are desirable.

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REFERENCES

[1] Pancheva, D. and Lysenko, I., "Quasi-to-day fluctuations observed in the summer F region electron maximum", Bulgarian Geophysical Journal, 24 (1988).

[2] Forbes, J. M. and Leverony, S., "Quasi 16-day oscillation in the ionosphere", Geophysical Research Letters, 19, 981-984, https://doi.org/10.1029/92GL00399 (1992).

[3] Shalimov, S. I., Lapshin, V. M. and Haldoupis, C., "Structure of planetary disturbances of the mid-latitude ionosphere according to observations of GPS satellites", Cosmic Research, 44, 463-467, https://doi.org/10.1134/S0010952506060013 (2006).

[4] Hagan, M. E.,Forbes J. M. and ial, F., "Numerical investigation of the propagation of the quasi-two-day wave into the lower thermosphere", Journal Geophysical Research, Atmospheres, 98, 23193-23205, https://doi.org/10.1029/93JD02779 (1993).

[5] Forbes, J. M., "Tidal and planetary waves. In: Johnson, R. M., Kileen, T. I. (Eds), The upper mesosphere and lower thermosphere: a review of experiment and theory," Geophysical Monograph Series, 87, 67-87 (1995).

[6] Pogoreltsev, A., Vlasov, A., Frohlich, K. and Jacobi, C., "Planetary waves in coupling the lower and upper atmosphere", Journal Atmospheric Solar-Terrestrial Physics, 69, 2083-2101, https://doi.org/10.1016/j.jastp.2007.05.014 (2007).

[7] Lomb, N., "Least-squares frequency analysis of unequally spaced data", Astrophysics and space science, 39(2), 447–462 (1976).

[8] Scargle, J. D., "Statistical aspects of spectral analysis of unevenly spaced data", Astrophysical Journal, Part 1, 263, 835-853 (1982).

[9] Press, W., Teukolsky, S., Vetterling, W. and Flannery, B., "Numerical Recipes", Cambridge University Press, Cambridge (1992)

[10] Stray, N. H., Espy, P. J. Planetary wave-like oscillations in the ionosphere retrieved with the longitudinal chain of ionosondes at high northern latitudes. J. Atmos. Solar-Terr. Phys., 2018, 171, 225-233.

[11] Koval, A. V., Gavrilov, N. M., Pogoreltsev, A. I. and Shevchuk, N. O., "Propagation of stationary planetary waves to the thermosphere at different levels of solar activity", Journal Atmospheric Solar - Terrestrial Physics, 173, 140–149, https://doi.org/10.1016/j.jastp.2018.03.012 (2018).

[12] Koval, A. V., Gavrilov, N. M., Pogoreltsev, A. I. and Shevchuk, N. O., "Influence of solar activity on penetration of traveling planetary-scale waves from the troposphere into the thermosphere", Journal Geophysical Research, Space Physics, 123, https://doi.org/10.1029/2018JA025680 (2018).