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Features of atmospheric tide according to the Geophysical observatory Mikhnevo

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Abstract. Atmospheric tides refer to those oscillations in the atmosphere whose periods are integral fractions of a lunar or solar day. Atmospheric tides are, in small measure, gravitationally forced, they are primarily forced by daily variations in solar insolation. Based on the results of instrumental observations of micropulsations of atmospheric pressure, the main waves of the lunar-solar tide in the Earth's atmosphere are identified. The registration of micropulsations is obtained in the range from 0.1 MHz to 10 Hz in the Geophysical observatory Mikhnevo of Institute of Geosphere Dynamics of Russian Academy of Sciences located in the Moscow region in period 2008-2016. An estimate of the spectral characteristics of micropulsations was carried out using the maximum entropy method. In order to increase the level of discrimination related to the frequencies of tidal waves, the adaptive rejection filtering method was applied. It is shown that the spectral amplitudes with frequencies that coincide with the frequencies of the tidal waves change with time with a periodicity of about 29 days. The characteristics of modulation of the solar elliptic wave S_1 and the main solar wave S_2 by periods of 13.66, 27.55 days are obtained; as well as ~ 0.3, 0.5 and 1 year.

1. Introduction

Atmospheric tides refer to those oscillations in the atmosphere whose periods are integral fractions of a lunar or solar day. The 24-hour Fourier component is referred to as a diurnal tide, the 12-hour component as a semidiurnal tide. The total tidal variation is referred to as the daily variation. Although atmospheric tides are, in small measure, gravitationally forced, they are primarily forced by daily variations in solar insolation. Tides, as defined above, exist on a variety of scales; generally only those tidal oscillations on a global scale are considered in tidal theory. Moreover, one distinguishes between migrating tides (which are functions of local time) and non-migrating tides (which depend on both local time and longitude).

The research of tidal effects in the Earth's atmosphere is of considerable interest not only in terms of improving and developing new atmospheric models, which, along with scalar information, requires information about its vector characteristics, but also for providing high-precision satellite positioning systems and solving problems associated with the propagation of radio waves, since the state of the ionosphere depends to a large extent on the wind system and, consequently, the atmospheric pressure gradients at the thermospheric heights. The urgency of the study of the atmospheric tide is also due to a number of other reasons. Attracting information on tidal fluctuations in the atmosphere, one can consider the problems associated with the possibility of detecting and monitoring weather, or even climate changes, caused by natural and man-made impacts on the Earth's atmosphere. It is also not excluded that the knowledge of the temporal and spatial variations of tidal effects will make it possible to approach the establishment of mechanisms for the formation of cyclones and anticyclones.

The known difficulties associated with the study of the atmospheric tide are primarily due to the fact that in the atmosphere, in contrast to the tide in the solid geospheres, significant material movements are permissible. The possibility of establishing the basic mechanisms of the atmospheric tide is associated with the accumulation of observational data. Unfortunately, such data is still not enough. This is due to the difficulties in isolating the tidal component from atmospheric pressure fluctuations, and also because sufficiently weak tidal effects are camouflaged by powerful atmospheric cyclonic processes.

Most of the work in the study of the atmospheric tide [1-9] is mainly of a theoretical nature and is based on models. The researches carried out based on the results of instrumental observations [10-12], even with the use of long time series of atmospheric pressure records make it possible to distinguish only a small part of the tidal waves in the atmosphere. Tidal waves S_2 (main solar period, 12 hours), M_2 (main lunar period, 12.42 hours), S_1 (elliptical solar period, 24 hours) and M_1 (elliptical lunar period, 24.84 hours) were clearly identified. Tidal waves ψ_1, K_1, P_1 and O_1 are less clearly marked.

In the present work, the possibility of isolating tidal waves in the Earth's atmosphere is considered on the basis of an analysis of long time series of data obtained as a result of instrumental observations performed at the Earth's surface and containing information not only about atmospheric pressure fluctuations but also about its micropulsations.

2. Initial data

As the initial data, a series of instrumental observations of atmospheric pressure was performed in the conditions of the Geophysical observatory Mikhnevo of Institute of Geosphere Dynamics of Russian Academy of Sciences (54.9595º N, 37.7664º E) in the period from 2008 to 2016 [13, 14]. Simultaneously with the atmospheric pressure P_0, its variations $P(t)$ were recorded in the frequency band 10^{-3} - 10 Hz. The registration of the meteorological parameters, including P_0, was carried out using the Davis Vantage Pro2 meteorological station (Fig. 1). To measure micropulses of atmospheric pressure, a microbarometer MB-03 was used, equipped with a system of spatial filters to suppress wind noise (Fig. 2) [15, 16]. To reduce the effect of temperature drift, the microbarometer is installed in a well 2 m deep.

Figure 1. Davis Vantage Pro2 meteorological station

Figure 2. Appearance of MB-03 microbarometer with a system of wind-suppressing filters at the measuring platform

The results of registration in the form of digital series $P(t)$ are accumulated on hard carriers and presented on the website of Institute of Geosphere Dynamics of Russian Academy of Sciences (http://idg.chph.ras.ru/~mikhnevo/).

The preparation of the data consisted in the removal of spikes using a "box-and-whiskers diagram" [17] and using the criteria proposed in [18-20]. Omissions in temporal realizations, including those resulting from the removal of spikes, were removed with a small amount by linear interpolation, in the case of long intervals of missing values, a double Fourier transform was used to reconstruct the series [21].

For the analysis, digital series of data were formed with a discreteness of 1 min. An estimate of the spectrum of atmospheric pressure micropulsations $P(t)$ was performed by parametric autoregression method [22, 23]. In order to increase the level of discrimination of quasi-harmonic spectral components close in time, in addition to parametric spectral analysis, we also used the method of separating harmonic components using narrow-band adaptive notch filters [24], whose advantage lies in the simplicity of choosing the desired frequency, unlimited suppression of neighboring frequencies. In the present work, when the quality factor of the filter is $1 \cdot 10^4$ - $2 \cdot 10^4$ that provides a frequency resolution of $8 \cdot 10^{-6}$ 1/h, i.e. periodic harmonics stand out with an accuracy of 0.0046 h. Such a resolution allows even the closest waves to be distinguished: T_2, S_2 and R_2, whose periods differ by 0.016 h.

3. Results of analysis of atmospheric pressure micropulsations

The use of the proposed approach, based on the analysis of the spectral characteristics of micropulsations of atmospheric pressure, made it possible to single out the entire series of tidal waves. Fig. 3 and Fig. 4 show the spectral density of atmospheric pressure micropulsations versus frequency for daily and semidiurnal constituents. Fig. 5 and Fig. 6 demonstrate fragments of spectra in the vicinity of frequencies corresponding to tidal waves S_1 and S_2, respectively.

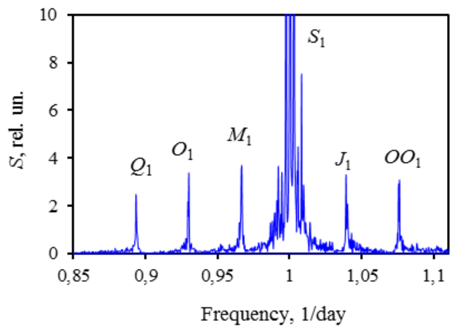

Figure 3. Spectrum of atmospheric pressure micropulsations in diurnal range

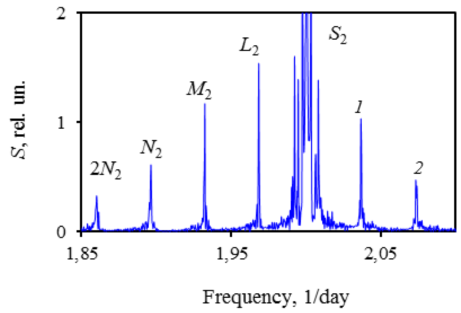

Figure 4. Spectrum of atmospheric pressure micropulsations in semidiurnal range

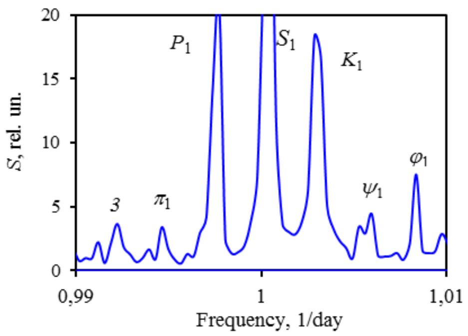

Figure 5. Fragment of the spectrum of atmospheric pressure micropulsation in diurnal range

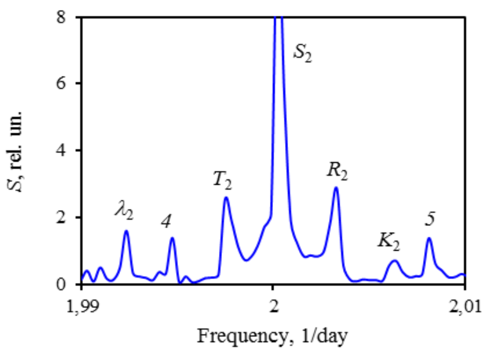

Figure 6. Fragment of the spectrum of atmospheric pressure micropulsations in semidiurnal range

It can be seen from the Fig. 3-6 that along with the pronounced quasiharmonic spectral peaks corresponding to the known tidal waves, which are marked in accordance with the accepted designations, additional peaks 1-5 are identified, the cause of which will be discussed below.

It should be especially noted that in addition to diurnal and semidiurnal waves, the long-period tidal waves (Fig. 6) are distinctly distinguished in the spectrum of micropulsations of atmospheric pressure: lunar declination wave M_f (period of 13.66 days) and lunar elliptic wave M_m (period of 27.5 days).

The obtained results indicate that the analysis of atmospheric micropulsations using data obtained from measurements at the Earth's surface allows us to distinguish a wide range of tidal waves in the Earth's atmosphere. It is important to note that the data presented in Fig. 4 and Fig. 5 show that the maximum spectral amplitudes in the vicinity of diurnal and semidiurnal variations are characterized by tidal waves of solar origin S_1 and S_2. This fully corresponds to the known notions of the predominant influence of solar warming of the atmosphere with characteristic periods of 12 hours and 24 hours [1].

An analysis of the obtained data shows that the amplitudes of the tidal waves vary considerably with time. As an example, Fig. 7 shows the variations of the relative spectral amplitudes of the main tidal waves, calculated from the data of the present work. The periodicity in the changes of the quantities under consideration is clearly visible. For example, the amplitude of the tidal wave K_2 varies with time with a period of ~ 4.8 months. However, the behavior of the amplitude of the solar elliptic wave S_1, whose amplitude periodically reaches its maximum values is of greater interest, it is so small that it does not allow us to single out the methods used in this research.

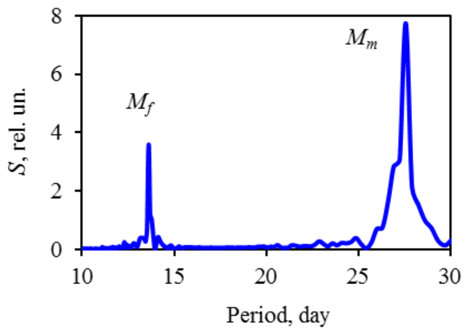

Figure 7. Fragment of spectrum of atmospheric pressure micropulsations in 13 and 27 day range

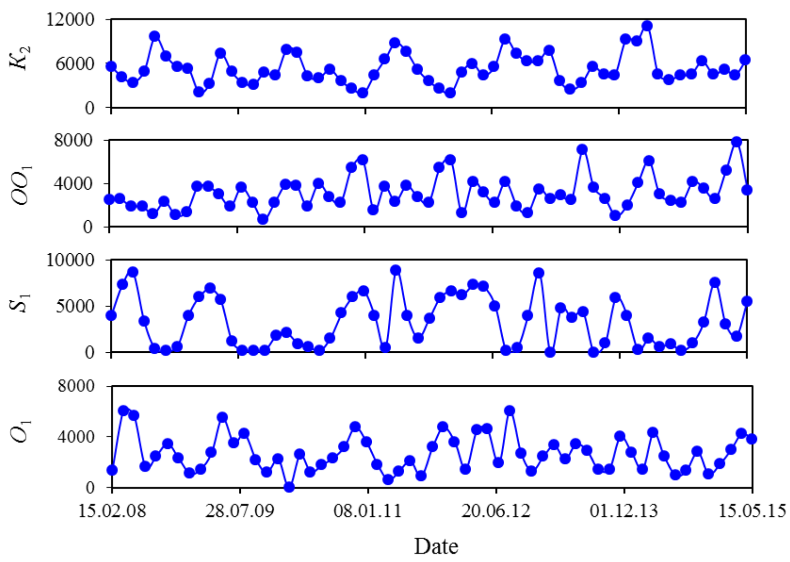

Figure 8. Variation of the spectral amplitudes of the main tidal waves

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4. Modulation of tidal wave

The nonlinearity of the processes occurring in the atmosphere leads to modulation of the fundamental atmospheric pressure fluctuations, which are associated, in particular, with tidal waves. It is known [25] that in the case when oscillations with frequency ω are superimposed with oscillations with a lower frequency Ω, the resultant amplitude-modulated oscillations P are written in the form:

$$P = V\cos(\omega t + \varphi) + 0.5Vm\cos[(\omega + \Omega)t + \Phi] + 0.5Vm\cos[(\omega - \Omega)t + \varphi + \Phi], \quad (1)$$

where V, ω and φ are the amplitude, the circular frequency and the initial phase of the carrier wave, respectively; m is the depth of modulation; Ω and Φ the frequency and phase modulation of the amplitude of the carrier wave, respectively; t is time. This expression reflects the nature of the amplitude-modulated oscillation including the carrier wave (the first summand) and the harmonic components with frequencies ω + Ω (upper sideband) and ω − Ω (lower sideband). In this case, the amplitudes of the side components are determined by the value $0.5Vm$.

Taking (1) into account, let us analyse the graphs shown in Fig. 2-5. It is clearly seen in these figures that the central spectral peaks associated with the waves S_1 and S_2 are accompanied by a series of equidistant peaks. Thus, the pair of spectral peaks symmetrically located to S_1, corresponding to the tidal waves P_1 and K_1, are spaced from the peak S_1 by ~ 0.0027 1/day with accuracy not worse than 2.5%. In accordance with (1), the superposition of the central S_1 and the two sideband oscillations P_1 and K_1 characterizes the amplitude modulation of the diurnal fluctuations S_1 by the period of ~ 1 year. Simultaneously, in the diurnal fragments of the spectrum there are spectral peaks with frequencies of ~0.994 1/day and ~1.0054 1/day. These are tidal waves ψ_1 and π_1, which in accordance with (1) arise as a result of modulation of diurnal fluctuations of atmospheric pressure by a half-year period (182 days). Thus, tidal waves P_1 and K_1 can be considered with practical accuracy as sideband of an amplitude-modulated oscillation with a carrier frequency of 1/day with a modulation period of ~ 1 year, and waves ψ_1 and π_1 are sideband of an amplitude-modulated oscillation with period modulation of 0.5 years.

As a result of modulation of diurnal fluctuations of atmospheric pressure by a third-year period, there are also spectral peaks with frequencies of ~ 0.9922 1/day (peak *3* in Fig. 4) and ~ 1.0082 1/day. (peak *1* in Fig. 4), which are equidistant from the S_1 wave by 0.0082 1/day with an accuracy not worse than 2%, and this corresponds to a modulation period of ~ 122 days.

Analysis of the spectra shown in Fig. 2, shows that the triplet of spectral peaks identified with the tidal waves O_1, S_1 and J_1, demonstrates the modulation of the S_1 wave by a period of 27.5 days. Another triple of spectral peaks, identified with the tidal waves M_1, S_1 and OO_1, demonstrates the modulation of the S_1 wave with a period of 13.66 days.

Similarly, it is possible to establish the amplitude modulation of the tidal wave S_2. Indeed, considering the spectra shown in Fig. 3 and Fig. 5, we obtain: the triplet of spectral peaks identified with the tidal waves L_2, S_2 and the isolated peak *1* demonstrates the modulation of the S_2 wave by the period of 27.5 days. Another triple of spectral peaks identified with the tidal waves M_2, S_2 and the isolated peak *2* demonstrates the modulation of the S_2 wave by a period of 13.66 days. The superposition of the spectral peaks identified with the tidal waves T_2, S_2 and R_2 demonstrates the modulation of the S_2 wave by a period of ~ 1 year. The triplet of spectral peaks identified with the tidal waves K_2, S_2 and the spectral peak *4* demonstrates the modulation of the S_2 wave by a period of ~ 180 days. The triplet of spectral peaks identified with tidal waves λ_2, S_2 and the spectral peak *5* demonstrates the modulation of the S_2 wave by a period of ~ 120 days.

Thus, it can be stated that the main tidal waves of solar origin S_1 and S_2 are modulated by the annual, semi-annual, and third-year periods, and also by periods of 13.66 and 27.5 days. The spectral peaks *1 − 5*, isolated from the spectra of atmospheric pressure micropulsations, are a consequence of the indicated amplitude modulations.

An example of the amplitude-modulated oscillation formed by the waves S_1, P_1, K_1, π_1 and ψ_1 is shown in Fig. 8. It follows from the ratio of the amplitudes of these waves that the depth of modulation of S_1 by the annual period is $m \sim 0.9$, and the half-year period is $m \sim 0.2$. For the waves S_2, K_2, R_2, T_2 and *4*, the corresponding modulation values are estimated at values of ~ 0.5 and ~ 0.15.

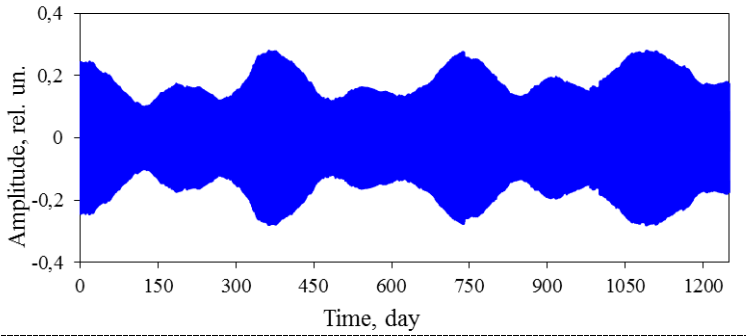

Figure 9. Example of an amplitude-modulated oscillation formed by waves S_1, P_1, K_1, π_1 and ψ_1

5. Conclusion

The proposed in paper approach, based on the analysis of the spectra of micropulsations of atmospheric pressure, makes it possible to define practically all known tidal waves in atmospheric pressure. It is important that for the separation of tidal waves it is permissible to use the results of recording at the Earth's surface, which greatly simplifies instrumental observations in the study of atmospheric processes.

In this paper, in addition to the previously identified tidal waves in variations of the atmospheric pressure S_2, M_2, S_1, M_1, ψ_1, K_1, P_1 and O_1, according to the registration data of its micropulsations, tidal waves M_f, M_m, λ_2, K_2, R_2, L_2, N_2, $2N_2$ T_2, Q_1, OO_1, J_1, φ_1, π_1 were distinguished. An evaluation of the spectral characteristics of micropulsations of atmospheric pressure over a long period of observations shows that diurnal and semidiurnal spectral peaks of variations in atmospheric pressure are accompanied by lateral equidistant spectral lines, which is a direct indication of the modulation of these spectral components. Modulation periods of the corresponding tidal waves are about 13.66; 27.5 days, as well as 1, 0.5 and a third of the year.

The results of this work can be in demand in the construction of a general model of the Earth's atmosphere and the establishment of the basic laws of atmospheric movements.

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