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STRUCTURE OF ATMOSPHERIC BOUNDARY LAYER ON
THE COAST OF BAIKAL LAKE ACCORDING TO RESULTS OF
REMOTE ACOUSTIC SOUNDING

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In the report we consider specific features of altitudinal-temporal structure of turbulent temperature pulsations of atmospheric boundary layer at the settlement Bolshie Koty on the coast of Baikal Lake. The measurements were performed using Doppler sodar Volna-3, owned by Institute of Atmospheric Optics SB RAS, at summertime in 2001-2002. We present the results of reconstruction of altitude profiles of normalized structure constants of temperature pulsations for different turbulence regimes. Frequent presence of internal gravity waves with different periods of oscillation is indicated.

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EXPERIMENTAL STUDY OF SOUND WAVE INTERFERENCE ON SHORT
NEAR-SURFACE PATHS

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We discuss the results of experiments dealing with interference of direct sound waves and waves, reflected from plane surface, for the frequency range 1.4 – 10.0 kHz. We considered different variants of placement of source and receiver of emission over reflecting surface. Experimental results are compared with theoretical insights into signal amplitude under conditions of surface reflections.

Study of interference of direct and surface-reflected sound waves on near-surface atmospheric paths remains urgent until presently. This is because of insufficient experimental elaboration of the issue of how mean values and turbulent pulsations of wind velocity and temperature, as well as surface roughness, influence the amplitude and phase of interfering waves.

The report discusses the theoretical and experimental results dealing with interference of sound waves of audible range, propagating along short near-surface paths. The main purpose of the work is to gain methodical and technological experience of accomplishment of experiments in interference, which would ensure correct quantitative comparison of theoretical and experimental results.

The standard theoretical analysis of interference generally does not account for such features of the real experiments as frequency dependence of sensitivity of receiving-transmitting channel, non-sphericity of direction pattern (DP) of the sound sources and a number of other parameters and interrelations. However, in quantitative comparisons of theoretical and experimental results, this should be taken into account. In this regard, we refined the corresponding formulas available in the literature. Without inclusion of the effect of mean motions in the atmosphere and for zero vertical temperature gradient, the formula for the square of amplitude of sound pressure can be represented as

$$p^2(f) = A^2(f)B^2(f) r_d^{-2} e^{-2r_d\alpha(f)} \{g^2(\theta_d, f) + |Q|^2 g^2(\theta_r, f) + 2|Q| C(f) g(\theta_d, f) g(\theta_r, f) \cos[k(r_1 + r_2 - r_d) + \Omega]\}. \quad (1)$$

Here $A(f)$ is amplitude-frequency characteristic (AFC) of source, $B(f)$ is AFC of receiver, $g(\theta, f)$ is source DP normalized with respect to amplitude (DP of microphone is assumed to be spherical), θ_d is angle between source DP axis and direction of receiving microphone, θ_r is direction toward the point of reflection from the surface, r_d is distance between source and receiving microphone, r_1 and r_2 are distances from source to reflection point and from reflection point to receiver respectively, $C(f)$ is the function associated with coherence of direct and reflected signals, $|Q|$ is absolute value of reflection coefficient, Ω is phase shift during signal reflection from the

surface (complex reflection coefficient $Q = |Q|e^{i\Omega}$), $\alpha(f)$ is coefficient of absorption of amplitude of sound signal per unit distance (it is calculated using ANSI standard taking into account current values of temperature, humidity, and air pressure, measured by ultrasonic meteorological station), $k = 2\pi f / c$ is wavenumber, f is frequency, and c is speed of sound. In derivation of (1) it was assumed that absorption of sound along straight-line path and along path with reflection is nearly the same, while in amplitude factors the equality $r_1 + r_2 \approx r_d$ is admitted.

In the course of work, changes of the source characteristics are possible, so a control over the emitted signal is necessary. For this, a calibration receiver should be placed near sound source. The effects of surface reflections on amplitude of signals of this receiver were neglected (this is justified for nonspherical-DP source used in these experiments).

Combination of signals of working and calibration receivers makes it possible to transform (1) to the formula, more convenient for comparison of experimental and theoretical results, namely

$$W_i^2(f) = p_i^2(f) / p_c^2(f) = \kappa_i^2(f) g^{-2}(\theta_c, f) r_c^2 r_d^{-2} e^{-2r_d\alpha(f)} \{g^2(\theta_d, f) + |Q|^2 g^2(\theta_r, f) + 2|Q| C(f) g(\theta_d, f) g(\theta_r, f) \cos[k(r_1 + r_2 - r_d) + \Omega]\}. \quad (2)$$

Here, index i denotes the working microphone number, $p_c(f)$ is amplitude of sound pressure on calibration microphone, r_c is distance from source to calibration microphone, θ_c is angle between DP axis and direction toward the calibration microphone. The parameter $\kappa_i(f) = p_i^o(f) / p_c^o(f)$ is required to account for the amplitude-frequency characteristics of microphones and estimated at the preliminary stage of work. The $p_i^o(f)$ and $p_c^o(f)$ measurements are made at DP axis of source at small distance from it, with calibration microphone replaced exactly by the working one. The source DP $g(\theta, f)$ is also measured at the preliminary stage. The approximation of experimental κ_i and g values by certain functions makes it possible to use them in (2) during calculations.

Fig. 1 is presented as an example illustrating the behavior of function $W(f)$ for different altitudes of receivers of emission and different pathlengths. In the calculations it was assumed that the emission source has spherical DP, turbulent velocity pulsations are absent, the parameter $\kappa_i(f) = 1$, air temperature is 20°C, relative humidity is 50%, atmospheric pressure is 1014 hPa, underlying surface is absolutely rigid ($|Q| = 1$), and there is no phase shift during sound reflection from the surface ($\Omega = 0$).

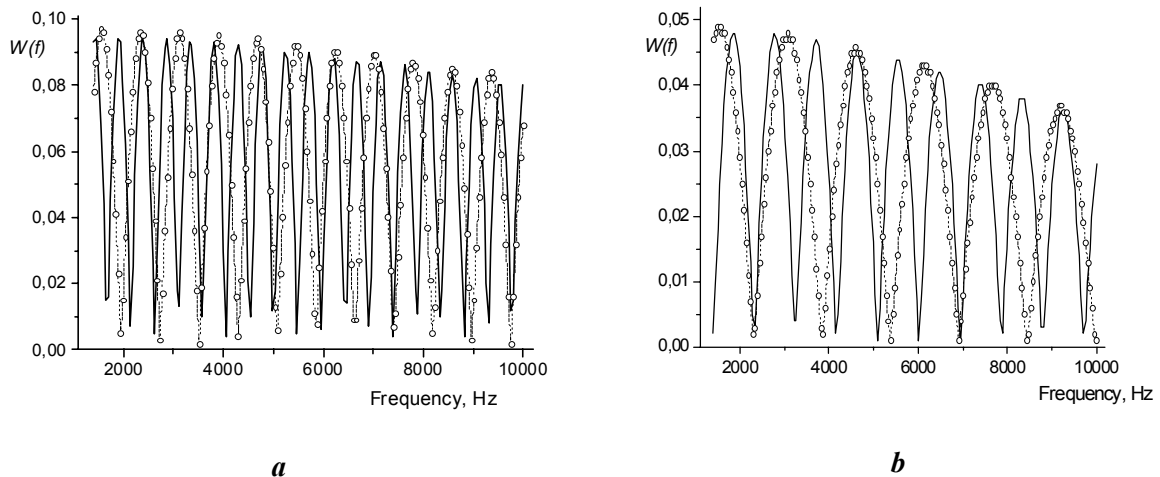


Fig. 1. Altitude of source is 1.5 m: pathlength is (a) 10 m and (b) 20 m. Solid lines are for receiver altitude 1.5 m, and lines plus symbols are for receiver altitude 2.5 m.

The results presented in Fig. 1 can be classified as a classic case of “wave” pattern of interference of direct and surface-reflected waves when sound absorption along propagation path is taken into consideration (explaining the decrease of function $W(f)$ with growth of frequency).

More interesting is the variant when DP of source differs from spherical. In this case, the direct wave and wave, coming after reflection from the surface, may have substantially different amplitudes which, together with the effects of sound absorption along the path, leads to case-specific behavior of the function $W(f)$.

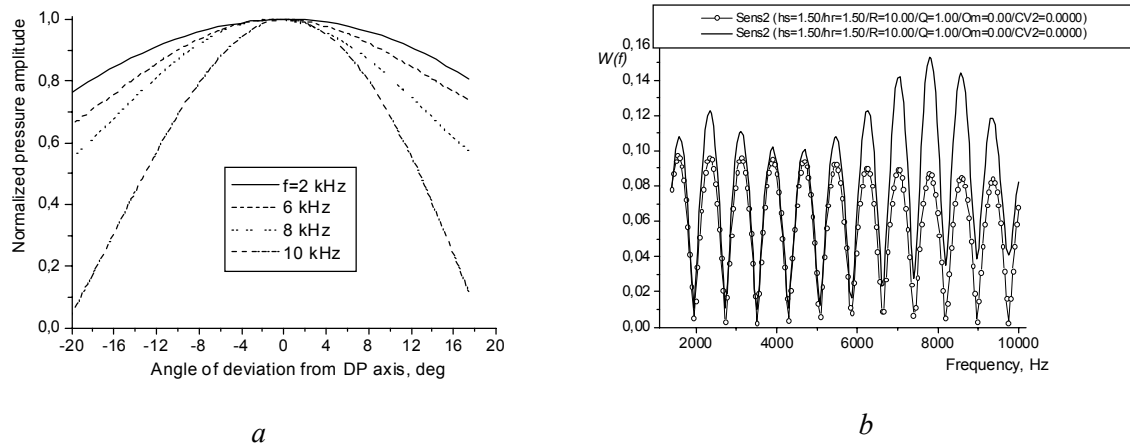


Fig. 2. (a) Approximation of normalized direction pattern of the real emission source for a few frequencies. (b) Signal amplitude calculated from formula (2) for spherical (line plus symbol) and nonspherical (solid line) emission sources. The receiver is in the plane of DP axis of source ($\theta_d = 0$). Altitudes of source and receiver of emission, as well as calibration microphone altitude, are all 1.5 m. The distance between source and working receiver is 10 m. Distance between source and calibration microphone is 1 m. Results are for rigid reflecting surface, parameter $\kappa_i(f) = 1$, air temperature 20°C, relative humidity 50%, and atmospheric pressure 1014 hPa.

As an example, Fig. 2 presents plots of approximation of real DP $g(\theta, f)$ for a few frequencies (Fig. 2a), as well as results of $W(f)$ calculations with use of $g(\theta, f) \neq 1$ and spherical DP (respectively the solid line and line plus symbol in Fig. 2b). Fig. 2b suggests that for nonspherical DP, modulation of interference “wave” takes place.

To check the theoretical views and study the influence of atmospheric conditions on interference of sound waves, we created an acoustical testbed containing control computer, which generated signals via standard soundboard and received signals through specialized multichannel analog-to-digital (AD) converter; amplifier of power of emitted signals; horn source of sound emission; receiving microphones located at different levels in vertical plane and connected to the corresponding multichannel amplifier of received signals, which in turn was connected to AD converter. In addition, near emission source we placed a calibration microphone, also connected to amplifier and AD converter. For control of current atmospheric conditions, we used ultrasonic meteorological station, located nearby the sound propagation path at a height of about 1.5 m. The testbed operation regime consisted of successive emission of a set of frequencies with automatic switch from one frequency to another.

An example of processing of experimental results is presented in Fig. 3. Measurements were made over relatively flat surface (building roof). Situation with quite weak wind was chosen. Of note is a satisfactory correspondence between experiment and theoretical calculations from formula (2), especially for low frequencies. Besides the frequency of occurrence of “waves”, the experimental data also track the “modulation” (predicted by formula (2)) due to DP nonsphericity. Degradation of quality of agreement between theory and experiment at higher frequencies seems to be due to neglect of the drop of coherence with growth of frequency, as well as to increase of distortions of phase progressions owing to mean values of wind velocity. Precisely these factors are the subject of our further research.

Summarizing, we can conclude that the developed methods make it possible to perform further experiments with the purpose of studying the influence of atmospheric conditions on formation of wave field, taking into account the surface reflections. The algorithms and programs, implemented in testbed for experimental data processing, ensure derivation of required information with sufficient speed and accuracy.

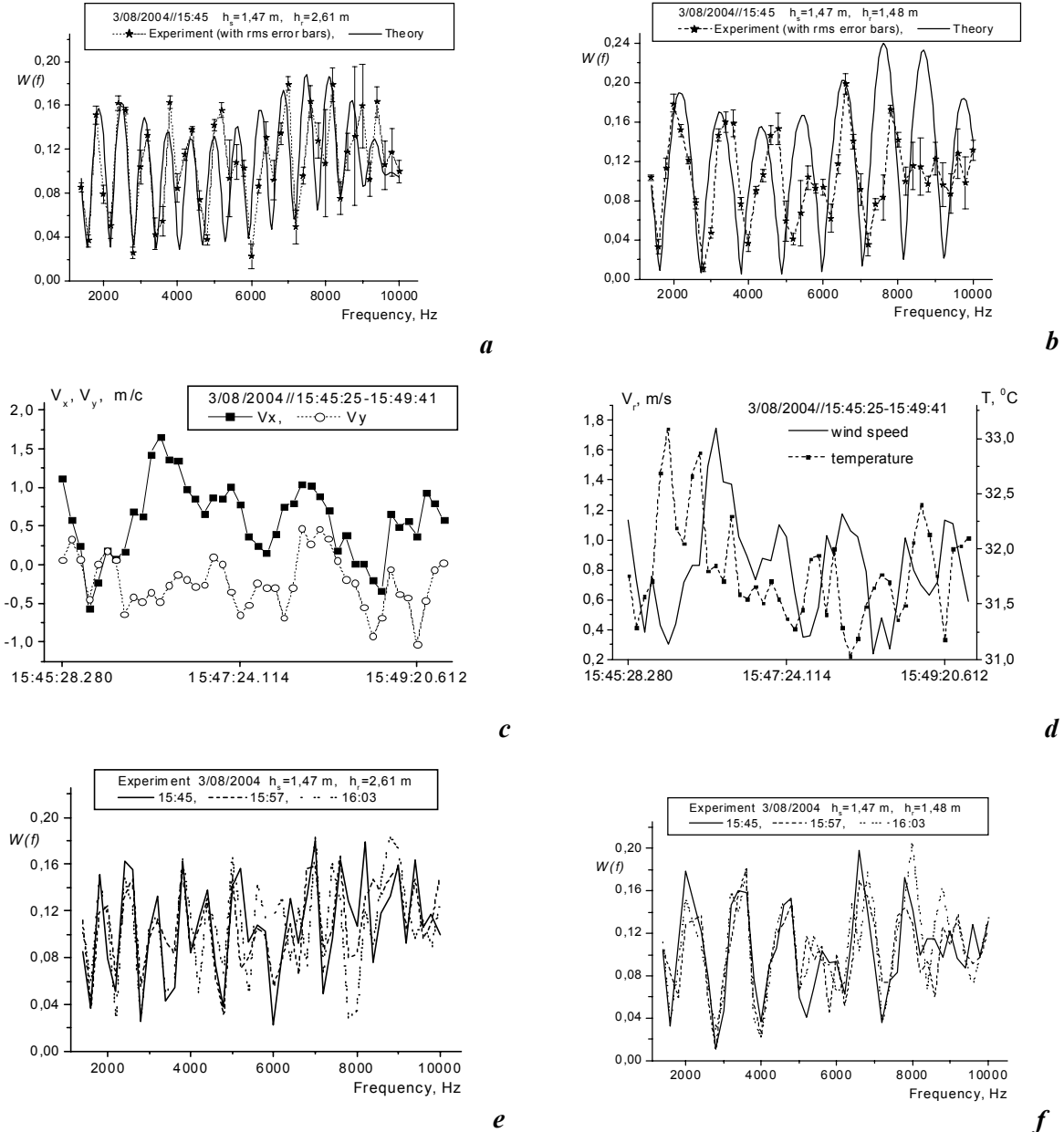


Fig. 3. Comparison of experimental and theoretical results for source and receiver of emission separated by 13.6 m, source altitude 1.47 m and receiver altitude: (a) 2.61 and (b) 1.48 m. On each experimental curve there is rms error bar. Shown are (c) along- (V_x) and cross- path (V_y) wind velocity components, and (d) horizontal wind speed and air temperature during measurements, as well as (d, e) frequency of occurrence of experimental data (for three different experiments). Source had DP as shown in Fig. 2a. Signal coherence in the calculations was set to 1 (totally coherent signals).

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