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PROPAGATION OF NARROW-BAND ACOUSTIC SIGNAL IN RANDOM WAVEGUIDE

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The results of the numerical experiment of long-range sound propagation in the near-bottom sound channel in the present of the internal waves are considered. The feasibility of the selection the signal corresponded to waveguide modes is discussed.

At present the different techniques of low-mode acoustic tomography are developed for diagnostics of large-scale inhomogeneities at sea shelf [1]. The techniques are based on the measurements of propagation time of low-frequency (f = 100÷400 Hz) acoustic signals corresponded to non-interacting normal waves (modes) of the near-bottom sound channel common to near-shore zone of the World Ocean. However the mode signal separation by using the difference in time propagation can meet with some difficulties. Firstly the difficulties are caused by strong sound attenuation in near-bottom sound channel. Secondly they may be associated with the peculiarities of waveguide dispersion in this channel. Thirdly they are produced by random inhomogeneities in the channel, which causes the mode interaction [2]. Sound attenuation, waveguide dispersion and particularly random inhomogeneities associated predominantly with internal waves (IW) have pronounced geographic specificity, in other words they have essentially different characteristics in dissimilar shallow water area. In this paper by using the numerical modeling we investigated the long-range ($r_r \cong 200$ km) propagation of the low-frequency narrow-band $(\Delta f / f \cong 0.1)$ acoustic signals in the near-bottom sound channel. (This channel is typical of the Barents sea). We studied the feasibility of the selection of the signal components corresponding to the individual normal waves.

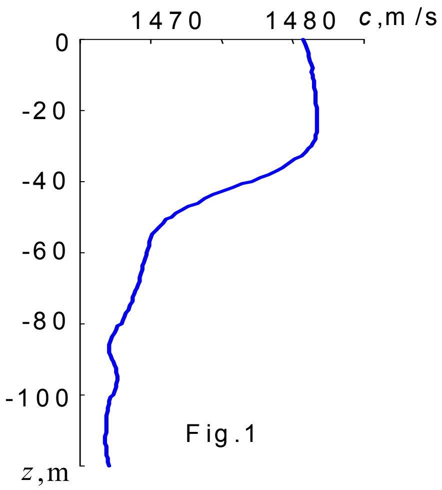

Fig.1

On numerical modeling we suppose that the acoustic waveguide with the fixed depth $H = 120$ m has the mean (unperturbed) profile[1] of sound speed plotted in fig. 1. For sea bottom the sound speed and density were chosen to be equal to $\tilde{n}_1 = 1750$ m/s and $\rho = 1.9$ g/cm^3. The coefficient α was assumed to be equal to $\alpha = 0.06$. This coefficient determines the imaginary part of the of the bottom refractive index $n_1 = \dfrac{c(H)}{c_1}\left(1 + i\dfrac{\alpha}{2}\right)$.

To perform the calculations of the refractive index $n(r,z)$ in the waveguide with the internal waves we assumed that $n^2(r,z) = c^2(H)/c^2(z) + \mu(r,z)$, where $\mu(r,z)$ is small in comparison with the first item and is equal to $\mu(r,z,t) = -2QN^2(z)\varsigma(r,z,t)$ [2]. Here r and z is longitudinal and cross co-ordinate, t is time, Q is the coefficient dependent on the physical properties of water. (Q is equal to $Q \cong 2.4$ s^2/m for seawater.) $N(z)$ is the buoyancy frequency, $\varsigma(r,z,t)$ are the vertical displacements caused by IW.

[1] The sound speed profile was recorded in the experiment in the Barents Sea.

The vertical displacements were calculated on the base of the known experimental data [3] about the internal waves characteristics in the Barents Sea. In so doing we use the realization of the trains of the nonlinear intensive IW, recorded in the experiment, and calculated realization of background internal waves with the statistic characteristic obtained from the analysis of the data, mentioned above. In particular, to perform the calculations we took into account that in the Barents Sea the spectrum of the background internal waves falls with frequency as $\Omega^{-1.6}$. The vertical displacements at a depth of 40 m, which were calculated in a similar manner and which were caused by both the intense nonlinear internal waves and the background internal waves are plotted in fig.2. We assumed that the similar vertical displacements exist along all acoustic track of length 200 km between the acoustic source and the receiver. We assumed as well that the field of the vertical displacements was moving along the track from the source toward the receiver with the typical velocity of the internal waves $v =$ 0.5 m/s. At the same time the displacements occurred synchronously in depth. Their depth dependence is

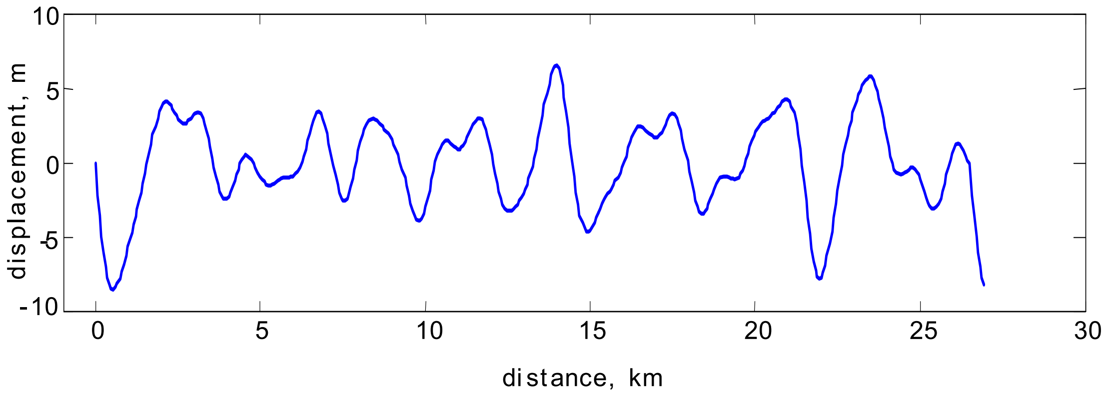

Fig. 2. The part of the realization of the vertical displacements of liquid, caused by IW

described by the eigen function of the first mode of IW. The last assumption corresponds to the model of quasi-plane single-mode internal waves moved in one direction. (The mentioned model is typical for sea shelf)

We assumed in the numerical experiment that the acoustic source and the receiver was spaced at the depth $z_s = 40$ m and $z_r = 50$ m correspondingly. The signals with hyperbolical frequency modulation (HFM) were radiated. We took the carrier frequency $f = 240$ Hz and the frequency band $\Delta f = 20$ Hz. To calculate the transfer function, the Green function $\Psi(r,z,\omega,t)$ is represented as sum of interacted with each other normal waves:

$$\Psi(r,z,\omega,t) = \sum_m^M \frac{C_m(r,\omega,t)}{\sqrt{\xi_m(\omega) r}} \psi_m(z,\omega) \quad (1)$$

where $\psi_m(z,\omega)$, $\xi_m(\omega) = q_m(\omega) + i\gamma_m(\omega)/2$ are the eigen functions and eigen values of the transverse Sturm-Liouville problem with boundary conditions at the bottom and at the surface. Mode amplitudes $\tilde{N}_m(r,\omega,t)$ were obtained through the numerical solution of the combined equations:

$$\frac{dC_m(r,\omega,t)}{dr} = i\xi_m(\omega)C_m(r,\omega,t) + i\sum_l^M \nu_{lm}(r,\omega,t)C_l(r,\omega,t) \quad (2)$$

$C_m(0,\omega) = \psi_m(z_s,\omega)$, $\nu_{lm}(r,\omega,t) = \dfrac{k^2}{2\sqrt{q_l(\omega)q_m(\omega)}} \int_0^H \mu(r,z,t)\psi_m(z,\omega)\psi_l(z,\omega)dz$, k -wave number.

The experimental results represented the time-dependent output signals of the optimal correlation receiver. The signals were calculated by the use of the following expression:

$$B(t) = \left| \int_{\Delta\omega} \Psi(r_r, z_r, \omega, t) |S(\omega)|^2 e^{-i\omega t} d\omega \right| \quad (3)$$

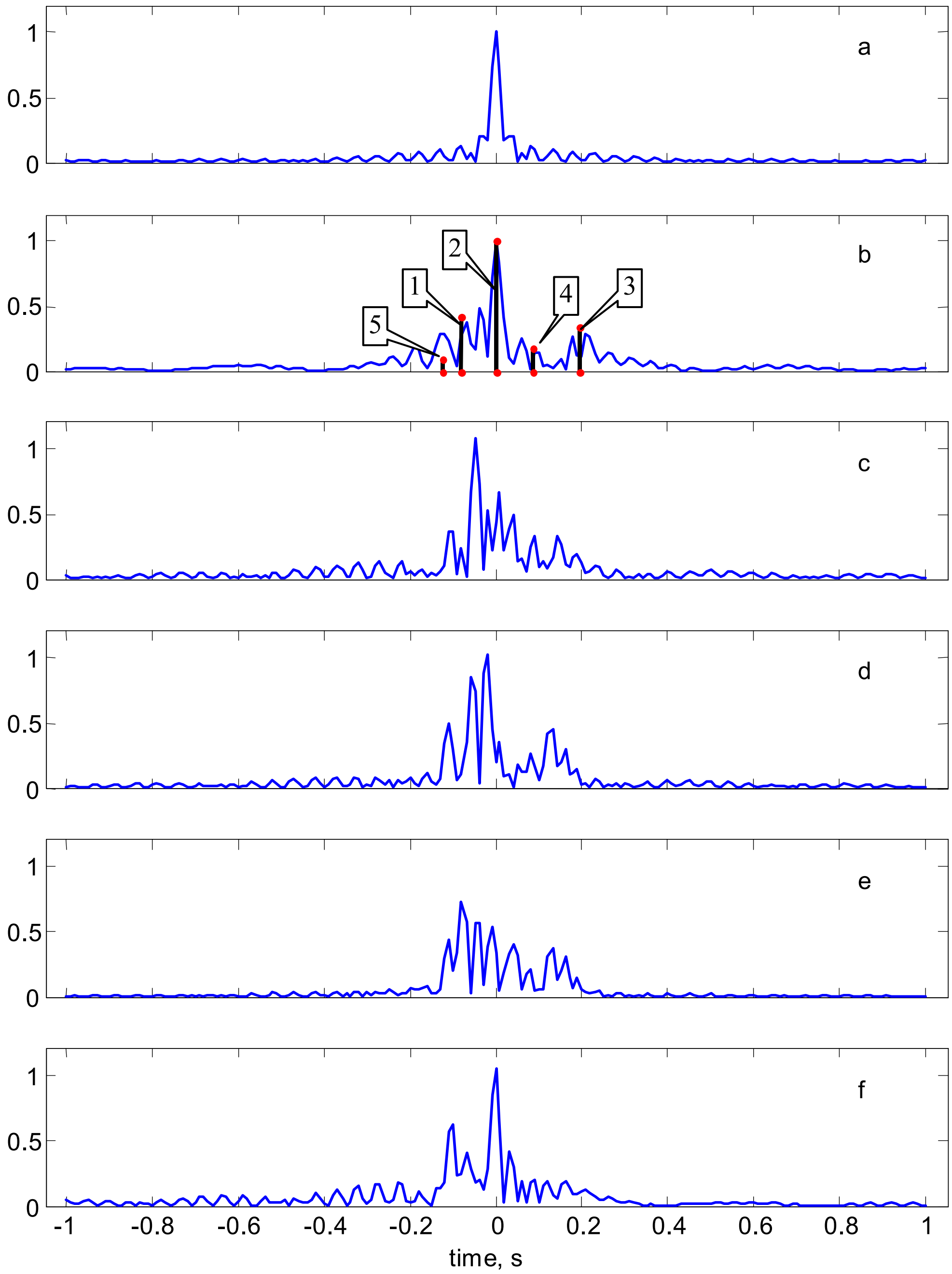

Fig. 3

where $S(\omega)$ is the spectrum of the radiated signal. The dependences $B(t)$ are plotted in fig.3. The autocorrelation function of the radiated signal are shown in fig.3a. Fig.3b corresponds the waveguide with invariable stratification without IW. (The transfer function of the channel does not depend on time.) The dependences $B(t)$ are normalized to the corresponding maximal values in fig. 3a and 3b. The fig. 3c-e demonstrate the output signals for the short radiated impulses with duration $\grave{O} = 25.6$ s. In these conditions the transfer function $\Psi(r,z,t)$ does not vary essentially during the radiation time. It may be considered as depending on time as depending on parameter. For this case the fig.3c corresponds to $t = 0$ s, fig.3d - $t = 10^4$ s, fig.3e - $t = 2*10^4$ s. The fig.3f demonstrates the value $B(t)$ when signal duration is equal to $\grave{O} = 2*10^4$ s and function $\Psi(r,z,\omega,t)$ is varied slowly during this time. The last figure corresponds the situation when the signals with great duration and small intensity are used for acoustic tomography. These are save signals from ecological point of view. In fig.3c-f the values $B(t)$ are normalized to the maximal value of the output signal plotted in fig.3b.

In fig.3b the vertical lines show the propagation times t_m for the signals corresponded the different waveguide modes ($t_m = r / v_m^{gr}$, v_m^{gr} is the grope velocity of the mode.). The lengths of the lines are proportional to the mode amplitudes. The numerals are in accord with the mode numbers in fig.3b.

The analysis of fig.3 allows define conclusions concerning the feasibility of the signal selection. (We keep in mind the signals corresponding the individual modes.) The selection is found to be infeasible even though the internal waves are absent, if we use only the difference in the propagation times. The variations in the group velocities are very small ($\Delta v^{gr} \cong$ 1 m/s), and consequently the differences in the propagation time are small also. In this case the signals of the weak modes are obscured by the "correlation" noise caused by the signals of the normal waves with greater intensity. In addition of that the group velocity dependence on mode number has no monotonic character. Frequency band increasing that causes decreasing of effective duration of $B(t)$ and decreasing of the "correlation" noise for HFM signals does not save the situation. For invariable distance the output signal distortions caused by intramode dispersion are feasible in this case. For example the intramode dispersion caused the splitting of the third mode impulse in fig.3b. It seems likely that the mentioned selection can be realized only by using the vertical array [2]. However it is apparent that in the presence of internal waves this method does not allow to select the signals corresponding to the non-interacting with each other modes, which propagate in the certain field of the sound channel and are insensitive to the variation of the sound speed in the other fields. Fig.3c-e demonstrate the strong mode interaction in the presence of IW. The interaction causes the structure variations of the received impulses as compared with the situation shown in fig.3b. In regard to the results concerning the using of the signals with great duration, the suppression of the signals corresponding the mode with the sufficiently high numbers, which were distorted because of the intramode dispersion, is noteworthy.

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