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AZIMUTHAL -FREQUENCY STRUCTURE OF SOUND FIELD, AT PRESENCE OF INTERNAL SOLITONS ON OCEANIC SHELF.

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The results of analysis of dynamic features of azimuthal-frequency structure of sound field is presented in the paper. It is shown that internal soliton cause significant refraction of sound rays propagating not just along front but and under angle more than 10 degrees at internal waves. The results of numerical modeling for hydro acoustic conditions of acoustic trace UD-WVLA of experiment SWARM'95 is presented in paper.

The developing of 3D model of broadband source sound field at presence of internal solitons (IS) is presented in given paper. In contrast to models which were used in previous papers of author: [1-3] for theoretical analysis of horizontal refraction and [4, 5] for understanding of experimental data, the approach presented in the given paper allows to analyze horizontal structure of sound field in broad range of angles up to ± 30 degrees in relation to front of IS. Necessity of approach developed in the paper is caused by the following. In practice it is very difficult to orient acoustic trace along front of IS exactly. So it is need to analyze data, obtained on acoustic trace oriented under different angles to IS front as a rule. For example, similar situation was in experiment SWARM'95 (see Figure 1)

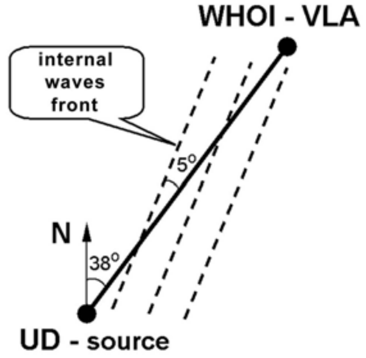

Fig. 1 Trace in experiment SWARM'95

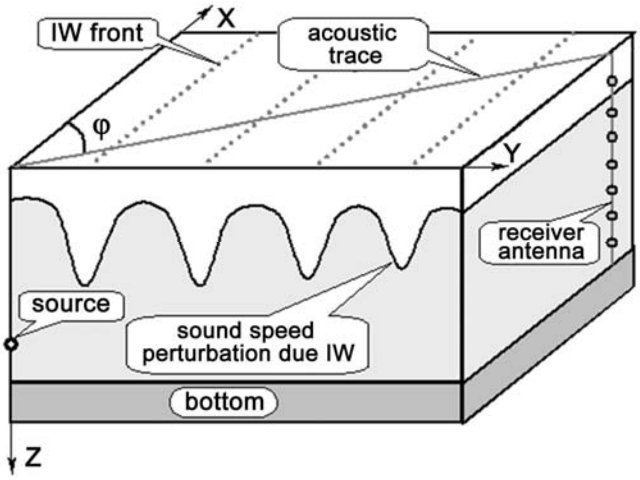

Fig. 2 Model of shallow water sound channel.

Let us consider 3D hydroacoustic waveguide in coordinates (X,Y,Z) shown on Figure 2. Waveguide is presented as water layer with sound speed profile $c(\vec{r},z)=c(z)+\delta c(\vec{r},z)$ (depth dependence $c(z)$ corresponds to experiment SWARM'95 [4-5]), limited by free surface $z=0$ and homogeneous absorbing half-space - bottom $z=H$, with density ρ_1 and sound speed: $c_1(1+i\alpha/2)$, where $\alpha=0.02$ - defined by absorbent features of bottom ($\rho_1=2000\,\text{kg/m}^3$, $c_1=1800$ m/s, $\alpha=0.02$). Space variations of sound speed $\delta c(\vec{r},z)$ are defined by IS:

$$\delta c(\vec{r},z)=-c(z)QN^2(z)\zeta(\vec{r},z) \tag{1}$$

Here $N(z)=\left(g\rho^{-1}\,d\rho/dz\right)^{1/2}$ - buoyancy frequency determined by density stratification of water layer, g - gravitational acceleration; $Q\approx 2.4$ s^2/m – constant determined by physical features of water, ζ -

vertical displacements of water layer, which according to domination of first gravity mode $\Phi(z)$, can be written in the following form:

$$\zeta(\vec{r},z)=\Phi(z)\zeta(\vec{r},z_0)\text{, where } \Phi(z_0)=1 \qquad (2)$$

Here $\zeta(r,z_0)$ - displacements of water layer on depth z_0 (Figure 2). Sound field in shallow water waveguide is defined by Helmholtz equation with corresponding boundary conditions:

$$\frac{\partial^2\Psi}{\partial r^2}+\frac{1}{r^2}\frac{\partial^2\Psi}{\partial\varphi^2}+\frac{\partial^2\Psi}{\partial z^2}+k^2n^2(r,\varphi,z)\Psi=0 \qquad (3)$$

Solution of given equation can be presented by the expression:

$$\Psi(r,\varphi,z)=\sum P_n(r,\varphi)\bar{\psi}_n(z) \qquad (4)$$

where $\bar{\psi}_n(z)$, $\bar{q}_n$ - eigen functions (modes) and eigen values (modal wavenumbers) of Sturm-Liouville problem for non-perturbed stratification $c(z)$. $P_n(r,\varphi)$ - defined by horizontal distribution of modal amplitude in horizontal plane. Within framework of ray approach $P_n(r,\varphi)$ can be presented in the following form[1]:

$$P_n(r,\varphi)=A_n(\vec{r})e^{i\theta_n(\vec{r})} \qquad (5)$$

Here $A_n(\vec{r})$ and $\theta_n(\vec{r})$ are defined by eikonal and transport equations correspondently:

$$\left(\nabla_r\theta_n\right)^2=\bar{q}_n^2\left(1+n_n^2(\vec{r})\right),\ 2\nabla_r A_n\nabla_r\theta_n+A_n\nabla_r^2\theta_n=0 \qquad (6)$$

Here $n_n(r,\varphi)=q_n(r,\varphi)/\bar{q}_n$, where $q_n(r,\varphi)$, $\bar{q}_n$ - wavenumber of mode $\bar{\psi}_n(z)$. Within framework of parabolic approximation:

$$P_n(r,\varphi)=F_n(r,\varphi)\exp(iq_nr), \qquad (7)$$

$$\frac{\partial F_n}{\partial r}=i\frac{1}{2\bar{q}_nr^2}\frac{\partial^2F_n}{\partial\varphi^2}+i\frac{\bar{q}_n\left(n_n^2(r,\varphi)-1\right)}{2}F_n \qquad (8)$$

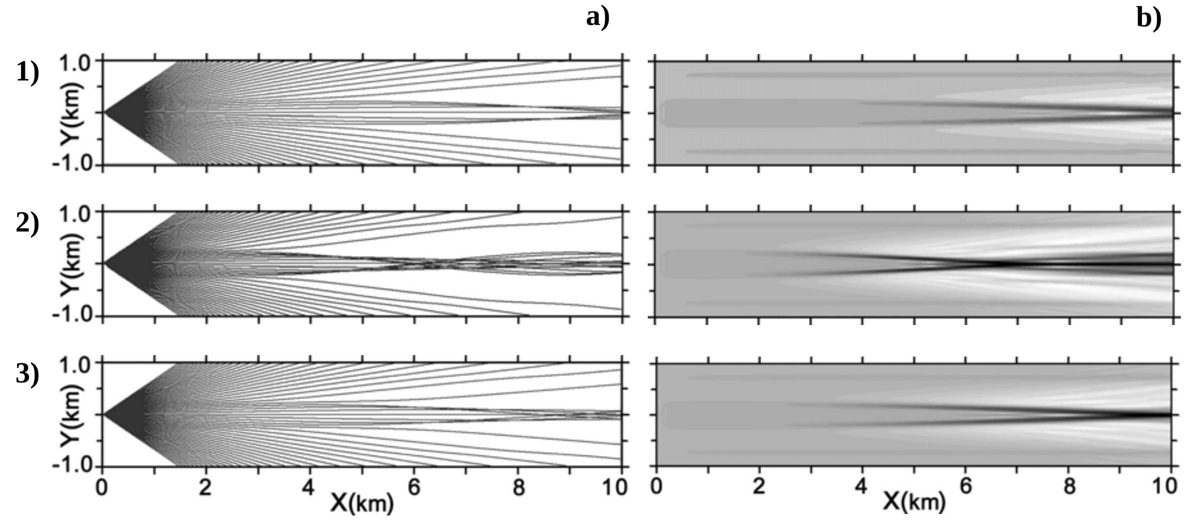

Fig. 3 Focusing of sound field on frequency 180 Hz: a) ray structure b) modal amplitude distribution; 1) first mode 2) second mode 3) third mode.

Numerical scheme of solution of equation (8) has the following form:

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[1] In the case, when several rays of same mode are in receiver point, in expression (5) it is need to introduce second index corresponding to different rays. See [2, 3].

$$F_n(r+\Delta r,\varphi) = \exp\left(-i\bar{q}_n \Delta r U(r,\varphi)\right) FFT\left\{\exp\left(i\bar{q}_n \Delta r V_n(r,\varphi)\right) FFT\left\{F_n(r,\varphi)\right\}\right\} \quad (9)$$

Here FFT - operator of Fourier transform in space of φ; $U_n(r,\varphi) = -(n_n(r,\varphi)-1)$ - operator in space of coordinates (r,φ); $V_n(r,s) = s^2/2r^2$ - operator in Fourier space of coordinates (r,s). It is shown in the paper [2, 3], that there is significant horizontal refraction of sound rays which leads to focusing of sound field horizontal distribution along IS front in the case when source is placed between adjacent IS (see Figure 3). On Figure 3 a) horizontal rays for modes with numbers 1-3 are shown. It is supposed that sound frequency 180 Hz. On Figure 3 b) the corresponding distributions $\left|F_n^f(\vec{r})\right|$ calculated within framework (7)-(9) are shown. There is significant horizontal refraction of sound rays which leads to defocusing of sound field horizontal distribution from IS front in the case when source is placed on crest of IS (see Figure 4). On Figure 4 a) horizontal rays for modes with numbers 1-3 are shown. It is supposed that sound frequency 180 Hz. On Figure 4 b) the corresponding distributions $\left|F_n^d(\vec{r})\right|$ calculated within framework (7)-(9) are shown.

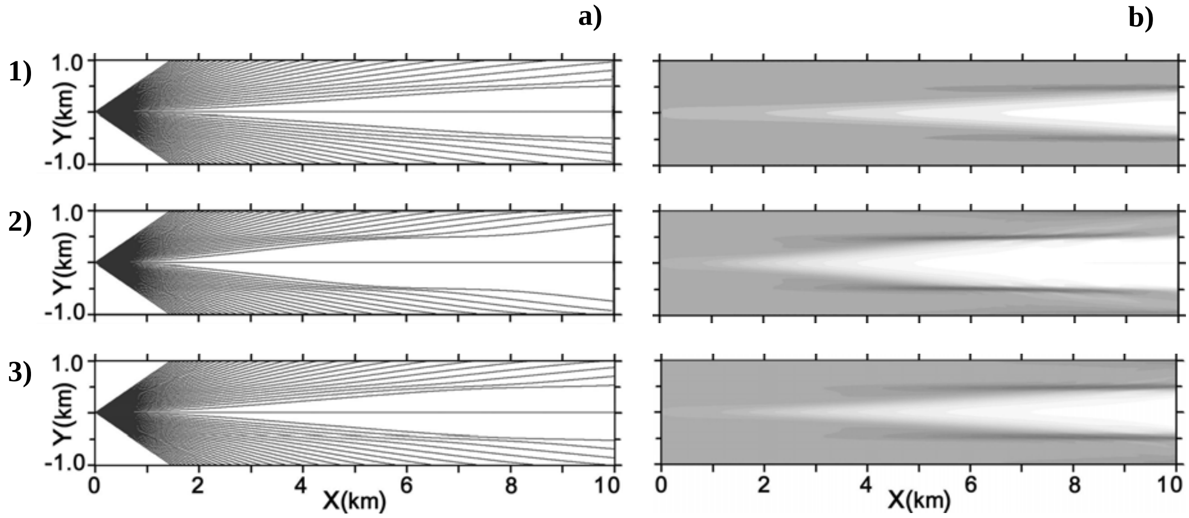

Fig. 4 Defocusing of sound field on frequency 180 Hz: a) ray structure b) modal amplitude distribution; 1) first mode 2) second mode 3) third mode.

We use value $\delta F_n(r,\varphi)$ for analysis of azimuthal-frequency distribution of sound field fluctuations caused by IS which is defined by expression:

$$\delta F_n(r,\varphi) = \frac{\left|F_n^f(r,\varphi) - F_n^d(r,\varphi)\right|}{\left|\bar{F}_n(r,\varphi)\right|} \quad (10)$$

Here $F_n^f(r,\varphi)$, $F_n^d(r,\varphi)$ - horizontal distribution of modal amplitude with number n, corresponding to focusing and defocusing along IS front. $\bar{F}_n(r,\varphi)$ - horizontal distribution of sound field at absence of IS. Value $\delta F_n(r,\varphi)$ - is relative amplitude of fluctuations of modal distribution sound field in horizontal plane. On Figure 5 It is shown the azimuthal-frequency distribution of relative amplitude $\delta F_n(r,\varphi)$ for first mode 5 a), second mode 5 b), third mode 5 c). Azimuthal-frequency distribution presented on Figure 5 corresponds to three values of distances r between source and receiver. Figure 5 1) $r = 5$ km, 2) $r = 7{,}5$ km, 3) $r = 10$ km. As it follows from results presented on Figure 5 the frequency ranges corresponding to maximal fluctuations of horizontal distribution are different for different modes. That one confirms conclusion of papers [2, 3] about selective nature of horizontal refraction caused by IS in relation of both frequency range and modal structure of field.

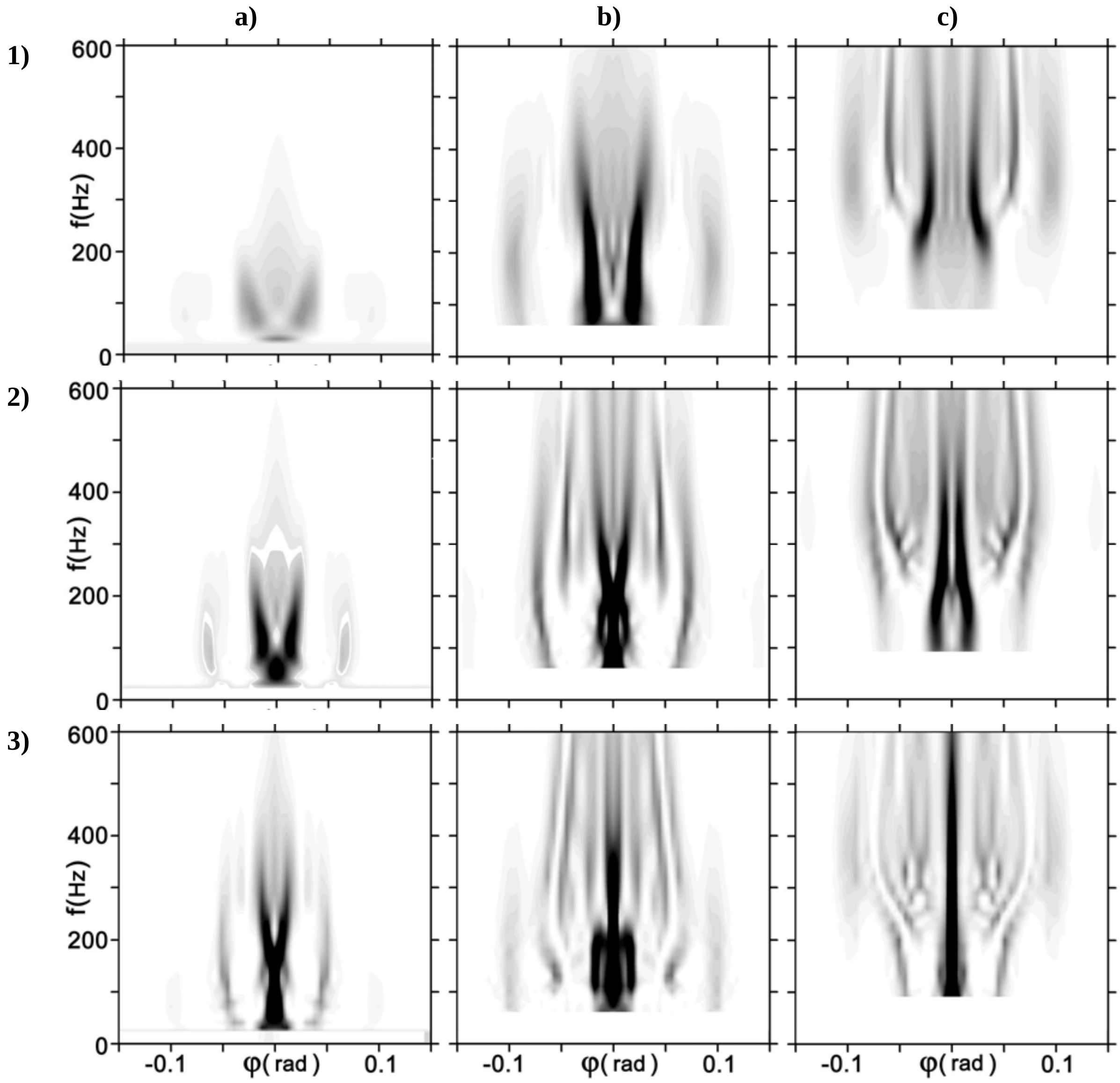

Fig. 5 Azimuthal-frequency distribution of fluctuations amplitude**:**
a) first mode b) second mode c) third mode; 1) $r = 5$ km 2) $r = 7.5$ km 3) $r = 10$ km.

However it should be noted that these frequency ranges are varied significantly in dependence from distance and angle частотные диапазоны. Work is supported by “Dynasty” Foundation.

REFERENCE

1. Pereselkov S.A. “Modeling of broadband sound pulses in shallow water at presence of internal soliton” // “Ocean acoustics” XI school-seminar, Moscow, 2006, P.134-137.

2. Katsnelson B.G., Pereselkov S.A. “Space-frequency dependence of horizontal structure of sound field at presence internal solitons in shallow water” // Acoust. zhurn., 2004, V.50, №, 2, P. 210-219.

3. Katsnelson B.G., Pereselkov S.A. “Horizontal refraction of low-frequency sound field, caused by packets of internal solitons in shallow water waveguide ” // Acoust. zhurn., 2000, V.46, №.6, P.774-788.

4. M.Badiey, B.Katsnelson, J.Lynch, S.Pereselkov “Frequency dependence and intensity fluctuations due to shallow water internal waves” // Journal of Acoustic Society of America (в печати).

5. M.Badiey, B.Katsnelson, J.Lynch, S.Pereselkov, W.Siegmann “Measurement and modeling of 3-D sound intensity variations due to shallow water internal waves” // Journal of Acoustic Society of America, Vol.117(2), 2005, p.613-625.