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Results of Investigating the Surficial and Internal Tides
Influence on Sound Propagation in the Shelf Zone
of the Sea of Japan

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Abstract - The results are given for the in situ and numerical studies of the surficial and internal tides influence on the propagation of the acoustic waves with the frequency making 315 Hz along the stationary paths of duration from 260 m up to 23 km, being oriented transverse the shelf of the Sea of Japan. It is found that the fluctuation of the intensity of the acoustic signals propagating along the elongated paths loses the linear relation to the wave-guide properties changes caused by the tide-forming forces, but their phase variations can be applied as quantitative indicators of their integral changes.

At present, for the monitoring of hydrophysical processes occurring in sea water areas, great hopes are cherished for the acoustic translucent methods based on probing the water medium by continuous and impulse signals [1]. Sound waves refract and scatter at the spatial non-homogeneities of sound velocity field typical for both frontal and vortex formations, and for the seasonal pycnocline disturbed by the internal tide wave running over it and by short internal waves (IW). Below the results are given for studies of the influence of the surficial tide upon the low-frequency acoustic field and the disturbances induced by it in hydrophysical fields of the Sea of Japan shelf. The study is based on analyzing the results of numerical experiments and in situ measurements carried out at stationary paths oriented transverse the shelf.

Water area, where the studies have been performed, is non-freezing. In winter the ice is formed just in the near-coastal zone and in the bays. In the same areas due to cooling (-1.8°C) and convective mixing it is formed a relatively heavy water which is sinking down the inclined slope up to the shelf edge, but at the same time it takes place the advection of warm water ($+0.5^{\circ}\text{C}$) from the Sea of Japan to the shelf area. Formation of seasonal thermocline starts in April and in July the temperature gradients ΔT and salinity ΔS in thermocline can reach $0.9^{\circ}\text{C}/\text{m}$ and $0.08\text{‰}/\text{m}$ correspondingly. In August, due to the wind-induced surge by the wind of southern and south-eastern direction, the seasonal thermocline is pushed out from the shallow-water part of the shelf. For instance, on August 26 of 1998 the thermocline reached the bottom at the depth of 65 m 9 km off the coast. In autumn the winds of the northern and north-western direction push the surficial warm water into the sea and at the expense of relatively cold ($+2.5^{\circ}\text{C}$) and salt (34.2‰) near-bottom water flowing into the shallow-water area of the shelf, the thermocline is formed once again in the near-coastal zone. This time of the year the thermocline with $\Delta T \approx 1^{\circ}\text{C}/\text{m}$ can extend from the shelf edge up to the near-coastal zone and it serves the upper margin of the near-bottom sound channel by the disturbed wave of the internal tide and shorter internal waves (IW).

The wave of the third tide is generated by the tidal currents near the shelf edge and it is distributed above the inclined bottom towards the coast this time as a free IW. Such wave propagation is influenced by numerous hydrophysical factors, and thus the waves of the internal tide registered in the shallow-water area of the shelf lose the periodicity of the surficial tide. The measurements have shown that when the thermocline stretches from the shelf edge up to the near-coastal zone, then two waves of the internal tide at a time can propagate along it. Numerical modeling of sound propagation was carried out for two spatial positions of the thermocline. Propagation of the acoustic waves with the frequency of 315 Hz was modeled by normal waves in adiabatic approximation with the help of MOATL Program [2]. The modeling has shown that the sound propagation of the given frequency is quite less influenced by the surficial tide rather than by the wave of the internal tide. Results of in situ measurements of variations of intensity I and phase j of the acoustic signals with the frequency of 315 Hz carried out during different seasons of the year at stationary paths oriented transverse the

shelf, are given in paper [3]. Tone signal with the frequency 315 Hz was emitted at the depth of 25 m. The reception of signals was performed at the shelf edge with the help of bottom hydrophones of autonomous radio-hydro-acoustic buoys and scalar-vector receiver of autonomous digital radio-hydro-acoustic station «Otklik-91D» deployed 3.7 km off the emitter.

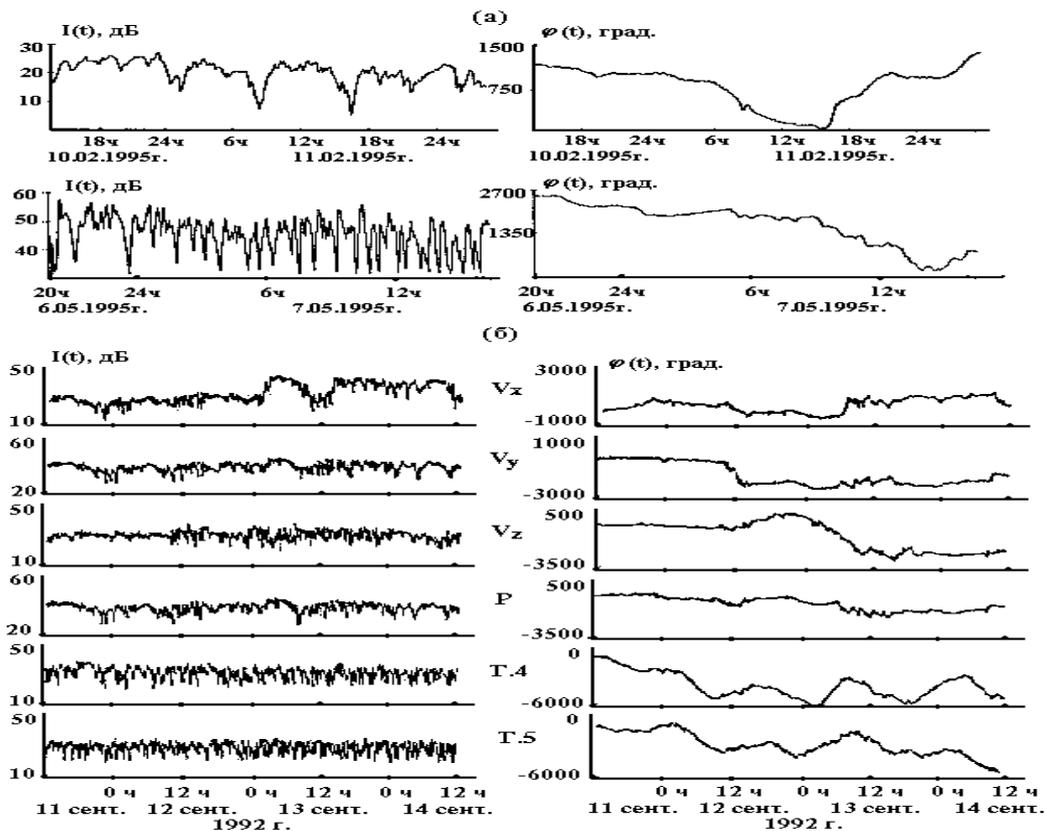


Fig.1.

In Fig.1 the plots of $I(t)$ and $\varphi(t)$ corresponding to the measurements performed on February 10-12, May 6-7, 1995 and September 11-14, 1992, as well as the theoretical estimations, show strong influence of the thermocline, disturbed by the internal tide wave, on the sound propagation in a shallow sea. According to winter hydrological data, the water along the acoustic route was non-homogeneous in temperature and we can even distinguish a front oriented along the shelf. Plot $I(t)$ (Fig.1a, February) with the intervals of 7-9 h shows the fall of signal level up to 10-15 dB, in the other year seasons the fading is observed more often. Non-regular semi-diurnal tide induces sea level changes up to the value of ≤ 30 cm. Schemes $\varphi(t)$ corresponding to the winter and spring measurements do not present the variations with the period of semi-diurnal surfacial tide, they are well observed in plots $\varphi(t)$ corresponding to the measurements performed synchronously at two routes (schemes T.4 and T.5 in Fig.1á) in September of 1992. This is related to «extinction» of the higher normal modes of the sound propagating in a shallow-water wave-guide. In this case in the reception point it interfere several first modes with similar values of group velocities of distribution, so for a change of summarized amplitude of signal in the reception point needed are considerable changes in conditions of their distribution. Thickness of the water layer varies with the period of semi-diurnal tide, but, according to the schemes of $\varphi(t)$ (February, May) the surfacial tide influence on the sound field is insignificant as compared to the spatial-temporal variations of temperature fronts. Spring decrease of periods of variations I is explained by refraction and scattering of the acoustic waves to spatial non-homogeneities of sound velocity generated by the IW. This leads to the

flows of energy from the lower modes to the modes of higher order and correspondingly compensate the «extinction» of high-frequency modes.

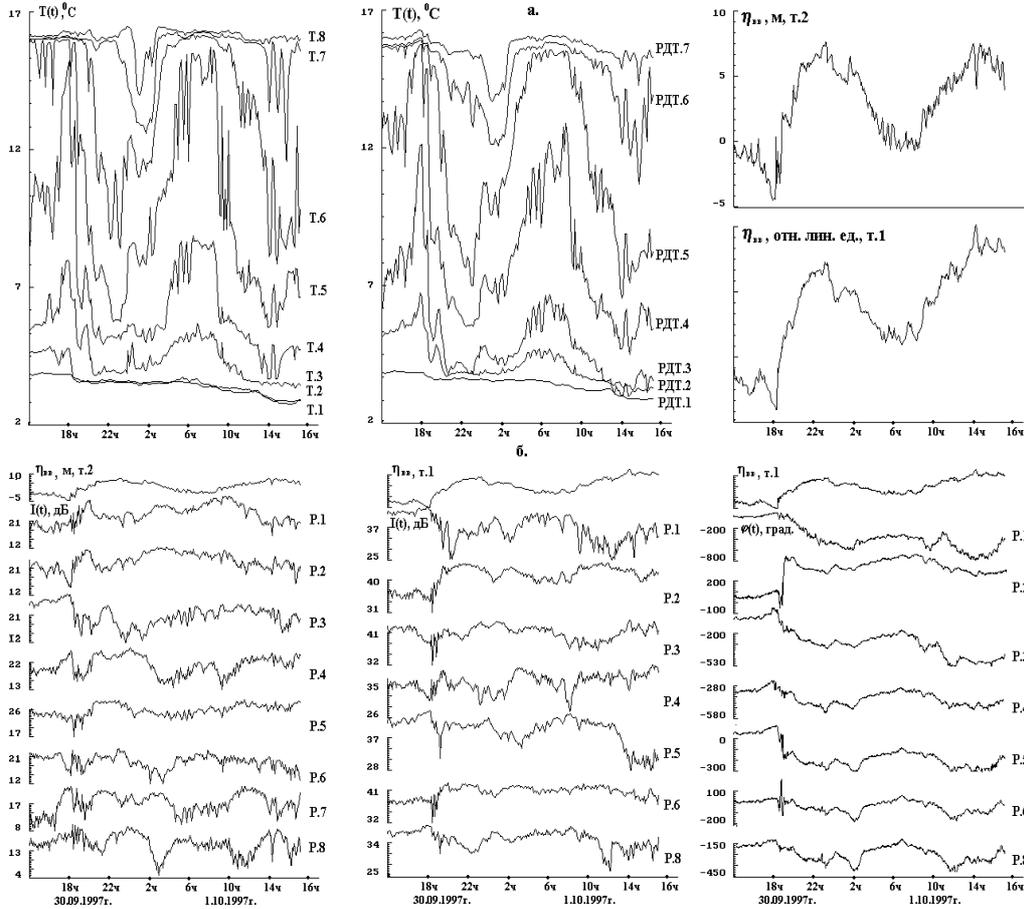


Fig.2.

Fig. 1а presents the plots $j(t)$ and $I(t)$ of the acoustic signals measured in September of 1992 at the distance of 3.7 km off the emitter. While for signals observed at the shelf edge (Schemes T.4 and T.5) it is possible to note the relative stationarity and stability of fluctuations $I(t)$ and $j(t)$, then near the coast, the schemes $I(t)$ and $j(t)$ show their strong variability in time.

Figure 2 presents the results of the acoustic-hydrophysical measurements performed at 420-meter path equipped with two vertical measuring systems stationarily erected in points $\delta.1$ and $\delta.2$ [4]. This figure shows the schemes of variations of water temperature in $\delta.2$ obtained with the help of point-like (T.1,..., T.8) and a chain of distributed ($\text{Ð}\text{Ä}\text{Ö}.1,\dots,\text{Ð}\text{Ä}\text{Ö}.7$) temperature sensors, profile $IW - h_{\text{ÄÄ}}$ in points $\delta.2$ and $\delta.1$, as well as schemes $I(t)$ and $j(t)$ of the acoustic field with the frequency of 315 Hz measured with the help of two vertical chains of 8 hydrophones with $\Delta z = 4.5$ m. Plots T(t) show the changes of the vertical structure of temperature field generated by the internal tide wave and short-period IW. According to Fig.2a the height of the wave of the internal tide at the study area in autumn reaches 14 m and together with the IW it induces syn-phasal vertical shifts of the water particles in a layer of 27 m thick. In plots $I(t)$ there are variations correlating with the IW propagation along the path. The internal tide influence is seen in plots $j(t)$. Variations of the phase of the acoustic signals propagating in winter [3] hydrological conditions along the route of 260 m, with the period of tide, didn't exceed 30° .

On the basis of the performed experiments, we can state the following. Fluctuations I of low-frequency acoustic signals propagating transverse the shelf along the extended routes, due to the

refraction on non-homogeneities of the sound velocity field, induced in water thickness by different hydrodynamic processes, loose their relation to the regular changes of the wave-guide properties generated by tide-forming forces. Phase variations, unlike the intensity, are not saturated [3] and they present the quantitative indicator of the integral changes of properties of the water layer of the acoustic wave-guide, note, that according to Fig. 1a the influence of the surfacial tide in winter-spring period at studied shelf is not significant in comparison to the variations, produced by frontal formations shifts. In autumn period $j(t)$ is conditioned by the internal tide wave.

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