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TO THE QUESTION ON UNDERWATER NOISE GENERATION BY LARGE-AMPLITUDE INTERNAL WAVES

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Preliminary results of new measurements of ambient noise in the ocean which origin is connected with sea surface wave enhancement due to large-amplitude internal waves. Investigations were carried out in May of 2006 from Taiwan research vessel in Luzon Strait. It was revealed an arising of ambient noise level (at frequency range 1-2 kHz) confined with time of internal wave passing. Ambient noise level connected with internal wave for these frequencies was higher to compare with level of noise generated by vessel's enginer. The main peculiarity of data obtained was connected with observed fast speed of solitary internal wave (3 m/s) of the second mode.

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MULTIFUNCTION ACOUSTIC HARDWARE AND SOFTWARE SYSTEM FOR THE SEA DYNAMIC PROCESSES MONITORING

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In the present paper, we present technical features and sea test results of multifunction acoustic hardware and software system functioning for the long term measurements and studies of the dynamics and structure of waters by the acoustic tomography methods. Permanently mounted on the diagnosed area in the Japan sea shelf zone acoustic receiving and transmitting systems (transmitters) allows one to conduct perennial monitoring of temperature and flow fields by the measured travel times of impulses propagating between corresponding points.

Introduction of acoustic methods into oceanographic measurements and into the monitoring of hydrophysical parameters of the ocean largely depends on the economical and technical expending. For instance, the acoustic tomography of the dynamics and structure of waters is obviously preferential in comparison with the conventional oceanographic methods and instruments. However, the solution of many problems requires the use of complicated and expensive systems. Consequently, it is urgent to develop the acoustic hardware for the remote acoustic monitoring of the dynamics and structure of water media on the basis of temperature and flow field reconstruction obtained from the measured acoustic impulse time-of-flight along the rays propagating from source to receiver, permanently mounted on the bottom. The papers (Akulichev et al. 2000, 2002, 2004) concerned the experimentally obtained results which served the basis for developing the multifunction acoustic hardware and software Complex to provide studies in the World Ocean shallow zones. The given paper presents the technical features and results of the experimental testing the functional capabilities of the Complex.

1. Multifunction acoustic hardware and software Complex for hydro-physical studies

A methodical principle of the Complex functioning is the use of multiplex phase-manipulated signals for marine environment sounding. It allows us to measure the waveguide pulse characteristic, i.e. to single out, identify and measure the travel times of impulses propagating along different ray trajectories in a diagnosed hydro-acoustic duct. Using the inversion by travel time one can reconstruct temperature and flow fields, tidal and inner waves parameters.

The Complex consists of two transceiving systems spaced at 2098 metres interval and connected by cables with the coastal laboratory (Fig.1). A near transceiving system permanently mounted at the distance of 400 meters off the shore at the depth of 39 meters (1 meter from the bottom) consists of two piezoceramic rings a meter in diameter. The Complex provides transmiting and receiving acoustic signals in a frequency range of 366 – 5000 Hz.

A remote transceiving system involves two hydrophones spaced at 3 metres interval and a piezoceramic source with the central frequency of 2500 Hz, it is placed in the center of the construction.

Acoustic centers of the hydrophones and source are located 35 centimeters above the bottom. The system is supplied with the sensors of depth (2.5 centimeters precision) and temperature (0.01 C^o precision). Remote control and power supply are performed by a four-core cable. The electronic part of the Complex consists of two separated blocks: coastal and marine ones. The blocks are connected by an analog-digital line. Acoustic signals are transmitted in analog form (each channel is transmitted by a separate line), temperature and pressure data - in digital form. Frequency-modulated digital signals from the sensors are added to the analog signal from the second hydrophone. Remote control instructions are transmitted from the coastal laboratory by the first hydrophone line.

The Complex was mounted in the East/Japan Sea shelf zone near Gamov Peninsula, on the acoustic and hydrophysical testing ground of the V.I. Il’ichev Pacific Oceanological Institute, FEB RAS. Bottom topography in the experimental area presents a flat shallow-water slope with a small gradient of the depths from 40 to 43 meters. Direction azimuth from the close system to the far system is 173 degrees that almost coincides with the North – South direction.

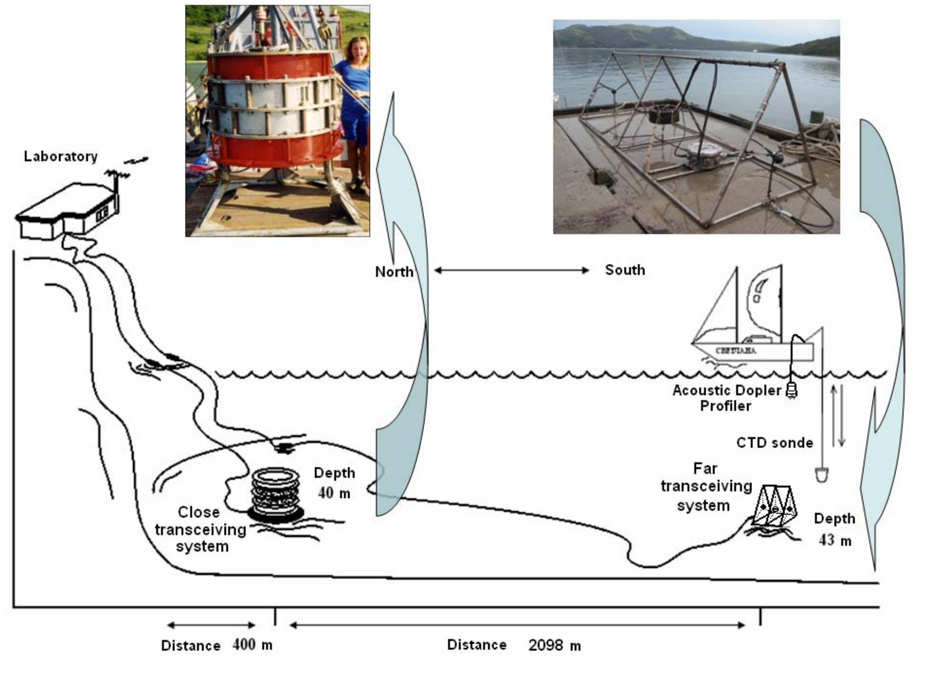

Fig.1 Scheme of the Complex hardware location.

A block diagram of the hardware and software Complex is shown in Fig. 2. In the waveguide pulse characteristic measuring mode, the transmission of signals is performed by the transducer of the near system, and signal reception is carried out by two hydrophones of the remote system. Preliminarily formed multiplex phase-manipulated signals (511 symbols, 4 periods of carrier frequency per symbol) are routed through the generating and amplifying system to the source. Signals and information from the depth and temperature sensors received by the hydrophones are amplified and transmitted to the analog-to-digital converter located at the coastal laboratory for registration and analysis.

In the head-on sounding mode intended for the flow velocity measurement the same multiplex signals are used. The signals synchronized by the common-timing system are transmitted simultaneously by the transducers of both systems, then, through commutators, they are received by the transducers of the near and remote systems and transmitted to the analog-to-digital converter located at the coastal laboratory.

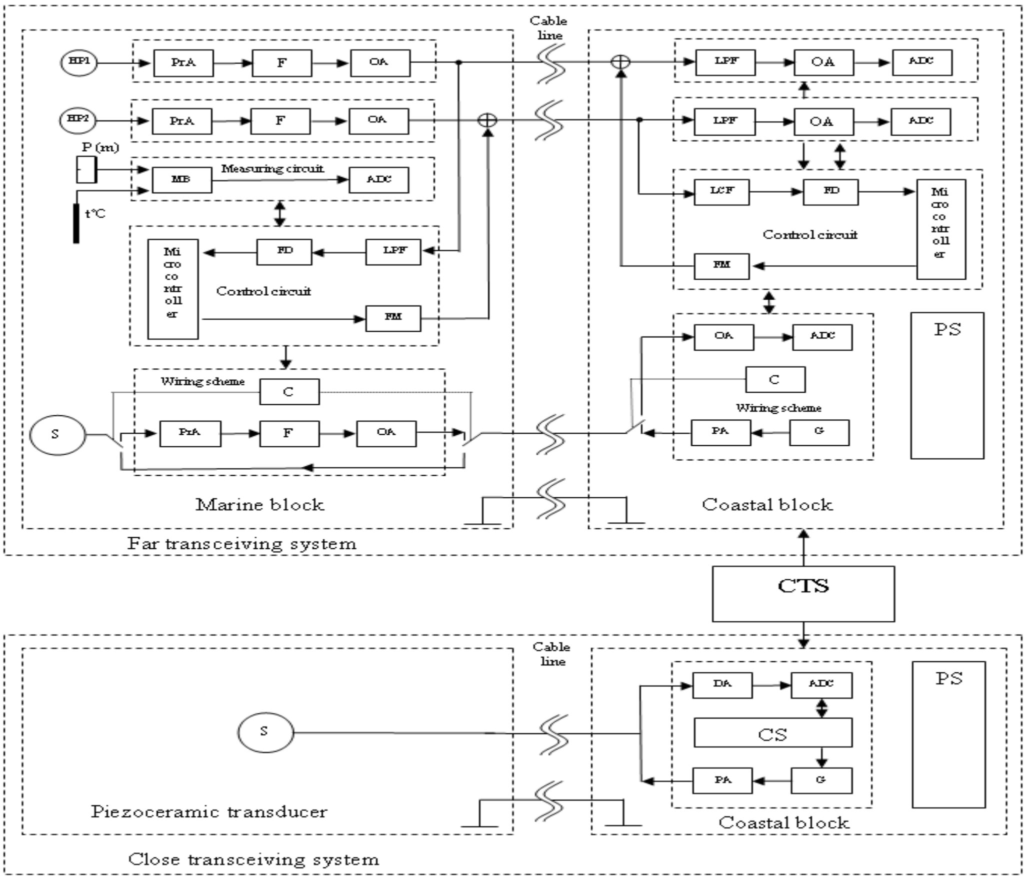

Fig.2 Block diagram of the hardware and software Complex: (HP) hydrophone, (PrA) preamplifier, (F) filter, (OA) operational amplifier, (ADC) analog-to-digital converter, (S) source, (PA) power amplifier, (CTS) common-timing system, (PS) power supply, (MB) measuring bridge, (C) commutator, (LPF) low-pass filter, (FD) frequency demodulator, (LCF) low-cut filter, (FM) frequency modulator, (G) generator, (DA) differential amplifier, (CS) control system.

The procedure for signal treatment is as follows. The cross-correlation function of received and transmitted signals is computed as

$$K_{ss_0}\left(\vec{r},\vec{r}_0,t,t_0\right)=\frac{1}{(2\pi)^2}\int_{-\infty}^{\infty}\left|S_0(\omega)\right|^2\cdot G\left(\omega,\vec{r},\vec{r}_0\right)\cdot e^{i\omega\left(t-t_0\right)}d\omega$$

where $S_0(\omega)=\int_{-\infty}^{\infty}s_0(t)\cdot e^{-i\omega t}dt$ is the Fourier spectrum of a transmitted signal,

$G(\omega,\vec{r},\vec{r}_0)=\sum_{j=1}^{N}A_j(\vec{r})\cdot e^{-i\omega t_j(\vec{r})}$ is the Green function in ray representation,

$t_j(\vec{r})$ and $A_j(\vec{r})$ are propagation time and amplitude of the signal, respectively, for a *i*th ray propagating from the source to the receiver that is located in point $\vec{r}$,
N – is the number of rays reaching the receiver.

As a result, we obtain the waveguide pulse characteristics or travel times of the acoustic energy arrivals, propagating along different ray trajectories. As shown below, the measured data can be used for studying and monitoring the dynamics and structure of the water medium in the given water area.

2. Experimental results of the dynamic processes studies in the East/Japan Sea shelf zone

Measurements were conducted 72 hours (3 days) practically monthly in 2006-2007 on the stationary acoustic path 2098 meters long. A yacht was anchored at the receiving point in summer months, and every hour measurements of the vertical profiles of temperature and salinity were taken from its board. Typical for every month pulse characteristics of the waveguide are shown in Fig.3.Analysis of these pulse characteristics allows us to note the following characteristic regularities.

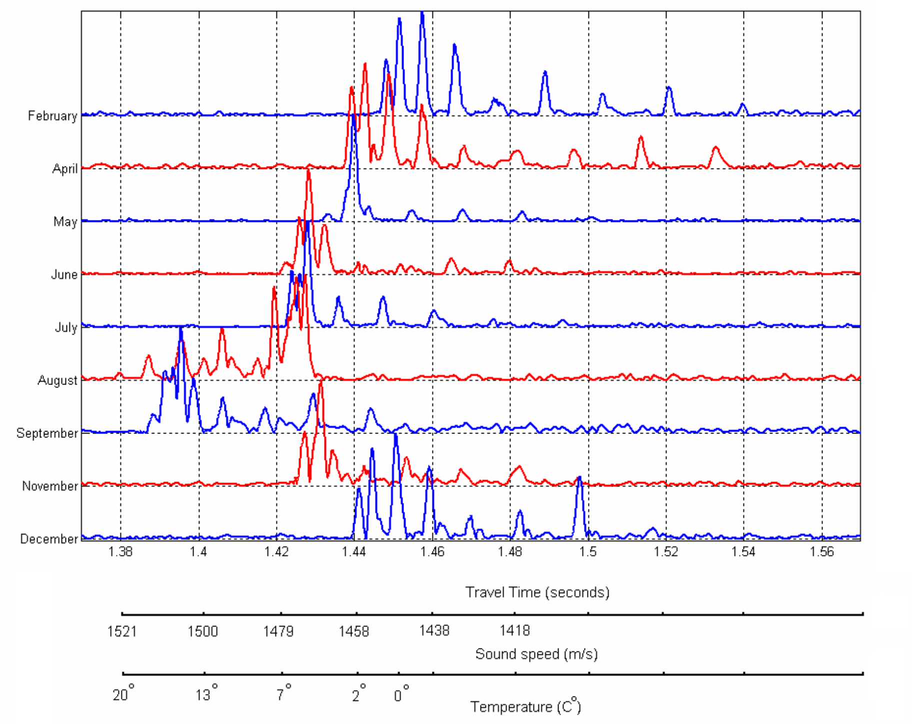

Fig.3. Normalized by amplitude pulse characteristics of the waveguide measured in the experimental area (2006 –2007).

1. The experimental conditions allow one to single out and identify up to nine impulses that propagate between the source and receiver along different ray trajectories.

2. From November to April the pulse characteristics are formed by the rays reflecting from the surface and the bottom from one up to nine times. This is due to the fact that in these months approximately constant temperature is observed with the depth, and rays do not refract. Intervals between pulses are similar for all months but the impulse response is shifted over the

time scale depending on phase velocities of pulses. The temperature in a water layer directly depends on the phase velocity determined from the known Del Grosso's equation. For the geometry of our experiment the phase and group velocities of the first pulses are approximately equal, and the temperature can be calculated using them (Fig.3).

3. In summer months, along with the upper water layers being warming-up, the rays emerging at small angles begin to refract, and between the first and second pulses, the pulse having passed without reflection from the surface is registered. Integral temperature of the diagnosed waveguide can be calculated by the group velocity of the first arrival.

4. In August, when cold tidal water forms the near-bottom sound channel, the rays emerging at small angles are captured by it, and pulses are propagating along the bottom at a minimal phase velocity equal to the group one. Referring to Fig.3, it can be seen that the late arrival has a velocity of 1475 m/s, hence, the temperature in the near-bottom layer equals 3°C. As to the integral temperature of the whole water column, it can be calculated by the group velocity of the first arrival, 20°C in this case.

For more accurate identification of ray arrivals, the computational modeling was carried out through using ray acoustics methods [4,5]. Evidently, both the amplitudes obtained experimentally, and the time-of-flight of sound impulses propagating along different ray trajectories are in good accord with the theoretical calculations that allows us to expect a successful application of this computational program for more accurate solution of the temperature field reconstruction problems in shallow water areas.

In October 2007, the studies of the possibility for remote measuring the flow velocity and direction with the use of multifunction acoustic hardware and software Complex were conducted.

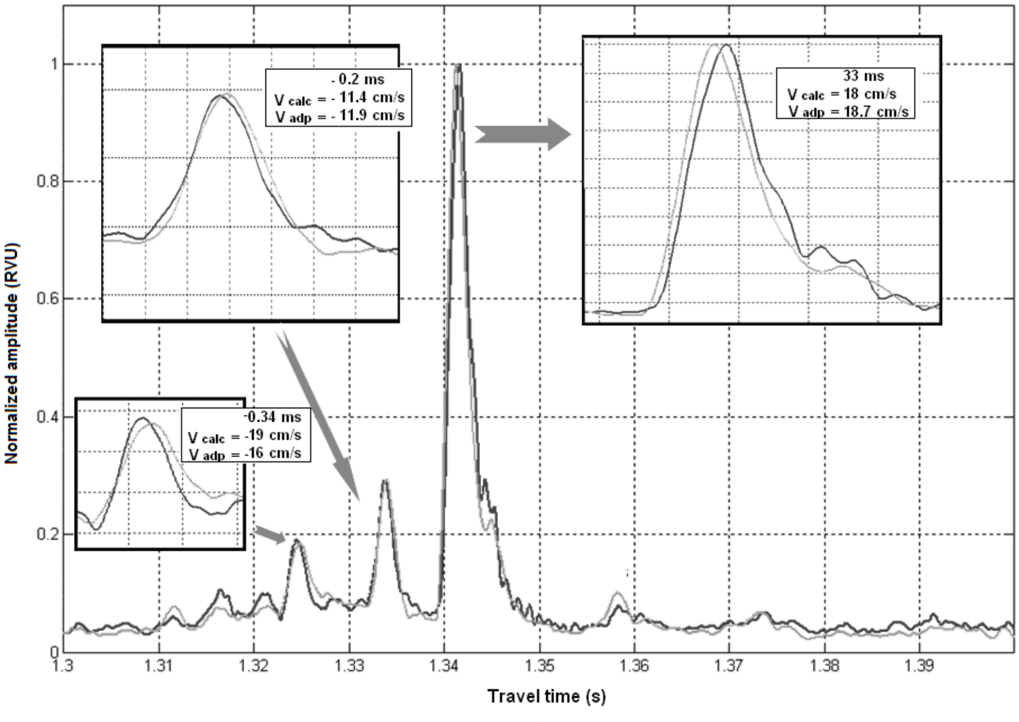

Fig.4 Pulse characteristics measured with the use of head-on sounding method:
dark curve – direction from the close system to the far system, light curve – direction from the far system to the close system.

The head-on transmission of the acoustic signals was performed synchronously once every minute. Then the cross-correlation function of the received and transmitted signals was computed for each propagation direction. The maximums of the function corresponding with the travel times of acoustic energy arrivals propagating along different ray trajectories to the reception point. The travel times of n -th impulse t_n^- and t_n^+, corresponding to the propagation of acoustic signals against and along the flow, are measured. Further, the sum of travel times $S_n=t_n^++t_n^-$ and their difference $\Delta t_n=t_n^--t_n^+$ are calculated, and the components of flow velocity $V_n = \Delta t_n \cdot c_n^2 / 2r$ on the path of r in length, associated with n -th impulse, and the velocity of signal propagation in the path $c_n=2r / S_n$ are finally determined.

Pulse characteristics measured with the use of a head-on sounding method are shown in Fig.4. The first five arrivals passed the path along different ray trajectories and numbers of reflections from the bottom and surface. The sixth arrival with the highest amplitude was formed by a group of rays propagating in a cold water near-bottom sound channel. A comparison between the pulse characteristics shows that the main regularities of forming the structure of the acoustic field are identical when propagating along and against the flow, i.e. the reciprocity principle is observed. Calculations of flow velocity and direction are made for 4th, 5th and 6th impulses, since they are stand out sharply against the noise. Analysis of the calculated data reveal that the flow direction in the near-bottom layer is outgoing from the coast, while the integral flow direction in a whole waveguide is toward the coast (Fig.4). The data are in good accord with the ADP measurements made in that time period.

Conclusions

The multifunctional features of the acoustic hardware and software Complex developed by the POI FEB RAS for studying and monitoring the dynamics and structure of the water medium in shelf zones are shown under field conditions. The methods of temperature and flow field reconstruction based on the data of acoustic sounding of shallow water areas by the multiplex phase manipulated signals are approved. It is proved experimentally that the Complex features allow one to study the dynamic processes on the scale of time-to-time variability from minutes to a year.

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