V.A.Akulichev, S.I.Kamenev, A.P.Leont'ev, Yu.N. Morgunov

ACOUSTIC TOMOGRAPHY OF DYNAMIC PROCESSES IN A SEA SHELF ZONE

Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences
43 Baltiyskaya Street, Vladivostok, 690041, Russia
Tel.: (423-2)311-631; Fax: (423-2)312-600
E-mail: kamenev@poi.dvo.ru, akulich@marine.febras.ru

Experimental data are presented on the use of single receiving and transmitting systems in acoustic tomography of dynamic processes in a shallow sea. The experiments are based on the use of the transmission tomography and opposite-direction sounding with complex phase-manipulated signals. The original data are those obtained by the authors in 1999–2002 years on the shelf of the Sea of Japan near the Gamov Peninsula, in the vicinity of the acoustical-hydrophysical experimental site of the Pacific Oceanological Institute, Far Eastern Branch of the Russian Academy of Sciences (POI FEB RAS). A possibility of using combined transmitting–receiving systems (transceivers) for monitoring the temperature and fields of currents in the ocean is demonstrated.

Studies of the POI FEB RAS is the improvement of instrumentation and methods of acoustic monitoring the water structure and dynamics in the World Ocean shallow seas and shelf zones. To solve the problems of acoustic tomography, telemetry, sound ranging we are engaged in research on mechanism of forming acoustic fields in the frequency range of 250-2500 Hz on the stationary paths of different length. For this purpose we developed a mobile, autonomous complex (set) of acoustic-hydrophysical measuring systems to study possibilities for applying acoustic methods of the evaluation of hydrophysical processes in shallow sea and the stability of underwater acoustic channel for data transmitting.

Presented in our works [1-7] are the measuring devices being part of the set, which are placed fixedly, or if necessary, on the acousto-hydrophysical polygon of the POI FEB RAS located off Cape Schultz in Posyet Bay in the Sea of Japan. They are acoustic transmitting and receiving systems, which provide to probe seawater areas by multiple phase-manipulated signals of M-codes with carrier frequencies from 250 to 2500 Hz. In our works a detailed performance of these systems and some results of the exploration of hydrophysical processes by application of them.

In this paper we present new engineering for equipping the evaluated water areas and some interesting results, in our view. Next figures illustrate the results of experiments with low-frequency (366 Hz) and high-frequency (2500 Hz) acoustic transceivers that we used for the trial of measurement practice of sea currents by the method of two-way propagation. The encouraging results, being in quite good agreement with those of oceanic measurements taken with traditional instruments, have been obtained.

Given in our works were the data of measuring the current field variability on an acoustic path of 18-km length with the use of transceivers operating at a center frequency of 250 Hz. More recently, we conducted experiments to study the capabilities of high-frequency transceivers for measuring the flow velocity in the sea on an acoustic path of 3-km length. The experiment is schematized in Figure 1.

The transmission of M-codes with 2500-Hz center frequency was performed during 15 hours in every minute. Figure 2 gives a fragment of waveguide pulsed characteristic, obtained through the cross-correlation processing of received and transmitted signals for an hour by the receiver of transceiver 1 (Figure 2a) and that of transceiver 2 (Figure 2b).

The same characteristic, 60 minutes-averaged, is presented in Figure 3. As these figures suggest, it is possible to note up to 5 arrivals of acoustic energy, clearly separated in time. In Figure 3, when averaging the earliest arrival, dotted in Figures 2a and 2b, did not reveal itself because its appearance was evidently concerned with wave oscillations of the near-bottom channel.

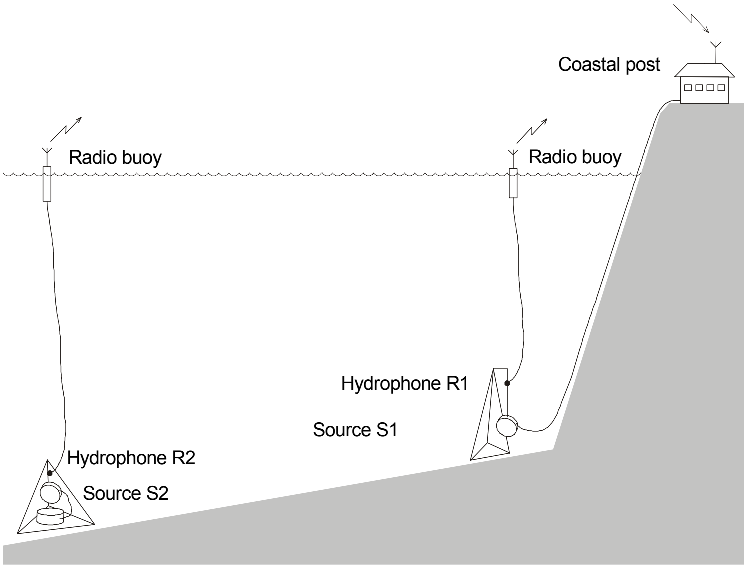

Figure 1. Scheme of transceiver experiments.

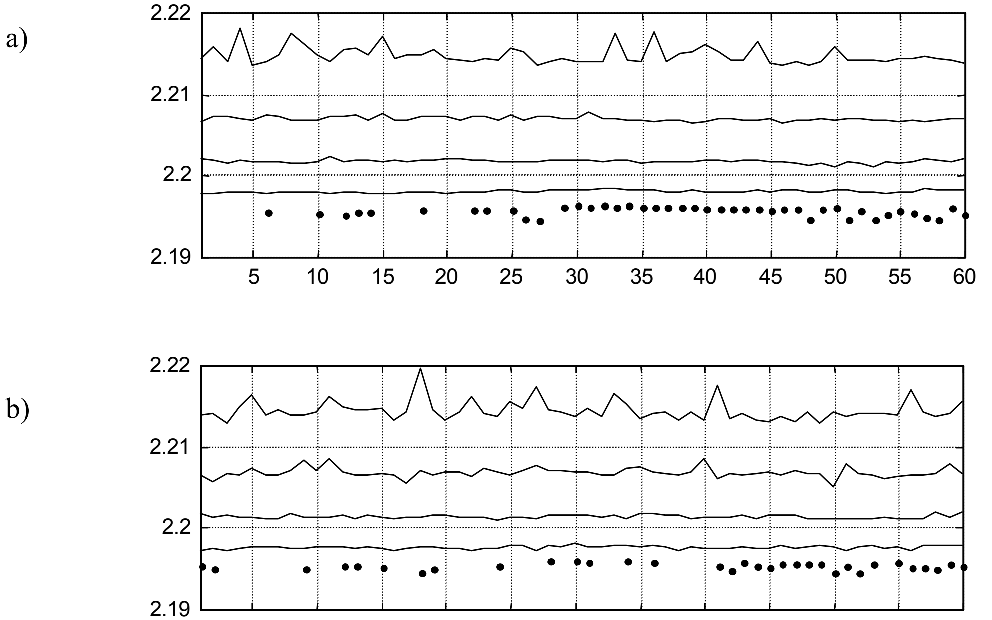

Figure.2. Time delays of ray arrivals (sec): a) R1-S2, b) R2-S1.

Analysis of Figure 3 shows that the noted acoustic energy shift in time for the case of propagation to and from the shore is connected with the current directed toward the shore, velocity projection of which onto the travel of propagation, calculated by the known expression, comprises 20 cm/sec.

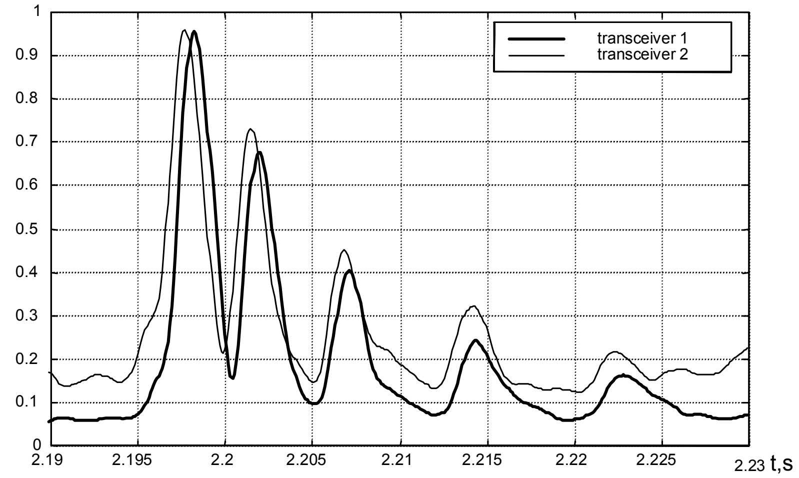

Figure 3. Averaged pulsed characteristics (2500 Hz).

An extended analysis disclosed the availability of counter-current, formed at regular intervals, noted from the time shift of the 3rd and 4th arrivals (Figure 4).

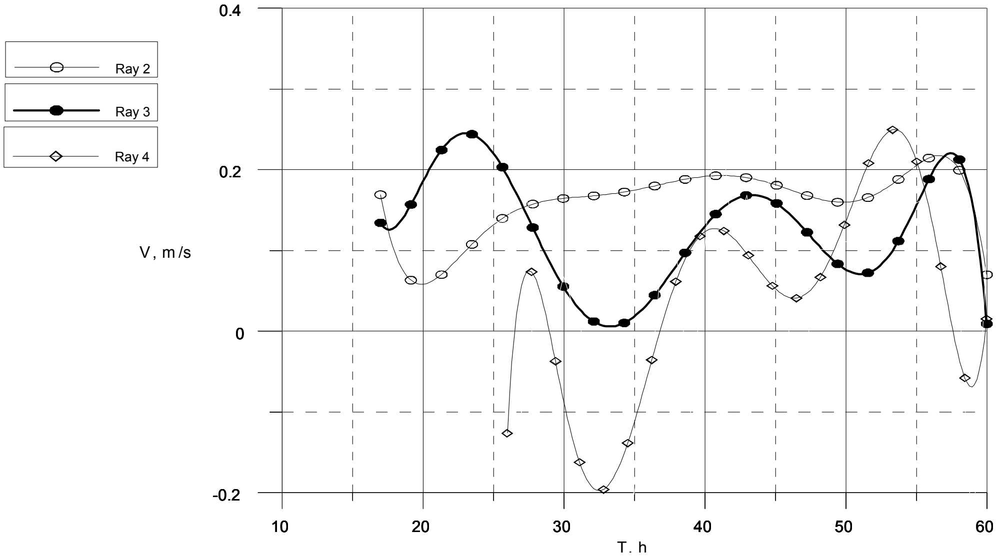

Figure 4. Current velocity, calculated by rays 2, 3 and 4.

It may be assumed that this is due to the major Primorien Current interaction with internal waves, the period of which being 15-20 minutes in this area, and we fixed it using a distributed thermistor. A stable current velocity, computed by the 1st and 2nd arrivals of acoustic energy propagating in the near-bottom sound channel, testifies that the main dynamic processes take place in this case in the upper layer of waveguide.

While studying the stability of underwater channel for data transmitting by M-codes, we managed to obtain some interesting results. This year we have carried out a run of experiments along this line. In the first place, we decreased the number of periods per symbol from 4 to 2 as the M-codes with a frequency of 366 Hz were transmitted. It enabled us to gain the resolution of ray arrivals and to improve the accuracy of determining time delays with little loss in noise resistance (Figure 5).

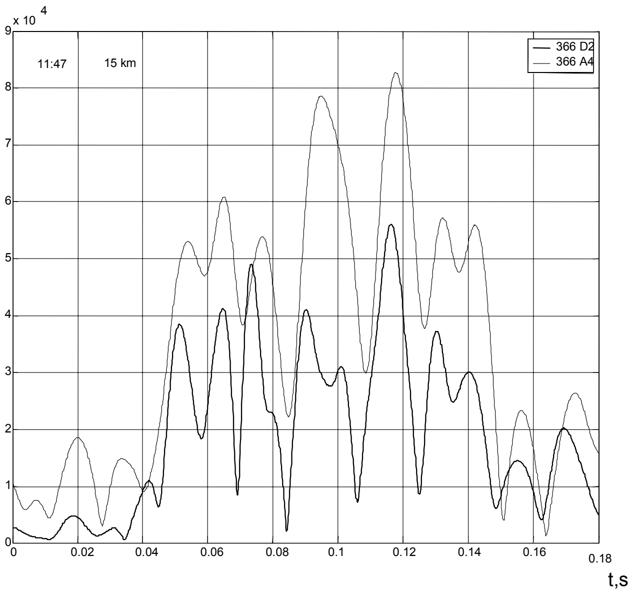

Figure 5. Averaged pulsed characteristics (366 Hz).

We next made 24-hourly probing our polygon simultaneously with every-minute transmitting the M-codes of 366-Hz and 2500-Hz center frequencies during reception at distances of 3 km, 10 km and 15 km from the sound source (Figure 6).

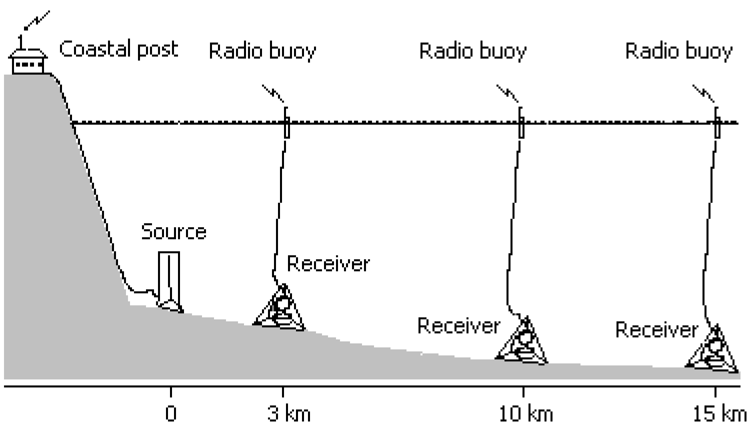

Figure 6. Scheme of propagation experiments.

The Figure 6 corresponded the situation when the hydrological conditions of a small negative temperature gradient with 19°C near the surface and 12°C near the bottom.

Shown in Figures 7 and 8 are the waveguide pulsed characteristics obtained by way of convolution of the transmitted and received signals at different distances of 3 km and 15 km away from the source. As illustrated in Figures 7 and 8, the amplitude-temporal structure of the waveguide pulsed characteristic is stable in nature at both frequencies over 3-km and 15-km extent alike. This is evidenced by the comparison of characteristics obtained through the use of one impulse and from averaging over 30 impulses (half an hour). We shall now highlight an important feature of creating a sound field at a distance of 15 km. The major energy of a high-frequency signal arrives at the hydrophone 0.03 sec before. Besides that, the individual arrival not registered by low-frequency frame is observed. The reason may have to do with the "lock-on" of a frequency signal by near-bottom sound channel and its propagation along shorter path than as for a low-frequency one. This factor is of applied significance in the technical implementation of the multi-frequency acoustic tomography of temperature and current fields since it allows to monitor them in the vertical plane one layer at a time. Yet another peculiarity, noted in these relationships, is that the low-frequency arrivals as if to be the envelope for the high-frequency ones.

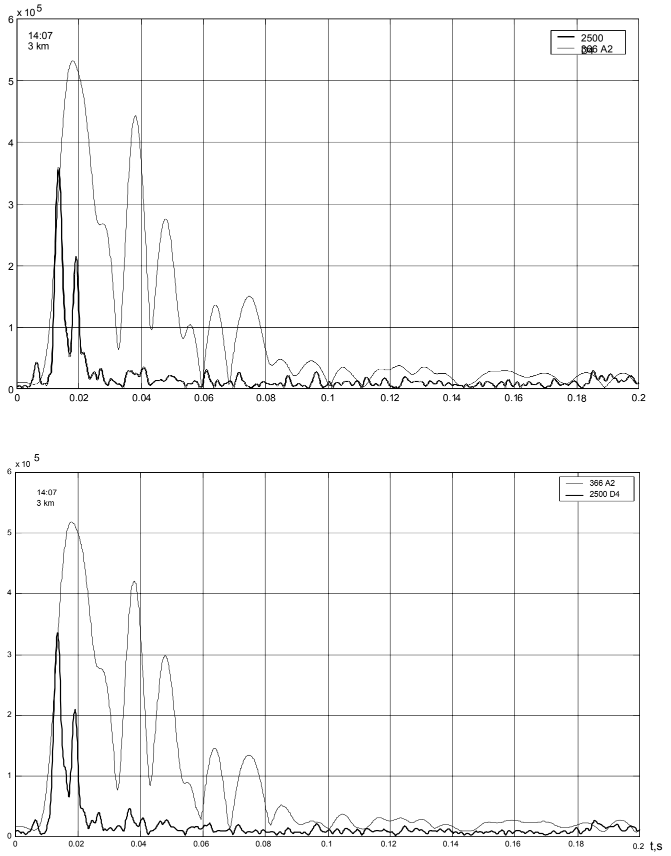

Figure 7. Pulsed characteristics at 3 km: one impulse (above) and averaged.

For the years immediately ahead we plan to conduct studies aimed at including the instruments, which provide to record not only the group but also the phase velocity of individual arrivals of acoustic energy on the stationary paths, into the set of measuring systems. This will permit to identify the arrivals more efficiently and to enhance the classification evidences of the detected inhomogeneities of sea medium. With this aim in view, we developed and put a few pressure gradient receivers to an evaluation, also attempted to combine the advantages of vector-phase reception with the benefits of sounding the sea medium by multiple phase-manipulated signals. By the use of it the phase velocity as a function of the propagation time of individual arrivals was obtained and the waveguide pulsed characteristic obtained for receiver channels.

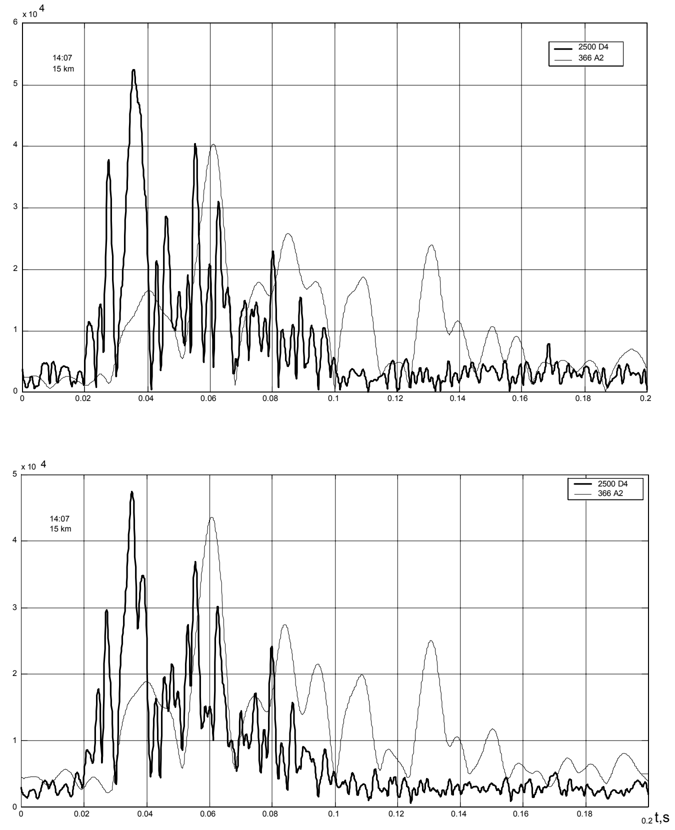

Figure 8. Pulsed characteristics at 15 km: one impulse (above) and averaged.

REFERENSES

1. V.A. Akulichev, V.V. Bezotvetnykh, S.I. Kamenev., E.V. Kuz'min, Yu.N. Morgunov, A.V. Nuzhdenko, and S.I. Penkin, "A Set of Acoustical Systems for Environment Monitoring on the Oceanic Shelf", *Proceedings of the IEEE Conference Oceans'99, MTS/IEEE*, Seattle, USA, Vol.2, 630-636,1999.

2. V.A. Akulichev, V.V. Bezotvetnykh, S.I. Kamenev., E.V. Kuz'min, Yu.N. Morgunov, A.V. Nuzhdenko, and S.I. Penkin, "Acoustic Tomography for Monitoring of the Japan Sea", *Proceedings of the Sevents Western Pacific Regional Acoustics Conference*, Kumamoto, Japan, Vol.2. 1159-1163, 2000.

3. V.A. Akulichev, V.V. Bezotvetnykh, S.I. Kamenev., E.V. Kuz'min, Yu.N. Morgunov, and A.V. Nuzhdenko, "The Japan/East Sea Acoustic Experiment (JESAEX) Project: Acoustic Tomography for Coastal Areas", *Proceedigns of the Conference of the Institute of Acoustics, Underwater Acoustic Group, ACOUSTICAL OCEANOGRAPHY*, Southampton, UK, 315-320, 2001.

4. V.A. Akulichev, V.V. Bezotvetnykh, S.I. Kamenev, E.V. Kuz’min, Yu.N. Morgunov, and A.V. Nuzhdenko, "Acoustic Tomography of Dynamic Processes in a Sea Shelf Zone with the Use of Complex Signals", *Acoustical Physics*, Vol.48, 1-7(2002).

5. V.A. Akulichev, V.V. Bezotvetnykh, S.I. Kamenev, E.V Kuz’min, Yu.N. Morgunov, and A. V. Nuzhdenko, "Acoustic Tomography of Dynamic Processes in the Water Medium in the Shelf Zone of the Japan Sea", *Doklady Earth Sciences*,Vol.381, 990-993(2001). (In Russian).

6. V.A. Akulichev, V.V. Bezotvetnykh, S.I. Kamenev, E.V. Kuz’min, Yu.N. Morgunov, A.V. Nuzhdenko, and S.I. Penkin, "Acoustohydrophysical Complex for Marine Tomographic Research", *Instruments and Experimental Techniques*, Vol.43, 829-832(2000). (In Russian).

7. V.V. Bezotvetnykh, S.I. Kamenev, E.V. Kuz’min, Yu.N. Morgunov, and A.V. Nuzhdenko, "An Acoustic Transceiver for Monitoring Dynamic Processes in the Ocean", *Instruments and Experimental Techniques*, Vol.45, 117-121(2002). (In Russian).