The Japan/East Sea Acoustic Experiment (JESAEX) Project: Acoustic tomography for coastal areas

V. A. Akulichev, V. V. Bezotvetnykh, S. I. Kamenev, E. V. Kuz'min, Yu. N. Morgunov, A. V. Nuzhdenko

Pacific Oceanological Institute, Far Eastern Branch, Russian Academy of Sciences,
43 Baltiyskaya Street, Vladivostok 690041, Russia. akulich@marine.febras.ru

Abstract

The data from an experiment undertaken in 1999 in the Japan Sea show a strong relationship between fluctuations in the water thermocline and multipath structures in the acoustic signals. Preliminary results are presented from a system designed to acoustically monitor the marine environment in the coastal regions of the Japan Sea. These results are combined with the data from experiments made in 2000, which involved insonifying along a stationary acoustical trace in the Japan Sea.

1. Introduction

In September-October of 1999 under the JESAEX (Japan/East Sea Acoustic Experiment) project, in the coastal zone of the Japan Sea experimental studies were performed on the acoustic monitoring of water temperature variations [1, 2]. Using multiplex phase-manipulated signals comprising M-codes with the center frequencies 250, 366, 406 and 604 Hz, the water medium on stationary traces was insonified. Cross-correlation processing of the transmitted and received signals allowed the impulse characteristic of the waveguide to be determined. It also demonstrated the effect on it of inhomogeneities of various temporal scales in the marine medium. Interrelations among the hydrophysical processes due to internal tides, and the propagation times between source and receiver for various groups of rays, were ascertained in the course of studies [3].

Supplementary investigations of sea water dynamics are required, if one is to increase the accuracy with which inhomogeneities in the ocean temperature along acoustic traces are to be reconstructed. This is a result of the dynamic processes that occur in shallow water. Some preliminary calculations, based on the theory of normal waves for a stationary trace with a length of 15 km and typical hydrologic conditions in the coastal zone, suggest that the acoustic travel times are strongly dependent on temperature gradient and flow velocity. In particular, because the sound speed can vary from 1500 to 1510 m/s near the bottom, to 1510 m/s in the upper layer, the time of arrival (for an assumed flow velocity of zero) can change by 0.034 s. The inclusion of a flow velocity of 1 m/s results in a decrease of the delay time (if the sound propagation is against the stream), or an increase (for sound propagation with the stream), by 0.007 m/s. Hence the error in taking the temperature may be of the order of 1°C. During May-November 2000, a series of experiments were conducted with the aim of improving the instrument support for monitoring acoustic propagation using two methods of measuring ocean flows: a two-way propagation technique [4] and the scintillation method [5].

2. Experiments using two-way propagation

2.1 Description of the Experiment Facilities

The two-way propagation technique involved transmitting sound in opposite directions along the same path. This was done to monitor the hydrophysical processes on the Japan Sea shelf in October 2000 on a stationary trace (Figure 1). To implement the above method, two identical electromagnetic-type sources S1 and S4 were developed with special purpose dampers intended for broadening the passband (Figure 2). They projected multiplex phase manipulated signals of M-code, with a symbol selection of 511 and carrier frequency of 250 Hz. These signals were transmitted every minute for several hours. Using the cable, source S1 was placed at a distance of 200 m from the shore and at a depth of 25 m (the bottom depth was 27 m). Autonomous source S4 was placed at a distance of 15 km offshore and at a depth of 75 m (the bottom depth was 76 m). The signals from receivers R1 and R2 were transmitted through radio communication channels to the coastal post. Receivers R1 and R2 were each fixed 20 cm from the center of their respective sources. Two systems with overlapping signal reception and transmission were packaged.

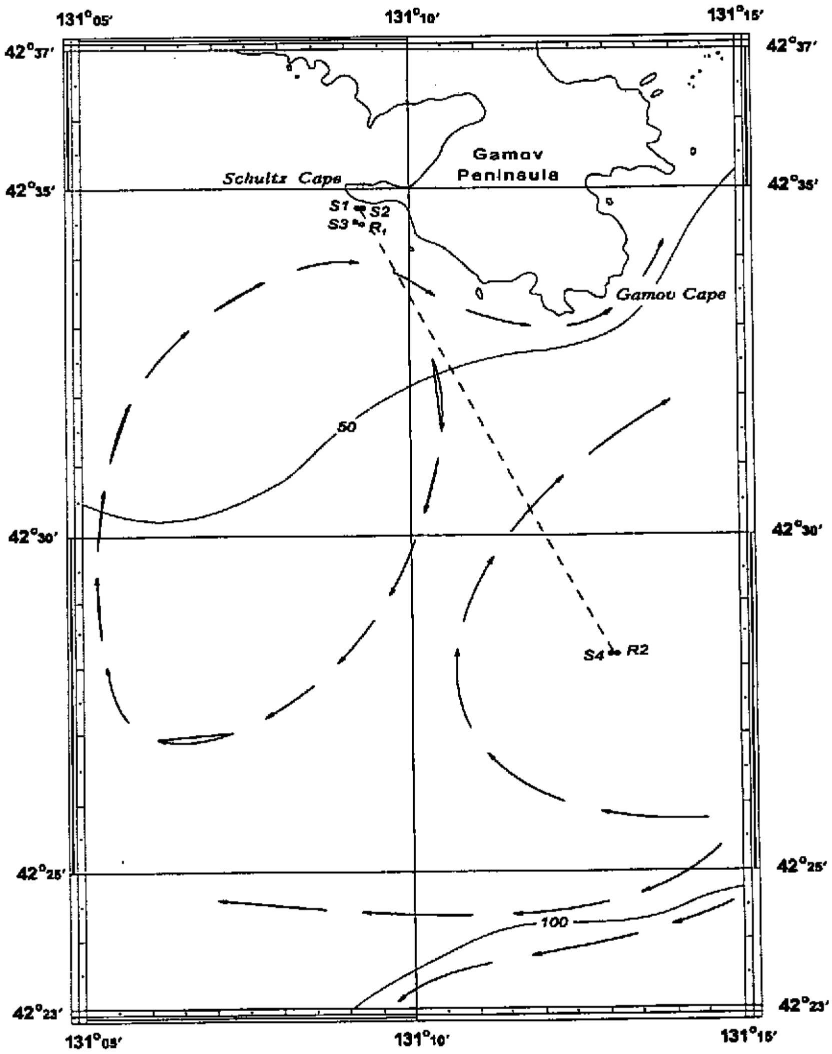

Figure 1. The arrangement of stationary transmitting and receiving systems near Gamov Peninsula in the Japan Sea, with current indicated

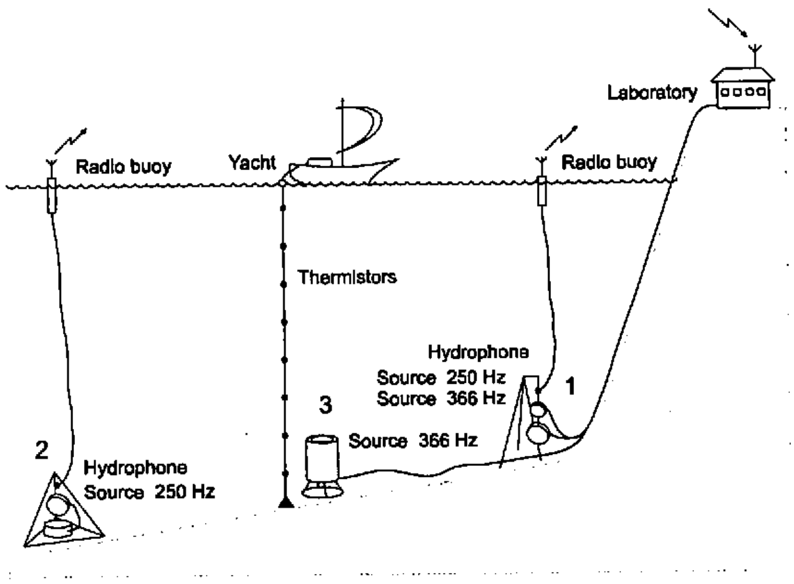

Figure 2. A set of acoustical systems on the shelf near Gamov Peninsula

The monitoring system, transmission and recording of signals were synchronized using the United World Time. For measuring the temperature dependence on depth, an 8-element chain of thermistors spaced 5 m apart in the layer up to 35 m from a surface was positioned 400 m from the shore. During October 2000 the hydrology within the area under investigation was characterized by a low negative temperature gradient from the surface to the floor, with a near-bottom channel being formed (Figure 3). The current pattern in this region is complex in nature, as a consequence of general water transport caused by the southward Primorien Current and tidal phenomena.

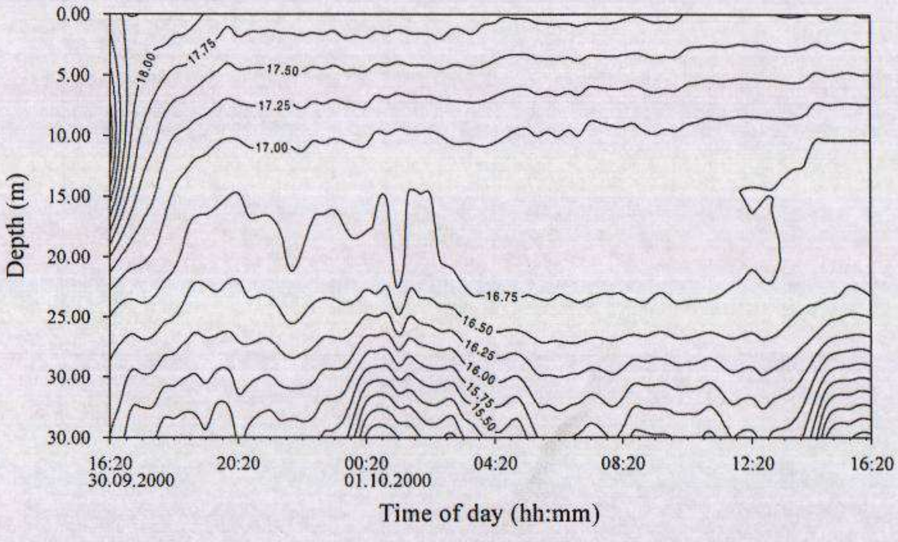

Figure 3. Dependence of water temperature in °C from time at different depths

2.2 Experimental Results

To follow the reciprocity principle is one of the main requirements when measuring the flow velocity by the two-way transmission method. In our experimental studies we approved and evaluated the procedures, allowing for drift of a transceiver, and for its vertical submergence from the yacht riding at two anchors. Observations for many hours have shown that these variants are suitable only for short durations of time when the reciprocity principle is kept. Most progress was made if both transceivers (S2-R2) and (S4-R1) were placed stationary near the bottom. Figure 4 shows variations in the impulse characteristic of the waveguide. It was obtained during cross-correlation processing of the received and transmitted signals that were propagating in opposite directions. As can be seen, the temporal parameters are very similar for one hour and a half.

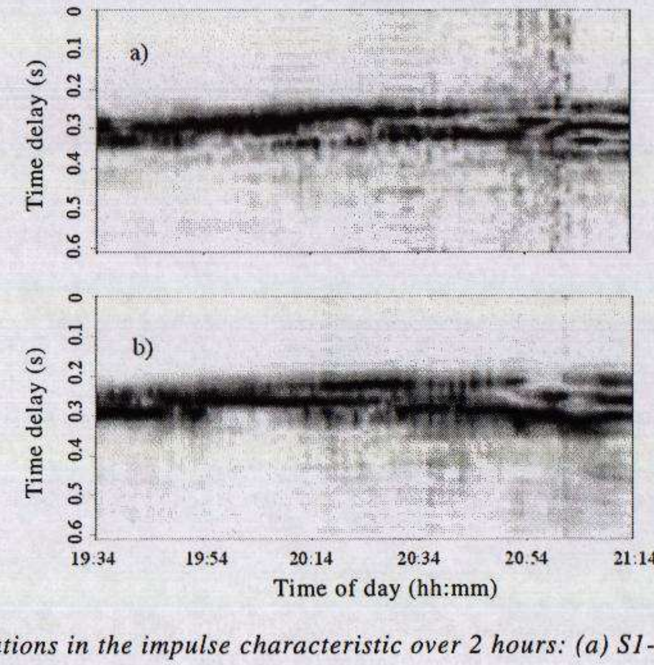

Figure 4. Variations in the impulse characteristic over 2 hours: (a) S1-R2, (b) S4-R1

The differences in the travel times of the basic groups of rays from which the water flow velocity between the transceivers is computed are visualized on Figure 5, where cross-correlation functions for two fixed moments of time are shown. Examples of the successful use of the two-way transmission method for measuring the flow velocity component on the path are found in the results of a 12-hour sounding, taken during the days of good weather and strong currents noted from the yacht.

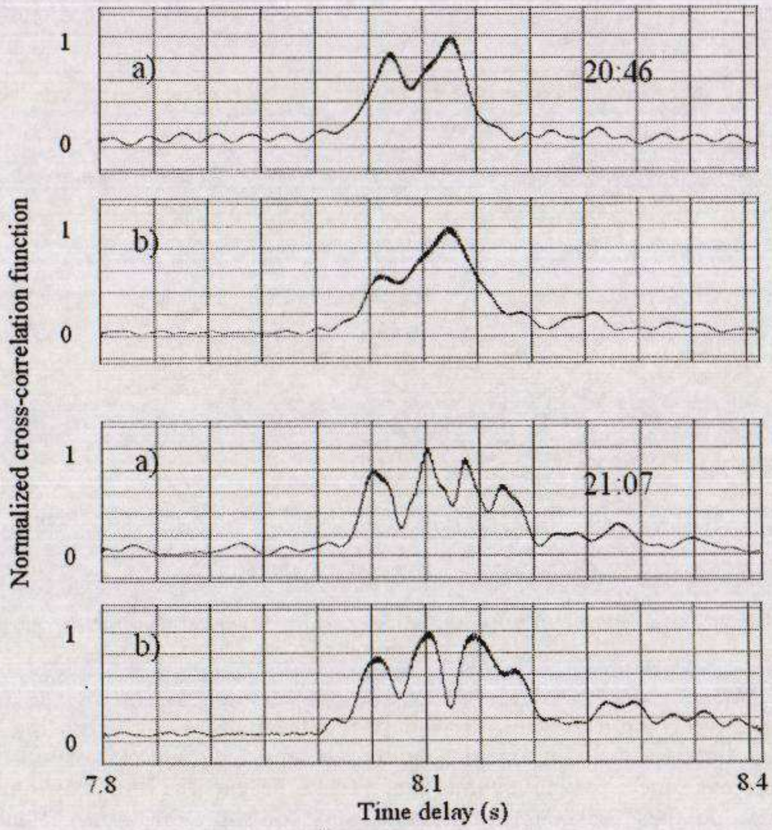

Figure 5. Two fragments of impulse characteristic from Figure 4: a) S1-R2, b) S4-R1

To calculate the averaged group delay time of individual normal waves by using the phase function for an acoustical field, we require an expression for the propagation time of the signals:

$$t_n^{\pm} = \int_0^r \frac{dr}{c_n(r) \pm V(r)}, \tag{1}$$

where $c_n(r)$ is the group velocity of the nth normal wave, $V(r)$ is the projection of the current velocity on the acoustical trace, which is dependent on the horizontal distance r, the $\pm$ sign corresponding to the direction of transmission.

As long as $c_n(r) >> V(r)$, we can write:

$$\Delta t = t_n^- - t_n^+ \approx 2\int_0^r \frac{V(r)\,dr}{c_n^2(r)}, \tag{2}$$

$$t_n^+ + t_n^- \approx 2\int_0^r \frac{dr}{c_n(r)}. \tag{3}$$

For the average values c_n and V we have:

$$V = \Delta t \cdot c_n^2 / 2r, \tag{4}$$

$$c_n = 2r / (t_n^+ + t_n^-). \tag{5}$$

The plot of the computed velocity component of flow directed along the path, and the rise of tide for this time interval, are shown in Figure 6. As illustrated by this figure, the velocity component of flow fluctuates mainly from 0.5 m/s to 1.0 m/s, and its out-of-order value of 0.2 m/s contemporises with phase of high tide. This fluctuation occurs because the major Primorien Current in this region has a basis vector co-linear with the direction of the tide. Moreover, the quantitative measurements of flow velocity observed from the yacht approximately agreed with calculations. Since the velocity was calculated as an integral estimate of flow velocity along the whole path, the geometry of the experiment must be made more complicated to increase the precision of measurements.

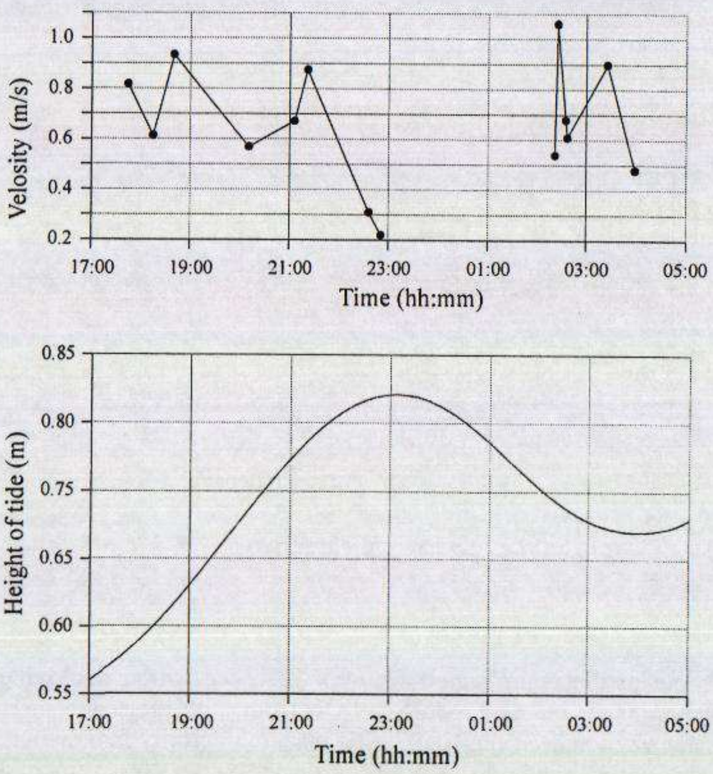

Figure 6. (a) Velocity component of flow directed along the trace, and (b) the height of the tide

It is necessary to note that the results described here are preliminary, since only approximate integrated estimations of the water flow velocity are presented. In the long term we plan to examine the difference in travel times of each modes, in order to estimate vertical distribution of water flow velocity in the sea.

3. Scintillation Method for Measurement of Flow Velocity

The possibility of applying the scintillation method to measure water velocity with the use of multiplex signals was studied as part of the tomography scheme of acoustic monitoring in the Sea of Japan shelf near the Gamov Peninsula [1, 2]. The two orthogonal phase-manipulated signals of M-codes (of 11.17 s duration, with 511 symbols and a carrier frequency of 366 Hz) were transmitted every minute synchronously from points S2 and S3 (Figure 2). Source S2 was placed at a depth of 25 m (the bottom depth was 27 m), source S3 was placed at a depth 38.5 m (the bottom depth was 40 m). The distance between sources S2 and S3 was 250 m. The signals from S2 and S3 were received by remote hydrophone R2. The distance from source S2 to receiver R2 was 15 km, the distance from source S3 to receiver R2 was 14.75 km. Signal data were transmitted through a radio-communication channel to the coastal post (Figure 2). At the same time the received and transmitted signals were processed by the cross-correlation way. Thus the impulse characteristic of the waveguide was determined every minute. The results of data processing, obtained for two traces (S2-R2) and (S3-R2) during a 3 hour period, are shown on Figure 7.

These results demonstrate the stability of the arrival of the fundamental mode. Later arrivals, containing significantly more acoustic energy than the background, occur with a period of about 1 hour. These are probably associated with the passage of internal waves in the region of water where the sources are located. Analysis of the temporal shifts between the two plots in Figure 7 allows estimation of the components of flow velocity along the trace using the scintillation method. Currently its value is estimated to be about 0.1 m/s.

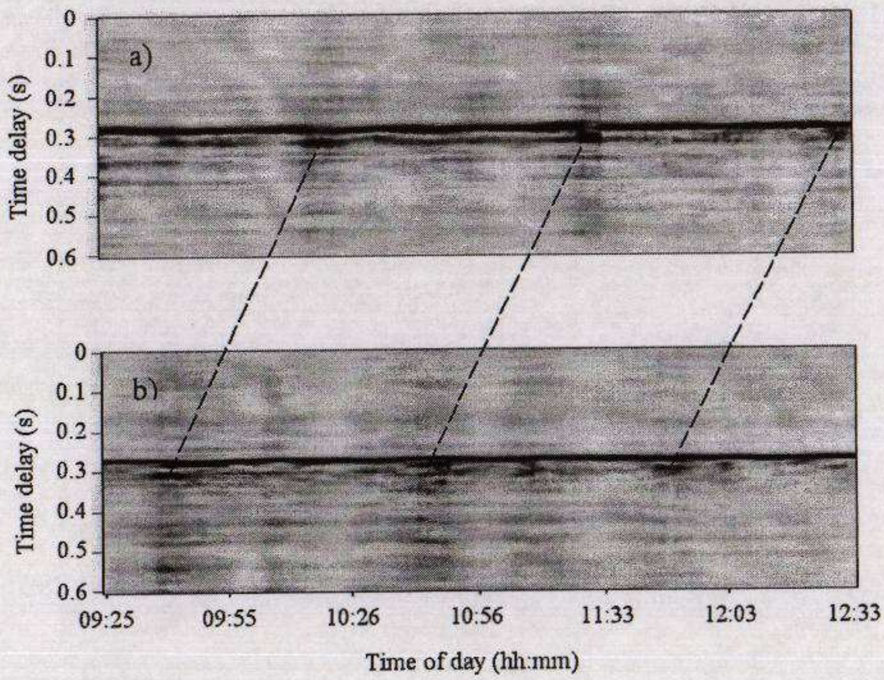

Figure 7. Variations in the impulse characteristic over 3 hours: a) S2-R2, b) S3-R2

4. Summary

The paper describes some of the complicated features observed whilst deploying an acousto-hydrophysical polygon near the Gamov Peninsula in the Japan Sea, containing facilities and instrumentation for monitoring dynamic processes in the deep sea and on the shelf. This research activity is aimed at assessing the feasibility of using propagation and scintillation methods to monitor the polygon flow velocity. The present experimental results enable us to improve the technical and methodological basis on which tomographic investigations are carried out in the Japan Sea.

Acknowledgment

This work was supported by Office of Naval (Dr. Jeffrey Simmen), and by the Applied Physics Laboratory, University of Washington, Seattle, WA, USA (Dr. Robert C. Spindel).

References

[1] Akulichev VA, Kamenev SI, Morgunov YuN, Nuzhdenko AV and Penkin SI. Instrumentation and methods for acoustical monitoring of the Sea of Japan shelf, in *Proceedings of International Symposium on Acoustic Tomography and Acoustic Thermometry*, JAMSTEC, Yokosuka, Japan, 1999, pp. 188-192

[2] Akulichev VA, Kamenev SI, Morgunov YuN, Nuzhdenko AV and Penkin SI. A Set of Acoustical Systems for Environment Monitoring on the Oceanic Shelf, in *Proceedings of the IEEE Conference Oceans'99*, MTS/IEEE, Seattle, USA, 1999, **2**, pp. 630-636

[3] Akulichev VA, Bezotvetnykh VV, Kamenev SI, Kuz'min EV, Morgunov YuN, Nuzhdenko AV and Penkin SI. Acoustic Tomography for Monitoring of the Japan Sea, in *Proceedings of the Seventh Western Pacific Regional Acoustics Conference*, WESTPRAC VII, Kumamoto, Japan, 2000, **2**, pp. 1159-1163

[4] Spindel RC. Ocean acoustic tomography, in *Proceedings of International Symposium on Acoustic Tomography and Acoustic Thermometry*, JAMSTEC, Yokosuka, Japan, 1997, pp.1-10

[5] Farmer DM and Crawford GB. Remote sensing of ocean flows by spatial filtering of acoustic scintillation: Observation. *Journal of Acoustical Society of America* 1991; **90**: 1582-1591