SYSTEM FOR BISTATIC MEASUREMENTS OF REVERBERATIONS IN THE SHALLOW SEA AREA

ZYGMUNT KLUSEK[*], ANDRZEJ ELMINOWICZ[**],
PIOTR MAJEWSKI[*], AGATA DRAGAN[*]

[*]Institute of Oceanology, PAS
55, Powstańców Warszawy St., 81-712 Sopot, Poland
klusek@iopan.gda.pl, piotr_m@iopan.gda.pl, adragan@iopan.gda.pl
[**]R&D Marine Technology Centre
62, Dickmana St., 81-109 Gdynia, Poland
andrzeje@ctm.gdynia.pl

In the paper a system for measurements of reverberations in the shallow sea environment is presented. The setup operated in 40–80 kHz frequency range with pseudomonochromatic pulses or chirp signal and has possibility to acquire bistatic scattered data. The system is constructed in such manner that depending on an experiment configuration we could perform measurements of the local 3D scattering strength of the bottom and/or far range bistatic reverberations from the sea surface, volume inhomogeneities and sea bottom. The final objective of the system is to give prognosis for probability of target detections when using bi- or multistatic barriers. Details of the individual blocks are given in the following sections and the technicalities of the design are given. Furthermore, some examples of data gathered during test of the equipment concerning assessment of the reverberation and local bistatic scattering features are presented.

INTRODUCTION

The scattering of acoustic signals on a wavy sea surface and rough sea bottom surface has been the subject of numerous field and theoretical investigations both in the past and nowadays.

Starting as early as in 70's, bistatic scattering investigations, firstly initiated in laboratory conditions and later transferred to the sea, the experiments and clarified them theories give only preliminaries concerning of angles and frequency dependencies of the bistatic scattering vs. sea state conditions or sediment's properties.

Nonetheless, our knowledge regarding values of bistatic signal scattering comparing to the simpler alternative of the back- or forward scattering is incomplete [1, 2, 3, 4, 5].

Contemporarily growing interest in the bistatic scattering is stimulated due to superior identification of targets and improved rate between reverberation levels and signals comparing to the monostatic backscattering scenarios. However, bistatic experiments require more complex setup in which specific geometry of position and orientation of transducers should be precisely realized. A newly assembled system aimed at measurements of bistatic reverberations of the sound from the seafloor, volume inhomogeneities and sea surface is presented below.

The system could work in two independent arrangements to measure local bistatic scattering from the sea bottom or the sea surface and to quantify sea reverberations in bistatic mode. During tests, an autonomous scanning passive sonar system was firstly deployed in well-characterized regions of the shallow water area of the Baltic Sea with recognized sound propagation conditions.

Three kinds of acoustic observations are presented. The first represents a specific and readily identifiable, single interaction observation of the biscattering in the region with acoustically hard bottom. The next data set concerning records of angular and frequency dependence of simple monostatic backscattering. And the final one experiments with measurements of the reverberation in the shallow sea area.

The data presented in this report were collected during experiments and trials performed for the grant purposes and constitute a by-product of the main goal of the project investigation.

1. MEASUREMENT SETUP

The acoustic measurement system could work in the two independent configurations – performing measurements of a local bistatic scattering coefficient at the sea bottom or the sea surface, or as a system for measurements of a far-range the bistatic reverberation, usually measured for low grazing angles.

The system in the last arrangement was planned to carry out the fundamental investigations aimed at planning of most favorable parameters of an anti-terrorist systems functioning in multistatic configurations for a given area.

The first arrangement has been aimed at the estimations and parameterization of angular and frequency dependence of the local bistatic scattering coefficient in the areas of interest. The purpose needed for modeling and prognosis the probability of target recognition immersed in the sea.

The setup operated in 40–80 kHz frequency band, acquired bistatic scattering data over a 100–200-m radius. The transmitted signals pulses or LMF (chirps) are formed and generated by a fast D/A and A/D card (NIDAQ 6251) and transmitters are driven by a power amplifier L2 of the Instruments Inc (USA).

Generally the output signals were formed with sampling frequency 350–500 kHz. The sampling frequency up to 250 kHz was used in each of input channel. During receiving echoes from the ship board, the same card is used also as the four channel digitizer. Signals were digitized with 16 bit A/D converters.

In the case of backscattering measurements, as transmitters and receivers, the TC2116 RESON broadband transducers were employed. The transmitters have a narrow directivity pattern with a full width at 50 kHz of 13.5° at one-half maximum power.

In the bistatic far-range configuration, the system consists of the two modules – the transmitting unit attached to a frame suspended from the ship and the receiving autonomous buoy with four hydrophones. The buoy consists of a steel, pressure container of 1m high and with 0.36 m diameter, which contain electronic components – a controlling computer, eight A/D converters with microprocessor and a power supplying battery set. The aerial of the Wi-Fi connector is freely floating on the sea surface. The view of the autonomous buoy is presented in the Fig. 1.

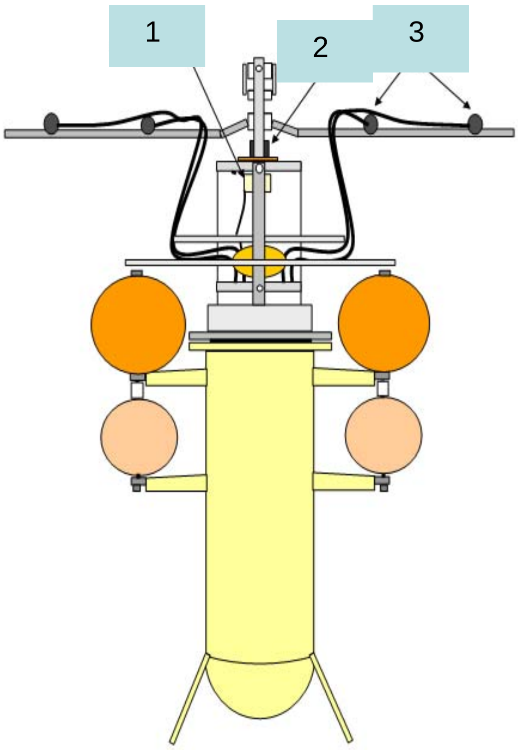

Fig. 1. The schemat of the autonomous module: 1 – electric motor, 2 – compass with inclinometer, 3 – hydrophones

In our tasks the receiving module array consisted of four omnidirectional broadband hydrophones (RESON TC4034) with nominal sensitivity of –192dB+/–2dB re 1V//µPa. It is noticeable, that the buoy could work as passive system recording ambient sea noise.

Additionally, the buoy is ready to work as the multistatic echosounder, when at the top of receiving array of spherical hydrophones the RESON TC2116 transducer is connected. The location of the buoy residency and the azimuth angle of the receiving array are recorded by a pressure sensor and an inclinometer coupled with magnetic compass both mounted on the array.

Batteries provide energy to operate the buoy board for about two week; however, the run time is depending on the rate at which data are acquired.

1.1 LOCAL BISTATIC SCATTERING COEFFICIENT

The measurements of the local bistatic scattering coefficients were accomplished from a construction, which allows us to perform measurements of bistatic scattering coefficient. The received part consists of the assemblage of four omnidirectional hydrophones also mounted equidistantly on a quarter-circle arch. Each of the four hydrophones was located at position which allows us to measure forward or bi-scattered signals at a grazing scattering angles ϕ_H of 15, 30, 45 and 60 degrees.

The frame construction permits alter the direction of the scattered (azimuth) angle θ_H which could be changed from 0 deg (for forward scattering) to 135 deg with the step of 45 degrees.

The backscattering for the scattered angle 180 deg was performed with one more frame unit. The active part consists of the two RESON TC2116 broadband transducers also located on the quarter-circle arch are hitched at the same set of (the) grazing angles as the hydrophones with the incident angles 15, 45, 60 and 75 degree.

The geometry of the system was planned in such manner that the bounced at the bottom acoustic ray between the any of transmitters and hydrophones was not dependent on the changes of the azimuth and scattering angle between the transmitters and hydrophones. The path of the acoustic signal scattered at the bottom from the transmitter to any of the hydrophones was equal 3.4 m.

For most configurations, the geometry of the construction and chosen pulses duration enables us undoubtedly distinguish between the direct path connecting transducers and the maximum in the bottom-bounce arrivals. For some configurations however, and with growing roughness of the bottom, a contamination from the transmitter side-lobes could be observed.

To obtain an angles dependence of bistatic scattering cross-section of the sea bottom into 16 directions (in the four azimuth and the four scattering angles) for the four incident wave angle.

It gives 64 values for each series of experiments at given frequency. Additionally it was necessary to perform several series of experiments with different pulse duration, frequency and type of a sounding signal. A basic sketch of the methodology the bottom bistatic scattering experiments is presented in Fig. 2 (left) where T means position of the transmitter, and different symbols indicate positions of the hydrophones. In the same figure on the right the photo of the frame is presented.

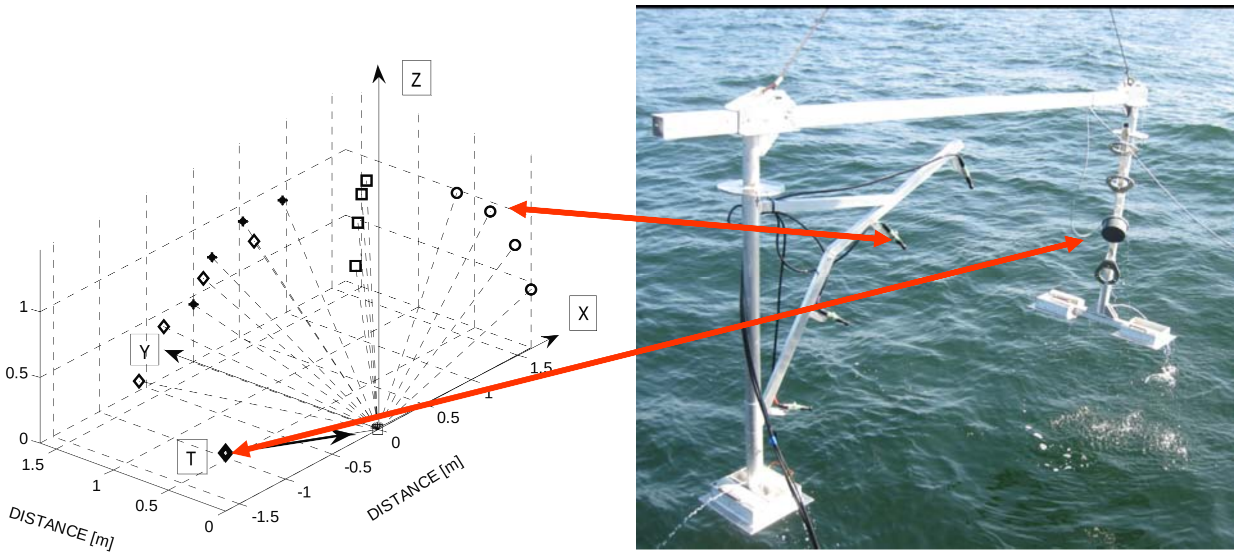

Fig. 2. Local bistatic scattering measurements.
The scheme of the measurements (on the left) and the frame (on the right)

1.2 FAR-RANGE BISTATIC SCATTERING MEASUREMENTS

As was mentioned above the system used in measurements of the far-range bistatic scattering consists of two independent modules. The transmitting module is arranged on the shipboard and the receiving one mounted on the automatic buoy anchored at the sea bottom. The receiving module includes movable acoustic receivers. The receiver array of four omnidirectional hydrophones mounted at the top of the buoy could perform horizontal scanning. Each continuously performed scan of the hydrophones covered a 190 deg, usually with one minute period. As for reception and concept of forming directivity, the receiver array works to a certain extent on the principle of time delay of signals.

Since the buoy's position may not be perfectly vertical, the receiving array is mounted on a three-axis Cardan suspension which allows the array to remain in a horizontal plane, regardless of the motion of the buoy body. The buoy is additionally arranged to carry the transducer as the transmitter. In this mode the system can works as autonomic sonar.

The communication between the buoy and the ship is achieved through the Wi-Fi modem. The aerial of the modem is attached to a float at the sea surface. The operator control remotely all parameters of the receiver system like signal amplifying, start of signal sampling, band-pass filters and A/D converter parameters through air using Wi-Fi.

Signals from hydrophones were amplified by the preamplifiers with automatically changed gain (the internal processing algorithm monitors the noise level on line, to avoid saturation and clipping), digitized with frequency up to 250 kHz per channel and stored on memory cards. The data was acquired at the 16-bit resolution in each channel. A signal flow diagram for the buoy is shown in Fig. 3.

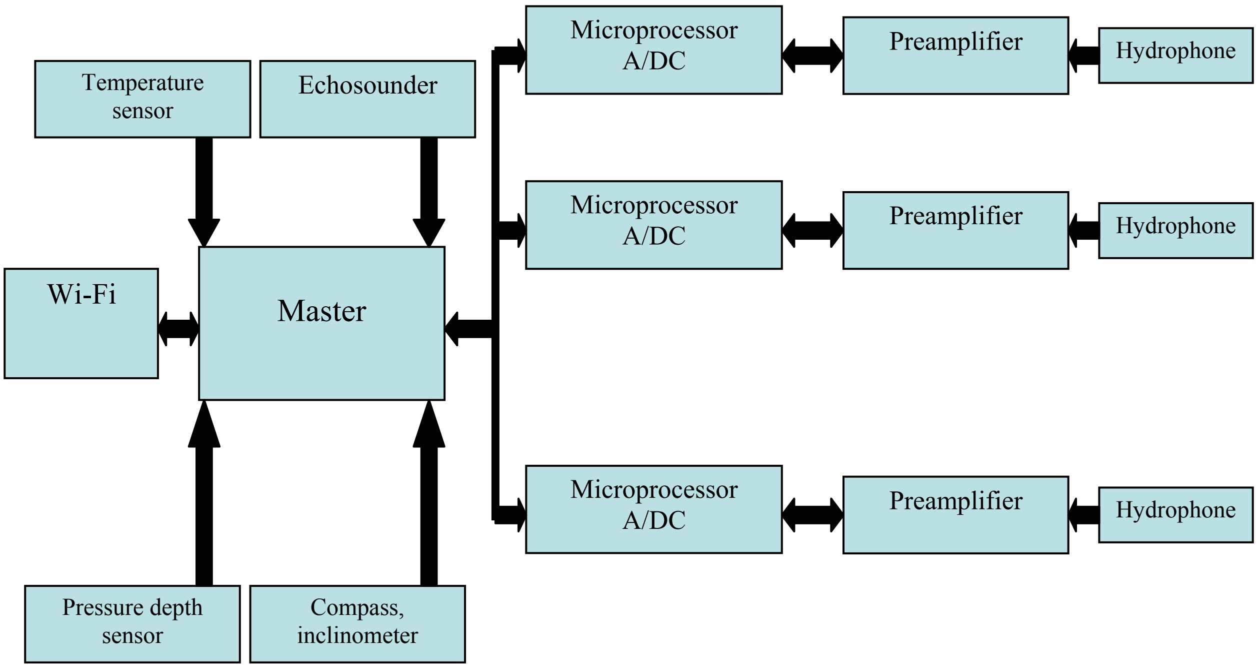

Fig. 3. Functional block diagram of the acoustic buoy working as the receiving module of the system for the bistatic reverberation measurements

2. DATA EXAMPLES

The tests of the system and experiments aimed at the measurements of reverberation level were performed in the coastal shallow water areas of PEZ from the board of rv 'Oceania' and my 'Safira'.

The trials and experiments could be grouped into three classes depending on the system's configuration:

- monostatic backscattering measurements from the sea bottom or the sea surface,
- measurements of 3D local bistatic scattering strength of sea bottom,

– 2D bistatic reverberation measurements, when the source was sited at the ship board and receivers placed to the receiving buoy.

Examples presented here were obtained at sea during the exercises in the coastal zone of the Southern Baltic Sea.

2.1 LOCAL BISTATIC SCATTERING

The examples of the 3D visualization of high frequency signal scattering from sea bottom are depicted below in the Fig. 4. The data are from shallow water in the area with the bottom covered by marine medium-grained sand. The sounding was performed with short pulses 0.3 ms, with central frequency F=45 kHz.

Fig. 4 illustrates the angular variability in the data: bottom reverberation of CW signals for all four values of grazing angles of incident waves. Generally, the same geometry was used at all frequencies and type of signals for the same ship positions.

Presented here is Bistatic Scattering Strengths evaluated according to formula

$$BSS(\phi_T, \phi_H, \theta_H, t) = RL - SL + 20\log(R_1(t)) + 20\log(R_1(t)) - 10\log(A(t))$$

where:
RL – the reverberation level in dB//1 μPa; SL – the source level in dB//1 μPa @ 1 m; $R_1(t)$ – the distance from the transmitter and to the scattering element of the sea bottom; $R_2(t)$ – the distance from the instantaneous scattering element of the sea bottom and a hydrophone; ϕ_i is the grazing angle for the incident wave; and θ_H, ϕ_H are the scattered (elevation angle) and bistatic (azimuth angle) angles respectively; A(t) – the instantaneous scattering area (the footprint of the acoustic beam on the bottom which is dependent on time) – determined numerically on the basis of information on the beam footprint on the sea bottom.

The colors represent a value of the computed bottom Bistatic Scattering Strengths. The cold (blue) colors for the lowest level of the biscattering, the hot ones for the highest values.

2.2 FAR-RANGE REVERBERATIONS

The pattern of behavior or reverberation in the case of very shallow water 10.7 m depth for a CW 40 kHz pulse and a chirp signal in frequency range 40–60 kHz is illustrated in the Fig. 5. In each panel echoes for different horizontal directions are presented.

In the presented examples, as a receiver platform was the buoy equipped with a linear acoustic array consisted of 4 omnidirectional hydrophones. The sensors were linearly spaced with $x = 0.65$ m. The sampling frequency was 250 kHz.

During the experiment, the buoy was suspended from the ship and programmed to perform a slow moving survey over the target field. The ship was anchored.

The transmissions were synchronize with the receiving cycle triggering a 0.3 or 10 milisecond ping in one second sequence (narrowband pulses or chirp signals respectively). The source was positioned at the depth of 2 m in close proximity to the hydrophone array. The transmitter's grazing angle 45 deg. At the distance 40 m a spherical buoy was deployed as the reference target. Presented echoes from the chirp signals are after convolve procedure with the replica of the emitted signal.

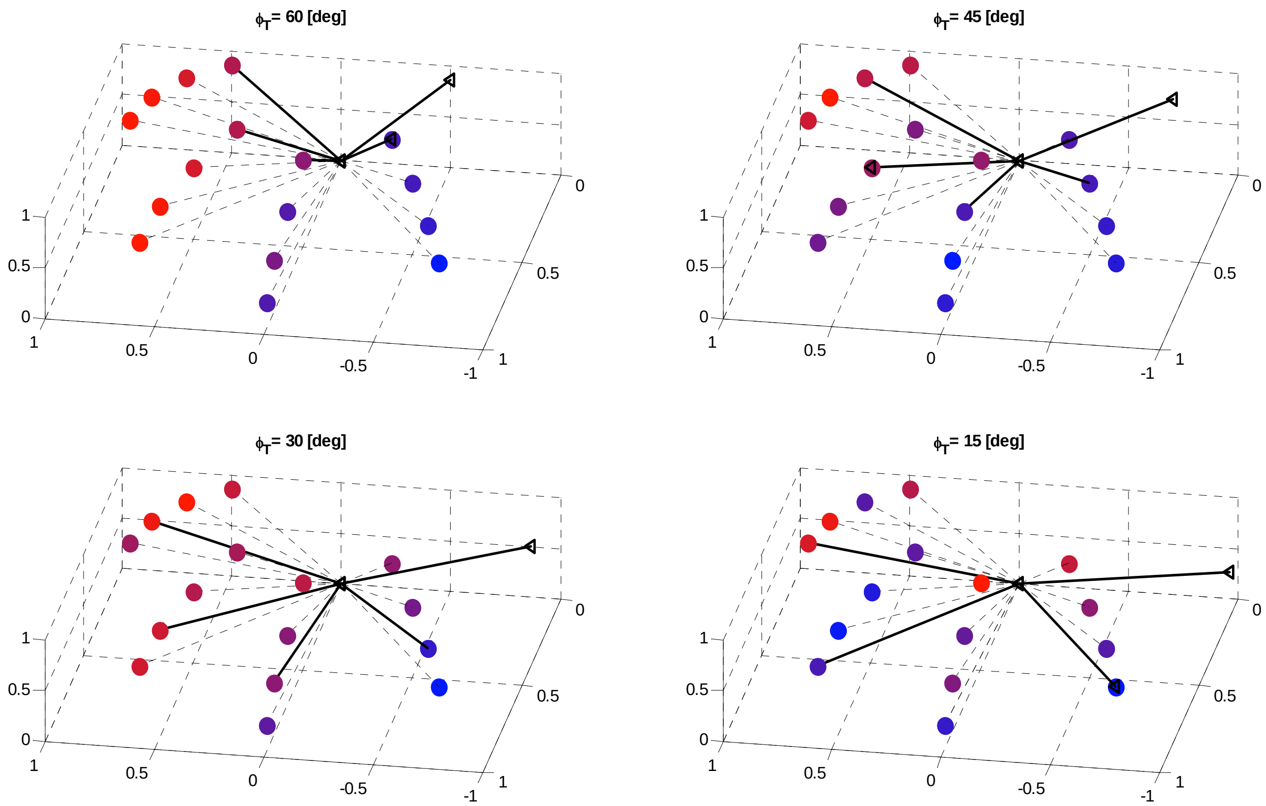

Fig. 4. The angular variability in the bottom bistatic scattering strength
at 45 KHz, for four incident angles

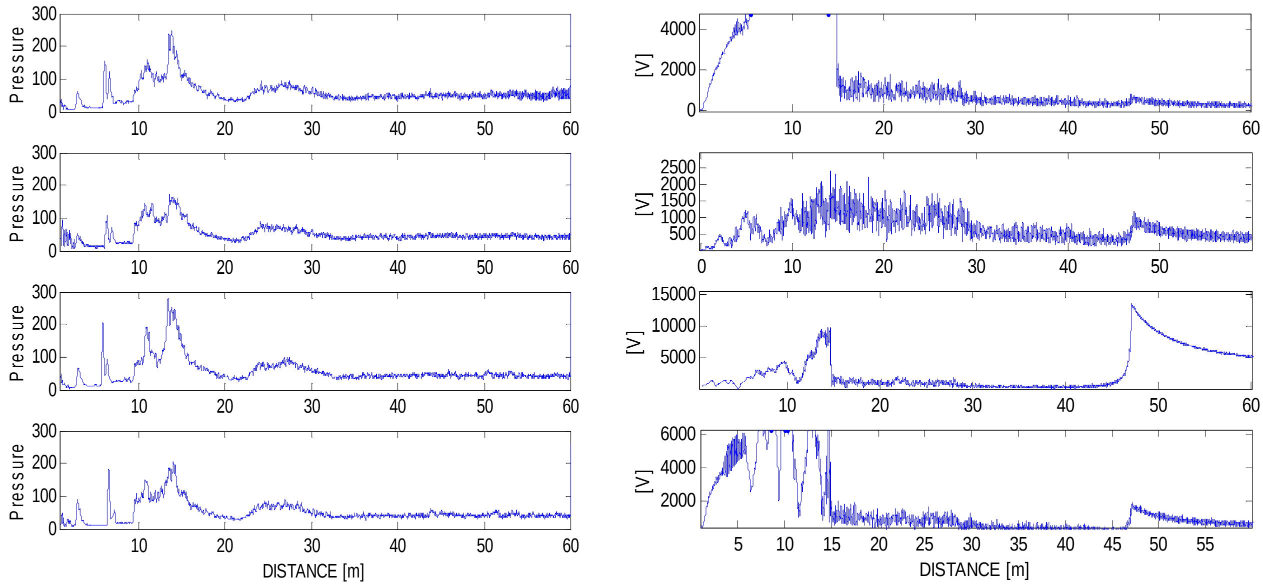

Fig. 5. Reverberations for the short narrowband signals (left) and chirp signals (right)
after convolution with the replica of emitted signal

3. CONCLUSIONS

The results of trials suggested that the proposed technique for calculating the level of reverberation both for and chirp sounding signals reproduces qualitatively correctly a number of environmental propagation effects caused by the influence of bottom bistatic scattering. The main goal for constructing presented equipment was the efficient assessment of reverberation data in given area i.e., to obtain tactically relevant information for an efficiency of system working in tactically relevant time frame. The novelty of the constructed system was to receive reverberation data to extract acoustic parameters for propagation and bistatic semi-empirical sonar modelling. The detection of a target in the shallow sea where strong reverberation has place support information about chirp signals over narrowband pulses particularly in the bistatic configuration.

In the so called far range reverberation measurements we observe that the main input is from the scattering which occurs only once, however there are multiple bottom bounces in the propagation paths. In numerous cases, when transmitters are place shallowly, the first return from the bubbles clouds are saturated which makes the direct detection of targets poor. What's more low-angle scattering is often masked by stronger steep-angle scattering. Even a simple operational model could be useful in interpreting reverberation data, and producing a model-data map which can be used for planning the bistatic hydroacoustic barriers.

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