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6. AUTHOR(S)
Anatoliy N. Ivakin

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Applied Physics Laboratory
University of Washington
1013 NE 40th St.
Seattle, WA 98105-6698

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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
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875 North Randolph St., Ste. 1425
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13. ABSTRACT (Maximum 200 words)
The long-term goal of this research is to develop a package of upgraded bottom reverberation codes based on up-to-date understanding of the physics and mechanisms of sound-seabed interaction. The specific scientific objective of this project is to develop a prototype for a package of physics-based bottom reverberation codes which would be self-consistent and practical. It assumes that the codes would be tested by practical use, particularly by including in analysis of existing seabed scattering database. In this project, scattering data obtained at recent sediment acoustics experiments in shallow water (SAX04) and in laboratory conditions (LMA-CNRS, France) have been used successfully for such testing. The self-consistency and practicality assume also that the codes are able to take into account general characteristics of acoustic systems, such as their directivity and frequency bandwidth (for both narrow- and broad-band systems), and use practically measurable environmental inputs. A first version of such package has been developed in this project that can represent a foundation for development of an up-to-date, physics based interface between acoustic response of the system, such as time series of the reverberation signal, and seabed geoacoustic and geotechnical parameters, such as sediment density, sound speed, attenuation, grain size and others.

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Updates for Bottom Reverberation Codes

Anatoliy N. Ivakin
Applied Physics Laboratory,
College of Ocean and Fishery Sciences, University of Washington,
1013 NE 40th Street, Seattle, Washington 98105
phone: (206) 616-4808, fax: (206) 543-6785, email: ivakin@apl.washington.edu

Award Number: N00014-01-G-0460/37

LONG-TERM GOALS

The long-term goal of this research is to develop an upgradable package of bottom reverberation codes based on up-to-date understanding the physics and mechanisms of sound-seabed interaction.

OBJECTIVES

The short-term scientific objective of this project was to develop a prototype or a first version for a package of bottom reverberation codes which would be practical, self-consistent, and based on up-to-date understanding the physics of seabed acoustic scattering. It assumes that the codes will be tested by practical use, particularly by including in analysis of bottom reverberation measured at recent sediment acoustics experiments in shallow water (SAX04). Another possibility for testing the codes would be their use in processing the sediment scattering data obtained in laboratory conditions (LMA-CNRS, France). The self-consistency and practicality assume also that the codes would be able to take into account general characteristics of acoustic systems used in practice, such as their directivity and frequency bandwidth (for both narrow- and broad-band systems), and would use practically measurable environmental inputs. The package would represent a foundation for development of an up-to-date, physics based, upgradable interface between a practically measured echo signal, or reverberation time series, and seabed geoacoustic and geotechnical parameters, such as the sediment density, sound speed, attenuation, grain size and others.

APPROACH

The package of bottom reverberation codes, for brevity BOREC, consists of two major blocks. First one, BOREC/1, provides a relationship of seabed environmental inputs and frequency-angular dependence of the bottom scattering strength. It is based on certain assumptions of seabed scattering mechanisms, such as bottom roughness, sediment heterogeneity (continuous and/or discrete), etc. Therefore, it includes a number of codes corresponding to various mechanisms of seabed scattering. This block can be upgraded by adding new codes based on up-to-date modeling results appearing in sediment scattering physics. The block itself represents a reversible interface. This means that it can be used in both forward and inverse problems: for prediction of the scattering strength once the sediment properties are known, and for inversion of the sediment parameters if the scattering strength is known and a mechanism of scattering is identified.

The second block of the package, BOREC/2, provides a relationship of the bottom scattering strength and practically measured acoustic system response, such as time series of the reverberation signal. It consists of codes taking into account general characteristics of acoustic systems, such as their directivity and frequency bandwidth (for both narrow- and broad-band systems) and corresponding processing algorithms relevant to specific systems. This block is also reversible. In the forward problem, this means that once the scattering strength is known as a function of frequency and angles of incidence, given characteristics of used acoustic system, the bottom reverberation statistical prediction can be made, e.g., the reverberation intensity can be predicted as a function of time, frequency and direction. In the inverse problem, this means that the codes take into account up-to-date processing algorithms for inversion of the scattering strength from measurements of bottom reverberation using various acoustic systems and various types of the primary signals.

In the frame of an ONR-OA project [1], a model of discrete scattering in marine sediments, the "inclusion scattering" model, has been developed. This model has been demonstrated as a good descriptor of seabed backscattering measured at SAX99 [2]. The model considers discrete scatterers larger than mean grain size, such as coarse sand particles, gravel, shells, shelled animals, etc., as inclusions embedded in a fluid half-space with effective parameters, density, sound speed and attenuation, corresponding to various types of sediments. The model provides a relationship between the sediment grain size distribution, which is a common characteristic of the sediment environmental description, and the bottom scattering strength. Therefore, the model input and output parameters are consistent with both acoustic and environmental data sets obtained at recent sediment acoustics experiments SAX99/SAX04, and this model can be chosen as a base for a reversible interface in the first block of the bottom reverberation codes developed in this project, BOREC/1.

Recent modeling shows that most informative analysis of acoustic scattering from the seabed assumes that scattering data are obtained in a wide range of frequencies [2,3]. Using broad-band transducers can provide such a possibility. However, traditional narrow-band approaches for extraction of fundamental scattering characteristics, such as the bottom scattering strength, from measured echo time series (described, e.g., in [4], ch.G.2) need some modifications to be applicable for broad-band transducers. With such modifications, upon their incorporating in the second block of the package, BOREC/2, it would become possible to develop a practical tool for processing and analysis of scattering data and extracting the bottom scattering strength from measurements made by systems with an arbitrary frequency bandwidth, narrow-band and/or broad-band.

WORK COMPLETED AND RESULTS

Initially, the first block of the program, BOREC/1, was developed. It represents a modified and systemized version of MATLAB codes used previouly for analysis of the SAX99 sediment scattering data [2]. Then it was incorporated in analysis of recent sediment acoustics experiments in shallow water environment, SAX04, and its capabilities to serve as an interface between acoustic measurements and environmental parameters were tested. Details of this testing will be presented in future publications. In short, the testing procedure can be described as follows [3].

The acoustic experiments at SAX04 were accompanied by extensive measurements of the sediment properties. For example, the sediment density, sound speed and attenuation measured at the SAX04 experiment provided a base for description of acoustic penetration and propagation in the sediment used in the "inclusion scattering" model. To provide other necessary inputs to the model and ground truth for the model/data comparisons, in the frame of another ONR project [5], we analyzed 13 sediment samples taken at the SAX04 site (provided by M. Richardson of NRL). The two visually different classes of grains, sand particles and shells (mostly shell hash), were segregated from each other and analyzed separately. A general result of this analysis is that shells can be considered as a separate mode in the size distribution dominating at the large grain sizes (larger than about 2 mm), or as a sparse suspension of non-spherical inclusions in the more homogeneous and uniform substrate of densely packed, more round and smaller sand particles.

The non-spherical shape of shell particles was considered using a simple modification of the previously published version of the "inclusion scattering" model [2]. It was assumed that the intensity of scattering from non-spherical particles, after incoherent averaging over their possible orientations, can be approximated by that for spherical particles with the same equivalent radius. With this modification, the obtained sediment particle size distributions were used as inputs to this model to provide comparison with the SAX04 multi-frequency acoustic backscatter data.

The seabed reverberation data were provided by K.Williams of APL (to be published) in the form of frequency-angular dependencies of the backscattering strength. Using BOREC/1, it was shown that the "inclusion scattering" model is capable of providing a reasonable interpretation of the data [3]. For example, the frequency dependence has two different slopes at low and high frequencies (bi-power law dependence). The analysis has shown that such dependence can be explained if the sediment grain size distribution for coarse fractions follows also the bi-power law dependence. Considering the two power exponents and the level of the size distribution as free parameters, the difference between measured and calculated backscatter was minimized. The corresponding values of the inverted parameters were used in a bi-power law estimate for the grain size distribution function. The result of such acoustic data inversion was compared with the ground truth data (independently measured grain size distributions) and a qualitative agreement was obtained. Therefore, BOREC/1 was successfully incorporated into analysis of SAX04 seabed reverberation data, the data processing and inversion for the sediment properties.

Testing the second block of the program, BOREC/2, was conducted in the frame of another ONR-OA project [6]. The details and results of these tests are described in the paper submitted for publication [7]. A copy of the paper is attached. In short, the testing procedure can be described as follows. Experiments on high frequency broad band scattering from water saturated sandy sediments were conducted (in collaboration with J.-P. Sessarego) at the water tank facility of the Laboratory of Mechanics and Acoustics of the National Center of Scientific Research (LMA-CNRS), Marseille, France. To be applicable to analysis of broad-band measurements, traditional narrow-band approaches for extraction of the the bottom scattering strength from measured echo time series (described, e.g., in [4]) have to be modified. Such modifications were developed in this project and taken into account in BOREC/2.

With these modifications, BOREC/2 was applied to the data processing and analysis for extracting the bottom scattering strength from broad band reverberation measurements. The tests have shown that the result of such extracting is indeed the scattering strength, a quantity independent from the acoustic system characteristics such as the form of the radiated signal (or its frequency spectrum) and the directivity (which for broad band sources is different for different frequencies), as well as from parameters of used processing algorithms (such as time-window width). A scaling analysis has proved that the extracted scattering strength is defined only by intrinsic properties of the sediment and particularly its granular structure (the mean grain size / wavelength ratio). Therefore, BOREC/2 was successfully incorporated into analysis of broad band reverberation data, the data processing and inversion for the sediment fundamental physical quantity, the scattering strength.

It can be concluded that the short-term objectives of this project have been achieved and the work has been accomplished. Specifically, a prototype or a first version for a package of bottom reverberation codes, BOREC, has been developed based on up-to-date physics of seabed scattering. The package has been successfully tested by practical use, particularly by including in analysis of scattering data obtained at recent sediment acoustics experiments in shallow water environment (SAX04), as well as those obtained in laboratory conditions (LMA-CNRS, France). The package takes into account general characteristics of used acoustic systems, such as their directivity and frequency band width (for both narrow- and broad-band systems), and uses practically measurable environmental inputs. Therefore, this package can be considered as a foundation for development of an up-to-date physics based interface between acoustic response of the system and seabed geoacoustic and geotechnical parameters. The package is self-consistent, practical and easy to upgrade using other results of seabed scattering modeling (see, e.g., [8-11]).

IMPACT/APPLICATIONS

This research will contribute to development of an improved tool for acoustic sensing of marine environment. The results of this work are used currently for the SAX04 data analysis funded by ONR-OA. These results are proposed for use also in analysis of acoustic and environmental data in future experiments and for further development of remote sensing techniques. In particular, these results can provide a base for modifications of inversion technique using angular dependencies of seabed scattering (obtained, e.g., with multi-beam sonar). Such a technique can be used in the follow-on analysis for the Ripple DRI 2007 Martha's Vineyard field experiment sponsored by ONR-CG, where a wide angular range, from shallow grazing angles to near normal incidence, will be used.

TRANSITIONS

The codes developed in this project can contribute to other research projects considering bottom reverberation, its processing, prediction and inversions for seabed properties. In particular, it can be considered as a possible supplement to GABIM and related Navy sponsored programs, which currently do not represent a complete consideration of all the major mechanisms of seabed reverberation. For example, they do not take into account the mechanism of discrete scattering in marine sediments, described by the "inclusion scattering" model used in this project.

RELATED PROJECTS

This research is closely related to projects providing environmental and acoustic data analysis and modeling for the ONR-OA SAX04 and ONR-CG Ripple DRI programs. Also, this research is related to the PI's project "High Frequency Scattering from Water Saturated Sandy Sediments: Laboratory Study" currently funded by ONR, Ocean Acoustics. This work was conducted in collaboration with investigators at the APL-UW, NRL and CNRS-Marseille (Drs. K. Williams, M. Richardson, J.-P. Sessarego, and others).

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