

ACOUSTIC SCATTERING MODELS OF ZOOPLANKTON AND MICROSTRUCTURE

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LONG TERM GOALS

To understand the acoustic reverberation properties of zooplankton and microstructure. The results will lead to improved capability in 1) predicting sonar performance and 2) use of sonars in the mapping of the zooplankton and microstructure.

OBJECTIVES

To understand the physics of the scattering by naturally occurring (complex) bodies so that realistic acoustic scattering models of zooplankton and microstructure can be developed.

APPROACH

The research is a balance of theoretical analysis, numerical simulations, and experimentation in the laboratory and local waters at WHOI. The theories are approximate and have included various ray, volume integration, and modal-series-based solutions. An acoustic pulse-echo laboratory is used to collect backscatter data off of the animals and turbulence over a wide range of acoustic frequencies (24 kHz to 1 MHz) and all angles of orientation (0 to 360 degrees in 1-degree steps). A high performance towed platform (BIOMAPER-II) is used to simultaneously collect acoustic backscatter data (transducers at five frequencies (43 kHz to 1 MHz) looking up and down), video data, and environmental data (temperature, etc.).

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WORK COMPLETED

A number of major tasks were completed this year involving various parallel efforts of theoretical, laboratory, and field work.

1) PUBLICATIONS. In FY96, two peer-reviewed papers appeared in print, four peer-reviewed papers previously submitted were revised and resubmitted (three of the four are in press at the end of the fiscal year), four new papers were submitted for peer-reviewed journals (three of which were accepted by the end of the fiscal year), and three more manuscripts were in draft stage at the end of the fiscal year. One conference proceedings was also published this year. 2) ACOUSTIC SCATTERING MODELING. A model was developed to describe the scattering of sound by elongated organisms near end-on incidence. The model takes into account volume heterogeneities and boundary roughness. 3) ECHO CLASSIFICATION MODELING. Several approaches were developed in order to classify the echoes in terms of probability of scatterer type and orientation. 4) DATA ANALYSIS. Various scattering models, pulse compression, and classification algorithms were compared with laboratory data involving zooplankton from several different anatomical groups (fluid-like (euphausiids), elastic shelled (gastropods), and gas-bearing (siphonophores)). 5) LABORATORY EXPERIMENTATION: ZOOPLANKTON. An extensive set of laboratory measurements on the acoustic backscatter by shelled animals was completed. A type of local benthic snail that is morphologically similar to certain abundant pelagic snails was used so that the data set could provide insight into acoustic scattering by the seafloor when populated by beds of certain shelled bodies as well as scattering by the water column when populated by the swimming shelled snails. The experiments were conducted with a wide range of acoustic frequencies (24 kHz to 1 MHz), angle of orientation (0 to 360 degrees in 1-degree increments), and animal size (six sizes). All combinations of frequencies and orientations were performed for one animal while subsets of the above frequencies were performed for the other animals. 6) LABORATORY EXPERIMENTATION: TURBULENCE. An extensive set of measurements was conducted in a 17-m-long flume at WHOI in which the water flowed over a sand-covered bottom. After sand ripples had formed, the measurements were conducted over a wide range of flow rates. Acoustic echoes at 420 kHz were collected over the full range of flow rates. Many pings per flow rate were collected so that statistics of the echoes could be analyzed. The turbulent field was characterized for each flow rate with both laser and acoustic velocimeters. Temperature microstructure was also measured with a high speed probe. 7) TEST AND EVALUATION CRUISE OF THE BIOMAPER-II SYSTEM. The test and evaluation cruise was conducted in July, 1997 in the Gulf of Maine. Hardware and software involving the various sensors (acoustics, video plankton recorder, environmental) and associated data acquisition, recording, and display were tested. In addition, the tow characteristics, tow-yo capability, and deployment/retrieval procedures were evaluated.

RESULTS

MODELING. In previous models of the elongated bodies, boundary roughness and volume inhomogeneities of the individual scatterers were not taken into account and the scattering predictions were roughly 20 dB lower than observed. By taking into account the roughness of the outer boundary and inhomogeneities of the material properties, the predictions for at and near

end-on incidence scattering raised significantly up to the observed levels. This new understanding, coupled with our previous understanding of the scattering for near broadside incidence, has resulted in a formulation that is usable over all angles of incidence.

CLASSIFICATION. Application of the physics-based classification approach as well as the empirical classification approaches to the scattering data have shown that it is feasible to classify animals acoustically according to their gross anatomical features (fluid-like versus gas-bearing versus elastic shelled). The classification schemes take advantage of the differences in scattering behavior of the different animal types. The studies also showed the range of limitations (ambiguities) of the approaches as a function of animal type, approach type, and behavioral conditions.

LABORATORY EXPERIMENTATION. The zooplankton experiments demonstrated that the scattering by the shelled bodies is a complex function of animal size and orientation, as well as acoustic frequency. There is evidence of different types of waves (direct echoes from front interface and back interface (when the opercular opening is facing the transducer), as well as circumferential waves) that give rise to the strong structure (peaks and deep nulls) in the plots of target strength versus frequency. The turbulence experiments showed there to be direct correlation between acoustic backscatter levels and flow rate. Since the degree of turbulence is a function of flow rate, there is a correlation between the acoustic backscatter levels and turbulence.

TEST AND EVALUATION CRUISE OF THE BIOMAPER-II. The results of the cruise indicate that the BIOMAPER-II hardware will be able to provide very high quality data (for example, low noise electronics in the echo sounders) and that the system can be made operational through improvements in the software by the vendor. This conclusion was verified after subsequent modification of the software and a very successful science cruise in the Gulf of Maine in October, 1997.

IMPACT

The impact from these results is two-fold: 1) Through development of these models, as motivated by the zooplankton and microstructure applications, we have formulated analytical and experimental approaches for the description of the scattering of sound by bodies with complex shapes and material property compositions. The approaches are applicable to a wide range of body types (beyond the specific cases of zooplankton and microstructure). In addition to the successful application to zooplankton and microstructure they have, for example, been successfully applied to irregular metallic structures. 2) The development of these scattering models has improved the accuracy of interpretation of acoustic surveys of zooplankton and microstructure as discussed in the papers published this year.

TRANSITIONS

1) Some of our acoustic scattering models have already been used by NUWC/Newport for performance predictions of one of their high frequency acoustics systems. 2) In addition, we have identified two types of zooplankton (siphonophores and pteropods) that have high enough target strengths and occur in sufficiently high numbers that they could interfere with the performance of certain high frequency acoustics systems. By use of our zooplankton scattering models, we have already provided a plausible explanation for some anomalous ("false target") returns in MK48 ADCAP torpedo reverberation data collected by NUWC/Newport that could

not be explained by predictions of scattering by the seafloor or sea surface. 3) We have recently conducted high frequency acoustic and video surveys of the Gulf of Maine and observed high concentrations of the gas-bearing animals. The upcoming analysis will give us information on the target strengths of these animals *at depth* which will help simulation personnel in the Navy make better predictions of sonar performance. 4) We have observed a strong resonance-like feature in the scattering by one size class of benthic elastic shelled bodies at 24 kHz. Since certain regions of the seafloor are heavily populated by shelled bodies, this information will be useful to Navy sonar performance modelers for reverberation predictions.

RELATED PROJECTS

1) We have applied experimental methods and scattering models developed as well as equipment purchased under this grant toward at-sea laboratory experiments funded by NSF grant OCE-9201264. 2) We have applied some of the scattering models developed under this grant to help in interpreting acoustic survey data collected over the Georges Bank (a shallow water coastal region). The data were collected under NOAA grant NA16RC0515 as part of the US GLOBEC program.

REFERENCES

DEVELOPMENT OF ACOUSTIC SCATTERING MODELS AND APPLICATIONS TO LABORATORY DATA

- 1) Stanton, T.K., D. Chu, P.H. Wiebe, L. Martin and R.L. Eastwood (in press). "Sound Scattering by Several Zooplankton Groups I: Experimental Determination of Dominant Scattering Mechanisms," J. Acoust. Soc. Am.
- 2) Stanton, T.K., D. Chu, and P.H. Wiebe (in press). "Sound Scattering by Several Zooplankton Groups II: Scattering Models," J. Acoust. Soc. Am.
- 3) Stanton, T.K., P.H. Wiebe, and D. Chu (in press). "Differences Between Sound Scattering by Weakly Scattering Spheres and Finite Length Cylinders with Applications to Sound Scattering by Zooplankton," J. Acoust. Soc. Am.
- 4) Monger, B.C., S. Chinniah-Chandy, E. Meir, S. Billings, C.H. Green, and P.H. Wiebe (accepted). "Sound Scattering by the Gelatinous Zooplankters *Aequorea victoria* and *Pleurobrachia bachei*," Deep Sea Res.
- 5) McGehee, D.E., R.L. O'Driscoll, and L.V. Martin Traykovski (accepted). "Effects of Orientation on Acoustic Scattering from Antarctic Krill at 120 kHz," Deep Sea Res.
- 6) Chu, D., and T.K. Stanton (submitted). "Application of Pulse Compression Techniques to Broadband Acoustic Scattering by Live Individual Zooplankton," J. Acoust. Soc. Am.

APPLICATION OF SCATTERING MODELS TO HIGH FREQUENCY ACOUSTIC SURVEYS AND OTHER IN SITU STUDIES

- 7) Wiebe, P.H., D.G. Mountain, T.K. Stanton, C.H. Greene, G. Lough, S. Kaartvedt, J. Dawson, and N. Copley (1996). "Acoustical Study of the Spatial Distribution of Plankton on Georges Bank and the Relationship Between Volume Backscattering Strength and the Taxonomic Composition of the Plankton," *Deep-Sea Research II*, 43, 1971-2001.
- 8) Wiebe, P.H., T.K. Stanton, M. Benfield, D. Mountain, and C. Greene (1997). "High Frequency Acoustic Volume Backscattering in the Georges Bank Coastal Region and Its Interpretation Using Scattering Models," *IEEE J. Ocean. Eng.*, 22, 445-464.
- 9) Wiebe, P.H. and T.K. Stanton (1997). "High Frequency Acoustic Surveys of a Shallow Water Region and Associated Scattering Models from Naturally Occurring Complex Bodies," *Proceedings of the 1997 International Conference on Shallow Water Acoustics*, Beijing, China.
- 10) Greene, C.H., P.H. Wiebe, A.J. Pershing, G. Gal, J.M. Popp, N.J. Copley, T.C. Austin, A.M. Bradley, R.G. Goldsborough, J. Dawson, R. Hendershott, and S. Kaartvedt (accepted). "Assessing the Distribution and Abundance of Zooplankton: A Comparison of Acoustic and Net-Sampling Methods with D-BAD MOCNESS," *Deep Sea Res.*
- 11) Benfield, M.C., P.H. Wiebe, T.K. Stanton, C.S. Davis, S.M. Gallagher, and C.H. Greene (submitted). "Estimating the Spatial Distribution of Zooplankton Biomass by Combining Video Plankton Recorder and Single-Frequency Acoustic Data," *Deep Sea Res.*