Acoustic Scattering Classification of Zooplankton and Microstructure

Timothy K. Stanton
Applied Ocean Physics and Engineering Department
Woods Hole Oceanographic Institution
Bigelow 201, MS #11
Woods Hole, MA 02543
phone: (508) 289-2757 fax: (508) 457-2194 email: tstanton@whoi.edu

Peter H. Wiebe
Department of Biology
Woods Hole Oceanographic Institution
Redfield 2-26, MS #33
Woods Hole, MA 02543
phone: (508) 289-2313 fax: (508) 457-2134 email: pwiebe@whoi.edu

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http://www.oal.whoi.edu/tstanton

LONG-TERM GOALS

To understand the acoustic reverberation properties of zooplankton and microstructure. This new understanding 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 or processes. Realistic acoustic scattering models of zooplankton and microstructure will be developed and applied to high-frequency acoustic surveys.

APPROACH

The research program has been a combination of theoretical analysis, numerical simulations, and experimentation in the laboratory and waters near WHOI. The acoustic scattering 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 with animals over a wide range of acoustic frequencies (24 kHz - 1 MHz) and all angles of orientation (0 to 360 degrees in 1-degree steps). The system is also used in a more limited capacity (fewer frequencies, no variations of orientation) to measure scattering by microstructure. A high performance towed platform (BIOMAPER-II) is used to simultaneously collect acoustic backscatter data (transducers at five frequencies spanning the range of 43 kHz to 1 MHz and looking both up and down), video data, and environmental data temperature, etc. Tim Stanton has led the laboratory measurements and the development and application of scattering models while Peter Wiebe leads the field surveys and interpretation. Dezhang Chu has also played a key role in the laboratory and modeling work while Joe Warren and Andone Lavery have played key roles in the surveys and classification.

WORK COMPLETED

A number of major tasks were completed this year involving various parallel efforts focused principally on a scattering-model-based classification of our high-frequency acoustics survey data.

1) PUBLICATIONS. In FY02, two journal articles and two proceedings papers appeared in print, two previously submitted papers have been accepted and/or are now in press, and three new papers were submitted. Also, our book that was accepted in a previous year is near completion with publication expected for next year.

2) ANALYSIS OF BIOMAPER-II CRUISE DATA. This year, our effort focused on interpreting the data from three study areas in the Gulf of Maine in terms of the biology and microstructure present. Interpretation relied on data processed in the previous year involving a combination of high frequency acoustic echo data, video plankton recorder data, and environment data, all collected simultaneously using the BIOMAPER-II system in the Gulf of Maine. MOCNESS net sample data were also a major part of the analysis. In each of the three areas, the proportions with which the scattering resulting from microstructure and each of the various anatomical groups of animals have been estimated. Inferences have been made from each of the three areas of important biological and physical parameters and correlations made between the presence of the various types of organisms relative to the spatial variability of the environment.

RESULTS

Through our analysis detailed below, we have determined the spatial variability of various dominant scatterers over a broad scale, at high resolution, and in relation to their environment. We have found that, depending on the study area and depth within the water column, different scatterers will dominant the scattering. Although there was a strong correlation between the presence of organisms and the environment (such as the thermocline), the bio-physical relationship varied between sites and was a function of organism type.

1) *DISCRIMINATING BETWEEN SCATTERING BY ZOOPLANKTON AND MICROSTRUCTURE.* We have found that in the three study areas in the Gulf of Maine region, the zooplankton appeared to have dominated the scattering throughout the water column in each of the areas except for the upper water column in one of the areas. In this latter section of data, the environmental data showed much variability in the water density due to overturning while the organisms caught in the net tows could not account for the acoustic scattering. To within the limitations of the instrumentation and scattering models used, the scattering in the upper water column is consistent with that due to turbulent temperature microstructure.

2) *QUANTIFYING SCATTERING BY ZOOPLANKTON AND MICROSTRUCTURE.* After determining the most significant sources of scattering in each of the three study areas, we have produced 2-D maps of zooplankton size, numerical density of the zooplankton, and dissipation rate of the turbulent kinetic energy. In the sections of the water column where the zooplankton dominated the scattering, different organisms dominated the scattering in different areas. In some cases, siphonophores dominated the scattering; in other cases, euphausiids were the dominant scatterers; and

in another area, it was a combination of organisms (such as euphausiids and pteropods) that contributed the most to the scattering.

3) *QUANTIFYING DISTRIBUTIONS OF SIPHONULAE*. As reported above and in last year's report, we have discovered a significant presence of siphonulae (juvenile form of siphonophores) through the use of BIOMAPER-II acoustics and video systems. Because of their fragility, these organisms are significantly under-registered through conventional net-capture means. Our analysis has determined that these organisms reside at significantly different depths than the majority of the other organisms (by both biomass and abundance) (Fig. 1).

IMPACT/APPLICATIONS

The impact and applications of these results are significant:

1) In early studies involving use of acoustics to study the presence of marine life, the acoustic echo was assumed to be due solely to the organisms and furthermore, to monotonically increase with biomass. Our studies have shown that not only do the echoes not necessarily increase with biomass, but there are conditions under which the echoes could be attributable principally to microstructure. These studies are therefore making impact on the community through development and use of advanced quantitative methodology.

2) Through the use of the advanced instrument platform BIOMAPER-II and supporting acoustic scattering models that we have developed, we have determined the spatial variability of the various dominant sound scatterers as well as the varying degree to which their distribution is correlated with the physical environment. The understanding of biological and physical processes and their inter-relationship has therefore been advanced.

3) A particular noteworthy result has been our determination of the distribution of siphonulae through use of the BIOMAPER-II system. This organism has been grossly under-reported in the past due to their fragility and we have demonstrated a viable means, through the combined use of the BIOMAPER-II system and scattering models, for studying the organism.

TRANSITIONS

1) Numerous laboratories outside WHOI have been applying the models developed in this project (or derivatives of the models) to assess marine life. For example, in this past year, papers have been submitted or presentations given by Dr. Mark Trevorrow (Defense Research and Development, Canada), Dr. David Demer (Southwest Fisheries Science Center, US), and Dr. Gustavo Colombo (INIDEP, Argentina) that use our models or derivatives of them.

2) Some of our acoustic scattering models have been used in the past by NUWC/Newport in sonar performance predictions in their development of the standoff system, which remains operational.

3) Although this is not a new transition, it is one that has been recently brought to our attention: The early acoustic scattering models involving scattering by finite cylinders were applied by personnel at Navy laboratories to describe the acoustic scattering in the near-field by submarines. The references are:

"The development and validation of a sound field separation technique; A requirement for holographic processing of near-field scattering measurements", by Dr. F.D. Groutage, Naval Surface Warfare Center (NSWC), Carderock Division, DET Puget Sound, Mr. J.D. Schempp, NSWC, Carderock Division, DET Puget Sound, Mr. E.W. Swenson, West Sound Associates, Inc., SADP-U93/00025-1910 January 1993, UNCLASSIFIED.

"Near-field target strength system acoustic field separation risk assessments: Separation of acoustic fields" Final Report, Dec. 17, 1992, and Appendices dated Dec. 23, 1992, West Sound Associates Technical Report, by E.W. Swenson and G.F. Denny.

RELATED PROJECTS

We have recently applied our laboratory, signal processing, and scattering methods to three other projects: 1) Measurements and modeling of acoustic scattering by fish (funded by another grant by ONR and NOAA). 2) Measurements and modeling of acoustic scattering by benthic shelled animals (funded by another grant by ONR). 3) Measurements of biotechnical properties (sound speed and mass density) of various zooplankton (funded through a private grant and NSF).

PUBLICATIONS

Benfield, M.C., A. Lavery, P.H. Wiebe, C.H. Greene, T.K. Stanton, and N. Copley (submitted), "Distributions of physonect siphonulae in the Gulf of Maine and their potential as important sources of acoustic scattering," J. Limnol. Oceanogr.

Foote, K.G. and T.K. Stanton (accepted), Observing Aquatic Organisms by Sound and Light, Springer-Verlag.

Lavery, A.C., T.K. Stanton, D.E. McGehee, and D. Chu (2002), "Three-dimensional modeling of acoustic backscattering from fluid-like zooplankton," J. Acoust. Soc. Am. 111, 1197-1210.

Lavery, A.C., T.K. Stanton, and P.H. Wiebe (2002), "Variability in high frequency acoustic backscattering in the water column," in Proceedings of Conference on Impact of Littoral Environmental Variability on Acoustic Predictions and Sonar Performance (Ed. N.G. Pace and F.B. Jensen, Kluwer Academic Publishers) 63-70.

Lavery, A.C., T.K. Stanton (2002), "Acoustic scattering models of zooplankton," Bioacoustics 12 (2/3), 268-270.

Lavery, A.C., R.W. Schmitt, and T.K. Stanton (submitted), "High-frequency acoustic scattering from turbulent oceanic microstructure: the importance of density fluctuations," J. Acoust. Soc. Am.

Warren, J.D., T.K. Stanton, D.E. McGehee, and D. Chu (2002), "Influence of animal behavior on acoustic estimates of zooplankton properties," IEEE J. Ocean Eng. 27, 130-138.

Warren, J.D., T.K. Stanton, P.H. Wiebe, and H.E. Seim (submitted), "Inference of biological and physical parameters in an internal wave using multiple frequency acoustic scattering data," ICES J. Mar. Sci.

Wiebe, P.H., T.K. Stanton, C.H. Greene, M.C. Benfield, H.M. Sosik, T. Austin, J.D. Warren, and T. Hammar (in press), "Biomapper-II: An integrated instrument platform for coupled biological and physical measurements in coastal and oceanic regimes," IEEE J. Ocean. Eng.

Wiebe, P.H. and M.C. Benfield (in press), "From the Hensen Net toward 4D biological oceanography," Progress in Oceanography.

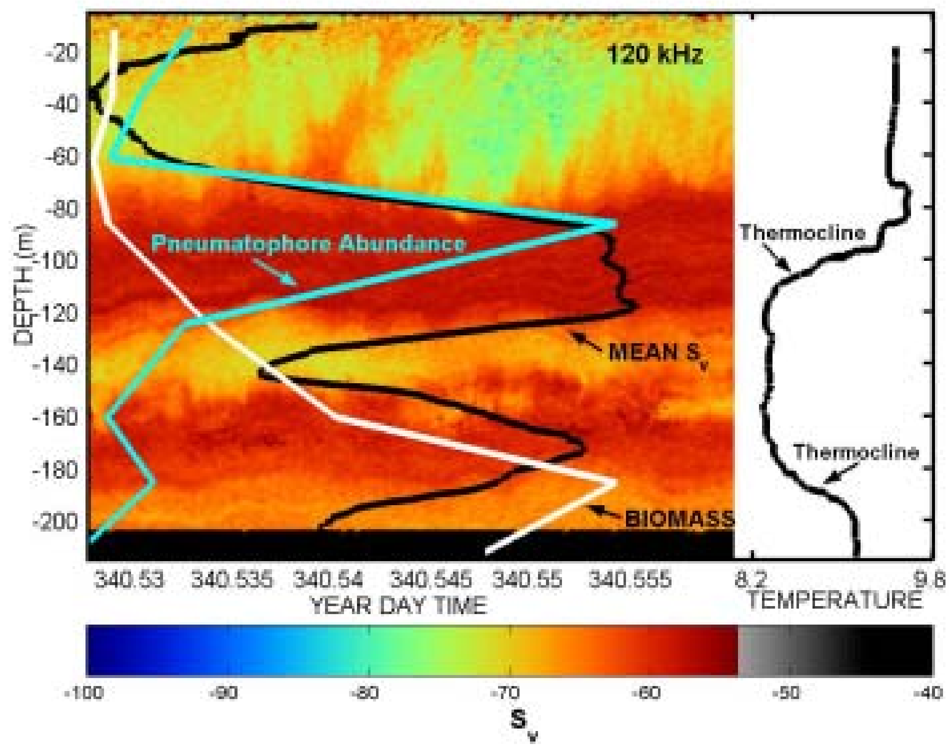

Figure 1. Comparison between acoustic scattering strength, total biomass, siphonophore abundance, and water temperature, throughout the water column in a one-hour section of a transect in Jordan Basin in the Gulf of Maine. Siphonophores are zooplankton that contain a gas inclusion or pneumatophore. The 120 kHz acoustic data (Sv) is shown in color contour or echogram form with its mean value superimposed. The plot shows two scattering layers located at or just above the thermoclines with similar scattering levels. Analysis of the frequency dependence of the scattering (through use of several of the BIOMAPER-II acoustic channels) in combination with scattering models, video plankton recorder (VPR) data, and MOCNESS net tow data indicates that both of the scattering layers at this location are associated with the presence of zooplankton with an almost negligible contribution from microstructure. The VPR and MOCNESS systems provided information on taxa, size, and orientation for various points in the water column in this area, while the additional information from multi-frequency acoustic systems in combination with scattering models provided information on the dominant scatterers and size over much more of the water column.

A particularly striking result is that, although the majority of the biomass resides in the lower scattering layer near the lower thermocline, the siphonophores principally reside in the upper layer near the upper thermocline. Because of their gas inclusion, these organisms produce significant levels of scattering in the upper layer, resulting in an appearance of similar biomass in the two layers in this single frequency plot. Because of their fragility, these organisms normally are grossly under-recorded in traditional sampling systems (nets typically destroy their tissue). However, with the combined use of scattering models with data from the multi-frequency acoustic, MOCNESS, and VPR systems, these organisms were detected and sized, and their spatial distribution correlated with the environment.