Advanced Multi-Frequency Inversion Methods for Classifying Acoustic Scatterers

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Contract Number: N00014-00-D-0122, Award Number: N00014-01-1-0305
http://zooplankton.lsu.edu/scattering_models/MultifreqInverseMethods.html

LONG-TERM GOALS

The goals of this study are to develop species- and life-stage-specific acoustic scattering models based on morphologically-accurate digitizations of preserved or live-imaged zooplankton from coastal waters. These models will estimate scattering strength as a function of acoustical frequency, animal size, taxon, and orientation relative to the incidence angle. These predictions will improve our ability to estimate animal abundances by taxon/morphological class via inversion.

OBJECTIVES

1) Develop lists of commonly occurring zooplankton species and life-stages as functions of the time of year for the Georges Bank/Gulf of Maine and the northern Gulf of Mexico;
2) Obtain representative images of taxa from the species lists using data from the Video Plankton Recorder, other video sources, photos of living and dead specimens, and scientific illustrations;
3) Develop acoustic scattering models based on digitized image; and
4) Provide methodology and model data to the oceanographic community via the world-wide-web.

APPROACH

Acoustical scattering models of zooplankton have generally been developed by modeling target taxa as relatively simple geometric shapes. As our understanding of scattering models has improved, there has been a progression towards the use of higher resolution, more anatomically correct scattering models (e.g. Stanton and Chu, 2000). Our approach follows this direction and we are attempting to develop models of scattering derived from digitizations of actual zooplankton shapes. These shapes will be derived from both *in situ* video images and preserved samples. One of the advantages of this approach is that orientation data can frequently be derived from *in situ* images of plankton (e.g. Benfield *et al*. 2000). Knowledge of the orientations of zooplankton may be critical in predicting scattering because the target strength can vary substantially depending upon the angle of incidence of the acoustic wave relative to the orientation of the animal.

This is a collaborative project between LSU and BAE SYSTEMS. LSU is collecting the various images of zooplankton and developing lists of dominant taxa by season for our study areas while BAE SYSTEMS and LSU are digitizing the images and developing the scattering models.

At the inception of this project we planned to use VPR data from the Gulf of Maine/Georges Bank region collected during cruises undertaken during October 1997; October and December 1998; and October and December 1999. We selected these data because these cruises contained concurrent, VPR and multi-frequency acoustic data collected by the BIOMAPER II vehicle, punctuated by MOCNESS samples. Data from the Gulf of Mexico included 1m^2 net samples collected in the summer of 2000 approximately 50 km SW of the Mississippi River along with SEAMAP zooplankton records. The latter were to be used to estimate seasonal periodicity.

WORK COMPLETED

We have assembled large numbers of potentially suitable VPR images of a variety of zooplankton taxa. The majority of these were digitized directly from videotape recorded during cruise EN331 during December 1999. These images were evaluated by McGehee at BAE SYSTEMS who concluded that the images lacked sufficient detail to use as a basis for digitization of morphologically accurate silhouettes. While the VPR dataset will provide essential data on *in vivo* orientation, we turned to preserved samples of zooplankton collected with the 1m^2 MOCNESS for higher resolution morphological data. Dr. Peter Wiebe at Woods Hole Oceanographic Institution has begun digitizing silhouette photographs (Ortner *et al*. 1979) of zooplankton collected in our study area. These high-resolution (1200 dpi) images appear well suited for development of morphological silhouettes. Even small copepods contain sufficient detail to resolve their shapes. We have completed digitization of a variety of copepod taxa from silhouette or other microscope-derived images. A very high resolution, large format scanner at LSU has been adapted to scan samples of zooplankton collected in the Gulf of Mexico so that they can be digitized in the same manner as the Gulf of Maine samples.

The digitized images of copepods have been used to develop models of acoustical scattering based on the DWBA model (Stanton *et al*. 1998) as a function of size, orientation, and acoustical frequency. The methodology used to create the models, example data, and results have been published in a publicly accessible website that allows users to view images and data of scattering models for taxa we have analyzed. In addition, the site allows users to create their own scattering models for taxa and sizes that may be of particular interest. In the future, models created by users will be incorporated into the site database. The URL is: http://zooplankton.lsu.edu/scattering_models/MultifreqInverseMethods.html.

RESULTS

Images of zooplankton derived from VPR surveys generally lacked sufficient detail to provide useful digitizations of zooplankton from which to derive scattering models. The reason appears to be the relatively low resolution of the VPR images (72 dpi). Nevertheless, these images have value because they provide essential information on typical orientations and postures of live zooplankton. High-resolution scans of preserved zooplankton provide sufficient detail to create scattering models. In addition, an atlas of marine and estuarine zooplankton from the Gulf of Maine (Gerber, 2000) has just been published and it contains detailed line drawings of many of the taxa of interest in this study and has been used to supplement the silhouette-based models. We have completed the analysis of the taxa summarized in Table 1. These include taxa from the Gulf of Maine/Georges Bank, the Ligurian Sea, the Gulf of Mexico, and the Southern Ocean. We continue to add taxa from these regions.

Table 1. Summary of taxa for which DWBA models have been developed.

GULF OF MAINE/ GEORGES BANK	OTHER REGIONS
Acartia tonsa	*Clausocalanus* sp. (Ligurian Sea)
Calanus finmarchicus (adult female)	*Corycaeus* sp. (Ligurian Sea)
Calanus finmarchicus (CV)	*Helectinosoma* sp. (Gulf of Mexico)
Centropages typicus	*Oithona* sp. (Ligurian Sea)
Paraeuchaeta norvegica	*Euphausia superba (Southern Ocean)*
Pseudocalanus spp.	*Lucifer faxoni*. (Gulf of Mexico)

A series of Matlab programs were used to calculate the target strength of the model at acoustical frequencies from 10 kHz to 5 MHz. At each frequency, we computed the backscattering amplitude f_{bs} , backscattering cross-section σ_{bs}, and target strength TS 10,000 times using a randomly assigned angle of incidence. This approach permits the data to be examined in a variety of ways. For example the expected value of backscattering from all angles may be presented as a function of frequency (Fig. 1). Alternately, backscattering may be determined as a function of incidence angle at any arbitrary frequency (Fig. 2).

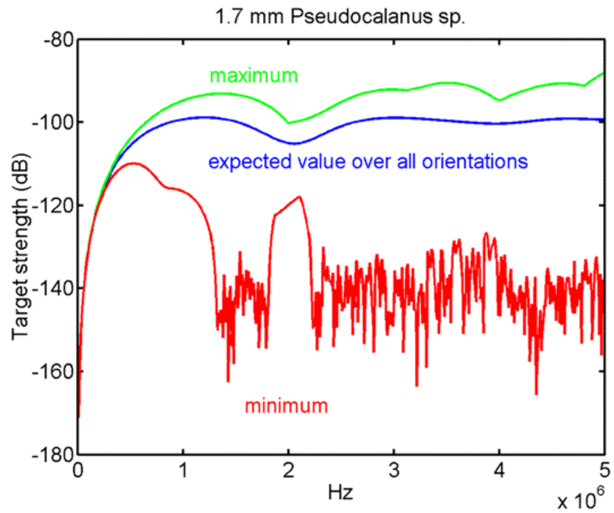

Figure 1. Acoustic target strength as a function of frequency (10 kHz steps, 0 - 5 MHz) for the DWBA model of Pseudocalanus sp. Each expected value is the average of 10,000 randomly selected angles of incidence. Maximum and minimum values are also calculated.

IMPACT/APPLICATIONS

ONR has allocated significant resources to the development of both sophisticated acoustic scattering models and multiple-frequency systems such as TAPS and BIOMAPER II. This research is a logical extension in merging those two lines of research. The long-range goal of this research is to develop a method that can be tailored to any multi-frequency or broadband acoustic system to provide real-time classification of scatterers.

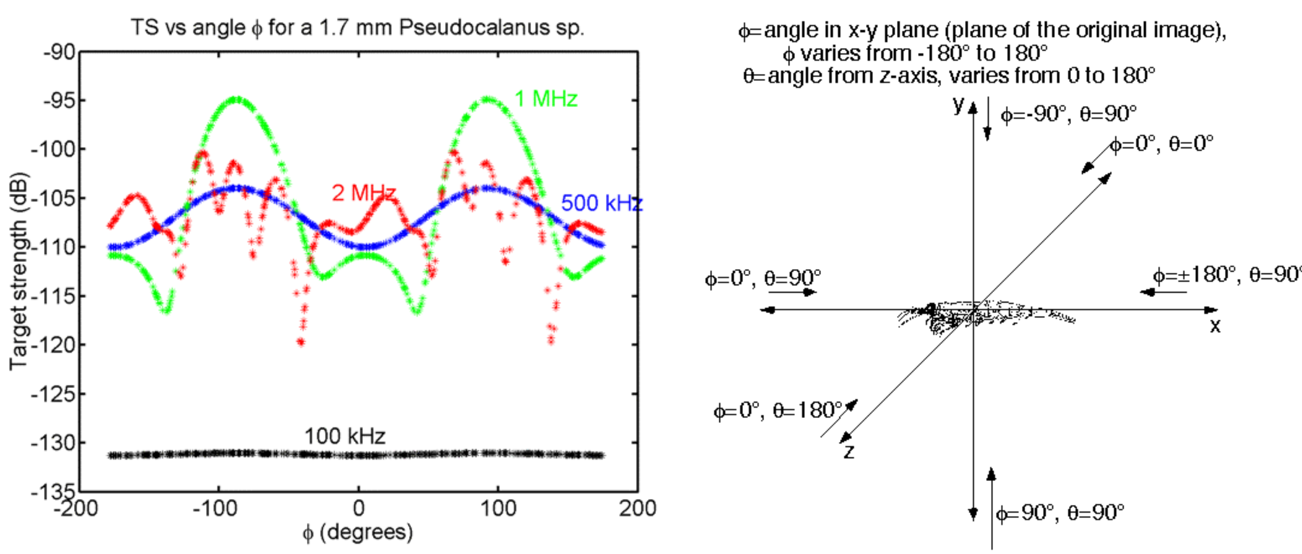

Figure 2. Acoustic target strength as a function of incidence angle at frequencies ranging from 100 kHz to 2 MHz for the DWBA model of Pseudocalanus sp.

The goal of biological oceanographers is to be able to determine: (1) what organisms are present in a given ecosystem; (2) at what abundance levels the organisms are present; (3) how they are distributed; and (4) what the factors are that control their abundances. This means we must be able to detect, count, and classify the organisms. There are currently three general ways of going about these tasks: nets and pumps, optics, and acoustics. Each of these has certain advantages and disadvantages. The present work seeks to integrate the data from acoustics and independent sampling systems to provide a better view of the distributions of animals in the oceans.

The presence, abundance and dynamics of life in the sea at all trophic levels have both direct and indirect impacts on the ability of MCM, ASW, undersea warfare, expeditionary warfare, and special operations forces to perform their missions. Zooplankton and micronekton in the water column can control the optical properties of interest through grazing on phytoplankton. They may also interfere with operational and planned Navy acoustic systems. Many zooplanktors are bioluminescent or influence the distribution and abundances of bioluminescent organisms at higher trophic levels. It has become increasingly important for the Navy to be able to know in real time what organisms are present in the water column and in what quantities. This study is aimed at directly assessing that need.

TRANSITIONS

The numerical approaches and code developed under this contract were used by Kringel *et al*. (2003) to explain acoustic scattering from layers of mysids migrating vertically from the seabed.

We are presently attempting to integrate multi-frequency acoustic and optical data collected by the BIOMAPER II vehicle in the Gulf of Maine during 1997-1999. Comparisons of the datasets indicate relationships between acoustical scattering layers and the presence of individual zooplankton taxa. In collaboration with colleagues at the Woods Hole Oceanographic Institution, we have interpreted the patterns of multifrequency acoustic scattering using existing scattering models and predicted abundances from the VPR (Benfield *et al*. 2003). The techniques developed in this project will provide an alternative methodology for combining the information content of optics and acoustics to estimate taxon-specific distributions of zooplankton biomass in the water column.

Images of *Euphausia pacifica* collected using the ZOOVIS instrument (see related projects) provide a means of estimating the orientation of individuals in the water column with concurrent acoustic data. An undergraduate student at LSU is digitizing preserved specimens of *E. pacifica* over a range of orientations. These digitizations and the methodology developed in this project are being used to estimate the relationship between target strength and orientation. The results will be compared with TS estimates predicted for horizontally digitized animals with different angles of incidence. This will allow us to understand how well our scattering model predicts the target strength of non-horizontally oriented euphausiids.

RELATED PROJECTS

Project N00014-98-1-0563 “Development of a Vertically Profiling, High-Resolution, Digital Still Camera System” has produced an *in situ* optical profiling system called ZOOVIS. This camera system was deployed in Knight Inlet, BC in November 2001 as part of another ONR-funded project (N00014-02-1-0012 “Zooplankton Aggregation Near Sills) to examine aggregation of zooplankton near sills. ZOOVIS has potentially higher resolution than the VPR when imaging larger volumes and generates images with sufficient detail as well as orientation information for incorporation into the present study.

We are currently digitizing ZOOVIS images to estimate how changes in orientation alter the target strength of individuals.

REFERENCES

Benfield, M.C., C.S. Davis and S.M. Gallager. 2000. Estimating the in-situ orientation of *Calanus finmarchicus* on Georges Bank using the Video Plankton Recorder. Plankton Biol. Ecol. 47: 69-72.

Benfield, M.C., A.C. Lavery, P.H. Wiebe, C.H. Greene, T.K. Stanton, and N.J. Copley. 2003. Distributions of physonect siphonulae in the Gulf of Maine and their potential as important sources of acoustic scattering. Can J. Fish. Aquat Sci. 60:759-772.

Gerber, R.P. 2000. A manual to zooplankton identification for the coasts and estuaries of the Gulf of Maine region. Acadia Productions, Brunswick, Maine.

Kringel, K., P. A. Jumars, and D. V. Holliday. 2003. A shallow scattering layer: High-resolution acoustic analysis of nocturnal vertical migration from the seabed. Limnol. Oceanogr., 48(3): 1223-1234

Ortner, P.B., S.R. Cummings, R.P. Aftring, H.E. Edgerton 1979. Silhouette photography of oceanic zooplankton. Nature 277: 50-51.

Stanton, T.K. and D. Chu. 2000. Review and recommendations for modeling of acoustic scattering by fluid-like elongated zooplankton: Euphausiids and copepods. ICES J. mar. Sci. 57: 793-807.

Stanton, T. K., Chu, D. and Wiebe, P. H. 1998. Sound scattering by several zooplankton groups. II: Scattering models. J. Acoust. Soc. Am., 103(1): 236-253.