Development and Applications of Technology for Sensing Zooplankton

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LONG-TERM GOALS

The long-term goal of our research is to improve our ability to observe the ocean's plants, animals, and their physical and chemical environment at critical scales that control how they live, reproduce, and die.

OBJECTIVES

During this year the main thrust of our work has involved the development of unique new methods to enable the use of simultaneous multi-static, multi-frequency scattering for studing small aquatic zooplankters and micronekton. Fulfillment of a secondary objective has involved providing a low level of continuing technical support and advice to several federally-funded (ONR and NOAA) principal investigators (PIs) who are using multi-frequency acoustics to address a variety of their own science questions (e.g., Abello *et al.* 2005; McGehee, Demer and Warren 2004; Taylor *et al.* 2005; Warren *et al.* 2004).

APPROACH

Our main research thrust now involves a transition of what we have learned about simultaneous multi-frequency, multi-static scattering processes in laboratory tank experiments into an advanced sea-going instrument for studying zooplankton. Our research effort has been dedicated to:

1) modeling to relate backscattering from individuals to volume backscattering over narrow ranges of target azimuth; and

2) developing the necessary hardware for measuring multi-angle, multi-frequency acoustical scattering from small volumes in the ocean.

By combining multi-static scattering with multi-frequency methods we hope to extract better estimates of size than can be accomplished with multi-frequency measurements alone. This technique also offers a possibility for extracting shape and some key biophysical properties that may be useful in remote identification of the scattering organisms.

WORK COMPLETED

Last year, our primary efforts involved the deployment of acoustical sensors at a variety of candidate sites for an anticipated large ONR-funded, multi-investigator field experiment. That research project evolved and is now focused on Layered Organization in the Coastal Ocean (LOCO). The first exhaustive LOCO field study was completed in mid-September 2005. Our previous work under this task was one of the factors that led the LOCO group to choose to work in Monterey Bay, CA. The Quicklook task is now completed. Our participation in LOCO was funded by a new task and the annual report on that work can be found elsewhere in this compilation of annual ONR-sponsored research reports.

RESULTS

Much of our effort this year has been aimed at constructing a measurement system that would allow us to obtain scattering data from zooplankton both in the laboratory and in the field, using broadband signals and a variety of bi-static scattering angles. In the process, several design issues had to be addressed.

One of these involved the effect of sample volume size on actual bi-static angles. Our current multi-frequency backscatter systems employ acoustic beams on the order of 10° effective width and pulse lengths selected to obtain sample volumes, at a range of ca. 1 m, of about 1-2 liters. Up to now, we have ignored the fact that individual scatterers within this ensonified volume present slightly different aspect angles (up to ±5°) to incident sound beams. For a multi-static system, where measurements at several bi-static backscattering angles are to be made, we thought it unlikely that we could continue to ignore this issue.

We generated computer simulations of volume scattering from a cloud of randomly-located scatterers in a multi-static situation and compared these (normalized) predictions to those for a single scatterer at the mean bi-static angle of the simulation. The scatterer type selected for modeling was a truncated fluid sphere -- the model we have employed for many years for backscattering from zooplankters that generally resemble copepods. This model contains the basic frequency-angle dependence of a fluid sphere but is generally less sensitive to precise spherical geometry, a shape that rarely occurs in the zooplankton.

Each panel of Fig. 1 depicts the normalized volume scattering from 25 scatterers randomly located in a volume compared to that from a single scatterer located on-axis. The abcissa is non-dimensional frequency, the product of scatterer size and frequency. At backscattering angles (0°), it can be seen that our election to ignore the effects of small bi-static angles was warranted, as both curves overlay.

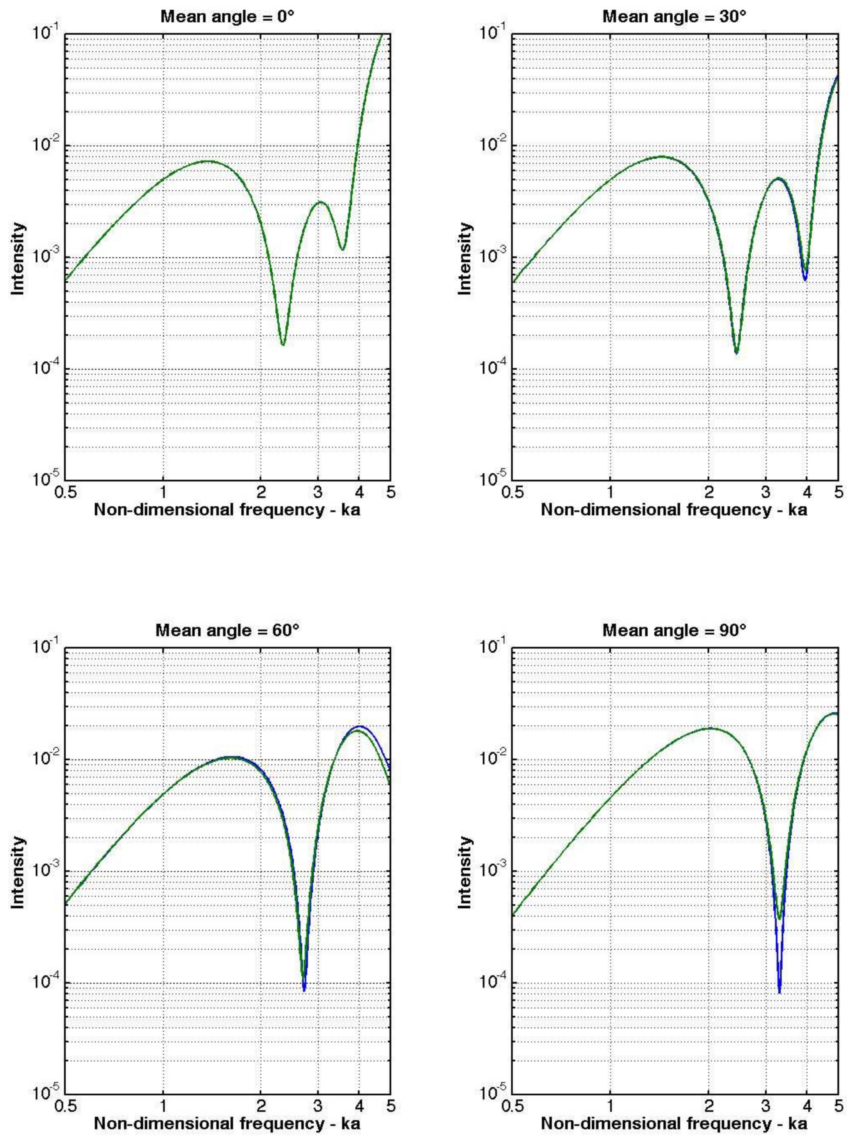

Figure 1: The theoretical spectra for acoustical scattering from a single particle (blue curve) and twenty-five randomly positioned particles (green curve) in a small volume (normalized in level to make a comparison of the spectral shape meaningful) are compared for four distinct geometries. In the upper left panel, the angle between the incident and reflected sound beams is 0° (backscattering) and there is no discernable difference between the curves. At bistatic angles of 30°, 60° and 90° (observation angle orthogonal to the incident beam), the differences in the scattered intensity levels are small and are most pronounced in the scattering nulls.

As the bi-static angle increases towards 90°, the effect of a spread of actual bi-static angles can be seen to affect the depth of the nulls, with the 25-scatter case causing the nulls to be less pronounced. Note also how the shape of the curve in non-dimensional frequency changes with bi-static angle. At 90°, the location of the null is moved upward slightly in non-dimensional frequency as well. This complication means that estimates of size-abundance using data near 90° will depend upon abundance -- in other words, a different model may be required depending upon whether single or multiple scatterers are present in the ensonified volume.

For our prototype measurement system, the model issue has been simplified by reducing the sample volume to a size that would preferentially select single scatterers. A frame has been fabricated consisting of a 45-cm diameter hoop, supported on short legs and suspended from a single point by three vertical curved tubes to which can be attached an electronics case(s) and a CTD. The arrangement of parts is such that water can flow freely inside the center of the hoop, which contains the acoustic sample volume. The nominal range to the sample volume is 20 cm.

A 50-watt pulser has been designed and fabricated to produce 1-8 cycle transmissions. This allows adjustment of the bandwidth of the ensonifying signals. A set of broadband amplifiers with computer-controlled gains has also been constructed. An analog-to-digital converter (ADC) card permits synchronous digitization of echo signals using a common ADC clock (in case the phase of the signals proves important for precise localization within the sample volume). A sound speed board will be used to measure the time-of-flight across the array on each ping. This value is to be used on the ensuing ping to center the sampled data at the center of the ring. A Persistor CF-2 single-board-computer (SBC) with 64 Mbytes of mass storage has been procured and an interface board fabricated to permit control of each of the sensor subsystems. The next step in the development involves a sequence of testing in a laboratory tank, followed by testing in the sea. For reasons of efficiency, our plan is to coordinate this testing with sea-going opportunities provided by our participation in the LOCO program.

IMPACT/APPLICATIONS

Observation of aquatic animals in their natural environments continues to pose a major challenge in both biological oceanography and limnology. Critical processes in feeding, reproduction, growth, and predation occur at scales from fractions of millimeters up to scales that far exceed the ambits of individuals. Our work is focused on the invention and development of new, high-resolution methods and technology for observing zooplankton and micronekton *in situ*. An increasing body of evidence suggests that fine-scale vertical structures are ecologically critical. However, the mechanisms involved in their formation and utilization by different trophic assemblages are still largely unknown. Phytoplankton and zooplankton impact marine optics and underwater acoustics through both scattering and absorption. High production of phytoplankton may lead to the production of numerous small gas bubbles, which can have significant impacts on both optical and acoustical propagation, as well as measurements of ocean color. As many sensors used by naval forces rely on either optical or acoustical energy, the distribution of marine life potentially impacts current and future naval systems used in shallow water, where both mine detection and ASW operations must be conducted prior to engaging in expeditionary warfare.

TRANSITIONS

Our research and development into advanced acoustical tools for detecting and describing vertical distributions of zooplankton in the coastal zone have resulted in a variety of new tools that are now being applied to a new ONR research initiative on “Layered Organization in the Coastal Ocean” (LOCO). We are bringing our experience in detecting and assessing thin layers of zooplankton and their predators to this new research program by participating directly in the research and by serving on the LOCO Scientific Steering Committee.

We also continue to support several of ONR’s principal investigators in the LOCO research project (e.g., Donaghay, McManus, Jumars, and Cowles) with the application of our latest hardware and software developments in our joint research activities. Working with Jeff Napp (NOAA/AFSC) under NOAA funding, we now have TAPS-8 data averaging *ca.* 4 months in duration during 2002, 2003 and 2004 from moorings in the Coastal Gulf of Alaska (Holliday *et al.* 2005). We are currently working with NOAA/AFSC and NOAA/PMEL to provide real-time data via satellite on zooplankton abundance using a TAPS-8 moored in the Bering Sea. Peter Jumars (U of Maine), his staff and students are currently using TAPS-6 sensors to study emergence and re-entry phenomena associated with benthopelagic organisms (Abello *et al.* 2005; Taylor *et al.* 2005). Emmanuel Boss (U of Maine) has recently deployed a TAPS-6 for research involving both optics and acoustics at the Martha’s Vineyard Coastal Observatory. Additionally, our methods and sensors have been adopted by marine scientists in France (Lebourges-Dhaussy), Japan (Furasawa) and Australia (Koslow) for use in their on-going research programs.

RELATED PROJECTS

Our “Quick-look” task under the current project strongly supported the successful development of the new multi-year ONR initiative related to understanding Layered Organization in the Coastal Ocean (LOCO). It was also extremely useful in selecting the first field site for LOCO. We continue to support our LOCO colleagues with real-time bioacoustics-based measurements of zooplankton distributions, but our own science emphasis in LOCO focuses on biological processes that may be responsible for generating very small bubbles in thin layers of phytoplankton. When present, these bubbles can significantly change the propagation and scattering of both light and sound in the sea.

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HONORS/AWARDS/PRIZES

D.V. Holliday, BAE Systems, Silver Medal in Acoustical Oceanography. Acoustical Society of America.