Development of Mid-Frequency Multibeam Sonar for Fisheries Applications

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LONG-TERM GOALS

The long-term goal of this program is to investigate the utility of mid-frequency (~10 kHz) acoustics to detect, enumerate, and identify pelagic fish distributions.

OBJECTIVES

Objectives of this research include: comparisons of fish backscatter models, models of mid frequency sound propagation, development of a mid-frequency multibeam sonar, and backscatter measurements using splitbeam echosounders and the multibeam sonar.

APPROACH

Our strategy integrates biological and physical model predictions with field measurements and will combine results in computer visualizations and animations. Efforts are directed in three primary areas: sound propagation modeling, fish backscatter modeling, and mid-frequency multibeam development and field measurements.

Sound propagation modeling efforts focus on continental shelf environments in the northeast Pacific including the Gulf of Alaska and along the Washington coast. Effects of multi-path propagation, water depth, substrate type, substrate and surface roughness, and range dependence on propagation, including temporal and spatial variability in the environment will be modeled.

Sound propagation characteristics will be combined with anatomical models of fish to examine backscatter from individuals and aggregations of fish. This approach will enable us to model potential detection strategies for different types of fish, their behaviors, and to predict variability in fish aggregation backscatter. Backscatter predictions for individuals within aggregations (i.e. the forward problem) will be compared to *in situ* measurements.

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To measure synoptic distributions of fish schools we will collect mid (10 kHz) and high (38 kHz) backscatter data from fish aggregations using a multibeam sonar and a splitbeam echosounder. The sonar is expected to detect fish at kilometer scale ranges while the echosounder will be used to detect aggregations and individual animals at ranges of hundreds of meters.

WORK COMPLETED

There were several notable accomplishments from the fish backscattering group for this reporting period. A study examining probabilistic classification of multi-frequency backscatter data was completed and published. An investigation examining the description and classification of fish aggregations was completed and is in review. A compilation of computer programs has been created to directly simulate known size, abundance, and orientation of walleye pollock populations for sound propagation model testing. A computer visualization was developed to compare acoustic backscatter from downward and angled splitbeam echosounders. Dr. Horne presented results from this study in a multibeam sonar workshop that examined the feasibility of using multibeam sonar to map and count Atlantic herring on the Scotia-Fundy continental shelf.

A numerical model of fish school scattering in a shallow water waveguide has been developed. Simulation results are being used to interpret field data.

The 2007 west coast field experiments to deploy the PIMS system at sea were canceled due to changes in the NOAA ship schedules. An alternative west coast field test is being planned, most likely without NOAA ship support. Calibration tests of the system were performed in Lake Washington in May 2007 using APL-UW vessels. The East coast field deployment of the PIMS system was accomplished as planned. Two major modificatioins to the PIMS system were implemented in 2007: 1) increase source level and modification to source array based on results of 2006 field tests; 2) a new deployment configuration enabling the deployment of the PIMS system from a morring, enabling autonomous operation.

RESULTS

Fish Backscatter Models:

To classify multifrequency acoustic data, a robust probabilistic technique, using expectation maximization of finite mixture models (EMFMM), was developed to categorize backscatter. To investigate the consistency of this approach we examined the mid-Atlantic ridge, a species-rich, relatively unknown ecosystem, and the Gulf of Alaska, a low-diversity, well known ecosystem. Probabilities of membership to clusters were used to classify each sample. The number of clusters was determined using the Bayesian Information Criterion. In the three frequency (18, 120, 200 kHz) Gulf of Alaska data, both biological and physical features were grouped in distinct clusters with high probabilities (Fig. 1). Clusters were identified containing dense schools of walleye pollock near the bottom, a midwater small fish layer, a bottom krill layer, background noise, and the acoustic transducer saturation signal.

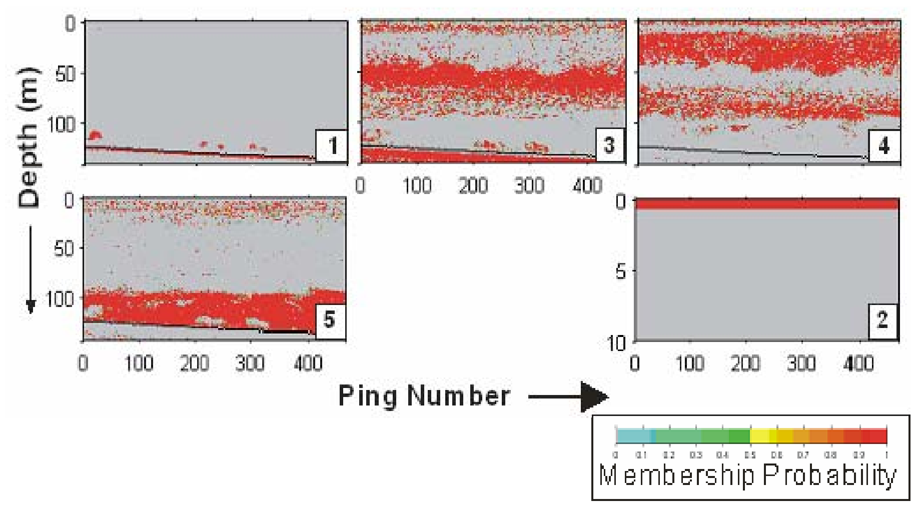

Figure 1. Membership probabilities of multifrequency data from the Gulf of Alaska containing: 1) walleye pollock aggregations, 2) transducer saturation, 3) small fish, 4) background noise, and 5) a krill layer.

We believe that EMFMM provides objective, probabilistic classification and can incorporate additional spatial or other discriminatory data. This approach is appropriate to categorize data from poorly known ecosystems and has the potential for automated processing of large data sets.

To support the sound propagation modeling effort, three-dimensional walleye pollock (*Theragra chalcogramma*) aggregations were created using probabilistic arguments and 38 kHz echosounder data collected in the Bering Sea. A graphical interface (SGeMS) addition to the GSLib (Geostatistics Library) code was utilized to analyze, interpret, and visualize two dimensional walleye pollock acoustic reflectivity (i.e. backscatter) data. Variogram parameters fitted to acoustic transect data area used to create a two-dimensional random distribution of walleye pollock backscatter (Fig. 2a). The simulated backscatter data is vertically distributed in 10m bins throughout the water column (Fig. 2b) using an empirically-derived depth distribution model.

Waveguide Modeling:

Long range imaging of fish schools in a shallow water waveguide is complicated by multi-path arrivals and scattering. Time domain simulations of horizontal waveguide propagation and scattering using parabolic equation methods have been developed to simulate the imaging of fish schools. Simulations are being used to interpret field data collected using the PIMS system and provide insight into the mechanism and limitations of waveguide backscatter imaging. Interpreting data from the backscatter of a disperse object in a waveguide requires simulation, as shadow zones, modal interference, absorption and scattering at sea surface and bottom significantly distorts imaging as a function of range. Figure 3 illustrates pulse propagation in a shallow water waveguide at two range increments (150m and 1000m). The top panel shows a 5ms rectangular pulse after propagating 150m in ~80m of water. The first arrival is the direct path; the second arrival is the first surface bounce. The same situation is illustrated below where the propagation range is 1000m. With increased range, the clear distinction between multiple arrivals is lost, creating a more complicated and distorted image.

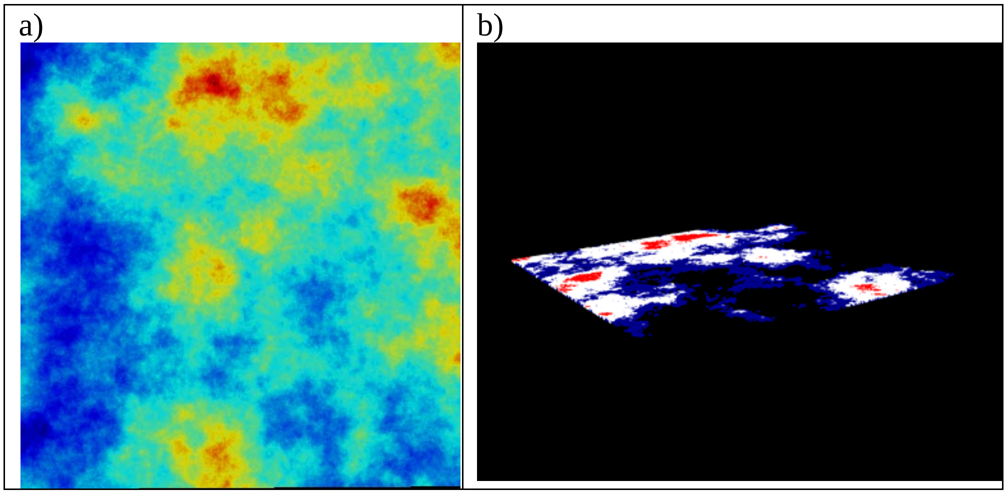

Figure 2. a) Example of a two-dimensional walleye pollock (*Theragra chalcogramma*) acoustic backscatter distribution generated using SGeMS where low density is blue and high density is red. b) Three-dimensional walleye pollock density distributions grouped near bottom (blue), middle water column (white), and near surface (red) layers.

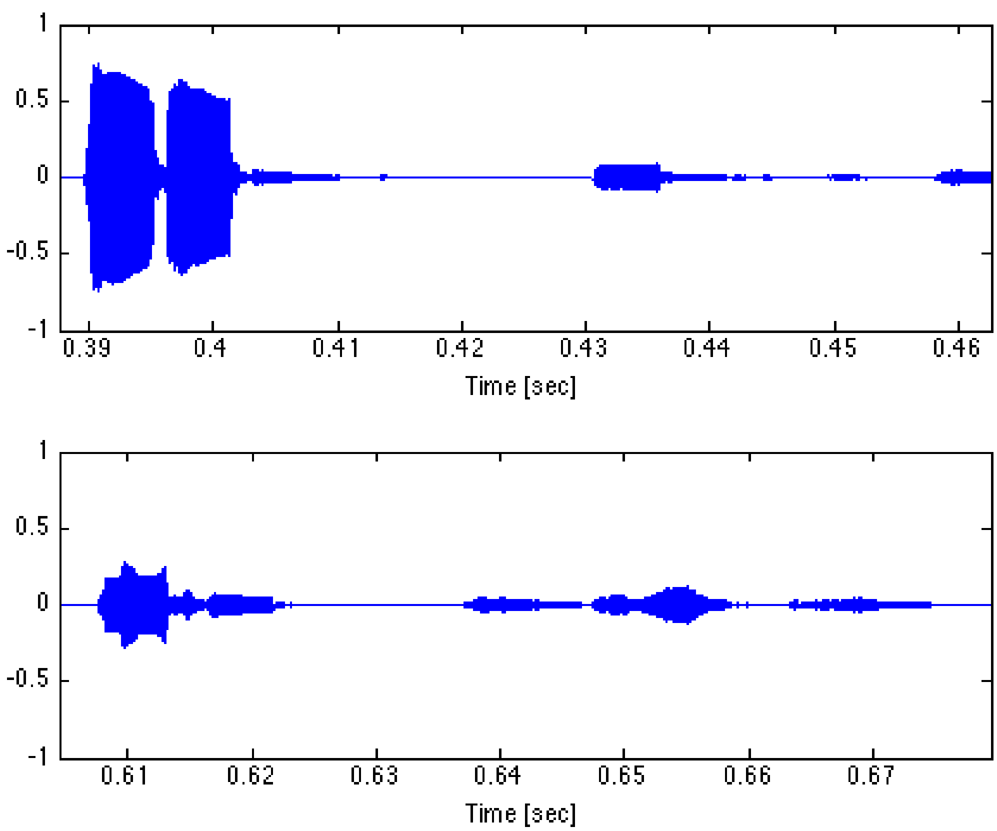

Figure 3: Propagation and scattering of a 5ms rectangular pulse (12 kHz) in a ~80m oceanic waveguide. Top panel show propagation over 150m range, and bottom panel over 1000m.

In addition to propagation modeling, a model of fish school backscatter has been developed. Here we combine probabilistic models of fish school aggregations (as discussed above) with time-domain models of waveguide propagation and scattering, to simulate fish school imaging.

Development of a mid-frequency imaging sonar:

Development of the Pelagic Imaging Mid-frequency Sonar (PIMS) is completed and efforts are focused on new field experiments and analysis of data previously collected. Field experiments have been performed at Kodiak Island in 2006 and the NJ coast in 2006 and 2007. Partially in response to the first year experiments, a new mooring deployment configuration for the PIMS system was developed. In addition to reducing ship noise contamination of the sonar signal, the moorings enabled a time series of 2D waveguide images to be collected at a single location while the ship performs down-looking sonar surveys and net tows in a area centered on the mooring.

Figure 4 illustrates the mooring deployment configuration. The PIMS was suspended from surface floats that acted as a spar buoy, decoupling the sea surface motion from the sonar. A battery buoy supplies power to the PIMS and control/data communications with Wifi Ethernet telemetry to the ship. The buoy system was tied to a light buoy and mooring anchor to prevent the system from drifting. Batteries provided power for continuous acoustic imaging over a 24 hour period with images taken at a five minute intervals.

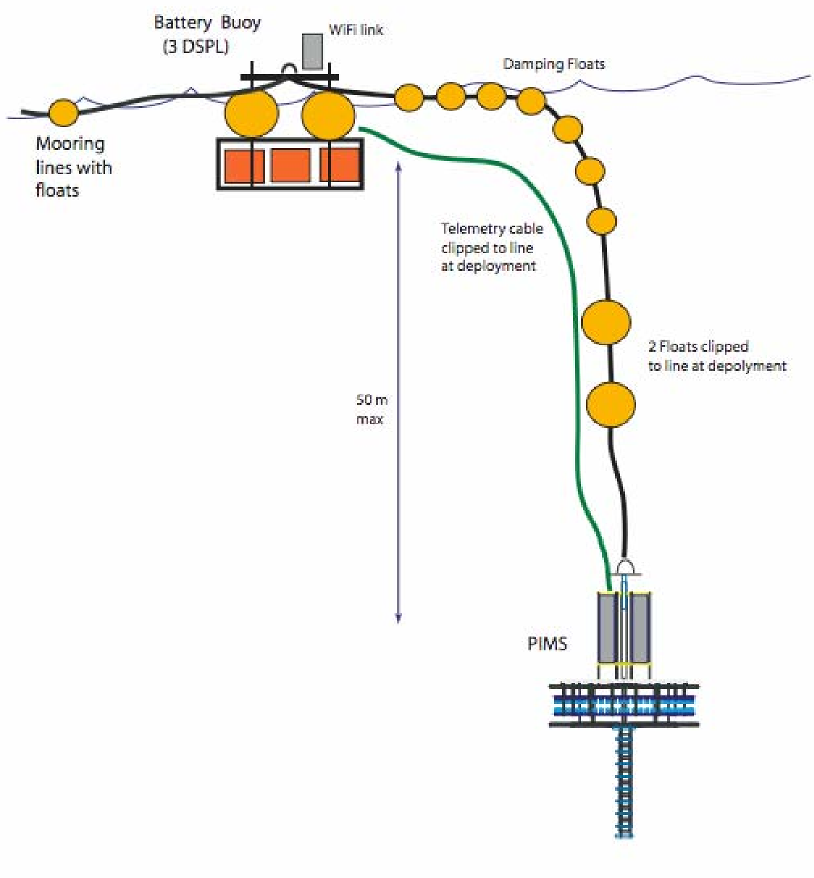

FIGURE 4: PIMS mooring configuration

The system was deployed as part of the NOPP east coast experiments (Bird et al). A west coast deployment of the system is being planned. The challenge will be to deploy the system in an area where the objectives of long range waveguide imaging of fish schools can be accomplished with no NOAA ship support and unplanned third year funding cuts by NOAA.

IMPACT/APPLICATIONS

National Security

The multibeam system (PIMMS) is a sonar technology that could be used to image anthropogenic and biologic objects in any water column.

Economic Development

The multibeam system (PIMMS) potentially provides a tool for synoptic (i.e. seconds) mapping of fish distributions at intermediate spatial scales (i.e. kilometers), which can be deployed as part of ocean observatories.

Quality of Life

The use of synoptic imaging tools should increase the ability to design acoustic surveys to accurately estimate population abundances of commercially important fish and zooplankton species. As part of an ocean observatory, this system can be used to monitor ecosystem dynamics.

Science Education and Communication

A wiki has been created for collaborative efforts among the PI's.

RELATED PROJECTS

The multibeam sonar developed in this project was also deployed in the in the mid-Atlantic Bight in support of the NOPP sponsored project entitled, "Novel Acoustic Techniques to Measure Schooling in Pelagic Fish in the Context of an Operational Coastal Ocean Observatory."

PUBLICATIONS

Anderson, C.I.H., J.K. Horne, and J. Boyle. 2007. Applying a robust probabilistic classification technique to multi-frequency fisheries acoustics data. (DOI: 10.1121/1.2731016) Journal of the Acoustical Society of America 121: EL230-EL237.

Burgos, J.M. and J.K. Horne. Acoustic characterization and classification of pelagic organisms distributions. ICES Journal of Marine Science (in review).