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 (1-10 kHz) acoustics to detect, enumerate, and identify pelagic fish distributions. Our strategy integrates model predictions with field measurements and will combine results in computer visualizations and animations.

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 approach integrates three primary efforts: sound propagation modeling, fish backscatter modeling, and mid-frequency multibeam development and application.

Sound propagation modeling will focus on the shallow water environments of the Gulf of Alaska and the northeast Pacific. We will investigate effects of multi-path and range dependence on propagation, including temporal and spatial variability in the environment. To model the effects of seafloor scattering and a temporally evolving rough sea surface we will use a modified parabolic wave equation (PE) code (Rosenberg 1999). To initiate modeling of reverberation caused by steep bathymetric features or a rocky seafloor, we will use the Gaussian RAy Bundle (GRAB) model (Weinburg and Keenan 1996) and PE based scattering approximations (Ratilal et al. 2003). To compare mid-frequency backscatter measurements with higher frequency echo integration methods, significant waveguide effects must be resolved. Determining the sample volume (i.e. volume of water ensonified) as a pulse propagates horizontally in shallow water will require modeling multi-path structure and scattering as a function of beam orientation (Fig. 1).

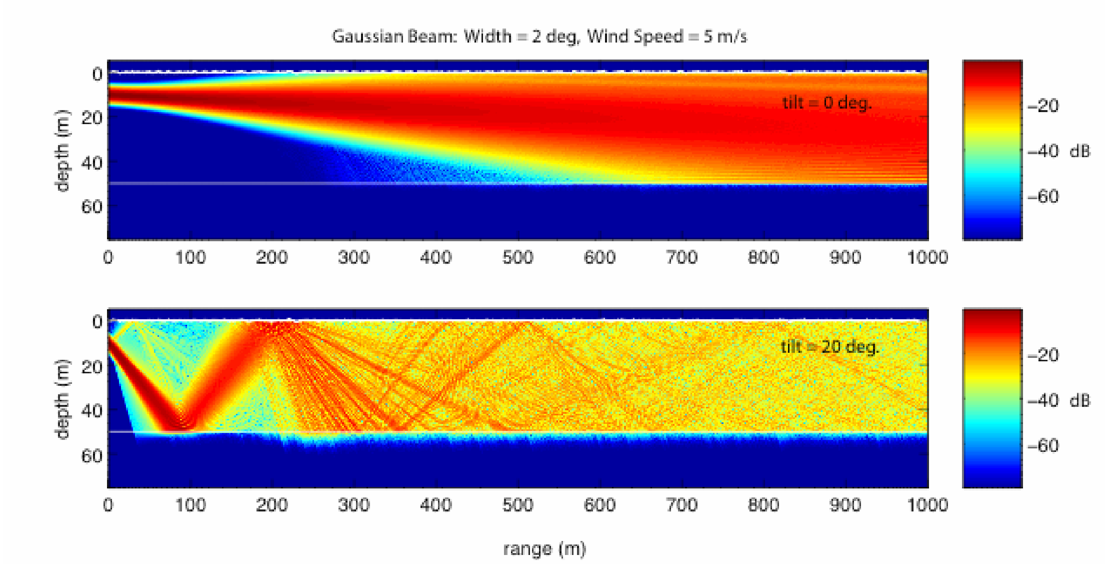

Figure 1. Beam orientation and resulting waveguide effect for a 10 kHz, Gaussian beam (beamwidth 2 degrees) in a rough sea surface waveguide with a wind speed of 5 m/s.

We will combine sound propagation and reverberation models with backscatter models of fish to examine individual and group scattering characteristics. This approach will enable us to model potential detection strategies for different types of fish, their behaviors, and to predict variability in fish aggregation scattering. Results from this work will be used to guide field measurement experimental design and the subsequent interpretation of the data. The Kirchhoff-ray mode (KRM) backscatter model is used to predict individual backscatter as a function of acoustic wavelength, fish length, and fish orientation (i.e. aspect, roll) (example Fig. 2). Scattering predictions for individuals within aggregations (i.e. the forward problem) will be compared to *in situ* measurements.

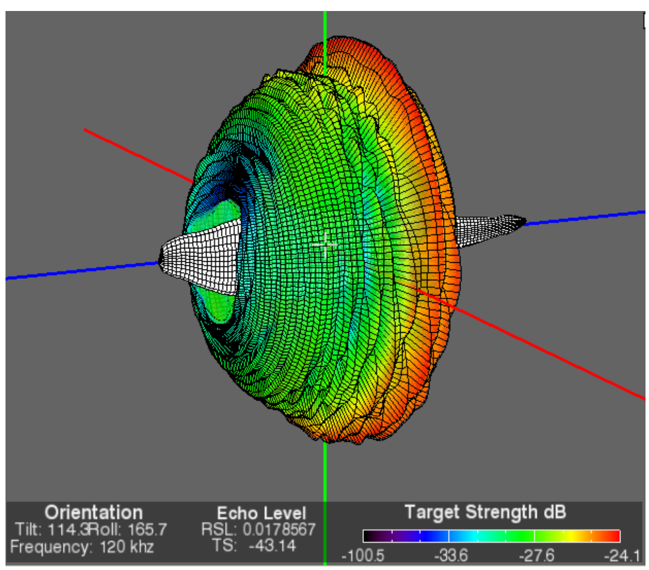

Figure 2. Kirchhoff-ray mode predicted backscatter of a 39 cm walleye pollock (*Theragra chalcogramma*) at 120 kHz. Backscatter intensity is represented in two ways, distance from the center of the swimbladder (short low, long high) and by color (blue low, red high). Backscatter estimates are resolved in two degree increments in the tilt and in the roll planes.

The mid-frequency multi-beam system is a new method to visualize fish distributions at intermediate ranges. To ensure synoptic measurements, we will evaluate mid-frequency reverberation and bistatic scattering from fish in shallow water waveguides. A multi-beam sonar system operating at 5-15 kHz will be developed at the Applied Physics Laboratory (APL), University of Washington. Figure 3 illustrates the revised equipment configuration. By orienting the multi-beam system to look into the water column (instead of looking down) we can investigate fish scattering in two regimes: 1) direct path scattering for swath mapping of the water column, and 2) waveguide scattering where propagation paths can be much longer than the direct path. Direct path scattering is scattering from the water column prior to the first interaction with the seafloor or sea surface. Waveguide scattering occurs after the first interaction with the seafloor or sea surface.

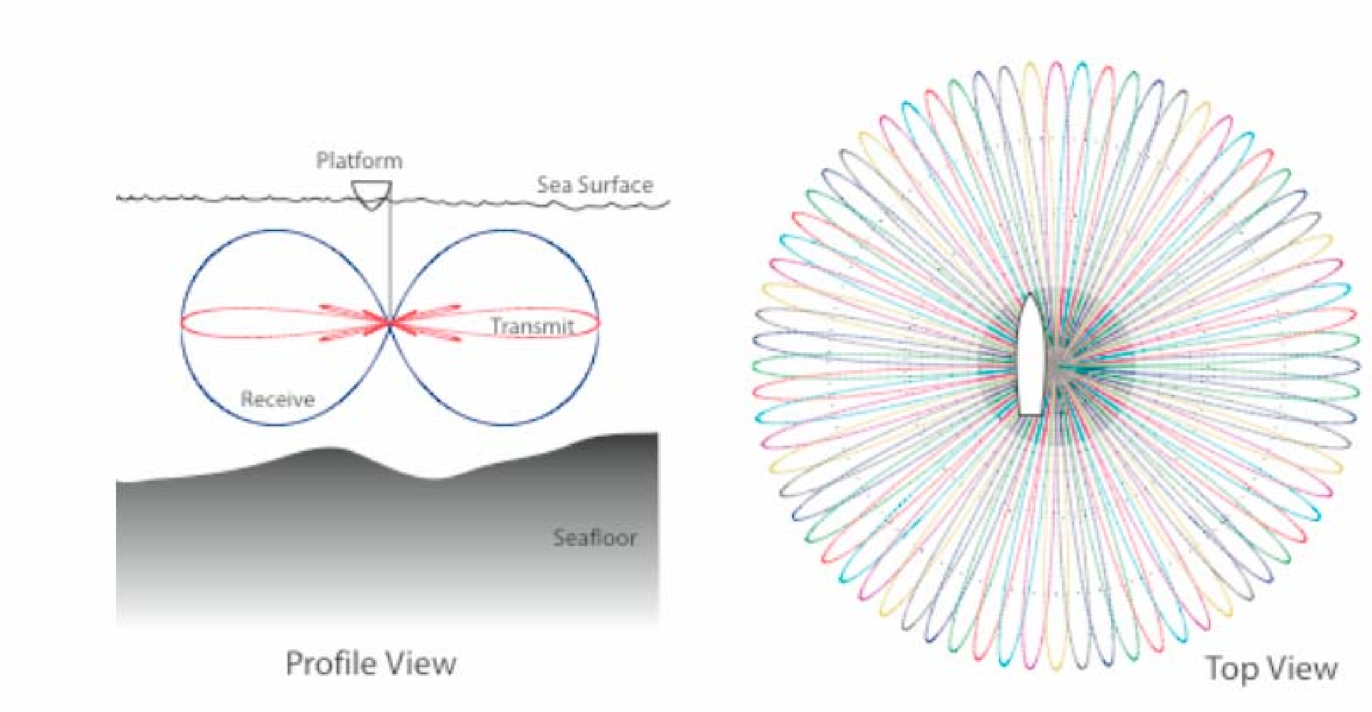

Figure 3: Deployment geometry and imaging volume of the mid-frequency circular array illustrating the receive and transmit beam patterns.

WORK COMPLETED

The initiation of this project was delayed several months due to incompatible administration requirements among participating agencies. Scheduling changes have been implemented to re-align research activities. Integration of backscatter model predictions from individuals to aggregations of fish continues. Visualization of aggregation backscatter includes each fish within the beam and an echogram of the water column. The backscattering workshop planned for 2005 had to be postponed. The availability of high-resolution, bathymetric data sets for the eastern Bering Sea and Pacific coastal shelves is being investigated. Integration of propagation models to suit conditions on the eastern continental shelves has begun. Design and fabrication of the mid-frequency, multi-beam sonar is well underway. Initial system fabrication is anticipated to be complete by spring 2006. A prototype receive array has been constructed and preliminary tests have been conducted.

RESULTS

Backscattering coefficients from individual fish within the transducer beam can now be plotted as integrated backscatter by depth bin in real time as the fish school simulator and animator is running (Fig. 4). Once orientation of each fish is calculated, the appropriate intensity is extracted from a backscatter matrix of pitch, yaw, and roll orientations.

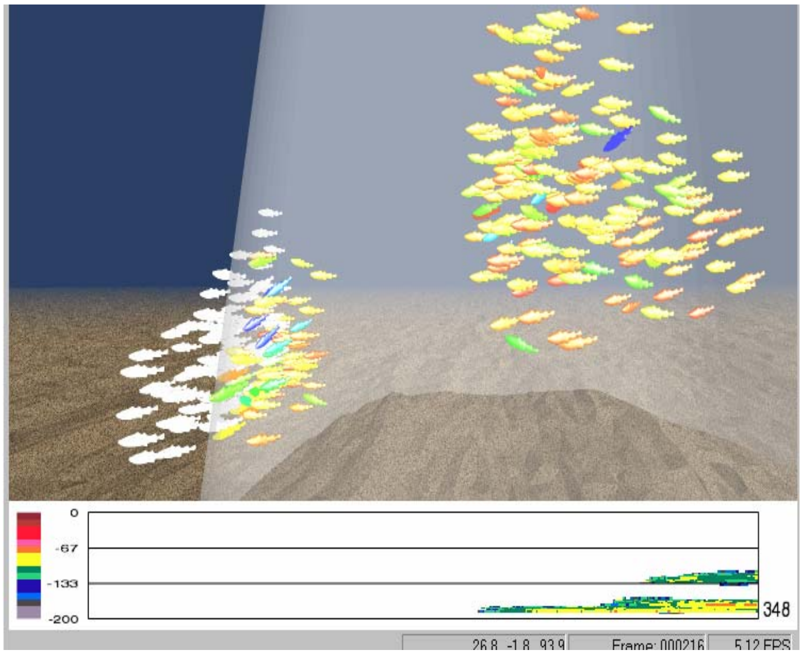

Figure 4. Individual and group backscatter from juvenile walleye pollock within a 120 kHz echosounder beam. Color indicates backscatter intensity depending on size, orientation, and location in the beam.

A prototype receive array consisting of 24 elements has been tested in local waters. This revised design is a significant change from the originally proposed configuration. A circular receive array combined with a linear omni-directional transmit array has replaced the original a linear array of receiving hydrophones. The circular array design will simultaneously image a 360 degree sector, require minimal deck space, and be deployable from standard hydrographic winches with little manpower. The original array would require a complex deployment to maintain direction, more deck space (because it would be 3 meters long), and potentially require special winches and cables. To ensure high resolution imaging, the number of hydrophones in the system has been increased. This was facilitated by using more cost effective hydrophones than initially considered (the price decreased from $1000 per unit to $100). The system will be reconfigurable to include up to 96 receiving hydrophones. The nominal number of receiving hydrophones used will be 64, creating beams with a 5 degree horizontal resolution (Figure 3). The vertical imaging resolution of the system (as illustrated in the profile view of Figure 3) is defined by the intersection of the receiver and transmitter beams. Therefore, vertical imaging resolution can be achieved by either steering the narrow transmit beam in elevation or by moving the whole system up and down through the water column as a profiler (Fig. 5).

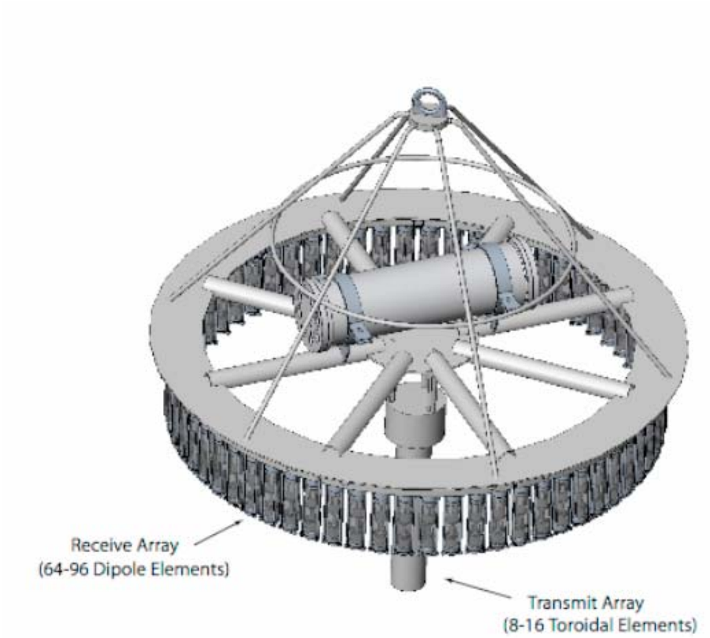

Figure 5: Mechanical illustration of the circular mid-frequency imaging system showing the geometry of receive and transmit hydrophones and the single cable deployment configuration.

IMPACT/APPLICATIONS

Mid-frequency multibeam sonars are not currently used in fisheries research or ecosystem monitoring. Deployment of this system will permit autonomous experiments for short periods, intermittent use during ship-based platforms to map regional distributions of fish, or long-term deployments within an ocean observatory. Short-term deployments may be used to quantify temporal and spatial scale-dependent movement by fish aggregations. Effects of movement on abundance estimates from ship-based acoustic surveys have not been extensively quantified. Combining longer range mid-frequency sensing with mobile echosounder-based surveys increases the synopticity of any survey using echosounders or swath multibeam sonars in isolation. Mapping regional scale fish distributions enables effective use of adaptive survey designs and the ability to quantify migrations of fish aggregations during surveys. Incorporating remote sensing instruments with kilometer range detection capabilities enables large volumes of water to be continuously monitored. Timing of annual fish migrations, changes in spatial distributions relative to environmental conditions, and temporal trends in biomass are all potential applications for a mid-frequency multibeam system.

RELATED PROJECTS

The multibeam sonar developed in this project is also being used in the project entitled, “Novel Acoustic Techniques to Measure Schooling in Pelagic Fish in the Context of an Operational Coastal Ocean Observatory.” The related project will combine splitbeam echosounders and direct sampling with multibeam sonar installed on an AUV to synoptically examine fish school distributions in a nearshore ocean observatory.

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