Acoustic Clutter in Continental Shelf Environments

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LONG-TERM GOALS

Acoustic clutter is the primary problem encountered by active sonar systems operating in Continental Shelf environments. Clutter is defined as any returns from the environment that stand prominently above the diffuse and temporally decaying reverberation background and so can be confused with or camouflage returns from an intended target such as an underwater vehicle. Many environmental factors may contribute to acoustic clutter and adversely affect the performance of tactical Navy sonar by introducing false alarms in the system. In order to develop adaptive algorithms or technology to mitigate acoustic clutter, it is critical to identify, understand, and be able to accurately model the leading order physical mechanisms which cause clutter in existing sonar systems. The long-term goal of this program is to determine and understand the physical mechanisms that cause acoustic clutter in continental shelf environments and to use this knowledge to develop predictive tools to enhance the detection, localization and classification of underwater targets.

OBJECTIVES

The primary objectives of this program are:

(1) Experimental demonstration with Gulf of Maine 2006, MAE 2003 and ARE 2001 data that the primary cause of *discrete and target-like* clutter observed in the Gulf of Maine and New Jersey Strataform area is due to scattering from small, isolated, but densely populated fish schools typically spanning a 100-m to 1-km diameter. These schools have similar sizes and move at rates similar to those of a slow-moving submarine.

(2) Preparation and implementation of an at-sea experiment in Georges Bank in the Gulf of Maine, in conjunction with the US National Marine Fisheries Service Annual Herring Survey, to determine whether fish are dominant cause of clutter in this distinctive environment with significant batymetric and oceanographic variations.

(3) Characterization of the temporal and spatial properties of biological clutter as well as correlation to oceanographic or geophysical properties of the environment. This includes examination of clutter features over the full diurnal cycle, including both day and night observations.

(4) Determination of the physical scattering mechanisms causing biological clutter and their variation with fish species, depth, size and population density.

(5) Experimental determination of the extent to which volume reverberation from fish is responsible for the overall diffuse background reverberation that is often nominally attributed seafloor scattering.

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(6) Development and use of a new, rapid, rigorous and unified range-dependent reverberation and waveguide target scattering model based on the parabolic equation, a Fleet standard, to quantitatively determine the fundamental physical mechanisms responsible for clutter in active sonar operation in Continental Shelf environments and to provide predictive tools to mitigate or tactically exploit clutter.

(7) Application of a newly developed theory by the PI and his group to explain the experimentally observed fluctuations in clutter, reverberation and calibrated target returns in shallow water. This includes application of the only approach in existence for 3-D calculations of the mean forward propagated field and covariance in a random waveguide.

APPROACH

The approach is to combine the analysis of experimental data with full-field waveguide modeling of forward propagation, clutter, acoustic reverberation, and target scattering. Under the Acoustic Clutter Program the Acoustic Clutter Reconnaissance Experiment (ARE) 2001 was primarily aimed at just establishing the presence and persistence of acoustic clutter off the New Jersey continental shelf. The Main Acoustics Experiment (MAE) 2003 was designed to be very controlled, so that the actual mechanisms for the clutter could be established. It also had precise calibration so that theories and models could be accurately tested and validated. Full-field 3-D stochastic waveguide propagation and scattering models, simulations and statistical studies helped direct experiment design and support the analysis and interpretation of experiment results. The Gulf of Maine 2006 experiment was used to more carefully study simultaneously the local scattering characteristics as well as long range returns from both small schools and large shoals that lead to clutter in Navy sonar systems. This was done by use of both long-range Navy sonars in the low to mid frequency range as well as local conventional fish finding sonar and trawl vessels over an extended period of 3 weeks during both daytime and night time to examine the full diurnal variations of clutter.

WORK COMPLETED / RESULTS

The Gulf of Maine 2006 Experiment., conducted for roughly 3 weeks at sea from Sept-Oct, was a great success in demonstrating that discrete clutter events are consistently the major clutter problem in a region with significant bathymetric relief and variable oceanography. It was also a great success in determining that even in environments where fish populations are very deep with significant swimbladder compaction, and localized in very small schools, they still are the dominant source of acoustic clutter at long range. We showed that many behavioral characteristics of the fish populations, including many unexpected diurnal idiosyncrasies, can be used to distinguish clutter from intended targets if sufficient time is allowed for monitoring. We demonstrated that many frequency characteristics of the long-range clutter returns can be also used to help classify the bioclutter and distinguish it from intended targets.

Important new results from the Acoustic Clutter program are as follows:

(1) We have demonstrated that fish schools are dominant cause of acoustic clutter in continental shelf environment using data from Acoustic Clutter Experiment 2001, 2003 and the Gulf of Maine experiment of 2006. We showed in the Gulf of Maine as well as in the New Jersey Continental shelf that clutter features move with similar speed as underwater targets such as submarines and their

spatial coherence scale is similar to many underwater targets, so that they can be easily confused with and misidentified as submarines.

(2) We have used novel analytic expressions that we derived for the mean, mutual intensity, and spatial covariance of the 3-D acoustic field forward propagated through a random ocean waveguide containing 3-D random surface and volume inhomogeneities to analytically explain the temporal coherence of sound transmissions through both deep and shallow water ocean waveguides as well as attenuation, dispersion and field variance due to 3-D multiple scattering along the transmission path. For the deep ocean, our results explain the very short autocorrelation time scale of sound, which is only a fraction of the internal wave time scale. They also explain the strange oscillations in attenuation at very long ranges as a function of frequency in the very low frequency regime as a consequence of 3-D scattering effects. In continental shelf environments, the expressions help to explain the time scales necessary for important Guassian field averaging techniques to be valid, and quantify the role of bubbles due to wind-waves and fish schools on the frequency-dependent attenuation, dispersion and variance of forward propagated sound.

(3) We have developed a new, innovative *array invariant* source localization technique in a dispersive waveguide that requires no *a priori* knowledge of the environment [P36-P38]. The array invariant techniques enable simple, robust, and instantaneous source-range estimation in a horizontally-stratified ocean waveguide from passive beam-time intensity data obtained after conventional plane-wave beamforming of acoustic array measurements. The array invariant method is applicable for both broadband transient source signatures and continuous broadband random noise signatures. The method has significant advantages over existing source localization methods such as matched field processing or the waveguide invariant. First, no knowledge of the environment is required except that the received field should not be dominated by purely waterborne propagation. Second, range can be estimated in real time with little computational effort beyond plane-wave beamforming. Third, array gain is fully exploited. The method has been applied to data from the Main Acoustic Clutter Experiment of 2003 for source ranges between 1 to 8 km, where it is shown that simple, accurate, and computationally efficient source range estimates can be made. The method is now being applied to new data from the Gulf of Maine 2006 experiment.

IMPACT/APPLICATIONS

- We have provided temporal and spatial characteristics of clutter features caused by fish schools in continental shelf environment. From a navy sonar perspective, understanding these characteristics of clutter features will help in the development of adaptive sonar which is capable of distinguishing bioclutter features from intended, man-made targets.

- Analytic expressions have been derived for the first time to describe the mean and covariance of the acoustic field after multiple forward scattering through a random ocean waveguide with arbitrary 3-D inhomogeneities. This is extremely important for active, as well as passive, sonar systems in detecting and identifying objects in a waveguide.

- The analytic expressions for the forward-propagated field have been be applied to explain the short temporal coherence observed for sound propagating through both deep ocean and shallow water waveguides.

- We have developed a novel passive source localization method in an ocean waveguide, called the array invariant, that requires no a priori knowledge of the wave propagation environment or extensive numerical computations. The array invariant method has tremendous potential application in shallow-water surveillance missions and anti-submarine warfare.

TRANSITIONS

Transition of the Acoustic Clutter Program is already significant as documented by the great amount of Naval Research now focusing on clutter issues in active sonar which was spearheaded and guided by this Acoustic Clutter Program.

RELATED PROJECTS

Other organizations participating in the Geoclutter Program are Northeastern University, Natioanl Marine Fisheries Service, Institute of Marine Research Norway, NRL, ARL-PSU..

RECENT JOURNAL PUBLICATIONS

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T.R. Chen, P. Ratilal and N.C. Makris, "Mean and variance of the forward field propagated through three-dimensional random internal waves in a continental-shelf waveguide," J. Acoust. Soc. Am. 118, 3532-3559 (2005).

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N.C. Makris, P. Ratilal, D. Symonds, S. Jagannathan, S. Lee, R. Nero, "Fish population and behavior revealed by instantaneous continental-shelf-scale imaging," Science 311, 660-663 (Feb. 3, 2006). See extensive online supporting material and movies at Science website via free link on acoustics.mit.edu/faculty/makris/makris.html (Also featured in Nature Feb 9, 2006 "Research Highlights," Physics Today "Search and Discover," April, 2006, and elsewhere.)