

Remote Sensing in Fluctuating Range-Dependent Littoral Environments with Clutter

Purnima Ratilal

Northeastern University, 409 Dana Research Center, Boston, MA 02115.
phone: (617) 373-8458 fax: (617) 373-8627 email: purnima@ece.neu.edu

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<http://www.ece.neu.edu/faculty/purnima/>

LONG-TERM GOALS AND OBJECTIVES

To understand and characterize acoustic clutter and background reverberation in long range sonars operating in range-dependent continental shelf environments. Develop operational and signal processing techniques to distinguish biological or geological clutter from scattered returns due to man-made targets. In the second area, the dominant causes of fluctuation in measured acoustic signals is examined and used to determine the extent to which environmental variabilities limit our ability to perform source localization and environmental parameter estimation through match-field processing and beamforming in fluctuating ocean waveguides.

APPROACH

The approach combines analysis of experimental data acquired using a long range sonar system with development of theoretical physics-based multi-static scattering and reverberation models. The acoustic data analysed in this proposal are from the Geoclutter 2001 and 2003 experiments on the New Jersey Strataform.[1,2] In Sep. 2006, we acquired another brand new set of acoustic data with a long range sonar on Georges Bank in the Gulf of Maine. Our approach involves the following.

- Identify and determine the dominant sources of scattering and reverberation in continental shelf environments
- Correlate scattered field levels with physical and acoustic properties of the scatterer.
- Develop models for target scattering and environmental reverberation in fluctuating, dispersive, and range-dependent continental shelf environments
- Develop inverse methods for estimating properties of objects from their scattered fields.
- Develop signal and image processing methods to distinguish man-made targets from biology and other features in the environment.

WORK COMPLETED AND RESULTS

1. Design and Conduct of OAWRS Experiment 2006 on Georges Bank

We designed and conducted a major ocean acoustics waveguide remote sensing (OAWRS) experiment off the Gulf of Maine from Sep 18 to Oct 7, 2006. The experiment involved coordinating resources, personnel and equipment on board 4 research vessels. A low frequency long range active sonar was

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deployed to instantaneously image vast areas near and on Georges Bank spanning over 100 km in diameter. The Gulf of Maine is a complex continental shelf environment with regions that contain both gradual as well as significant bathymetric relief. The preliminary findings of the experiment are as follows.

- The majority of strong scattered returns were found to be both temporally and spatially varying and were attributed to fish. The nature of the scattered returns depended on the fish species. Discrete and highly localized (target-like) scattered returns from smaller dense fish groups, as well as congregations of a massive shoal were observed on Georges bank. Concurrent echosounding measurements with conventional downward directed fish-finding sonar confirmed the presence of fish in these locations. Trawl measurements in the massive shoal areas indicated the fish were mostly Atlantic herring known to spawn on Georges Bank at this time of the year. We tracked the migration of the herring shoal over a period of 10 days covering the diurnal cycles for fish behaviour over this time. The schools were usually highly dispersed in the day time raising the overall background levels in the sonar imagery. In the evenings, we observed the schools getting more concentrated leading to stronger scattered returns. The schools were also observed on certain days to migrate upwards from waters deeper than 200 m to the shallow waters of George's Bank around 50 to 100 m to spawn.
- The scattering from fish was found to be dependent on the imaging frequency of the long range sonar. Some fish were found to return higher scattered fields at around 400 Hz than at an octave higher at roughly 1 k Hz. The herring for instance gave stronger returns at 1 kHz than they did at 415 Hz in general.
- There were several scattered returns that were observed to be temporally and spatially stationary over the 10 day measurement period. Some of these returns could be correlated to geologic features such as the Linden-Kohl Knolls and the Howell Swell in the Gulf of Maine. Origin of some of the other stable scattered returns are yet to be identified.
- The main findings from the current experiment on the Gulf of Maine is consistent with the findings of the Geoclutter program that the dominant scatterers for long range sonars in shallow continental shelf environments devoid of bathymetric relief are schools of fish.
- Extensive modelling of transmission loss [3] and sea bottom reverberation [3,4,6] in the highly range-dependent environment of Georges Bank were conducted prior to and during the experiment using the parabolic equation approach. During the experiment, the daily XBT and CTD measurements were used to derive the sound speed profile in the water column and used as inputs in the numerical models. These results were used to guide the design of the experiment in the choice of source and receiver locations and depths. The geometry of the measurement setup were selected to enhance imaging of fish by maximizing the field incident on and subsequently scattered from fish and also simultaneously minimizing the reverberation from the environment.
- We also observed close to a hundred pilot whales on Sep 21 and 22 on Georges bank and made recordings of the whale calls. The pilot whales call were of several kHz frequency range. Also recordings of humpback whales below 1 kHz range were continuously recorded during the experiment.
- We expect to spend the next one year analyzing this data set to make estimates of the population of herring imaged with OAWRS. We will investigate the nature of the scattered returns from both

biology and geology in the Gulf of Maine. We will also work on deriving approaches that can be used in Naval operations to distinguish fish returns from those of man-made targets.

2. Development of a calibrated Rayleigh-Born sea bottom volume reverberation model for range dependent continental shelf environments

A theoretical and numerical model for reverberation due to volume inhomogeneities in the sea bottom based on Green's theorem is currently under development. [3,4,5,6] The expected reverberation intensity in this model depends on the statistical moments of the fractional changes in compressibility and density, which scatter like monopoles and dipoles respectively, and the coherence volume of the inhomogeneities. The model is being calibrated using data acquired with a long range sonar on the New Jersey continental shelf during the 2001 and 2003 acoustic experiments of the ONR Geoclutter Program. An approach for distinguishing moving clutter from statistically stationary background reverberation in long range sonar imagery has been developed. [5,6] Geoacoustic parameters needed for the calibration are either derived from previous geophysical surveys of the region or estimated from reverberation data. The numerical reverberation model employs the Navy standard range-dependent propagation model based on the parabolic equation, RAM, and can be readily incorporated into current Navy systems.

3. Empirical and theoretical determination of the fluctuation and range-dependent degradation in the match filtered output for broadband acoustic data

Match-filtering or pulse compression is a technique frequently used to process broadband ocean-acoustic signals in order to improve the temporal resolution and signal-to-noise ratio of a sonar system. Understanding the degradation in the match-filter output is essential for accurately calibrating transmission loss in the environment and for making reliable estimates of target properties, such as scatter strengths of objects and abundances of fish schools, from their scattered fields. During the Geoclutter 2003 experiment, short duration broadband pulses with 50 to 150 Hz bandwidths in the 300 Hz to 1.5 kHz frequency range were transmitted at 50 s intervals from a vertical source array at varying ranges from the receiver. The broadband transmission data has been processed in a variety of ways; by Parseval's sum, match-filter, and as an instantaneous single frequency transmission. Our analysis shows that the Parseval sum and match-filter outputs for the direct arrival have significantly smaller standard deviations of 3 to 4 dB compared to the 5.6 dB standard deviation of the instantaneous single frequency transmission, as shown in fig. 1. The ping to ping fluctuations in the measured acoustic data are a result of changes in the waveguide modal interference structure due to both motion of the array and presence of time-dependent random internal waves. We also calibrated the degradation in the match-filter output over range and find it to be approximately 0.1dB/km on average for the New Jersey Strataform site. We will account for these observations by developing statistical models for the broadband acoustic data and by modeling the broadband acoustic propagation in both a static waveguide and a fluctuating waveguide using Monte-Carlo simulations. [7] This analysis will also be extended to the scattered field from fish and the calibrated BBN targets, as well as environmental reverberation. Previous work in this area was focused on instantaneous or time-averaged narrowband transmission data. [8,9,10]

4. Tracking fish motion and behavior with acoustic flow

A potential approach for distinguishing scattering from man-made targets and that from biology in long range active sonar imagery is to examine the spatial distribution of the scattered returns and track their evolution in time. Here, we explored the approaches for tracking both large shoals and smaller

isolated fish groups over space and time from images of fish population density acquired during the Geoclutter 2003 experiment on the New Jersey shelf. [11] One method uses density thresholds to segment coherent population centers and track their centroids. These data are then used to compute differential velocities between population centers and to determine the rate at which information may be transmitted across a population center. We also examining the possibility of applying optical flow concepts from machine vision [12] as a global approach for estimating fish velocity at every pixel in the fish density image. The analogous acoustic flow is computed based on changes in acoustic intensity over space and time. Acoustic flow automatically tracks fish motion within a school or shoal and migration across fish bridges connecting shoals segments. [8] We also investigate the possibility of using acoustic flow for navigating the ocean environment and correcting for errors in charting acoustic returns, for instance caused by array-heading sensor.

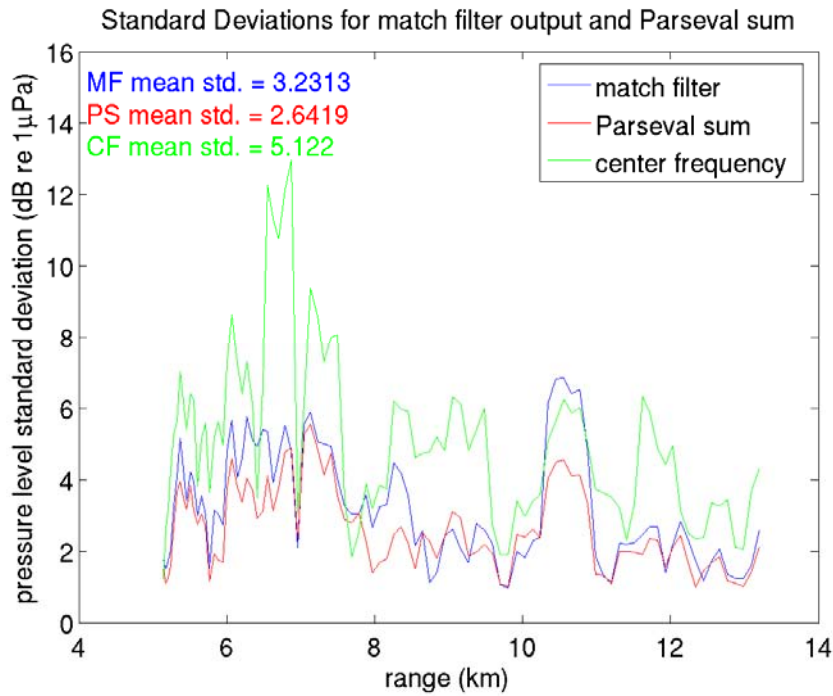
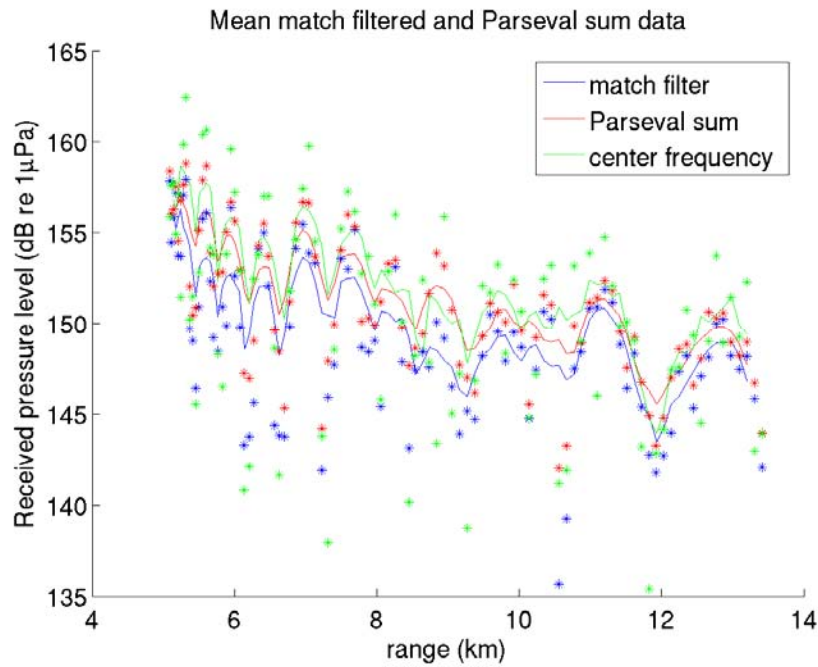


Figure 1: Statistics of broadband acoustic data from 390 to 440 Hz propagated from a stationary source to a receiver moving at 2 m/s through the ocean waveguide on the New Jersey Strataform. The Parseval sum obtained by integrating the signal energy over the 50 Hz bandwidth has the smallest fluctuation as compared to the output of the match-filter and the center frequency.

IMPACT/APPLICATIONS

We have demonstrated that the dominant source of both target and non-target like clutter that can either confuse or camouflage returns from an underwater vehicle in general continental shelf areas is fish.

RELATED PROJECTS

Research on several of the areas listed above are being conducted in collaboration with Nick Makris and his team at MIT. The results of this research also supports the National Oceanographic and Partnership Program (NOPP) on fish sensing and imaging.

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HONORS/AWARDS/PRIZES

PI awarded the 2006 Bruce Lindsay Award by the Acoustical Society of America.