Environmental Effects on High-Frequency Seafloor Scattering Statistics

Anthony P. Lyons
The Pennsylvania State University
Applied Research Laboratory, P.O. Box 30
State College, PA 16804-0030
phone: (814) 863-9895 fax: (814) 863-8783 email: apl2@psu.edu

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LONG-TERM GOALS

The long-term goals of this research program are to determine and characterize the causes of clutter in the output of high-frequency sonar systems operating in shallow water areas that have spatially heterogeneous seafloors and to link a statistical characterization of returns to the environment through models.

OBJECTIVES

Future mine-hunting sonars will be higher in frequency and broadband and therefore much higher in resolution. Heavy-tailed scattered amplitude distribution functions (acoustic clutter) will be one of the primary factors limiting the performance of these types of MCM hunting and classification sonar systems in shallow water.

The specific objectives of this project are:

1. Through analysis of experimental data and modeling, determine the primary causes of clutter observed in high-frequency sonar systems in shallow water.
2. Develop methods for characterizing, modeling and predicting the effects of clutter on current and future MCM systems.
3. Define an adaptive strategy to a given environment for mitigating the effects of clutter on mine hunting systems.

APPROACH

The objectives of this project are being achieved through a combination of at-sea measurements and modeling primarily at frequencies between 30 and 300 kHz. Data sets consist of high-frequency oblique incidence acoustic measurement taken during various high-frequency SACLANT Undersea Research Centre (SACLANTCEN) experiments (such as CLUTTER03 – May 2003) as well as during the MAPLE multi-sensor fusion experiment (Chief Scientists: E. Pouliquen and M. Trevorrow) which was part of a Joint Research Project (JRP) between SACLANTCEN and Defense Research and Development Canada (DRDC) that took place in June 2001. Ground truth for the high-frequency scattered amplitude variability component of these experiments consisted of a combination of digital seafloor stereo photography, high-resolution side scan sonar records and sediment grab samples, which are being examined to determine the causes of non-Rayleigh reverberation at high frequency and

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14. ABSTRACT
The long-term goals of this research program are to determine and characterize the causes of clutter in the output of high-frequency sonar systems operating in shallow water areas that have spatially heterogeneous seafloors and to link a statistical characterization of returns to the environment through models.

15. SUBJECT TERMS

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where possible to quantitatively estimate the heterogeneity of seafloor properties, e.g., patch sizes, composition, etc.

The data from these experiments are providing images and data for forming and testing hypotheses on the causes of clutter, for characterizing and formulating a connection with environmental factors (geological/biological patchiness) and for exploring the dependence of clutter on system characteristics such as frequency, incidence angle or pulse length. A variety of areas with more complicated bottom properties such as with shellfish, sea grass, or rocks, were found during the experiment. The diversity of sites studied allows an excellent opportunity to examine the statistics of scattering from a wide variety of extreme seafloor environments in terms of acoustic clutter.

WORK COMPLETED

Based on initial background study and examination of bottom photographs of heterogeneous seafloors taken during the SACLANTCEN/DRDC(CA) JRP experiment, undertaken to determine the various causes of non-Rayleigh envelope distributions (clutter) in shallow water, a second JRP clutter experiment, CLUTTER03 was planned. This experiment took place at Elba Island, Italy and was designed to test new ideas and models that have be developed over the past year in conjunction with Doug Abraham. Sites with both discrete scatterers and patches of scatterers were examined using calibrated acoustic systems with frequencies from 30 – 300 kHz. These data are being examined to see if the angular and frequency changes in the scattering statistics arising from the scattering physics can be predicted by models which take into account patchiness in seafloor scattering properties often found in shallow water areas.

In continuing collaboration with Doug Abraham, predictive models for the statistical distribution of the envelope resulting from over-resolution (in terms of the sonar resolution cell size) have been developed. This work is based on the patch-scattering model developed last year which links environmental parameter to the final statistical distributions and which has been favorably compared to the high-frequency acoustic data. Two additional studies listed in the publications section of this document are related to determining the properties of scattering patches important to the patch scattering model using X-ray computed tomography and to predicting the scattered returns from patches of shell hash found in many places including sites off of Panama City. Sample results of this scattering model are presented in the next section. Also underway are initial discussions with with APL/UW on incorporating a statistical component into the 2004 follow-on experiment to the 1999 SAX99 high-frequency acoustic scattering experiment.

RESULTS

Local hydrodynamic or biological influences often produce seafloors in shallow water that consist of differing types of material. The scattering properties from the components of these kinds of seafloors may have a complicated relationship in terms of their frequency dependence and/or angular response. Consequently, this relationship directly influences the angular and frequency response of the scattered envelope distributions. The probability distribution function (PDF) for a scattering scenario such as this is not easy to obtain analytically. However, a recently developed model for a patchy seafloor with a single dominating component allows for numerical analysis of the envelope PDF for more complicated seafloors. An important component of this model is the acousic response of seafloor patches with strong scattering such as shell hash material. A model for this type of material is lacking and has been developed for input into the patch scattering model. Results are given below.

A simulation of the total backscattering strength versus grazing angle for a sandy shell filled sediment is presented in Fig. 1. The solid line on the figure represents the total scattering strength, the dash-dotted line the component due to interface roughness, and the dotted line shows volume scattering component due to the shell piece distribution. The top panel in the figure shows the simulation predictions for a frequency of 20 kHz while the lower panel shows predictions for 100 kHz. Volume scattering due to the shell pieces is very low at 20 kHz and contributes very little to the total scattering strength. At 100 kHz and above the critical angle (approximately 30^o), scattering from the shell hash contributes up to 4 dB, an amount that should be observable in experimental data. Simulations of scattering strength as function of frequency are presented in Fig. 2 for 20^o (top) grazing angle and 40^o grazing angle (bottom). Below the critical angle, the volume scattering component is extremely small and doesn't appreciably contribute to the total scattering strength due to the lack of penetration for the range of frequencies studied in this paper. Above the critical angle however and above approximately 60 kHz the volume scattering contribution dominates that due to the interface.

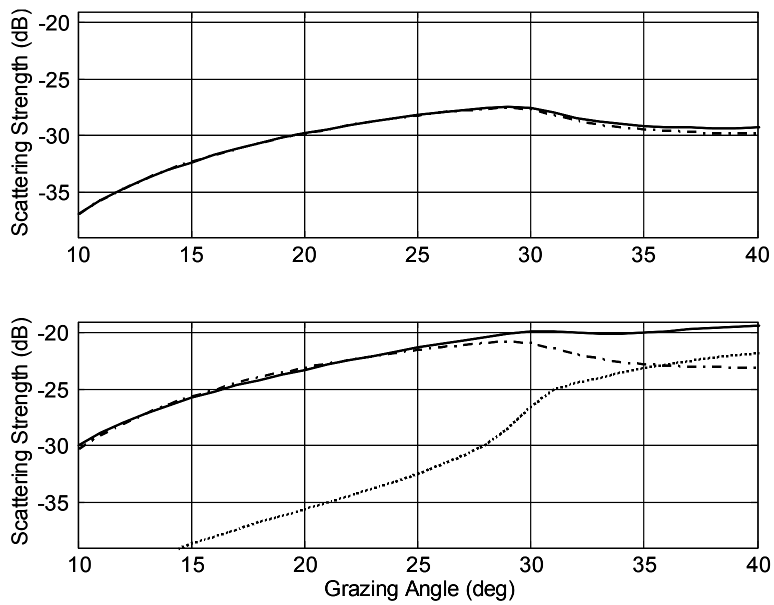

Figure 1. Predicted volume (dotted line), interface (dash-dotted line) and total scattering strength (solid line) versus grazing angle at 20 kHz (top) and 100 kHz (bottom).

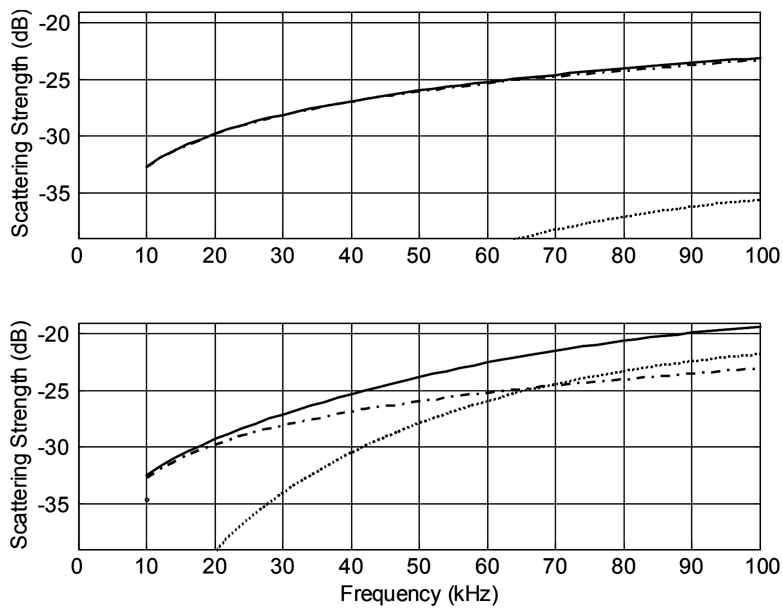

Figure 2. Predicted volume (dotted line), interface (dash-dotted line) and total scattering strength (solid line) versus frequency at 20^o (top) and 40^o grazing angle (bottom).

IMPACT/APPLICATIONS

This research is providing an improved understanding of the link between environmental parameters and system factors in causing clutter, as well as models and methods for characterizing, predicting and mitigating clutter. This study is leading to methods for modeling and predicting acoustic clutter that may be used to minimize the negative impact of clutter on detection and classification of targets on or near the seafloor in shallow water. Knowledge gained will help in the development of reverberation simulation tools, adaptive systems for sonar clutter reduction and methods for rapid environmental assessment techniques for estimating the strength of clutter for a given area

TRANSITIONS

The statistical models of clutter that have been explored and developed over the past year are being quickly incorporated into the ARL-PSU Technology Requirements Model (TRM), a high fidelity, physics-based digital simulator for evaluating dynamic engagements and torpedo defense studies. A compound model, namely the K-distribution, which has had success in the modeling of radar clutter and sonar reverberation at a variety of frequencies and scales, is being implemented as a statistical model for clutter. Additionally, a more generic model, (based on the results of the project reported in this annual report) which links a physical description of the environment (e.g., densities of scatterers, clustering of scatterers, scattering strength of scatterers, etc.) to scattering statistics via K-distribution parameters is being examined for inclusion into TRM. This relationship will allow efficient simulation of false alarms and false targets for many different scenarios for which experimental data do not exist.

RELATED PROJECTS

A related ONR project is Characterizing and Modeling the Torpedo Clutter Environment managed by David Drumheller, code 333.

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HONORS/AWARDS/PRIZES

Anthony P. Lyons, The Pennsylvania State University, A.B. Wood Medal, Institute of Acoustics, United Kingdom.