Statistics of High Frequency Acoustic Boundary Scattering and Vector Ambient Noise Fields

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Grant Number: N00014-04-1-0013

LONG-TERM GOALS

The long-term goal of the present high-frequency scattering statistics work is to examine the links between environmental parameters of shallow water boundaries and the statistics of high frequency, broadband acoustic fields using a combination of at-sea measurements, ground truth and theoretical modeling. The influence of the properties of the boundaries to the scattered envelope statistics and noise fields will be examined in detail. The proposed project is designed to (1) examine experimental acoustic data to determine how environmental properties (e.g. roughness or bubble clouds) influence statistical distributions obtained with broadband, acoustic systems in shallow water including SAS and vector sensor systems; (2) test current models or develop models where none exist which link measured environmental parameters (e.g. roughness, bubble distributions) and system characteristics (e.g. bandwidth, frequency) to predict these statistics in realistic shallow-water ocean environments. The proposed effort will lead to methods for modeling and predicting properties that may be used to minimize the negative impact of the environment on: 1) detection and classification of targets on or near the seafloor in shallow water; and 2) processing of data taken with vector sensor arrays.

OBJECTIVES

The importance of the present work lies in the ability to link scattered envelope distributions to measurable environmental properties such as seafloor patch size, composition or roughness. In conjunction with sonar system parameters, this link will provide the foundation necessary for solving several important problems related to the SAS detection of targets. The direct link between system and environmental parameters via scattering models to the statistical distributions will allow: performance prediction for different systems based on environmental properties, extrapolation of performance to other system/bandwidths, and optimization of sonar parameters to the local environment. Concisely the project objectives are:

1. Through analysis of experimental data and modeling, determine the frequency, bandwidth and grazing angle dependence of seafloor and sea surface scattered amplitude distributions observed in high-frequency sonar systems operating in shallow water.

2. Using ground truth and scattering models, develop methods for predicting the effects on current and future high bandwidth sonar systems.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30 SEP 2009	**Annual**	**00-00-2009 to 00-00-2009**

4. TITLE AND SUBTITLE
Statistics Of High Frequency Acoustic Boundary Scattering And Vector Ambient Noise Fields

5a. CONTRACT NUMBER

5b. GRANT NUMBER

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
The Pennsylvania State University,Applied Research Laboratory,P.O. Box 30,State College,PA,16804

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

13. SUPPLEMENTARY NOTES
Code 1 only

14. ABSTRACT
The long-term goal of the present high-frequency scattering statistics work is to examine the links between environmental parameters of shallow water boundaries and the statistics of high frequency, broadband acoustic fields using a combination of at-sea measurements, ground truth and theoretical modeling. The influence of the properties of the boundaries to the scattered envelope statistics and noise fields will be examined in detail. The proposed project is designed to (1) examine experimental acoustic data to determine how environmental properties (e.g. roughness or bubble clouds) influence statistical distributions obtained with broadband, acoustic systems in shallow water including SAS and vector sensor systems; (2) test current models or develop models where none exist which link measured environmental parameters (e.g. roughness, bubble distributions) and system characteristics (e.g. bandwidth, frequency) to predict these statistics in realistic shallow-water ocean environments. The proposed effort will lead to methods for modeling and predicting properties that may be used to minimize the negative impact of the environment on: 1) detection and classification of targets on or near the seafloor in shallow water; and 2) processing of data taken with vector sensor arrays.

15. SUBJECT TERMS

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			
unclassified	**unclassified**	**unclassified**	**Same as Report (SAR)**	**8**	

3. Define adaptive strategies to a given environment for mitigating the effects if the environment on sonar systems.

4. Collect vector active source and ambient noise data using vector sensor in a variety of environmental conditions.

APPROACH

Experimental studies designed to link models of amplitude statistics to scattering models in order to improve predictive capabilities for high-frequency acoustic systems operating in shallow water areas are lacking. This research program will attempt to characterize the frequency and grazing angle dependence of clutter in the output of high-frequency sonar systems operating in shallow water and link the statistical characterization of returns to the environment through models which will aid in the prediction of environmental effects on future MCM acoustic systems. These goals will be achieved through a combination of at-sea measurements and modeling primarily at frequencies between 20 and 200 kHz. Experimental acoustic data sets will consist of high-frequency narrow and broadband single beam collected as part of a Joint Research Project (JRP) with the NATO Undersea Research Centre (NURC), multi-beam data collected recently by ARL at Seneca Lake, as well as Synthetic Aperture Sonar (SAS) on a rail data that has been collected by the Applied Physics Lab–University of Washington (APL-UW) as part of the SAX04 experiment and SAS data provided by NSWC-Panama City.

In order to measure vector ambient noise fields, two orthogonal arrays of vector sensors will be deployed within the shallow water environment of AUTEC, Andros Island for a long term study of the acoustic ambient noise intensity as related to weather and waves. The long deployment period (8-12 months) will also allow for multiple opportunities to gather data sets with active sources and on isolated AUTEC vessel traffic (harbor security), as well as to investigate the ability to utilize surface generated noise to study the geo-acoustic characteristics of the ocean bottom. Deployment at AUTEC is unique in that there is no local industry, commercial traffic or significant sources of anthropogenic ambient noise in the 50Hz to 6 kHz region thereby allowing this study to provide baseline performance information on the natural characteristics of acoustic intensity fields in shallow water.

WORK COMPLETED

Work was completed this year on analysis of Synthetic Aperture Sonar (SAS) data acquired from the Applied Physics Laboratory -University of Washington during the ONR sponsored SAX04 experiment and SAS data obtained from NSWC - Panama City. Both of these data sets contributed to our understanding of non-Rayleigh envelope distributions and speckle as a function of the resolution of these high-frequency imaging systems and to furthering the development of predictive models of the image statistics. We specifically looked at how SAS image statistics depend on range and cross range resolution for seafloors where the seafloor acoustic response is anisotropic due to sediment ripples. The effect on SAS image statistics of ripple-induced amplitude variations was also examined; sample results of which are given below. The usefulness of techniques used in Synthetic Aperture Radar, such as multi-look processing, have also been explored. A student, Shawn Johnson, was involved with this work and has now graduated with a Ph.D. in Acoustics. Shawn is currently at the Applied Physics Laboratory – Johns Hopkins University and continues to work on related topics.

Initial analysis was begun for data collected at AUTEC on arrays consisting of Wilcoxon TV-001 vector sensors. The arrays, were in place from June to October, 2008. The sensors were placed in the form of a 'T' shape and were mounted on a tripod assembly with a $\lambda/2$ spacing at 3kHz or approximately 25cm. The sensor system was deployed at a height of 2 meters off the bottom in approximately 20 m of water. Data was acquired for 2 minutes, each hour, 24 hours a day using a 32 channel Nicolet Liberty data acquisition system and for 5 minutes, once a day for subsets of sensors in the array. AUTEC maintains a continuously operating wind/weather station that is less than 700 meters from the deployment area. This station's data is relayed through an existing RF network to a shore computer whose database is continually updated.

RESULTS

The characterization and modeling of synthetic aperture sonar (SAS) image statistics is of importance for developing target-on-background detection and classification algorithms and for developing specialized filters for speckle noise reduction. In the work completed this year, we developed a simple model to predict the impact of amplitude scaling caused by seafloor ripples on SAS image speckle statistics. The continuous variation in scattering strength produced by ripples (i.e., ripple-induced changes in seafloor slope) is treated as deterministic amplitude scaling on image speckle produced by the SAS imaging process. Changes in image statistics caused by ripples are quantified in terms of an effective K-distribution shape parameter. As will be shown in the following sample results, agreement between shape parameter estimated from the scaling model and from SAS data collected in experiments off Panama City, Florida and off the Liguria coast near La Spezia, Italy illustrate the efficacy of the model.

In order to test the scaling model we required estimates of shape parameter for the speckle component alone, α_0. The high-resolution of both data sets with respect to the ripple sizes (2 - 5 cm SAS resolution versus 60 - 100 cm ripple wavelength) allowed the underlying ripple-induced variations to be removed from the original SAS image data leaving only speckle. The larger-scale ripple features in the data were removed using a 2-dimensional CFAR normalizer. Figure 1 displays the underlying ripple background and the separated image speckle for the Liguria, Italy SSAM data. Using the speckle shape parameter and ripple dimensions as input, comparisons will be made between model results of effective shape parameter, α_1, and shape parameter estimated from the original data (which includes both ripple and speckle variations).

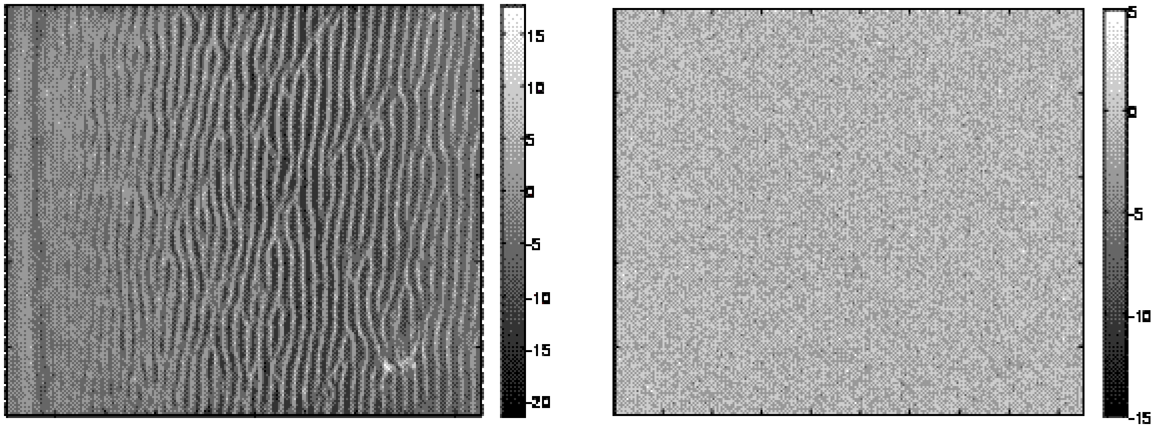

Figure 1. The larger scale underlying ripple caused amplitude variation (left) and the image speckle (right) separated via a 2-dimensional CFAR normalizer for the SSAM Liguria, Italy data set.

Figure 2 displays model results of effective shape parameter as a function of speckle shape parameter for various sample ripple shapes. As the ripple slopes are the same for the two experimental sites, model results are identical on Figure 2. It can been seen on this figure that the effective shape parameter tends to an asymptotic value for speckle shape parameters greater than about 10 and holds even for Rayleigh distributed speckle (i.e., as α_0 approaches infinity). It is also immediately obvious on this figure that although the $\cos^4$ ripple shape is the most non-Rayleigh (lowest shape parameter), it is still very close to the cosine and the Stokes ripple shape results.

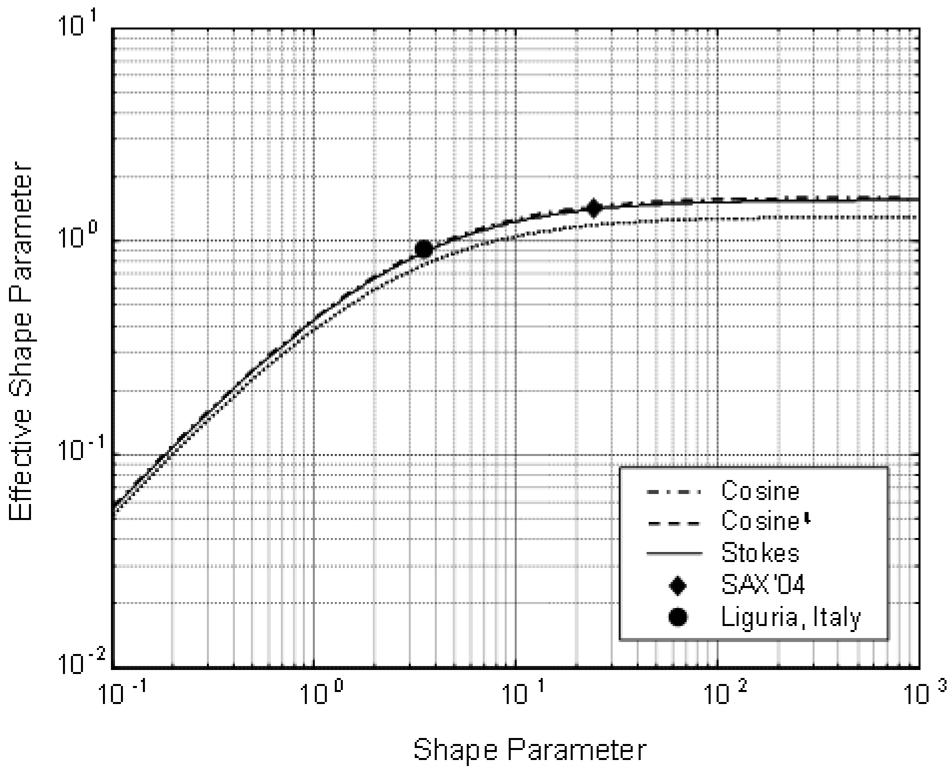

Figure 2. Effective K-distribution shape parameter as a function of speckle shape parameter for ripples of various shapes. The filled diamond and circle included on the plot show sample experimental data.

For α_0 smaller than 10 it may be possible to infer α_0 from SAS data given an estimate of ripple height and wavenumber only regardless of shape. As stated previously, α_0, a measure of speckle statistics, could be tied to other possible mechanisms affecting it such as small scale roughness or water column turbulence. Data points representing the SAX04 and SSAM Liguria Sea data are also shown on Figure 2. The agreement of the data with model predictions is very good.

The predicted effective shape parameter will be a function of the amplitude difference between the maximum and minimum slope of the ripple. If we assume the scattered amplitude differences due to slope changes are approximately piecewise linear for each mean angle we can estimate the effective shape parameter as a function of mean angle (or equivalently range). Using Lambert's Law (or any seafloor scattering model) this assumption would only be valid for grazing angles approaching and exceeding approximately 30^o if the range of relative angles with respect to the mean angle caused by the ripple slopes is small. While not strictly valid for the parameters we are using for the ripples in our case, we can get a feel for the effects on effective shape parameter of the shape of the scattering cross section as a function of angle (or equivalently as a function of range for a fixed system height).

Figure 3 shows a comparison between experimental estimates and model predictions of effective shape parameter versus range for the SSAM Liguria Sea data. A sliding window 2.5 m wide in range is used in making the shape parameter estimates. The model predictions use the same ripple parameters as before, the estimated speckle shape parameter of 3.4, and a system height of 5 m. The effective shape parameter is seen to decrease as a function of range (i.e., increase as the mean grazing angle increases from approximately 11^o at 25 m range to approximately 26^o at 10 m range). The model matches the data well except for the closest ranges (steepest angles) possibly due to violation of the linearity assumption mentioned previously and beyond approximately 19 m range due to the appearance at these low angles of ripple shadowing effects which serve to increase the variance in the data. It should be noted that it is not the underlying speckle statistics that are causing the overall decrease in the effective shape parameter versus range; it is the increasing slope of the scattering cross section at further ranges (smaller mean grazing angles). Model results for ripple heights of 0.015 m, 0.025 m and 0.035 m, showing the sensitivity of the result to ripple height are also shown on Figure 3. This sensitivity might allow ripple height to be easily inverted from SAS image data.

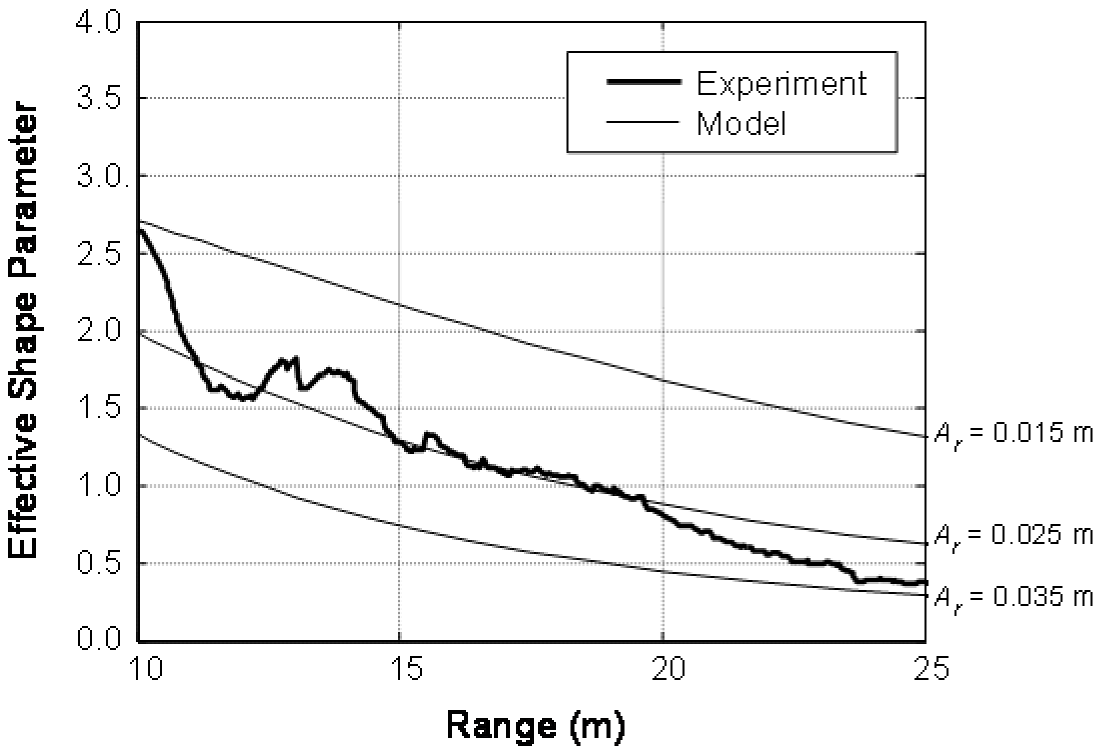

Figure 3. Experimental and model estimates of effective shape parameter as a function of range. Model results are shown for ripple amplitudes, A_r, of 0.015 m, 0.025 m, and 0.035 m.

IMPACT/APPLICATIONS

The scattering statistics research is providing an improved understanding of the link between environmental parameters and system factors in causing clutter in high-frequency imaging systems. 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 simulation tools, adaptive systems for sonar clutter reduction and rapid environmental assessment techniques for estimating the strength of clutter for a given area.

The study of the response of vector sensors to both active sources and noise fields has implications for the operation of future vector sensor sonar systems and methods used by the Navy. This study will lead to improved methods for modeling vector fields.

TRANSITIONS

The statistical models of clutter that have been explored and developed are being incorporated when possible into the ARL-PSU Technology Requirements Model (TRM), a high fidelity, physics-based digital simulator. Discussions are also under way to include models into simulations of Synthetic Aperture Sonar being developed at NSWC-Panama City. Vector sensor studies will yield guidance for future navy using arrays of these types of sensors.

RELATED PROJECTS

A related ONR project (Grant N00014-06-1-0245) is Characterizing and Modeling the Torpedo Clutter Environment managed by David Drumheller, code 333. Items were purchased for this project under a DURIP (Grant N00014-04-1-0445).

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