

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

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Award 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 system parameters such as frequency/bandwidth 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*

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1. REPORT DATE <b>30 SEP 2008</b>		2. REPORT TYPE <b>Annual</b>		3. DATES COVERED <b>00-00-2008 to 00-00-2008</b>	
4. TITLE AND SUBTITLE <b>Statistics Of High Frequency Acoustic Boundary Scattering And Vector Ambient Noise Fields</b>				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) <b>The Pennsylvania State University, Applied Research Laboratory, P.O. Box 30, State College, PA, 16804-0030</b>				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 <b>Approved for public release; distribution unlimited</b>					
13. SUPPLEMENTARY NOTES <b>code 1 only</b>					
14. ABSTRACT <b>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.</b>					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT <b>Same as Report (SAR)</b>	18. NUMBER OF PAGES <b>7</b>	19a. NAME OF RESPONSIBLE PERSON
a. REPORT <b>unclassified</b>	b. ABSTRACT <b>unclassified</b>	c. THIS PAGE <b>unclassified</b>			

3. Define an adaptive strategy 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 2 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.

In order to measure vector ambient noise fields, two orthogonal arrays of vector sensors will be deployed within the shallow water environment of AUTECH, 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 AUTECH 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 AUTECH 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 continued 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 are contributing to our understanding of non-Rayleigh envelope distributions as a function of the resolution of these high-frequency imaging systems and to furthering the development of predictive models of the image statistics. Ph.D. student Shawn Johnson is involved with this work. We have begun looking at how SAS statistics depend on range and cross range resolution for seafloors where the seafloor acoustic response is anisotropic due to sediment ripples. The usefulness of techniques used in Synthetic Aperture Radar, such as multi-look processing, are also being explored.

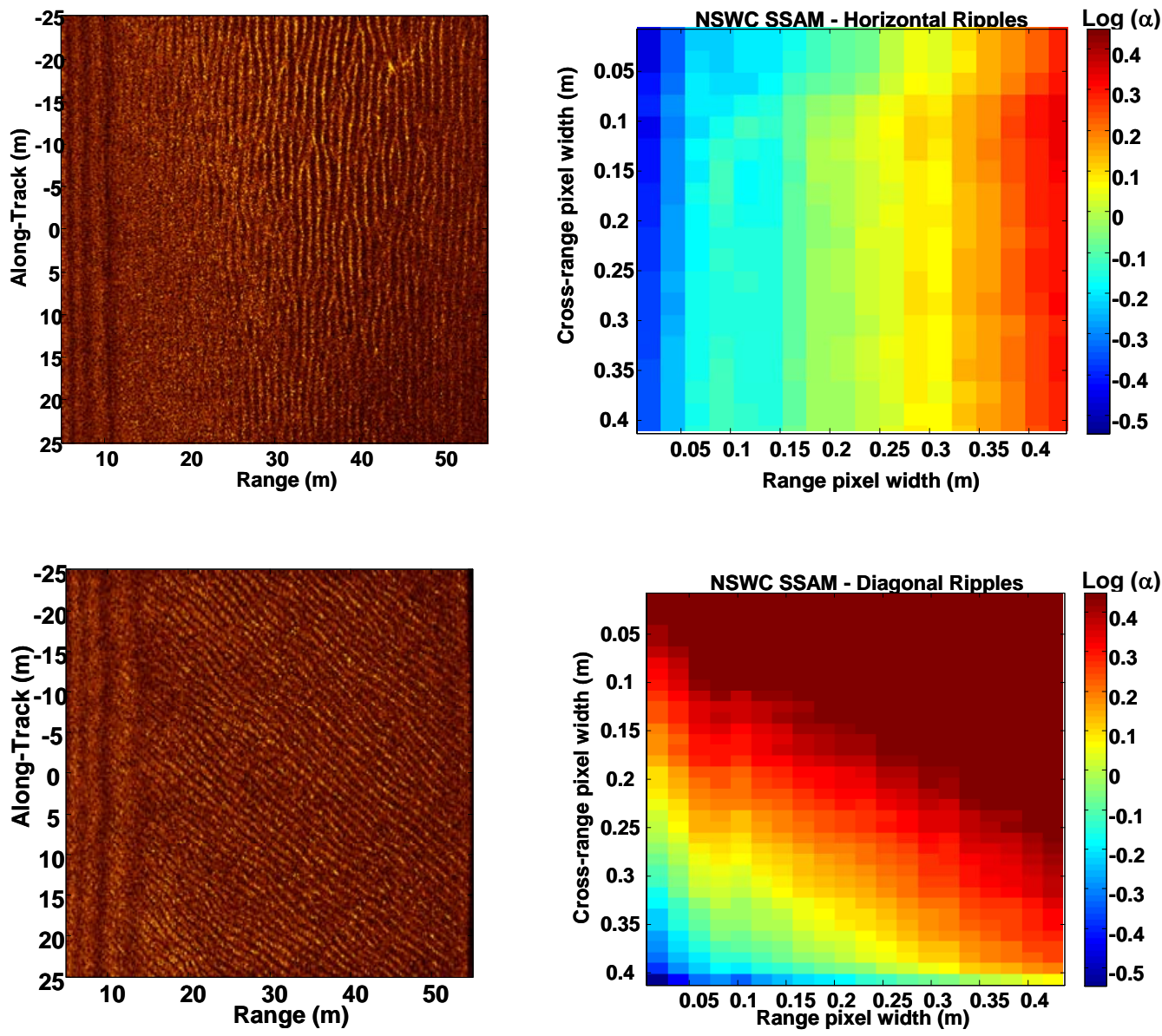
In conjunction with Dave Deveau of NUWC (Penn State Acoustics Ph.D. student), installation and initial analysis has begun for data collected on arrays consisting of Wilcoxon TV-001 vector sensors. The arrays, in place as of June, 2008, form a 'T' shape and are mounted on a tripod assembly. The sensors are placed at a  $\lambda/2$  spacing at 3kHz or approximately 25cm. The sensor system has been

deployed at a height of 2 meters off the bottom. A single 2000m length of armored electro-optical cable was run from a shore termination building to the array deployment location. The assembly was placed in approximately 20 meters water depth. Two active sources are positioned approximately 1700 m from the array. Initial tests have been performed to verify that the system is operational. Data is being 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. AUTECH 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. The environmental data will be extracted on a routine basis so that it may be correlated with the acoustic data. A directional wave-rider buoy owned by ARL-Penn State will be installed in October, 2008 and used for estimating wave heights.

The ambient noise intensity field will be estimated for each data set and then correlated to the measured weather/wave information for that time period. With this correlation, it may be possible to relate weather/wave activity to a specific intensity level versus direction. Active source data being collected will allow similar analysis on the stability of acoustic paths as a function of environmental conditions.

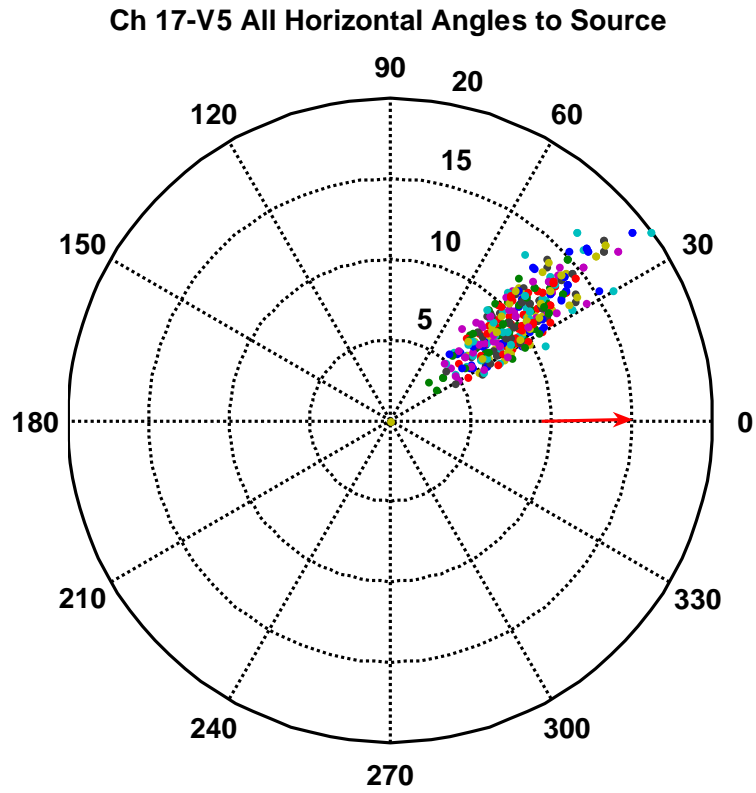
## RESULTS

Fig. 1 shows results from statistical analysis of the NSWC SSAM SAS data taken on a rippled seafloor. The shape parameter of the  $K$ -distribution was used as a metric for the non-Rayleighness of the probability distribution function (PDF) of the SAS data as a function of both along and across track resolution. The higher the shape parameter the closer to Rayleigh is the PDF. The images on the left of the figure show the SAS formed images of a rippled seafloor. On the right side of the figure are the estimates of  $\log_{10}$  shape parameter for the SAS images as a function of both along and across track resolution. Resolution is adjusted for this analysis by filtering in two-dimensional spatial frequency space. The data is very non-Rayleigh over all the resolutions bins for these two images, but do increase in level as the resolution is coarsened as seen in several previous studies. Fairly obvious in Fig. 1 is the strong correlation of the statistics with the ripple direction. This is a potentially important finding and could possibly be used as a strategy for reducing the heavy tails of the image PDF with knowledge of ripple direction, thereby increasing probabilities of detection in automated systems.

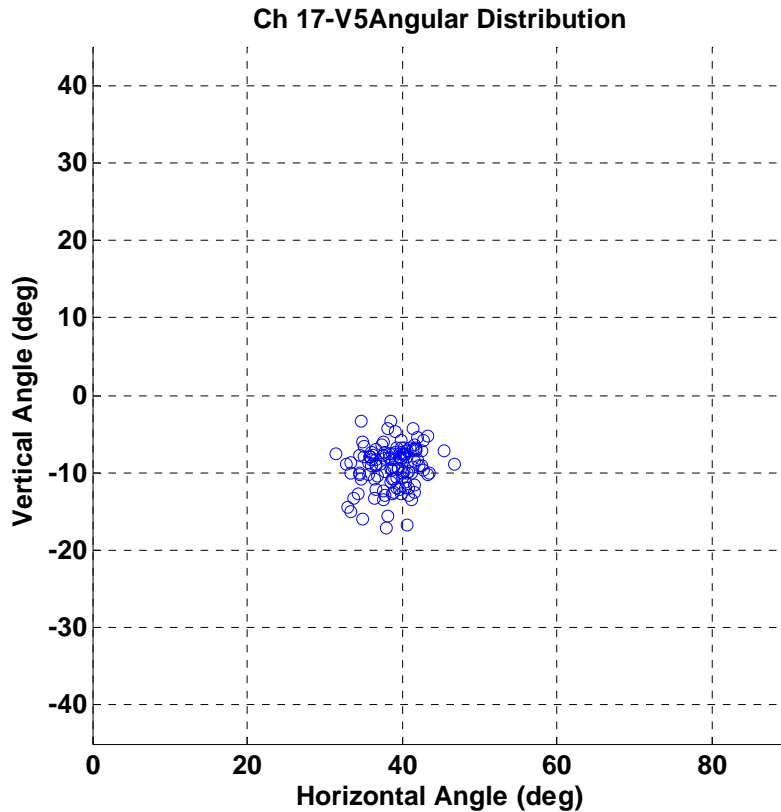


*Figure 1. Synthetic aperture sonar images of ripples fields oriented approximately parallel to the sonar track (top) and diagonally to the sonar track (bottom) and respective estimates of the  $\log_{10}$  of the shape parameter as a function of along and across track resolution.*

Figures 2 and 3 display initial tests of the vector sensor array using an active source. Fig. 2 shows the Horizontal intensity vector magnitude and direction for a series of 100 ms pulses from a 2 kHz source which is 1670 m away. The results are variable in both level and direction but are centered on the correct source direction. Fig. 3 shows the horizontal and vertical components of the intensity vector and illustrates the same variability in estimated source location. The variability in estimates of both the horizontal and vertical intensity vector components is striking and is possibly due to surface wave activity. A wave rider buoy is being installed in October, 2008 to better understand this phenomenon.



*Figure 2. Horizontal intensity vector magnitude and direction obtained on the vector sensor array and a series of 100 ms 2 kHz CW pulses. The source is at approximately 38 degrees and is 1670 m distant from the vector sensor array.*



*Figure 3. Estimated angles of the horizontal and vertical components of the intensity vector for the same source transmissions as in Fig. 2 .*

## **IMPACT/APPLICATIONS**

The scattering statistics research is providing an improved understanding of the link between environmental parameters and system factors in causing 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 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 quickly incorporated 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 by APL-UW. These models will allow efficient simulation of false alarms and

false targets for many different scenarios for which experimental data do not exist. Vector sensor ambient noise studies will yield guidance for future navy using arrays of these type 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).

## **PUBLICATIONS**

S.F. Johnson, A.P. Lyons, and D.A. Abraham, "Dependence of Synthetic Aperture Sonar Image Statistics on Resolution," in Proceedings of the International Symposium on Underwater Reverberation and Clutter, P.L. Nielsen, ed., Lerici, Italy, 9-12 September, 2008.

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