

# GOATS'2000

## Multi-static Active Acoustics in Shallow Water

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### LONG-TERM GOAL

Develop environmentally adaptive bi- and multi-static sonar concepts for autonomous underwater vehicle networks for detection and classification of proud and buried targets in very shallow water.

### OBJECTIVES

The objective of the ocean acoustics components of the GOATS project is to develop a fundamental understanding of the 3D acoustic environment associated with the mine countermeasures (MCM) problem in shallow water (SW) and very shallow water (VSW) and to develop efficient physics based propagation and scattering models incorporating aspect-dependent targets and seabed features, and the waveguide multipath effects. The goal is a consistent physics-based modeling framework for high-fidelity simulation of bi-and multistatic sonar configurations for VSW MCM. Specific scientific objectives include the investigation of mechanisms responsible for sub-critical penetration into sediments in the mid-frequency regime (1-20 kHz), the effects of sediment porosity, and the coupling between the structural acoustics of targets and the environmental acoustics of the littoral waveguides.

### APPROACH

The center piece of the research effort is the GOATS'2000 Joint Research Program (JRP) conducted by SACLANTCEN and MIT with ONR support. Building on the experience of the highly successful GOATS'98 pilot experiment (Schmidt *et al.*, 1998), the JRP combines a series of experiments, with the two major ones being planned for 2000 and 2002, and modeling and simulation work to explore the potential of autonomous underwater vehicle networks as platforms for new sonar concepts exploring the full 3-D acoustic environment of VSW. The GOATS'2000 experiment will incorporate 3-4 AUV's, two of which will be operated by MIT, one equipped with a combined side-scan/subbottom profiler, and one equipped with an 8-element acoustic array, an autonomous acquisition system and 2.4 Gflop of on-board computing power for autonomous processing and adaptive control. The first vehicle will be used as a rapid environmental assesment platform and as a bi-static source platform, which together with fixed parametric source capabilities will be used to insonify the seabed. The second AUV will be used for sampling the 3-D acoustic field either using fixed or adaptive survey patterns, and as a testbed for adaptive response to target detection.

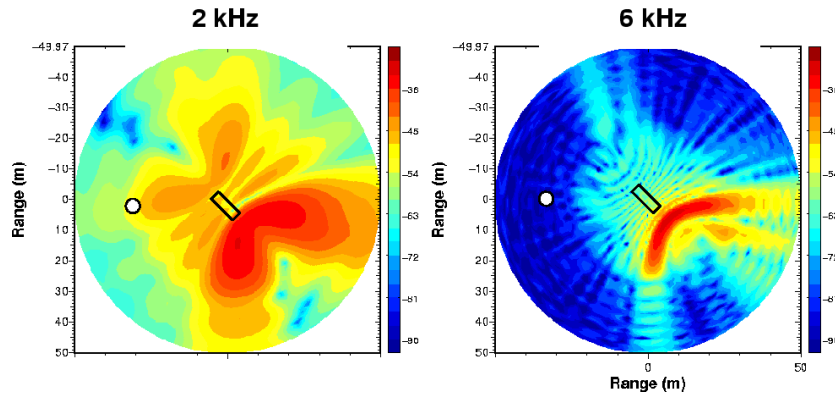
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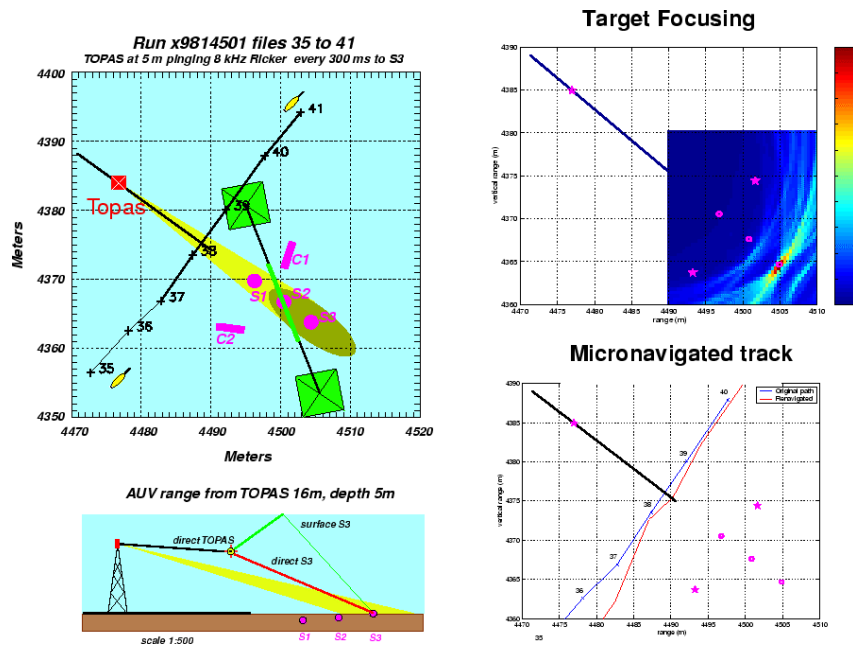
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The modeling effort is centered around the new OASES-3D capability developed at MIT (Lee 1999, Schmidt and Lee 1999). OASES-3D provides wave-theory modeling of the full 3-D acoustic environment associated with mono- and bi-static configurations in VSW with aspect-dependent targets and reverberation features. OASES-3D is being expanded to incorporate environmental acoustic features specifically associated with bi-static sonar concepts in shallow water, including aspect-dependent target models, seabed porosity, and scattering from anisotropic seabed roughness and volume inhomogeneities.

## WORK COMPLETED



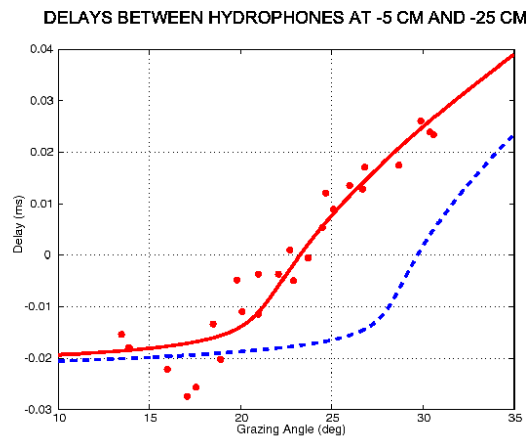
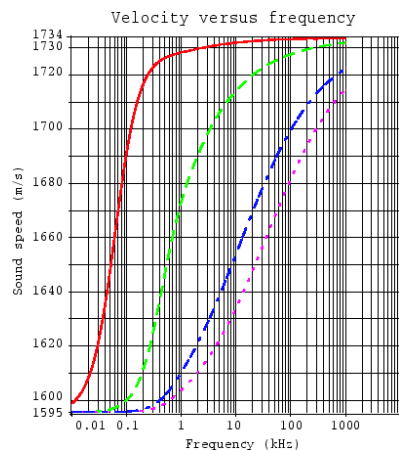
The OASES-3D target scattering and seabed reverberation model has been validated using analytical and independent numerical solutions, and extensively documented (Lee 1999). The experimental validation of the modeling framework has been initiated using the GOATS'98 dataset. A problem with the original dataset was a bias in the LBL navigation data for the AUV attributed to lack of DGPS coverage at Elba. Using a multi-path matching approach to the bi-static scattering from a strong target, we have successfully micro-navigated the AUV tracks. Also, the analysis of the GOATS'98 data has

been continuing to investigate the dominant mechanisms for sub-critical seabed penetration (Maguer *et al.* 1999).

A self-consistent theory of the three-dimensional seabed volume scattering problem has been developed and published (Tracey and Schmidt 1999). The theory has been reformulated within the Born-approximation and implemented in OASES to allow for time series simulations, initially for mono-static configurations (LePage and Schmidt 1999). This new modeling capability has been used to investigate the spectral differences between roughness and volume scattering.

On the experimental side the preparation for the GOATS'2000 experiment in Procchio Bay, Elba in Sep-Oct 2000 is well underway. An extensive environmental assessment survey of Procchio Bay will be performed using R/V Manning during a 2-week cruise in Oct. 1999. The interfacing between the AUV control computer and the acoustic acquisition system has been upgraded to allow control of the data recording either autonomously by the vehicle control or remotely through the RF or acoustic modems. In collaboration with Bluefin Robotics and Datasonics a second AUV is being equipped with a combined sidescan/sub-bottom profiling system which will be used for environmental assessment in GOATS'2000.

## RESULTS



The conclusions of earlier joint work with SACLANTCEN regarding the dominant mechanisms for sub-critical penetration into sediments has been confirmed using data recorded on the GOATS'98 buried hydrophone array, insonified using the TOPAS parametric source. Specifically the significance of the frequency dispersion in the mid-frequency regime has been confirmed. Thus, for OASES to reproduce the evanescent penetration at 2-5 kHz it was necessary to assume a much lower sound speed (~1625 m/s), than the 1720 m/s measured on cores at 200 kHz. It was shown that Biot theory could explain this dispersion. Thus, the red, green and magenta curves in the left diagram show the predicted dispersion for sand with permeabilities  $10^{-9}$ ,  $10^{-10}$ , and  $10^{-11}$  m<sup>2</sup>, respectively, clearly showing the sensitivity to this parameter. The permeability was measured directly to  $1.7 \cdot 10^{-11}$  m<sup>2</sup> on cores taken during GOATS'98, and the associated dispersion predicted by Biot theory is indicated by the blue, dashed-dotted curve, and is totally consistent with the earlier predicted dispersion. An independent estimate of the low-frequency sound-speed was achieved by measuring the relative arrival delay on one of the vertical buried arrays. The dependency of the delay on incident grazing angle is shown in the right diagram. The solid red curve shows the delay predicted theoretically assuming a sediment speed

of 1626 m/s, while the dashed blue curve shows the prediction assuming 1720 m/s as measured directly on the core, strongly supporting the conclusion that porosity-induced dispersion must be accounted for in this frequency regime for accurately predicting seabed penetration.

## **IMPACT/APPLICATION**

The long-term impact of this effort is the development of new sonar concepts for VSW MCM, which take optimum advantage of the mobility, autonomy and adaptiveness of the AOSN. For example, bi- and multi-static, low-frequency sonar configurations are being explored for buried mines in VSW, with the traditional high-resolution acoustic imaging being replaced by a 3-D acoustic field characterization as a combined detection and classification paradigm, exploring spatial and temporal characteristics which uniquely define the target and the reverberation environment.

## **TRANSITIONS**

The GOATS AUV effort has been and is conducted by the MIT Sea Grant AUV Laboratory, in part funded by this project and the AOSN MURI. A new AUV enterprise, Bluefin Robotics, is a spin-off from the MIT Laboratory, and is currently developing a new Odyssey III Battlefield Preparation AUV for ONR, building in part of experience from the GOATS'98 experiment (Schmidt *et al.*, 1998)

The 3-D acoustic models for VSW MCM environments developed under GOATS are being integrated in a multi-AUV simulation capability developed by the MIT Sea Grant AUV Laboratory and Bluefin Robotics under the ONR project (Code 321TS) "Sensor and Operational Tradeoffs for Multiple AUV MCM" (N00014-99-1-0851). Also, the simulation capability is being utilized and augmented under the ONR SBIR (code 321OE) "USBL Positioning of Littoral Swarm Systems" (N00014-97-C-0288) in collaboration with IS Robotics. The new OASES seabed reverberation modeling capability (LePage and Schmidt 1999) is the core modeling engine used by VASA Associates Inc. in the new FY00 ONR SBIR "Model-Based Beam-Time Arrival Matching" (N992-5039).

The OASES code continues to be maintained and expanded. It is continuously being exported or downloaded from the OASES web site (<http://acoustics.mit.edu/arctic0/henrik/ww/oases.html>), and used extensively by the community as a reference model for ocean seismo acoustics in general. In FY99 the user group has it particular expanded in the Far East (Japan, S. Korea, Taiwan, and Singapore), and East Europe (Hungary, Poland, Czech Rep., Russia).

## **RELATED PROJECTS**

This effort is part of the US component of the GOATS'2000 Joint Research Project (JRP) with the SACLANT Undersea Research Centre. The MIT GOATS effort is funded jointly by ONR codes 321OA (Simmen), 321OE (Swan), 321TS (Jacobson), and 322OM (Curtin).

The GOATS effort is strongly related to the ONR Autonomous Ocean Sampling Network (AOSN) initiative. Thus the GOATS'98 experimental effort was funded in part by the AOSN MURI, (PI: J. Bellingham). In terms of the fundamental seabed penetration physics there are strong relations to the High-Frequency Bottom Penetration DRI (PI: E. Thorsos). This effort also builds on acoustic modeling

efforts initiated under the Sea-Ice Mechanics Initiative (SIMI), and continued under funding from ONR code 321OA (Simmen).

With funding from the Sea Grant College program, a regional New England effort involving MIT, WHOI and URI is developing a new rigid mooring concept with GPS sensor tracking for long-term VSW acoustic experiments, e.g exploring reverberation and ambient noise statistics, and tomographic networks for littoral environments. The first scientific application concerns the spectral characteristics of seabed scattering and this work is using the new 3-D scattering models developed under this project extensively.

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