

# GOATS: MULTI-PLATFORM SONAR CONCEPT FOR COASTAL MINE COUNTERMEASURES

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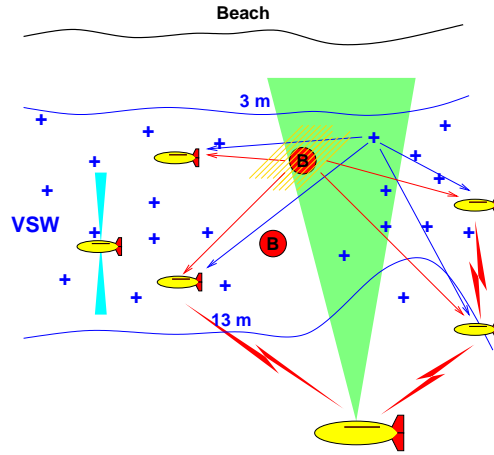
**Abstract** Recent progress in underwater robotics and acoustic communication has led to the development of a new paradigm in ocean science and technology, the Autonomous Ocean Sampling Network (AOSN). AOSN consists of a network of fixed moorings and/or autonomous underwater vehicles (AUV), tied together by state-of-the-art acoustic communication technology. The GOATS'2000 (Generic Oceanographic Array Technology Systems) Joint Research Program is aimed toward the development of environmentally adaptive AOSN technology specifically directed toward Rapid Environmental Assessment and Mine Counter Measures in coastal environments. The research program combines theory and modeling of the 3-D environmental acoustics with experiments involving AOSN and sensor technology. [Work supported by ONR and SACLANT]

**Keywords:** Mine Countermeasures, Autonomous Underwater Vehicles, Rapid Environmental Assessment, Shallow water, Sonars, Oceanography.

## 1. Introduction

Recent progress in underwater robotics and acoustic communication has led to the development of a new paradigm in ocean science and technology, the Autonomous Ocean Sampling Network (AOSN) [1]. AOSN consists of a network of fixed moorings and/or autonomous underwater

vehicles (AUV) tied together by state-of-the-art acoustic communication technology.



*Figure 1.* GOATS: Generic Ocean Array Technology Sonar concept for coastal MCM. A fleet of AUV's connected by an underwater communication network, and equipped with acoustic receiver arrays is used to measure the 3-D scattering from proud and buried targets insonified by a dedicated master AUV.

The Generic Ocean Array Technology Sonar (GOATS) concept for coastal mine countermeasures (MCM) is a derivative of AOSN specifically aimed at detecting and classifying targets on and within the seabed in very shallow water (VSW). A fleet of AUV's connected by an underwater communication network and equipped with acoustic receiver arrays is used to measure the 3-D scattering from proud and buried targets insonified by a low-frequency (1-20 kHz) projector mounted on a dedicated vehicle. The 3-D scattered field from seabed targets is target specific, and it is envisioned that by characterizing its spatial and temporal characteristics the fleet of AUV's may be capable of simultaneously detecting and classifying seabed objects. To optimally explore the acoustic signatures of the targets as classification, the bi-static sonar system should operate in the mid-frequency regime where both geometric and resonant target scattering are significant, which for meter size objects corresponds to the 1-20 kHz mid-frequency regime [2]. This relatively low active sonar frequency regime is also highly beneficial in terms of bottom penetration [3], suggesting that GOATS has significant potential for detection and classification of buried mines in very shallow water.

The potential of this new multi-static sonar concept for VSW MCM is explored as part of the GOATS'2000 Joint Research Project (JRP), a collaborative research effort between SACLANT Undersea Research

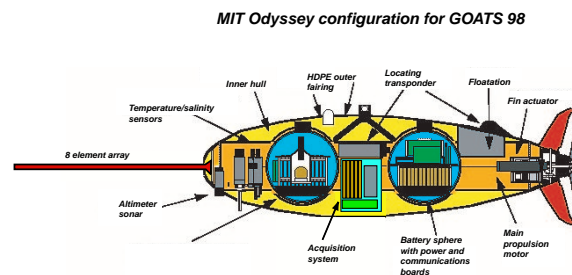
Centre, MIT, WHOI, FAU, and several other institutions in the US and Europe [4]. The central element of the JRP is a prototype underwater vehicle network operated remotely from the SACLANTCEN oceanographic vessel R/V Alliance, including moored sources and arrays, AUVs equipped with a variety of sensors, and reliable navigation and communication systems. The major environmental acoustics objective of the JRP is to use an acoustic array mounted on an AUV to characterize the spatial and temporal characteristics of the 3-D scattering from seabed targets and the associated reverberation, including the effects of multipaths. This effort is aimed at establishing the foundation for future multi-static sonar concepts exploring 3-D acoustic signatures for combined detection and classification in very shallow water, as envisioned in Fig. 1.

A major potential advantage of the AOSN concept is its adaptive sampling capabilities. The network can be designed to change its behavior dependent on the sensor responses. AUVs carrying MCM sonars can be programmed to change their survey patterns to optimize the classification of detected targets.

The GOATS effort will incrementally address the scientific and technological issues associated with the development of new AOSN-based MCM and REA concepts, including reliable communication and navigation capabilities. Building on the results of the GOATS'98 sea trial, the GOATS'2000 experiment is currently being carried out at Elba Island, Italy.

## 2. GOATS'98 Experiment

### 2.1 Odyssey II AUV



*Figure 2.* Configuration of Odyssey II AUV 'Xanthos' for acoustic measurements in GOATS'98. The AUV control electronics and batteries are located in two 17" Benthos glass spheres. An 8-element array is mounted in a 'swordfish' configuration, and connected to a dedicated acquisition system in the center well of the vehicle.

An Odyssey II class autonomous underwater vehicle was used as the platform for the mobile acoustic array in GOATS'98, Fig. 2. A substantial fraction of the vehicle is dedicated to wet volume, which enables the Odyssey II to support a wide range of payload systems that include CTD, ADCP/DVL, ADV, side-scan sonar, USBL tracking systems, OBS, and several video systems. The core vehicle has a depth rating of 6,000 m, weighs 120 kg, and measures 2.2 m in length and 0.6 m in diameter. It cruises at approximately 1.5 m/s (3 knots) with endurance in the range of 3-12 hours, depending on the battery installed and the load. The AUV used in GOATS'98 featured an acoustic array for bistatic reception, developed at SACLANTCEN, consisting of a line array, mounted in the vehicle's nose, in a 'swordfish' configuration, and an autonomous data acquisition system, installed in a watertight canister in the vehicle's payload bay.

### 3. Bistatic Synthetic Aperture Sonar Processing

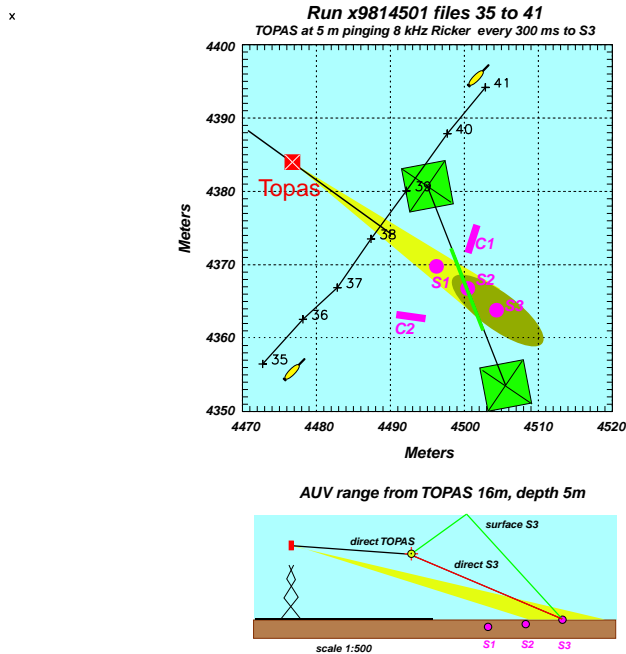


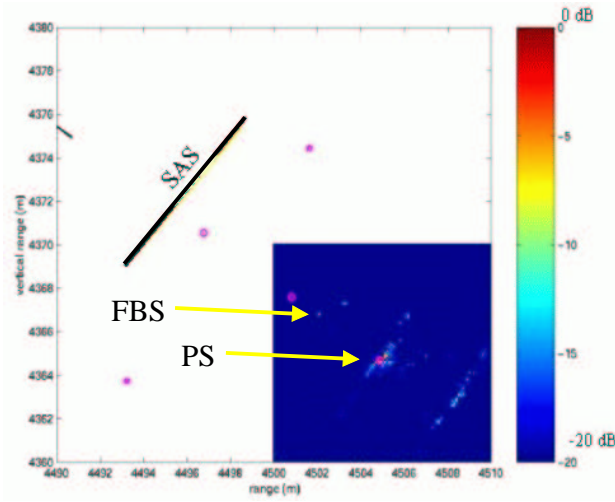
Figure 3. Bistatic sonar geometry. The TOPAS parametric source is insonifying the seabed with a footprint of approximately  $5 \times 10$  , centered on the half-buried spherical target S3. The Spherical target S2 is flush buried.

Figure 3 shows the bistatic sonar geometry of Mission X14501 of the Goats'98 experiment. The TOPAS parametric source is insonifying the seabed with a footprint of approximately  $5 \times 10$  , centered on the half-buried spherical target S3. The Spherical target S2 is flush buried. The Odyssey AUV is passing over the targets receiving the scattered field along its track, creating a synthetic aperture.

The synthetic aperture sonar (SAS) processing involved in the GOATS project differs from standard SAS imaging techniques in several important ways. The primary scientific issues that have been and will continue to be addressed are demonstration of the AUV as a viable and robust synthetic aperture sonar platform, extension of sonar processing techniques to bi- and multi-static scenarios and optimization of information processing for the robust detection and classification of man-made objects. To date, some progress has been made in all of these domains, although the final solutions remain a research concern.

The AUV has proven to be capable of providing a platform for synthetic aperture imaging [5, 6, 7]. Synthetic apertures of up to 10 times the physical aperture length have been used for imaging with the data received on the AUV-borne receiver. The maximum synthetic aperture length has in fact only been limited by the LBL navigation cycle that creates a gap in the acquired data. Such aperture extension provides both improved angular resolution and a significant reduction in the incoherent noise. Figure 4 shows a typical synthetic aperture image of the GOATS'98 target field, including the clear detection of a proud and a flush-buried sphere. The flush-buried sphere is detected despite the fact that it is insonified at a sub-critical grazing angle. Its location in the image is also slightly removed from its actual position. This apparent displacement was hypothesized to be caused by an unexpectedly strong delayed elastic return from the target. Frequency analysis and modeling results have since confirmed this theory.

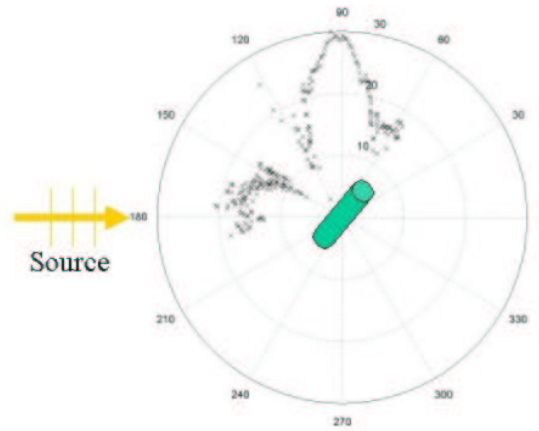
The extension of sonar processing techniques to bi- and multi-static scenarios has not yet been fully realized with respect to the AUV. One of the greatest challenges for monostatic SAS imaging has been platform motion compensation. A theoretical framework for bistatic motion compensation has been recently developed using the so-called "memory line" of rough surfaces [8], but has yet to be tested in a realistic environment. A greatly simplified, first order approximation of bistatic motion compensation with a stationary source was used in the GOATS'98 dataset, due to the lack of a synchronized source trigger. The GOATS 2000 dataset provides an opportunity to extend to full bistatic motion compensation with a stationary source. No dataset has yet been acquired for applying bistatic motion compensation with a moving source.



*Figure 4.* Bistatic synthetic aperture image of the GOATS'98 target field. A proud sphere (PS) and a flush-buried sphere (FBS) lie inside the source beam. Both are visible in the image, but the buried sphere appears displaced by about 1 m. This displacement is due to the fact that the imaged signal is a delayed elastic return, providing evidence for “anomalous” coupling between the evanescent sub-bottom field and the elastic target.

Another important application of bistatic scenarios is in the measurement of aspect-dependent target signatures. A stationary horizontal line array in the GOATS'98 experiment has been used to demonstrate the possibility of enhanced detection and classification with an appropriate bistatic configuration. Figure 5 clearly shows the preferential radiation of a flush-buried, fluid-filled cylinder in the GOATS'98 experiment. This regular radiation pattern provides clues to be applied for classification.

Due to limited resolution capability at the low frequencies required for seabed penetration, alternative information processing techniques are also being explored to maintain the significant classification clues while coherently combining as much information as possible. One such application has utilized wavelet packets for detecting and individually filtering direct and elastic returns [9]. This allows the different types of returns to be coherently combined in appropriate frequency bands and for the elastic returns to be associated with their respective direct returns.



*Figure 5.* Aspect-dependent radiated field of a flush-buried cylinder, as measured by a stationary horizontal line array. The signal measured at  $90^\circ$  from the source direction is  $15\text{ dB}$  higher than the backscattered signal. The shape of the radiation pattern also provides classification clues.

#### 4. Conclusion

The GOATS Joint Research Program provides a series of coordinated, incremental implementations of the Autonomous Ocean Sampling Network concept for coastal REA and MCM. As the first of a series of experiments exploring new sensor concepts for the AOSN, GOATS'98 provided a unique dataset for developing new low-frequency, bistatic synthetic aperture processing approaches for mine countermeasures in very shallow water. As demonstrated here, such approaches has significant potential for detection of buried object beyond the critical bottom penetration range of traditional high-frequency MCM sonar systems.

#### 5. Acknowledgments

The authors are highly appreciative of the collaboration with a large group of scientists and engineers from SACLANTCEN and MIT participating in the GOATS'98 experiment, and the crews of R/V Alliance and T/B Manning. This work is supported by the Office of Naval Research and SACLANT.





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