Multistatic Active Acoustics

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LONG-TERM GOAL

The long-term objective of this research is to develop a theoretical foundation for the design of new multi-static sonar concepts for littoral seabed imaging and mine counter measures (MCM) operations. Multistatic configurations have been made possible by the development of the new Autonomous Ocean Sampling Network (AOSN) concept, based on recent advances in underwater vehicle and communication technology.

SCIENTIFIC OBJECTIVES

The specific objective of this project is to develop and validate theoretical and numerical models of the 3-D spatial statistics of the seismo-acoustic field produced by targets on and within a rough elastic seabed. These models are then applied to develop an improved understanding of the dominant physical processes governing the performance of moderate-to-high frequency sonar systems for detection and classification of objects above and below the seabed in shallow water environments. Also, these models will be important processing tools for new 3-D physics-based seabed target detection and classification concepts.

TECHNICAL OBJECTIVES

The classical approach for bottom target detection and identification, is to image the bottom environment using a high-frequency, monostatic sonar system. Unfortunately, such high frequency systems are achieving resolution at the cost of severely limiting bottom penetration, in turn limiting the detection and classification of subbottom objects. The emergence of new underwater vehicle network concepts such as AOSN has created the opportunity of achieving resolution by opening the spatial aperture in multistatic configurations, in turn lowering the frequency requirements. Thus, such new multi-static sonar concepts have the potential of significantly improving the probability of detection and classification of buried objects. On the other hand the potential of such sonar systems is dependent on development of model-based, multistatic imaging concepts which explore the different physics and

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spatial properties of target scattering and reverberation in shallow water waveguides. The fundamental physics of multistatic seabed acoustics is poorly understood, and the development of such knowledge, and the associated improved multistatic modeling capability is the central objective of this project.

APPROACH

To address the significance of the various environmental features affecting the bottom target sonar performance, MIT is developing a modeling framework with consistent treatment of seabed elasticity, seabed interface roughness, volume inhomogeneity, and the waveguide physics. The centre piece of this modeling framework is the wavenumber integration approach of OASES for solving the wave equation in stratified media. To achieve a more complete description of realistic shallow water environments the base models are modified and expanded. Most recently, to allow modeling of 3-D, multi-static roughness reverberation, the roughness perturbation formulation of Kuperman and Schmidt has been modified to model 3-D reverberation from anisotropic roughness patches in a stratified shallow water environment [1]. This modeling capability allows for detailed analysis of the relative importance of roughness characteristics, bottom stratification and bottom elasticity in shaping the spatial characteristics of the reverberant field, and as mechanisms for subcritical penetration. The target scattering is modeled in a consistent manner. Using an approach similar to the one of Makris [2], the object scattering function is convolved with the incident field computed by a standard spectral propagation model, here OASES, to yield a virtual source, which is then implemented in a propagation model for computing the total waveguide scattering response. Here, the use of the 3-D version of OASES [3] allows for very efficient computation of the full azimuthal field distribution in stratified waveguides, for the targets as well as the seabed roughnmess reverberation. Ultimately the effort will provide a consistent, physics-based modeling capability for use in the design of new robust and accurate multi-static sonar processing concepts.

RESULTS

The development and validation of the model component associated with the 3-D reverberation from seabed roughness such as ripple-fields was completed in 1997. In a joint effort with SACLANT Undersea Research Centre in FY98, this new modeling capability has been applied to investigate the fundamental physics associated with subcritical penetration into sediments [4], and the physics of 3-D reverberation from anisotropic ripple fields [2].In a joint effort with SACLANTCEN the new models are being applied to analysis of data from a series of coordinated experiments near Elba, Italy. The first experiment was carried out in June 97 by SACLANCEN, using the parametric Topas source for insonifying the seabed at low grazing angles to investigate the bottom penetration issue. Hydrophones were buried at different depths in the seabed. Figure 1 shows an example of the results and the subsequent OASES analysis. The circles show experimental results for a hydrophone buried at 30 cm depth. The vertical axis represents sound pressure levels for unit incident pressure. The colors correspond to grazing incident angles 15, (magenta), 18 (green), 22 (blue) and 32 (red) degrees. The seabed critical angle is approximately 25 degrees. The solid lines indicate the direct transmission as predicted by OASES, corresponding to evanescent coupling for the three subcritical grazing angles. The dashed-dotted lines indicate the rough seabed scattering contribution as predicted by the OASES 3-D scattering model using an anisotropic ripple structure with spatial statistics similar to the one observed at the experimental site. These results strongly suggest that there is no 'anomalous' penetration in this frequency regime, and that evanescent coupling dominates below 5-6 kHz, while seabed scattering accounts for the penetration at higher frequencies. The analysis also showed that the frequency dependent properties of the porous sand cannot be ignored. Thus, the matching of the data required a compressional speed of 1685 m/s, whereas the core measurements performed at 200 kHz yielded 1730 m/s. However, this consistent with the predictions of the Biot theory for this type of sand. The GOATS`98 experiment was carried out at Marciana Marina in May 98 in a joint effort between MIT and SACLANTCEN [5]. This experiment focused on the 3-dimensional spatial characteristics of the scattering by proud and buried targets and the rough seabed reverberation in very shallow water. The seabed was insonified by the TOPAS parametric source, mounted on a 10 m tall tower, which could be repositioned along a rail on the seabed to vary the incident angle on a number of targets buried in the seabed. The scattered field was measured using fixed vertical and horizontal arrays, and a mobile, 8-element array mounted on an Odyssey Autonomous underwater vehicle (AUV). A total of 1 Terabyte of acoustic data were collected during the experiment, and the AUV turned out to provide an excellent acoustic platform. While the seabed was insonified by the TOPAS source at a repetition rate of 0.3 s, the AUV would complete a dense survey pattern over the target field to map the 3-D reverberation and target scattering. Fig. 2 shows an example of the data collected by the AUV during one such survey leg, with each trace corresponding to one TOPAS ping. The direct and surface reflected arrivals from the insonified targets are easily identified. Data of the form shown in Fig. 1 are currently being applied to investigate the performance of multistatic synthetic aperture imaging concepts for detection and classification of buried targets. In addition to the fundamental physics of bottom interaction, GOATS`98 had a number of systems oriented objectives. First of all, the performance of small AUV's as multistatic acoustic receiving platforms was successfully demonstrated. MIT Sea Grant was be responsible for this component, partially funded by SACLANT and the AOSN MURI (Curtin). Another systems objective was to test the hypothesis that significant improvement in detection and classification of buried objects can be achieved by multi-static configurations. This issue is being investigated through a joint data analysis effort at MIT and SACLANTCEN.

TRANSITIONS

In addition to serving as a tool for the multi-static reverberation modeling, the OASES code, already in wide-spread use in the underwater acoustics and seismic community, has continued to be upgraded in 1996. The newest export version (2.1) of OASES is available on the World Wide Web (ftp://keel.mit.edu/pub/oases/). In addition to upgraded versions at most US Navy laboratories and ONR sponsored universities in the US an Canada, installations in 1997 include universities and laboratories in Japan, South Korea, Israel, Germany, Norway, and Italy, among others. As part of the collaborative effort with SACLANTCEN on GOATS`98, the 3-D target and seabed scattering models have been transitioned to SACLANTCEN, where they are applied in the experiment planning and for analysis of past experimental data associated with sub-critical penetration. GOATS-2000, a Joint Research Project (JRP) involving MIT and SACLANTCEN as the leading institutions is being initiated, involving several field experiments, with the first to be executed in 2000.

RELATED PROJECTS

There is significant joint effort between this project and the ONR Sea Ice Mechanics (SIMI) effort, and the Haro Strait Frontal Dynamics PRIMER, in particular in terms of the acoustic model development. Also, there is a strong relation to the ONR MURI: Autonomous Oceanographic Sampling Networks (AOSN). The AUV component of the GOATS`98 experiment was funded in part by SACLANTCEN, but primarily through the MURI (Curtin). Along the same lines there are strong links to applied ONR programs associated with the role of underwater vehicles in the littoral battlespace, e.g. Very Shallow Water MCM (Swean). Also, the modeling effort has a close relationship to the NOPP 'Littoral Ocean

Observation and Prediction System' (Harvard, MIT et. al., Curtin), of which PI is a partner in charge of all acoustic modeling efforts. This effort is also closely related to the High-Frequency DRI (Thorsos, Simmen) in terms of objectives and experimental plans and procedures. However, the DRI has it focus at frequencies above 10 kHz, while the present effort is aimed at the mid-frequency, 1-10kHz regime.

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INVITED PRESENTATIONS

H. Schmidt, "AUV Technology in the Littoral Battlespace", SACLANT Undersea Research Centre: 73rd Meeting of the Scientific Committee of National Representatives, Oct. 12-16, 1998.

FIGURES

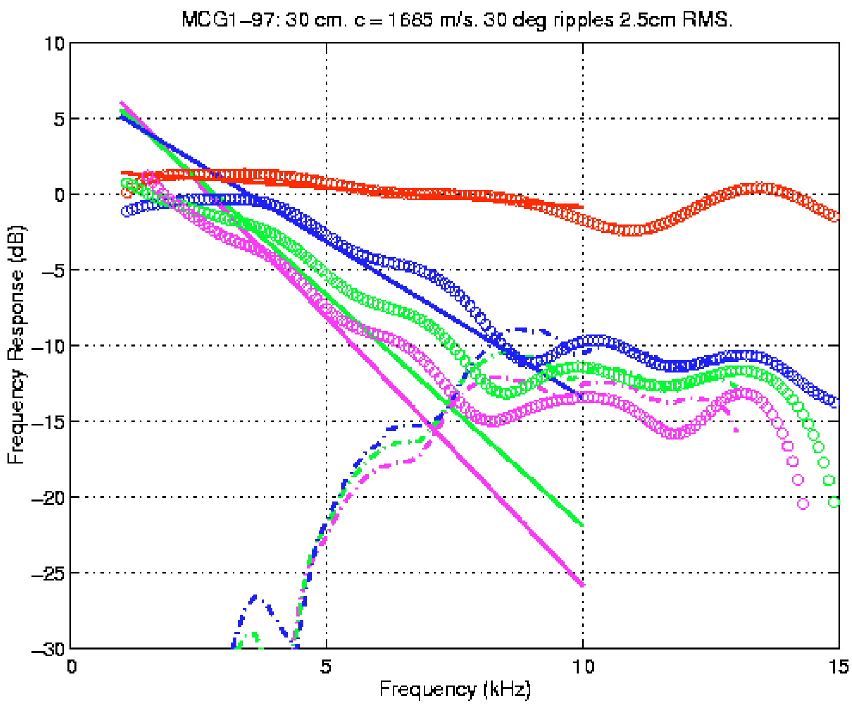

Fig. 1. Bottom penetration data collected by SACLANTCEN in June 1997, and modeled using the MIT OASES codes. The circles show experimental data obtained for a receiver buried 30 cm into the sediment. The solid lines indicates the OASES predictions of the evanescent coupling at different grazing angles of incidence, while the dashed curves show the OASES prediction of the contribution to penetration of the seabed ripple scattering.

GOATS'98

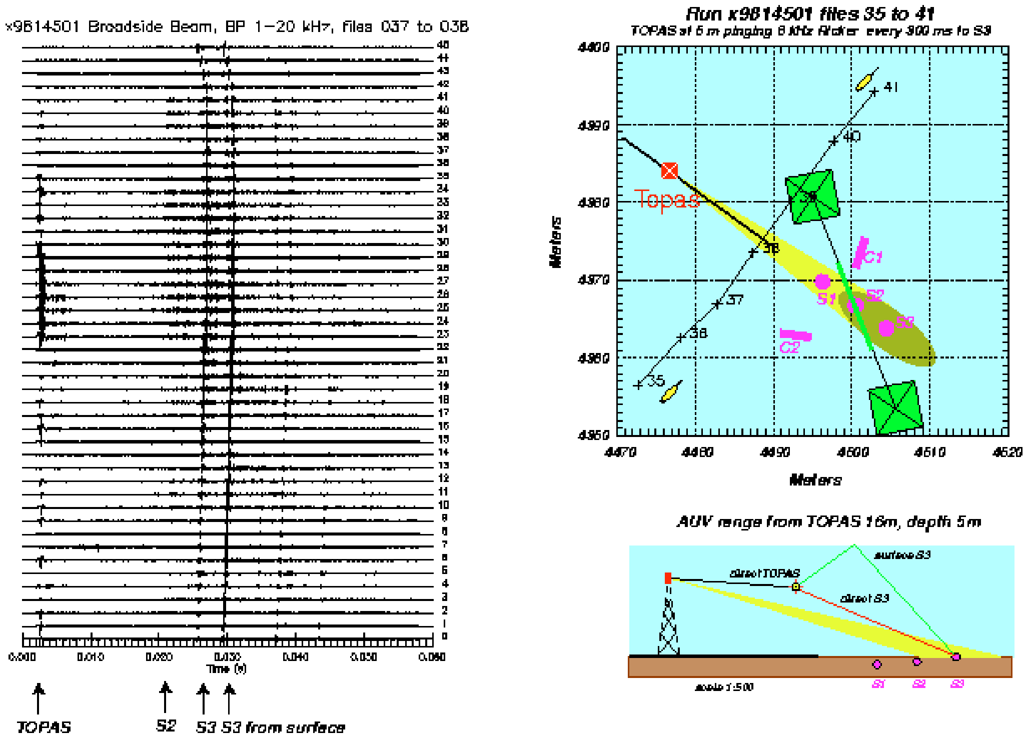

Fig. 2. Acoustic data recorded by AUV moving across target field insonified by TOPAS parametric source during GOATS`98. The arrivals are identified as the direct TOPAS signal and the direct and surface bounced scattered signals from the buried targets.