Uncertainty DRI
Adaptive Rapid Environmental Assessment

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LONG-TERM GOAL

Development and operational implementation of a new tactical tool for real-time assessment of the spatial and temporal statistics of the littoral acoustic environment, which is optimal in the context of sonar performance within the constraints of the deployable in-situ measurement resources.

OBJECTIVES

The objective of the AREA research is to develop a probabilistic methodology for optimal, in-situ assessment of the environmental parameters most critical to the uncertainty of the acoustic prediction, within constraints of the actual acoustic system configuration and the available tactical REA resources. The goal is an efficient modeling and simulation framework, which allows for real-time prediction of the reduction in sonar performance uncertainty associated with specific deployment strategies for the REA resources. Specific scientific objectives include a fundamental understanding of the relative significance of individual environmental parameters to performance of a specific sonar system and based on this understanding defining optimal parameterizations of the environmental parameters. Another crucial component is the classification of the limiting spatial and temporal scales, below which the in-situ sampling resources are totally inadequate and the uncertainty remains stochastic.

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APPROACH

Uncertainty propagates through the complete chain for sonar performance: environment, acoustics, processing, and operator. In regard so, the development of AREA is a close coupling of ocenography, geology, geophysics, acoustics, and signal processing, while being aware of the needs of the end user. It will be developed through a series of Observation System Simulation Experiments (OSSEs) [1] carried out in close collaboration with the two DRI partner teams, led by Allan Robinson (HU) and Charles Holland (PSU). The OSSEs will initially be based on the 1996 Shelf Break Primer experiment which had a strong oceanographic forecasting and acoustic components [2].

The center piece of the AREA concept is the optimal combination of classical environmental assessment based on databases and local measurements, and full-blown forecasting frameworks based on modeling and assimilation with adaptive in-situ sampling. The two partner teams provide the AREA team with their forecasts of the coupled PDFs for the seismo-acoustic parameter fields, and the associated spatial and temporal scales. The AREA team uses the ocean acoustic modeling and sonar processing frameworks to transform these into PDFs directly representing the associated effect on specific sonar performance metrics. Those performance forecasts are then used to identify optimal deployment patterns for the in-situ sampling resources such as XBT, CTD casts and AUV surveys. After the REA measurements have beem collected, they are fed back to both parter teams to update their environmental forecasts, which again pass through the sonar modeling framework, producing sonar performance predictions with sharper uncertainty.

The research effort is centered around the ocean acoustic modeling and sonar processing frameworks developed and maintained by the MIT ocean acoustics group [3, 4]. The sonar performance uncertainty associated with the oceanographic variability is most conveniently determined using Monte-Carlo simulations of the sonar response for random realizations of the oceanographic statistics predicted by the forecasting framework. In regard to the seabed variability, the OASES seismo-acoustic modeling framework [3] can be used to determine the sonar uncertainty associated with uncertainty from both large-scale deterministic variability and small-scale seabed roughness and volume inhomogeneities. Sonar performance metrics are easily built within the information theory framework, for example, using the Fisher Information Matrix (FIM), which specifies the asymptotic limit in mean-square estimation error and directly quantifies the parameter couplings [5, 6]. The FIM can be used together with an acoustic modeling framework to define an optimally uncoupled, or System-Orthogonal Acoustic Parameterization (SOAP), thus making it possible to identify the most significant environmental features observable in system response. Finally, to determine an optimal deployment of the REA resources it will be necessary to determine a Measure of Effectiveness (MOE) for each combination of critical environmental parameter, REA resource, and deployment pattern. These MOEs must be combined with a cost model to define a quantitative cost-effectiveness model for each resource/parameter combination. The development and validation of those models are major objectives of the AREA research effort.

WORK COMPLETED

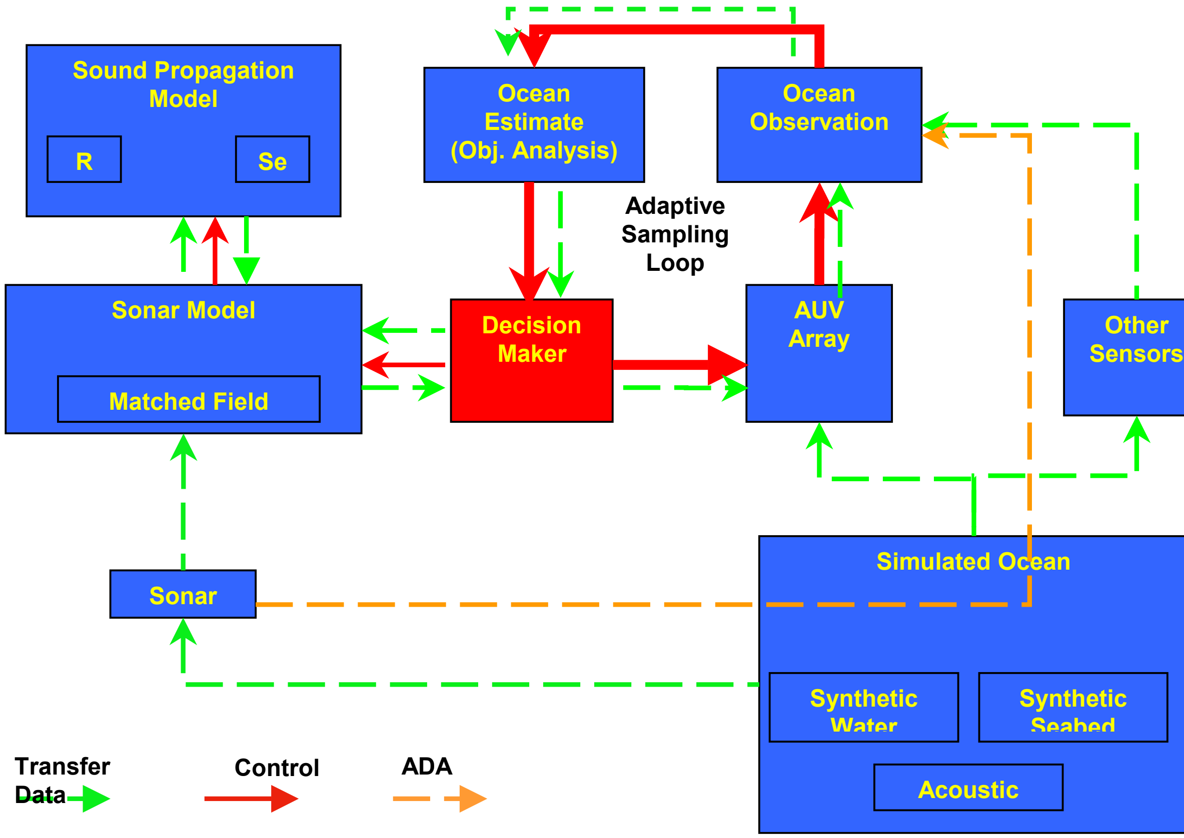

Figure 1. AREA simulation framework. A synthetic ocean generated byHOPS is 'sampled' by acoustic and non-acoustic sensors, combined into an 'Ocean Observation' picture, which is objectively analysed and fed to the core 'Decision Maker', which then optimally 'redeploys' the mobile resources (AUVs etc.) in the 'Simulated Ocean'.

A significant part of the MIT effort has been aimed at developing a 'Virtual Ocean' testbed for the area concept. The current framework is shown schematically in Fig. 1. A synthetic ocean, generated by the Harvard Ocean Prediction System (HOPS) is combined with a seabed model, and an environmental acoustic propagation framework to form a 'Virtual Ocean' which can be sampled using models of acoustic as well as non-acoustic sensors, on mobile or fixed platforms. The 'sampled' data are collected into an ocean observation picture, which is then used to create a current estimate of the ocean and acoustic environment and the associated uncertainties. The estimate is currently generated using objective analysis, but in the future it is envisioned that this step in a netcentric operational implementation will be performed using a modeling and assimilation framework such as HOPS. The ocean extimate and the associated uncertainty is then used by the core of the framework, the 'Decision Maker' (DM), to identify optimal re-deployment of the mobile sampling resources, e.g. AUV's. The DM is currently implemented using a Dynamic Programming approach. The adaptive sampling can either be controlled by the oceanographic estimate and uncertainty only, or using the estimates of the sonar uncertainty obtained using the sonar performancce model. The sonar performance model is currently using RAM as a computational engine, but in the future it will be being to using a more computationally efficient coupled mode framework such as CSNAP. The AREA simulation framework is modularly structured in MATLAB and C++, and is prepared for future expansion such as direct two-way coupling with HOPS and the incorporation of Acoustic Data Dssimilation (ADA) [7].

On the acoustic parameterization side, the development has been continued of a new system-optimal representation for sound velocity variation in the water column, capturing and parameterizing the oceanographic uncertainty most critical to the sonar performance prediction. This has led to a new set of orthorgonal basis for sound velocity representation in both range-independent and weakly range-dependent environments. Compared to the traditional Empirical Orthogonal Functions (EOFs), the expansion coefficients on this new basis are decoupled in terms of system response. A paper has been completed and submitted for publication in IEEE J. Oceanic Eng. [8].

RESULTS

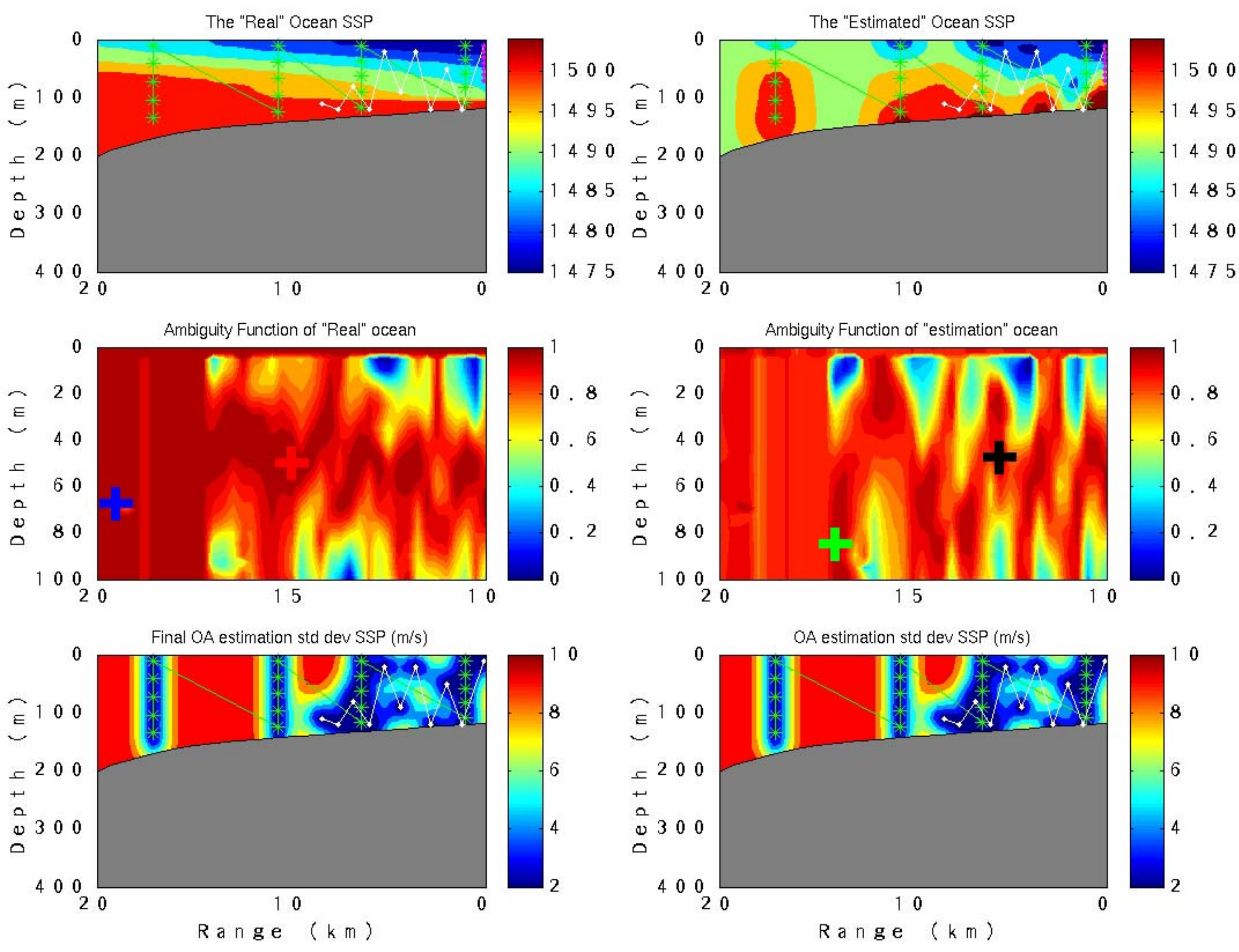

Figure 2: Adaptive oceanographic sampling using AUV for optimizing matched field source localizion performance.

The new AREA simulation framework has been appied to simulate adaptive sampling by underwater vehicles for optimizing matched field performance in the Shelf Break Primer area off New Jersey. An example of the results is shown in Fig. 2. The 'true' ocean sound speed generated by HOPS is shown in the upper left frame, with red indicating high sound speed, and blue low. An initial estimate of the oceanography was obtained using objective analysis (OA) of 4 simulated XBT casts using estimated vertical and horizontal correl;ation scales. An AUV was then sampling the oceanography along, by after each measurement using OA to determine where to maneuver, withing the speed constraints, of course, to decrease the acoustic uncertainty, leading to the irregular 'yo-yo' trachk shown in white in the upper right frame, together with the final SVP estimate. The associated uncertainties are shown in the lower plots, with blue indicating small uncertainty. The two plots in the second row show the ambiguity function for locating a source at 15 km range, using an array at 0 km. The left plot shows the 'true' ambigity function with the maximum corresponding to the true source position indicated by the red cross, and the maximum sidelobe indicated by the blue cross. The plot to the right shows the ambiguty function using the final SVP estimate shown in the upper right, and obviously the source is not properly located in this sampling scenario, even though the estimate error is small over 2/3 of the propagation path.

IMPACT/APPLICATION

The long-term impact of this effort is the development and operational implementation of a new tactical tool for real-time assessment of the littoral environment. Specifically, the AREA concept improves sonar performance prediction by capturing and then mitigating dominant environmental uncertainty under operational constraints, which takes optimum advantage of combining both oceanographic forecasting and sonar performance prediction components as well as the mobility, autonomy and adaptiveness of the REA resources. For example, the System-Orthogonal Acoustic Parametrization being developed provides a framework to connect oceanographic parametrization to sonar modeling as well as potentially to end user modeling. Also, the further development of the Acoustic Data Assimilation concept explored under this program has implications for futute through-the-sonar environmental assesment and Environmentally Adaptive Sonar Technology (EAST).

TRANSITIONS

A joint experiment with SACLANTCEN/HOPS is being planned, which includes HOPS nested forecasting, MFP experiment, real time adaptive rapid environmental assessment with AOSN. The AREA concept will then be tested and integrated to GOATS (Generic Ocean Array Technology Sonar) effort [9].

The OASES and CSNAP environmental acoustic modeling codes are used extensively in this work and continue to be maintained, expanded and made available to the community. It is continuously being exported or downloaded from the OASES web site, and used extensively by the community as a reference model for ocean seismo acoustics in general. (http://acoustics.mit.edu/arctic0/henrik/www/oases.html)

Among the new transitions to applied Navy programs, the OASES and CSNAP framework is being used extensively by Lockheed-Martin in relation to the NAVAIR Multi-Mission Aircraft (MMA) Program.

RELATED PROJECTS

This effort is part of the Uncertainty DRI. In terms of environmental input and forecasting, it is strongly related to two other DRI partner projects: HOPS (PI: A. Robinson) and SEABED (PI: C. Holland).

Regarding its REA resource deployment and experimental test, there are strong connections to the GOATS Joint Research Program conducted by SACLANTCEN and MIT with ONR support (Grant # N00014-97-1-0202). The adaptive sampling issues are strongly reklated to the new ONR SWAMSI program.

The OASES modeling framework being maintained and upgraded under this contract is being used intensively as part of the GOATS effort, aimed to developing 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.

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