

Capturing Uncertainty in the Common Tactical/Environmental Picture: Team Summary and APL-UW Contributions

Robert T. Miyamoto
Applied Physics Laboratory
University of Washington
1013 NE 40th Street
Seattle, WA 98105

Phone: (206) 543-1303 Fax: (206) 543-6785 Email: rtm@apl.washington.edu

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LONG-TERM GOALS

Use existing science to characterize, transfer, and represent the uncertainty in the tactical and environmental picture as it affects active acoustic detection of submarines.

OBJECTIVES

Project objectives for FY03 were to (1) coordinate a team of scientists from six institutions, to investigate how to characterize and represent undersea environmental uncertainty, (2) to develop a prototype capability to represent bottom and water column environmental uncertainty as probability distribution functions from which signal excess distributions can be computed, and (3) apply these results to a Bayesian likelihood ratio tracker as part of the end-to-end system. Scientists from four institutions are submitting independent reports. This paper addresses their work along with the accomplishments of APL-UW and NRL-DC. Specific questions explored by this project are: 1) how to characterize uncertainty in large-scale sound speed fields and generate a distribution of sound speed profiles, 2) can dynamic ocean models produce comparable water column profile statistics to historically measured, archived data and thus be used to enhance a statistical approach based on historical data, 3) how to characterize uncertainty in ocean bottom sediments, either through historical data or acoustic inversion techniques, and generate a distribution of bottom conditions, 4) what is the contribution of internal waves to water column sound speed uncertainty, and 5) given uncertainty of the ocean sound speed and the bottom, how to develop techniques to efficiently propagate the uncertainty through active acoustic models to components (e.g., transmission loss, reverberation level, and target signal excess, arrival structure, interference) to develop tactically relevant state estimation of undersea targets? Project scope prohibits the inclusion of other environmental components such as surface boundary impacts, volume reverberation, bathymetry, and ambient noise. However, this work sets up a framework by which these affects can be accommodated in the future. A related objective is to compute model and data sensitivities, investigate model parameter correlations, and optimal model parameterizations.

APPROACH

The team, headed by APL/UW, includes NRL-SSC, Oregon State University (OSU), ARL-UT, and Metron Corp., all funded under the ONR Capturing Uncertainty Departmental Research Initiative (DRI). NRL-DC is contributing valuable related work funded by ONR outside the DRI.

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NRL-SSC is providing the best ground truth, clustered sound speed profiles and incorporating dynamic ocean modeling as a foundation for more accurate three-dimensional sound speed profile distributions. It is providing geo-acoustic data for the geographic area selected for analysis, and APL-UW is synthesizing those inputs and others to produce a probability distribution of bottom properties. Discrete sets of input water column and bottom conditions are fed to the Comprehensive Acoustic System Simulation (CASS), run by APL-UW, to produce modeled distributions of reverberation time series and transmission loss for Metron. ARL-UT is supplying unique target strength model outputs to Metron but is also analyzing the statistical character of signal excess as it is affected by variability in transmission loss, reverberation level, and target characteristics. Metron is first translating these distributions of sonar performance and target strength estimations into likelihood functions and then applying target state heading (aspect) determinations in order to compute signal excess distributions. The mean values of these computations are used in a Bayesian track before detect system for multistatic active sonar, the Likelihood Ratio Tracker (LRT), to enhance target state estimation. Target state estimates arising from the LRT will reflect the input environmental (bottom and water column) uncertainty. Hence, by varying input environmental parameters in known ways, the effect on sonar performance and detection and tracking capability can be studied. NRL-DC is developing ways to cast target and environmental state estimations from the LRT in graphical form to provide visual representations of target and environmental uncertainty suitable for fleet operators. To compute model and data sensitivities, investigate model parameter correlations, and optimal model parameterizations, one can employ derivatives of the pressure with respect to density and bulk modulus, referred to as Frechet derivatives, to pre-compute measures of the model and data variance and resolutions

WORK COMPLETED

Early in FY03, the question of CASS' ability to reliably compute coherent reverberation, which was to have been used for detailed signal statistical analysis, was addressed. It was shown, through interaction with the author of CASS, Dr. Chic Weinberg of Anteon Corporation, that CASS cannot model coherent reverberation without anomalies that would have disrupted signal statistical analysis. In place of that effort, work was directed toward a functioning prototype capability of computing distributions of signal excess resulting from distributions of input water column and bottom characteristics. Additionally, focus shifted from surface ASW sonars to air ASW active sonars, to target better transition opportunities.

Estimates of the effects of macro-changes to the sound speed profile, combined with acoustic sound speed fluctuations due to background internal waves as a function of depth, range and time, were collaboratively developed between OSU and APL-UW for CASS input.

Bottom acoustic uncertainty in the East China Sea was explored by comparing histograms of bottom loss and backscattering calculated using a subset of APL-UW's GABIM model. Analysis compared the effects of two sources of geoacoustic parameter perturbations. First, there is observed uncertainty in grainsize measured in the field. Second, there is statistical uncertainty inherent in the empirical relationships between grainsize and geoacoustic parameters. These two perturbations were treated separately, and then together, through Monte Carlo simulations. Initial analysis of the histograms suggests that the effects of grainsize uncertainty in the ASIAEX area out-weighed the effects of the statistical uncertainty in the relationship between grainsize and geoacoustic parameters(see figure (1)).

For purposes of high-fidelity ocean model comparison with historical data, bottom and ocean environmental data for the Mid-Atlantic Bight was gathered by NRL-SSC. NRL-SSC provided

MODAS and clustered sets of historically measured summer time sound speed profiles for the ECS area (see figure (2)). These were used to build a simple PDF of water column characteristics. Using the BASIS model, ARL-UT constructed a realistic, bistatic model of target strength for a nuclear submarine of the sort often used in training exercises. This model was modified to provide a broadband target strength estimate by coherently summing narrow band target strength estimates. The model has now been incorporated into Metron's likelihood ratio tracker.

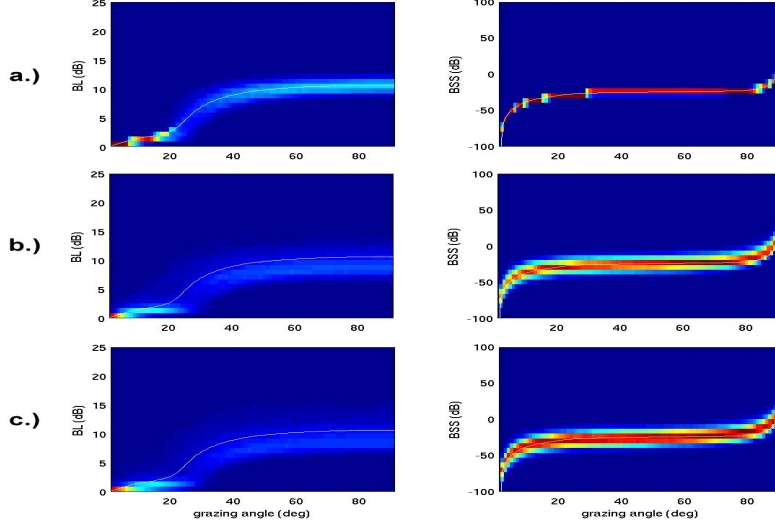


Figure (1). *Bottom loss and backscattering histograms for $\phi_{\text{sediment}}=4.5 \pm 0.8$, $\phi_{\text{basement}}=5.5 \pm 0.5$, $\text{sed_thickness}=10.5 \pm 4\text{m}$, $f=3500\text{Hz}$, $c_{\text{water}}=1480\text{m/s}$, $N=1000$. (a) results from perturbations of geoaoustic parameters based on the statistics of their empirical fit to a mean grainsize, (b) results from perturbations of grainsize, and (c) results from perturbations of both.*

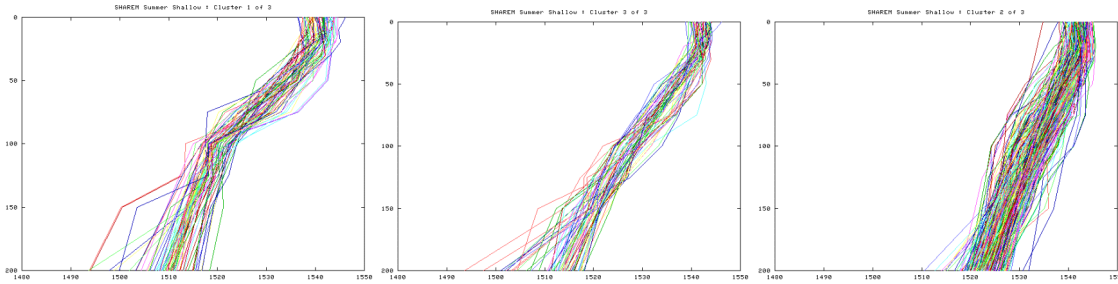


Figure (2) *SHAREM 134 sound speed profiles clustered in three groups. Summer, East China Sea.*

Metron modified the IASW version of LRT to include non kinematic state variables such as signal excess prediction error. Using environmental predictions and uncertainties representative of an area in the East China Sea, APL/UW and ARL/UT provided estimates of the distribution of prediction error in each component of the sonar equation. Metron combined these into an overall distribution on mean SE prediction error that is function of target state and developed a simulator to provide detection and false alarm responses for a simulated target, e.g., an example involving a buoy field similar to EER.

Model and data resolution matrices, $\mathbf{R}$ and $\mathbf{N}$, respectively, have been constructed to interpret model uniqueness and parameter coupling. The $M \times M$ model resolution matrix $\mathbf{R} = \mathbf{G}^{-g} \mathbf{G}$, where $\mathbf{G}$ is the $M \times N$ matrix of Frechet derivatives. The data resolution matrix $\mathbf{N} = \mathbf{G} \mathbf{G}^{-g}$. The $N \times N$ data resolution matrix $\mathbf{N}$ characterizes whether data can be independently predicted or resolved. The model resolution matrix is useful for predicting to what scale features can actually be resolved and for exposing parameter couplings, and the relative magnitude of the coupling.

RESULTS

Comparison of the propagation effects caused by background internal waves using substantially different sound speed profiles highlighted the general insensitivity of acoustics to background internal wave fields. Figure (3) shows both the five macro-profiles considered and, for each profile, the averaged result of the averaged intensities computed for fourteen time-steps each of five different internal wave model seeds. Spherical spreading is removed. APL-UW incorporated this input sound speed data into the CASS model along with bottom geo-acoustic data.

Simplified PDF's of bottom and water column properties, were developed as discrete inputs to CASS. From these inputs, APL-UW used CASS to develop transmission loss (TL) estimations and range-dependent estimations for bistatic reverberation level (RL). Figure (4) provides a sample of the RL outputs for two different bottom types and the same water column conditions.

Metron applied these discrete sets of RL and TL, along with target strength estimates from ARL-UT, thus accounting for mean SE prediction uncertainty in LRT. In the cases examined, LRT produced good estimates of target kinematic state and signal excess prediction error in the presence of large numbers of false detections and was able to track multiple targets, each having a different signal excess prediction error. Figure (5) shows the output from LRT run on multistatic active simulated data. Buoy (receiver and source) locations are indicated by white circles in the lower part of the figure on the left-hand side. Near the top of this figure, a high likelihood (red) area is evident where the target is located. The target's position is indicated by a white circle. Although work remains to account for full distributions of environmental variability, this work represents the initial step in building an end-to-end system to measure, transfer, and represent to fleet operators the effects of environmental uncertainty.

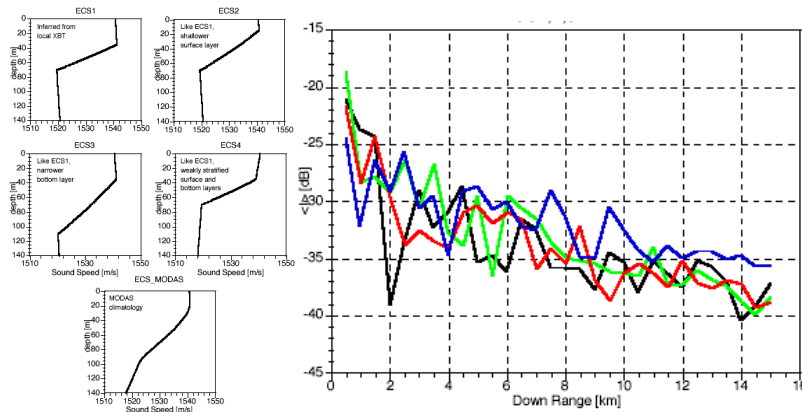


Figure (3) Sound speed profiles and resulting averaged intensities resulting from background internal wave effects. Black: ECS1, Green: ECS2, Red: ECS3, and Blue: ECS_MODAS (cylindrical spreading removed).

ARL-UT determined that the target strength component of the signal excess may be modeled by a Rician distribution (in linear units) to good approximation. Target strength at higher bandwidths tends to be smoother than that of narrow band, due to the effect of averaging over multiple frequency.

Variability due to fluctuations in target strength contribute a level of uncertainty comparable to that due to transmission loss. The statistical analysis of signal excess has shown that the distributions of mean reverberation levels and transmission loss with respect to internal wave fluctuations appear to be consistent with a normal distribution. The standard deviation of TL was in general much greater than that of RL. The standard deviation of RL tended to scale with the mean value, while that of TL tended to remain constant with respect to range and depth. For a realistic model of internal waves in the East China Sea, the standard deviation in signal excess due to TL and RL amounts to about 8 dB.

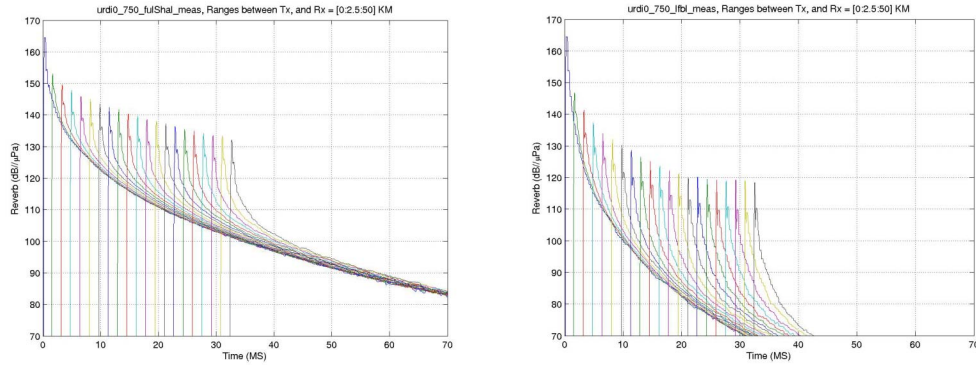


Figure (4) Representative reverberation time series curves resulting from NRL-SSC bottom geoaoustic data (left) and LFBL database data (right), with a locally measured sound speed profile. Reverberation is computed for 2.5km increments between transmitter and receiver from 0 to 50km.

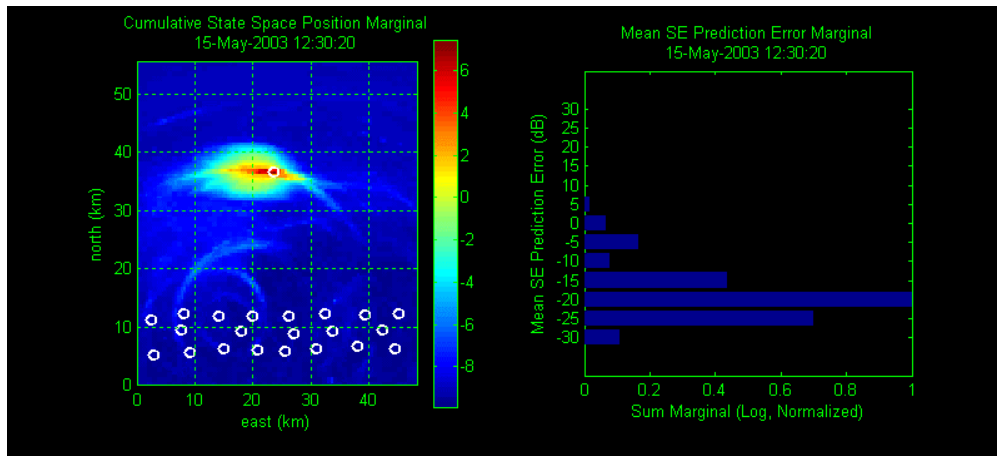


Figure (5) Cumulative Likelihood Ratio Surface and Marginal Distribution on SE Prediction Error

Frechet derivatives were shown to characterize parameter sensitivities, and can be represented as products of the Green's function for the medium and its vertical derivatives. This permits very efficient

computation of the derivatives. Only one pass of a forward modeling program is required for the computation. Any program which computes the Green's function or a suitable approximation to it will suffice. The model and data resolution matrices are built up from the derivatives and contain information about parameter resolvability, parameter coupling and data independence. Their computation requires no actual data for input. They can be an aid to experimental design.

IMPACT/APPLICATIONS

Results of the team's work will apply to numerous Navy acquisition programs. Virtually all Navy Tactical Decision aids used in air, submarine, and surface ASW and MCM communities will, in time, be modified to include methods developed from this program to quantify and represent to fleet operators the uncertainty of estimations of sensor performance. Results of the program will improve the ability of Navy personnel, from sonar system operators to battlegroup staff commanders, to understand how well their systems are working and how best to employ them. These results will similarly be used to provide environmental sampling recommendations to reduce uncertainty in critical parts of the battle space.

TRANSITIONS

ONR's Naval Underwater Warfare Technology (NUWT) program, formerly IASW CEP, is a targeted, funded landing pad for the U-DRI technology. The objectives of the three-year NUWT program (FY04-06) include environmental data fusion, development of a common, multi-platform maritime tactical picture, and improving single platform underwater warfare effectiveness through integration and management of organic acoustic and non-acoustic data. It is geared to integrate the discoveries of the U-DRI program to enhance ASW. PMA264 is developing TAMDA, which is both an environmental and tactical measurement buoy and a decision aid with which to acquire, assimilate and apply environmental data to sensor performance predictions. This funded program will make use of U-DRI discoveries in the decision aid portion of the program. STDA (surface and submarine) and CUP are three funded NAVSEA programs that are building decision aids for both the ASW operator and the ASW Commander (ASWC). These programs plan to integrate U-DRI technology through the APB-ARCI process which the programs employ. SPPFS, MEDAL, SIIP, and TDA IV&V are other similar, funded programs which can benefit from U-DRI technology and discoveries.

APL-UW will be contracting with SPAWAR, via N096, and ONR from FY04-06 to establish a Rapid Transition Prototype (RTP) program that will carry forward the substantial work done to date advancing the Sonar Environmental Parameter Estimation System (SEPES) and geoacoustic inversion. The objective of this project is to transition to the fleet integrated GCCS-M geoacoustic algorithm segments to fleet TDAs that 1) efficiently and with sufficient accuracy extract geo-acoustic parameters, 2) to the extent the measured data allow, resolves the ambiguity of inverted solutions that arises from limited grazing angle sampling, 3) provides, with the inverted data, critical operator feedback on the extent of utility of the data based on the character of the local inversion process, 4) distinguishes the regional distributions of bottom properties to support the development of bottom property probability distribution functions, and 5) interpolates and extrapolates inversion solutions into adjacent regions including a measure of uncertainty. Uncertainty DRI results have a clear transition to this new program.

RELATED PROJECTS

APL-UW is contracted with NAVAIR (PMA264) to assist with the EER Improvement Program. The objective of this program is to understand the limits of the tactical utility of the EER system and make suggestions for improving EER CONOPS by carefully planning for, collecting, and analyzing environmental and tactical information arising from EER exercises. This work gets at the core of the uncertainties associated with conducting one particularly difficult form of ASW and offers suggestions for improving system employment.