Multi-resolution Probabilistic Ocean Physics-Acoustic Modeling: Validation in the New Jersey Continental Shelf

P.F.J. Lermusiaux\textsuperscript{a}, P.J. Haley, Jr.\textsuperscript{a}, C. Mirabito\textsuperscript{a}, W.H. Ali\textsuperscript{a}, M. Bhabra\textsuperscript{a}, P. Abbot\textsuperscript{b}, C.-S. Chiu\textsuperscript{b}, C. Emerson\textsuperscript{b}

\textsuperscript{a}Massachusetts Institute of Technology; \textsuperscript{b}OASISLEX

\textsuperscript{*}Corresponding Author: pierre@mit.edu

Introduction. The littoral environment is especially demanding on tactical sonar systems, in large part because of the spatial and temporal variability of the highly-dynamic nonlinear ocean fields. The variability occurs on multiple scales in space and time, and involves multiple interacting processes, from internal tides and waves to meandering fronts, eddies, boundary layers, and strong air-sea interactions \cite{7, 8, 5, 6, 2}. The present goal is to improve the detection rate of targets through improved multi-resolution ocean modeling and probabilistic forecasting of littoral ocean variability relevant for underwater propagation. The acoustic emphasis is on transmission loss (TL) variability and on detection performance with 50 to 3000 Hz active signals. To exemplify the multi-resolution probabilistic modeling, we reconstruct the acoustic environment off the New Jersey continental shelf for the end of June 2009 (MAC DG-3 Test), modeling the ocean spatial-temporal variability and its impact on the transmission loss (TL) and detection performance. We utilize ocean and acoustic measurements to validate results.

Multi-resolution probabilistic ocean modeling. We ran probabilistic ocean scenario simulations using our multi-resolution MIT-MSEAS modeling system \cite{4, 3}, forced with NCEP NAM 32km atmospheric fluxes and high-resolution tides, and completed an ensemble of 1km-resolution ocean simulations around June 30, 2009. We downscaled initial conditions from HYCOM simulations. Our downscaling scheme used limited independent synoptic data-of-opportunity and our feature modeling capabilities to correct the coarse HYCOM fields. The effects of these corrections are illustrated in Fig. 1. In the left column, we compare HYCOM and MSEAS simulated profiles to independent XBT profiles (not utilized in any of the simulations). The independent data correction clearly corrects the temperature below 30m. The average RMS error is reduced by a factor of 3 and the average bias reduced by roughly a factor of 50. Looking at the 30m sound speeds and sound speeds along the XBT line, the data corrections introduce colder deep water on the shelf near the XBT region and also sharper gradients, both near the front and vertically. Sound speed gradients are similarly enhanced. Beyond improving our downscaled initial and boundary conditions, sensitivity studies were performed to improve our simulations. Notably, the boundary conditions and parameterizations were tuned to improve the vorticity at the open boundaries. We also completed additional comparisons with other independent oceanographic measurements, confirming the increased skill.

We designed a number of possible ocean scenario simulations using our MIT-MSEAS system, varying initial conditions and the details of the corrections with the limited data-of-opportunity. We also varied the tidal forcing, atmospheric forcing, model parameters, and so on. We ran many 1km-resolution ocean simulations for the end of June 2009, leading to a probabilistic representation of the ocean environment.

Probabilistic ocean environment. One of the biggest factors affecting the sound speed around the deeper XBTs and receivers near the shelfbreak is the tidal forcing. The tidal forcing and resulting generated internal tides and waves introduced significant changes in the sound speed over the time scale of the tidal cycle. Meanders, slope water eddies, and tidally driven motions of the shelfbreak front can also rapidly bring different sound speeds past the deeper XBTs and nearby receivers, and can lead to different TL performance. Atmospheric forcing was not found to be a factor in these simulations as there were no significant wind events between June 24 0Z and July 4 0Z. For the model parameters, the parametrization of bottom friction had a
minor effect. Decreasing the bottom friction permits slightly more movement of the foot of the shelfbreak front, allowing greater changes in sound speed at depth. Hudson Canyon was also found to have important environmental effects. The in situ synoptic data showed slightly colder water northeast of the canyon. Different initialization times allow our high-resolution simulations more time to generate features. We found that starting on June 26 or 28 produced qualitatively similar fields by June 30.

**Probabilistic acoustic modeling.** For the acoustics, we implemented a new efficient Narrow-Angle Parabolic Equation (NAPE) model, several accurate versions of the Wide-Angle PE (WAPE), and efficient algorithms for broadband propagation. For uncertainty predictions, we used our stochastic dynamically orthogonal PDEs for the standard NAPE [1].

**Probabilistic acoustic environment.** We ran underwater sound propagation parabolic equations for MAC DG-3 test, using our probabilistic modeling of the ocean environment as input. Specifically, we used our wide-angle parabolic equation (WAPE) acoustic models to predict TL fields between a single-frequency source and multiple receivers in the MAC DG-3 test. The TL fields were computed for the three sources and nine receivers for different times and different frequencies. In Fig. 2, we only show the results obtained for a few representative sections and for a high-frequency modulated (HFM) sound source at point D. We compare these prediction results to measurements obtained during the MAC DG-3 test. The predicted values are found to match well with the measured data (within 5 dB and small mean error). We showed improved ocean-acoustic accuracy compared to classic operational systems.

**References**


