Real-time Probabilistic Coupled Ocean Physics-Acoustics Forecasting and Data Assimilation for Underwater GPS


Introduction. The POSYDON program aims to develop a Global Positioning System (GPS) for underwater assets. The primary goals of our MIT effort are to: (1) Employ and develop our regional ocean modeling, data assimilation, and uncertainty quantification for the estimation of sound speed variability, coupled oceanographic-acoustic forecasting and inversion relevant to the POINT effort; (2) Apply our theory and schemes for optimal placement, path planning, and persistent ocean sampling with varied assets and acoustic source platforms; and (3) Further quantify the ocean dynamics and variability of the regional areas of interest, utilizing our multi-resolution data-assimilative ocean modeling and process studies.

As part of this program, we completed regional ocean modeling and forecasting for the Middle Atlantic Bight. Our realistic data-assimilative modeling involved real-time forecasting and data-driven simulations and analyses of the sound speed variability. To do so, we built on our experiences, especially on large and collaborative research initiatives. Our methods and software were used and further developed for POINT.

For this project, we also characterized and forecasted the oceanographic variability and uncertainty. Our MIT-MSEAS PE model of the temporal and spatial evolution of physical features and circulations has been validated through extensive measurements, and analysis in many regions. However, due to the uncertain initial and boundary conditions, and sub-grid-scale parameters, the variability of the environmental propagating medium is uncertain. Just as we now utilize probabilities for rain or bad weather on a daily basis, the proposed underwater communication and global positioning system for deep ocean navigation can also utilize and benefit from such information. Real-time integrated oceanographic-acoustic predictions must account for and forecast these uncertainties and their effects on sound propagation and communications.

For this “Precision Ocean Interrogation, Navigation, and Timing (POINT)” effort, we utilized our MIT Multidisciplinary Simulation, Estimation, and Assimilation System [MSEAS; 5, 6, 4]. The MSEAS software is used for fundamental research and for realistic simulations and predictions in varied regions of the world’s ocean, including monitoring, ecosystem prediction and environmental management, and importantly for the present project, real-time oceanographic-acoustic predictions and coupled ocean-acoustic data assimilation. For this exercise, we mainly employed our MIT-MSEAS hydrostatic PE code with a nonlinear free surface, based on second-order structured finite volumes.

Real-time exercise. The POSYDON Sea Exercise 2018 occurred in the Middle Atlantic–New York Bight Region for August 2018. In collaboration with the POINT team, our objectives were to utilize the MIT MSEAS system to: (i) Forecast the probability of high-resolution ocean fields using our multiscale Error Subspace Statistical Estimation (ESSE) methodology; (ii) transfer the corresponding distribution of the sound speed field to three-dimensional underwater sound propagation uncertainties; (iii) collect sufficient data to evaluate the accuracy of the Bayesian tomographic inversion and of its posterior estimates of range between transducers and sound velocity profiles (SVPs).

The MSEAS modeling system was set up in an implicit two-way nesting configuration. The ocean forecasts were initialized from 1/12° HYCOM analyses [1], downscaled to higher resolution and updated with ocean data from varied open sources of opportunity (CTDs, ARGO floats, gliders, SST, etc.) and with our MSEAS feature models for additional corrections. These ocean simulations are forced by atmospheric flux fields forecast by the GFS 1/4° model [7] from the National Centers for Environmental Prediction (NCEP) and tidal forcing from TPXO8 [2, 3], but updated for the high-resolution bathymetry, coastlines and for our quadratic bottom drag. For uncertainty predictions, ensemble forecasts were initialized using our ESSE procedures. For these ensemble forecasts 48 closely related tidal estimates were used for tidal forcings and small perturbations were applied to the atmospheric forcings.
Results. Daily deterministic and ensemble forecasts of 3-day duration were issued for the period 9–24 August 2018. Three regions of distinct water masses (on the continental shelf, over the continental slope and in the Sargasso Sea) were identified and the updates to HYCOM were made separately for each region, then melded across the shelfbreak front and the Gulf Stream, respectively. These corrected fields provided the subtidal initial and boundary conditions for the deterministic forecasts. Similarly, the ensemble perturbations were applied to the deterministic ICs in each region and melded across the respective fronts. The daily ensemble forecasts contained between 100–300 members. Both deterministic and ensemble forecasts were verified by independent data of opportunity, and both showed skill out to 3 days, as shown in fig. 1.

![Image](image-url)

Figure 1: MSEAS-PE fields and verification: (a) 2 m vorticity, (b) deterministic verification against CTD data, (c) 100 m standard deviation in sound speed, and (d) verification of ensemble against CTD data (note that realizations encompass data and standard deviation of the ensemble is a reasonable proxy for RMSE).

References


