Maximizing Effectiveness of Autonomous Underwater Vehicles

L.F. Smedstad,[1] C.N. Barron,[1] K.D. Heaney,[2]
G. Peggion,[3] and E.M. Coelho[3]
[1]*Oceanography Division*
[2]*Ocean Acoustical Services and Instrumentation Systems, Inc. (OASIS)*
[3]*University of New Orleans*

Introduction: Ocean gliders and other unmanned underwater vehicles play an increasingly important role for the U.S. Navy as a source of targeted environmental measurements. Glider pilots adjust navigation instructions for each platform in response to changing array distribution and local ocean conditions. Automated guidance for glider missions enables more effective use of growing numbers of ocean gliders without overtaxing limited human resources. NRL-developed systems to optimize glider placement and sampling direction initiated under the Office of Naval Research (ONR) Glider Observation Strategies (GOST) project have been transitioned to the Naval Oceanographic Office (NAVOCEANO). GOST is an autonomous system that develops preferred deployment and navigation plans for glider networks. GOST uses a genetic algorithm (GA)[1] that sorts through potential waypoints to identify glider paths that achieve optimal coverage. Under this approach, the relative merit of alternate pathsets are calculated using mission-appropriate cost functions that combine geographic coverage, forecast uncertainty, and environmental variability. Feedback from GOST-directed gliders into ocean models demonstrated improved ocean forecast skill in two NATO exercises, REP10 and Proud Manta 11. NAVOCEANO will conduct operational tests of the GOST system during the Navy's Trident Warrior 13 exercise.

Application of a Genetic Algorithm to Oceanography: GOST begins with the fundamental postulate that some sets of glider trajectories will be more useful than others. Once the relative merit of a potential set of observations can be quantified, a search algorithm can be implemented to isolate a preferred set. GOST communicates these preferences using cost functions that assign a value based on the time, location, and collective coverage of the glider array. Integrating the vector sum of the velocity and ocean currents reveals the series of observations that could be obtained by a glider. Included in GOST is the Environmental Measurements Path Planner (EMPath) software that contains the GA. Promoting a "survival of the fittest" approach, a randomized set of individuals and a specified number of reproductions (mating of successful individuals) creates generations of a solution. Each individual represents a different time/space transect pattern for multiple gliders, or sensor laydown, and the natural selection process deems which is best adapted for the mission criteria. EMPath outputs include a morphology figure to provide the user a visual level of confidence in the paths. The morphology computation is an estimate of the shape of the cost function that the genetic algorithm is using to optimize sensor locations. The preferred set of trajectories is communicable to the glider pilots as a set of waypoints and tolerances.

Benefit to Ocean Models and Tactical Decision Aids: The effectiveness of GOST guidance has been demonstrated in virtual and live glider exercises in which glider measurements are assimilated as vertical profile data to influence ocean forecasts. Coverage missions include time scales from days to weeks. A set of idealized Observation System Simulation Experiments (OSSEs) form the basis for the GOST 1.0 validation testing.[2] Acoustic products such as sonic layer depth (SLD) created from Relocatable Circulation Prediction System Navy Coastal Ocean Model (RELO NCOM) outputs are analyzed with and without glider assimilation. An assimilative RELO NCOM run designated as the true ocean state has relatively shallow SLD (Fig. 8(a)), while a nonassimilative version with overly deep SLD is the forecast that badly needs correcting (Fig. 8(b)). Using cost functions based on RELO NCOM forecast fields, GOST determines preferred trajectories for six simulated gliders that sample the true ocean. Assimilation of the glider profiles produces the beginnings of a clear correction (Fig. 8(c)) in the target area SLD forecast.

GOST-determined sampling in two NATO exercises has demonstrated the impact of glider observations on target-area forecasts. In the Marine Rapid Environmental Assessment (REP10) exercise off La Spezia, Italy, in August, 2010, the effectiveness of a single GOST-directed glider, known as Laura, relative to an alternative fixed survey with other sensors[3] reduced the maximum and mean root mean square (rms) errors relative to independent observation and more accurately located a cyclonic eddy on the western edge of the target area (Fig. 9). A similar exercise off the east coast of Sicily (Proud Manta 11) showed the effectiveness of GOST guidance for a pair of gliders. The glider sampling identified a previously undetected cold-core ring that significantly modified sound speed and acoustic transmission across the target area (Fig. 10).

Future Work: Additional work has begun on expanding the usefulness of a system of gliders with the Navy goals of tactical operations, sustained coverage, and feature definition in mind. All three of these have been present in some capacity on the NATO exercises. However, more automation and management of glider

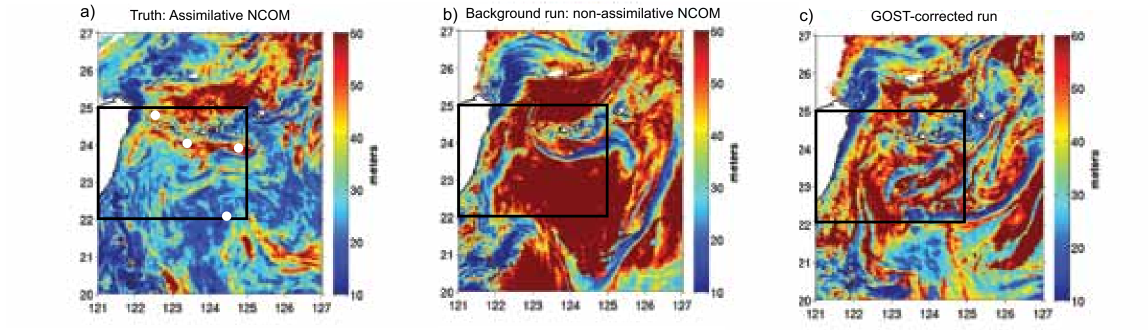

FIGURE 8
Sonic layer depth (SLD) has large differences between the case (a) assimilative run taken to represent the true ocean and the case (b) nonassimilative background run. GOST simulates glider observations (a; white circles) of the true ocean. When these are assimilated, the GOST-corrected forecast case (c) moves from deep background SLD (red) to the shallower SLDs (blue) found in the truth ocean, enabling more accurate predictions of upper-ocean acoustic transmission in the target area box.

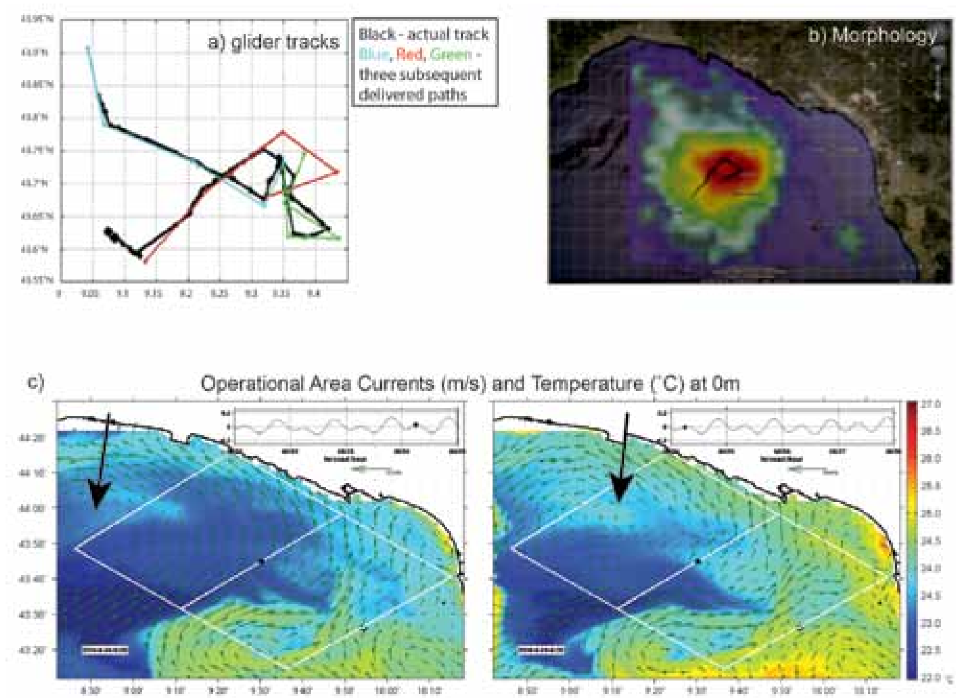

FIGURE 9
The feedback between gliders and models is shown from REP10 results. (a) Forecast target way-points for glider Laura were delivered every 48 hours. The actual trajectory of Laura over the week is shown in black. The gliders were able to follow suggeted paths (b) based on the cost function morphology as projected in Google™ Earth. (c) Assimilating glider data improved the forecast location of an eddy (arrows) in the model between a 78-hour forecast and a 6-hour forecast.

data is required. Additional testing of newer capabilities with EMPath can be conducted, such as roping off areas to protect gliders from entering naturally or politically hostile areas by geographic exclusion zones or other water space limitations. New options are in development to extend forecast horizons and facilitate glider rendezvous to reduce recovery time and cost at mission end. Optimized use of the expanding glider fleet is only possible with such systems to simplify control and management of these resources.

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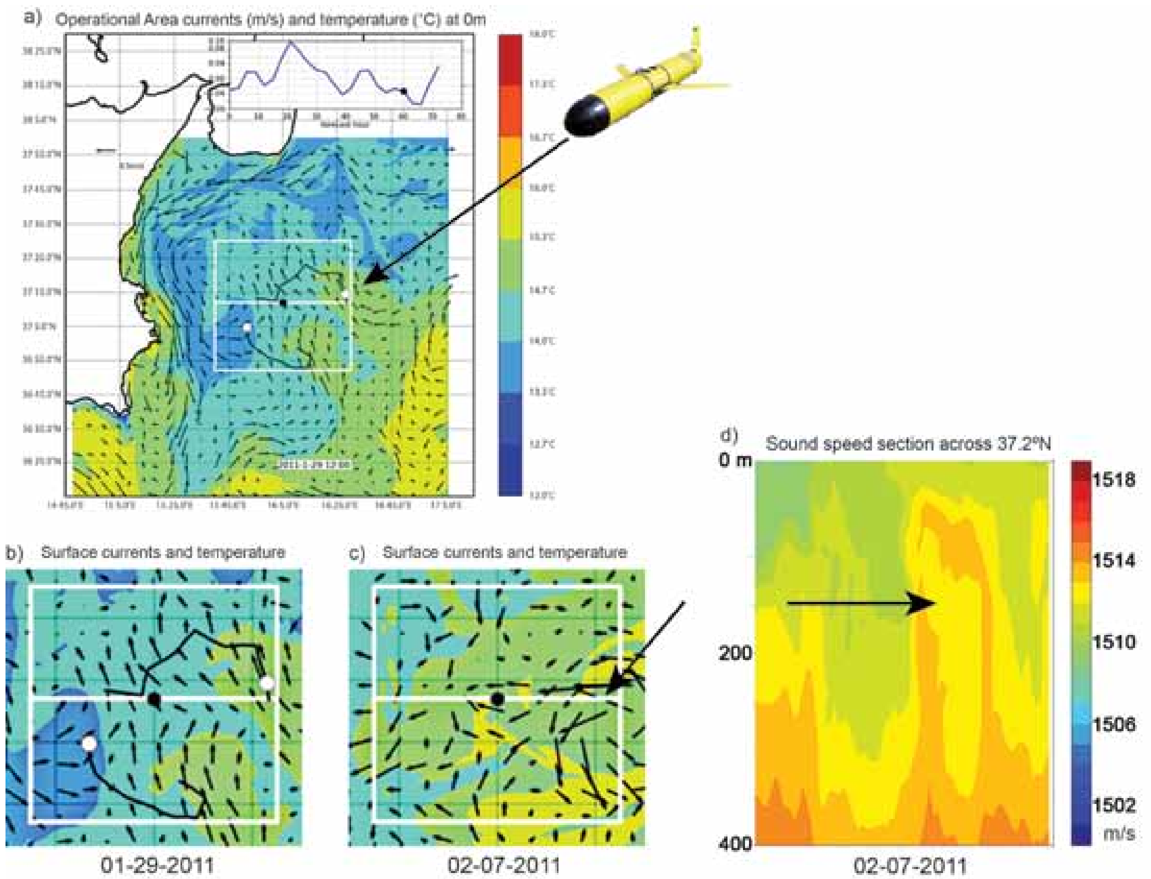

FIGURE 10
Example of feature definition mission: Surface currents and temperature before (a,b) and after (c,d) assimilation of observations from GOST-directed gliders during the NATO exercise Proud Manta in 2011 off the east cost of Sicily. The gliders identified a cold-core ring (arrows) that significantly modifies currents (c) and sound speed (d) in the operational area.

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WAVEWATCH III® Transition to Naval Operations

J.D. Dykes and W.E. Rogers
Oceanography Division

Supporting the Mission: Knowledge of the sea state and thus predictions of wave conditions in real time are important for naval operations. Two operational centers provide such support. Fleet Numerical Meteorology and Oceanography Center (FNMOC) in Monterey, California, produces and delivers wave forecasts covering large spatial scales and long time scales — for example, global 120-hour forecast fields of significant wave height — to support general operations. The Naval Oceanographic Office (NAVOCEANO) at Stennis Space Center, Mississippi, provides small-scale wave forecasts covering shorter intervals to support specific missions involving littoral waters and surf zones.

The Naval Research Laboratory (NRL) at Stennis Space Center has been the primary transition partner with NAVOCEANO and FNMOC for enabling technologies in wave forecasting for small and large scales. Now, in cooperation with the National Centers for Environmental Prediction (NOAA/NCEP), the latest version (v. 4.10) of the WAVEWATCH III® (WW3) wave model is being transitioned to NAVOCEANO and FNMOC, with additional updates coming later in 2013.