Evaluating and Extending Ensemble Predictions and Adaptive Sampling Guidance for Gliders and AUVs in Monterey Bay

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LONG-TERM GOALS

The 'adaptive' deployment of autonomous underwater vehicles (AUVs) in coastal waters is expected to form a large part of future Navy operations. To prepare for this, the Adaptive Sampling and Prediction (ASAP) team is charged with developing and investigating methods to direct and utilize such vehicles, in order to assimilate their data into numerical ocean models and predict future conditions as accurately as possible. The long-term goal of the PI is to work with the ASAP team to provide a reliable and relocatable ensemble modeling and adaptive sampling framework, from which informed decisions on deployment of AUVs can be made rapidly. In the future, the methodology could be used to ask advanced questions on optimal, cost-efficient design of sensors and platforms, in conjunction with glider/AUV planning software, survey error metrics etc.

OBJECTIVES

The primary objectives of the research effort are:

1. To evaluate the reliability of ensemble-based uncertainty predictions using the Regional Ocean Modeling System (ROMS) for Monterey Bay.

2. To evaluate the ability of the Ensemble Transform Kalman Filter (ETKF) adaptive sampling methodology to discriminate between effective and ineffective glider/AUV observations for reducing prediction error in ROMS.

3. To construct simple synthetic AUV and glider arrays based on 3-dimensional ETKF guidance.

APPROACH

The focus for the above objectives has been the Adaptive Sampling and Prediction (ASAP) field experiment, held in Monterey Bay in August 2006. Collaborators and their respective roles are:

Drs Yi Chao, Zhijin Li, and John Farrara, NASA Jet Propulsion Laboratory (JPL). (ROMS)

Dr Craig H. Bishop, NRL Monterey. (Ensemble construction, adaptive sampling)

Dr Pierre F. J. Lermusiaux, MIT. (Inter-comparison of adaptive sampling strategies)

Dr Yanwu Zhang and Dr James G. Bellingham, MBARI. (AUV survey error metrics)

On a previous ONR-sponsored effort (Grant Number N00014-03-1-0559), PI Majumdar developed the software architecture for daily real-time ROMS ensembles and ETKF adaptive sampling guidance, on

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14. ABSTRACT

The ?adaptive? deployment of autonomous underwater vehicles (AUVs) in coastal waters is expected to form a large part of future Navy operations. To prepare for this, the Adaptive Sampling and Prediction (ASAP) team is charged with developing and investigating methods to direct and utilize such vehicles, in order to assimilate their data into numerical ocean models and predict future conditions as accurately as possible. The long-term goal of the PI is to work with the ASAP team to provide a reliable and relocatable ensemble modeling and adaptive sampling framework, from which informed decisions on deployment of AUVs can be made rapidly. In the future, the methodology could be used to ask advanced questions on optimal, cost-efficient design of sensors and platforms, in conjunction with glider/AUV planning software, survey error metrics etc.

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JPL's supercomputing system (Chao et al. 2008). This effort is being revived by the PI and his assistant scientist, Dr Laurent Cherubin, who is now funded through the current grant (since June 2008). The first task has been to rerun and evaluate the ROMS ensembles. During Summer 2008, the architecture was imported onto the University of Miami Supercomputing System, and ROMS is now able to be run on the local system which provides considerably greater freedom to run large ensembles efficiently and store the data. Currently, the bulk formulation in ROMS is being investigated prior to ROMS ensembles being rerun for August 2003 (AOSN-II experiment) and August 2006 (ASAP experiment).

ROMS Model

Given the prohibitively high computational demand associated with the interaction between nested grids in the ROMS model integrations, a single-domain 1.67 km version of ROMS, with lateral boundary conditions provided by the 3-day ROMS control forecast from analysis, is being employed for the ensemble. ROMS is integrated out to 3 days, although a longer period will be considered.

ROMS Ensemble

Two ensemble perturbation methods were constructed as part of the previous ONR grant. The first aims to capture uncertainty in the ROMS initial conditions, via the breeding technique. The second perturbation method aims to capture uncertainty in the atmospheric wind stress fields at the ocean surface via a novel "space-time deformation" of the surface wind field. Preliminary results indicate that the initial condition perturbation technique adds more variance into the ensemble than the wind stress perturbations. The qualitative analysis of the ensemble is under way, and the ability of the ensemble to maintain a stable distribution of analysis error variance over the entire period will be assessed. The quantitative evaluation of the ability of the ensemble to predict error variance will follow common methods in the literature (e.g. Bishop et al. 2006), using the ROMS reanalysis as the 'ground truth' by which forecast errors are computed. The extent to which the ground truth is 'contained' within the ensemble will also be examined.

ETKF

The evaluation of the ETKF adaptive sampling guidance will be based on numerical 'data denial' experiments at JPL, in which data from a chosen glider or AUV will be removed prior to assimilation. In this way, the influence of data from gliders deemed likely or unlikely to reduce prediction error can be computed. The ETKF will be deemed successful if the actual reduction in ROMS prediction error variance due to the gliders that are deemed likely to be effective is significantly higher than the reduction of prediction error variance due to gliders that are deemed ineffective by the ETKF.

WORK COMPLETED

In the first four months of the project, the ROMS software has been transported successfully to the University of Miami, to expedite the ensemble computations.

The PI is currently preparing the ROMS/ETKF software for a new field experiment in Monterey Bay, to take place in October 2008. The software had been designed to be operational at short notice, and the October 2008 experiment provides a test of the efficiency of the set up.

RESULTS

ROMS integrations have been transferred to an advanced MATLAB GUI at Miami by Dr Cherubin, enabling the efficient visualization of a variety of fields. SST is shown in Fig. 1.

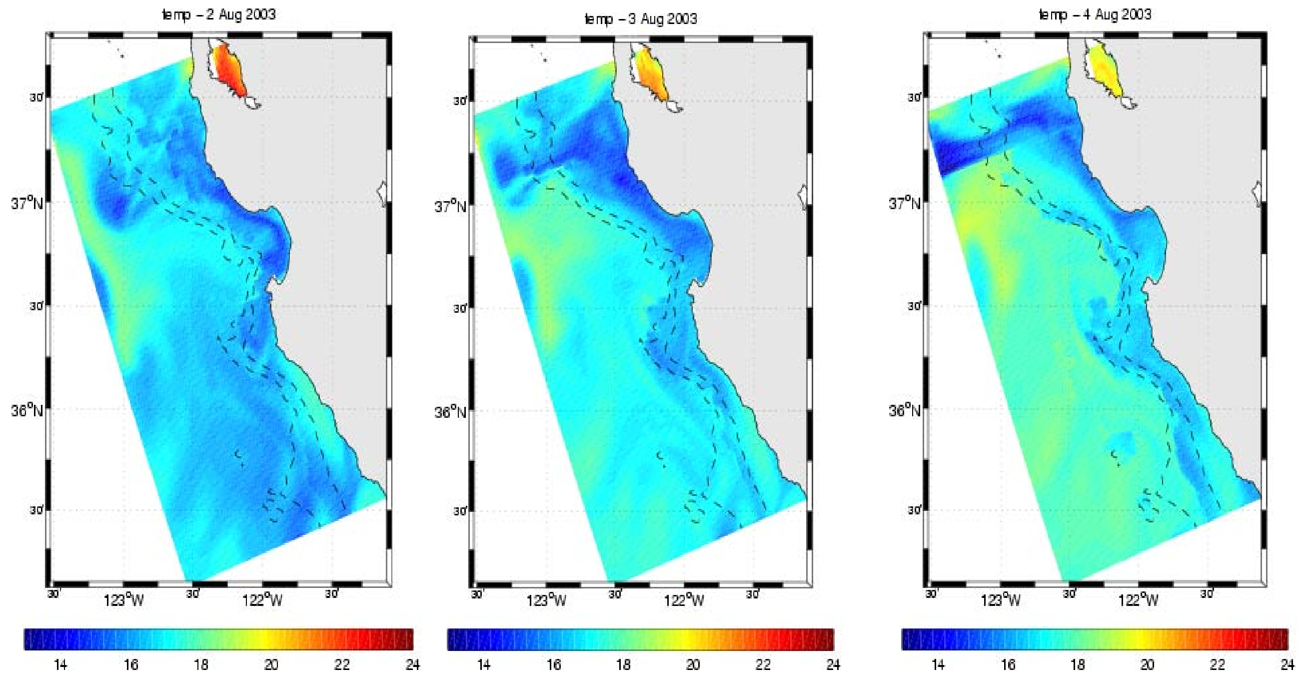

FIGURE 1. 1-3 day ROMS simulations of SST, integrated from the first day of the AOSN-II period (1 August 2003). The ROMS model is presently under evaluation before ensembles are computed.

IMPACT/APPLICATIONS

The primary application of the funded research is to predict ‘sensitive’ areas of the ocean in which autonomous underwater vehicles (both glider and propeller-driven) ought to be deployed, to improve numerical ocean model forecasts.

Other impacts of this research include:

(i) Improved scientific understanding of initial condition uncertainty, and the response of the ocean to wind stress and heat fluxes off central California.

(ii) Quantitative predictions of the effects of observations on numerical model analyses and forecasts, prior to the observations being deployed.

TRANSITIONS

The real-time ensemble forecasting and adaptive sampling software is being used as part of JPL's suite of operational products. The data format complies with the AOSN data policy.

RELATED PROJECTS

The ETKF adaptive sampling technique is currently being used for targeted satellite scans, aircraft reconnaissance, and balloon deployment to improve 1-7 day forecasts of hurricanes. The PI was one of the lead investigators in the recently concluded ONR Tropical Cyclone Structure (TCS-08) experiment in the western Pacific Ocean.

The PI is also presently conducting studies to test (i) the reliability of the ETKF in non-linear flow regimes and (ii) how to maximize useful error covariance information, given the necessarily small number of ensemble forecasts. The conclusions drawn from these studies will have a direct impact on the development of adaptive sampling methods for underwater vehicles such as gliders and AUVs.

The PI is also collaborating with Drs Craig Bishop at NRL Monterey on adaptive sampling, and the ensemble forecasting and ETKF software are being shared. An inter-comparison between results obtained using ROMS (this project) and the NCOM Ocean Model (used at NRL) will be conducted.

AUV survey error metrics have been designed by Drs Yanwu Zhang and James Bellingham at MBARI. These metrics will be coupled to ROMS ensemble and ETKF predictions to produce new 'dynamic' error metrics for AUV surveys, in collaboration with the PI.

Error statistics from the ensemble may be considered for the next generation of ROMS data assimilation developed at JPL.

REFERENCES

Bishop, C.H., B. J. Etherton and S. J. Majumdar, 2006: Verification region selection and data assimilation for adaptive sampling *Quart. J. Roy. Meteor. Soc.* 132, 915-933.

PUBLICATIONS

Chao, Y., J. D. Farrara, Z. Li, M. A. Moline, O. M. E. Schofield and S. J. Majumdar, 2008: Synergistic applications of Autonomous Underwater Vehicles and the Regional Ocean Modeling System in coastal ocean forecasting. *Limnology and Oceanography*, in press.