Coastal Ocean Observing System Modeling: Data Assimilation and Adaptive Sampling Design

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Award Number: N00014-05-1-0729
http://marine.rutgers.edu/po/sw06

LONG-TERM GOALS

Accurate analyses of ocean currents, waves, temperature and salinity are required in order to forecast sediment and bio-optical properties in coastal waters that are critical to the performance of naval environmental sensors and operations. Analyses of these features can be significantly improved through the combination of observations and models by advanced data assimilation. With ONR support, the Regional Ocean Modeling System (ROMS) code has undergone extensive development and is being adopted by an expanding user community for ocean reanalysis and forecast applications. An important new enhancement in the modeling system is the formulation of tangent linear and adjoint codes and, built upon these, the capability for 4-dimensional variational data assimilation, sensitivity and stability analysis, and optimum generation of forecast ensembles to explore predictability limits.

We will develop a coastal ocean modeling system that uses advanced data assimilation techniques with observations from new, rapidly deployable and relocatable coastal ocean observational assets to improve ocean forecasts in coastal regions that are of increasing interest to Navy operational requirements. Our system for regional ocean prediction will have the capability to use all available data from comprehensive coastal observational networks comprised of multiple CODAR installations, cabled observatories, autonomous gliders, and satellite imagery.

OBJECTIVES

To pursue the development of a prototype coastal ocean modeling, observation and prediction system for the Mid-Atlantic Bight. Specifically, we propose to:

(i) Demonstrate the capabilities of a limited area coastal modeling system nested within shelf and/or basin scale operational models that utilizes data sets provided by new, relocatable, coastal observational assets such as CODAR and AUVs.

Report Documentation Page

Form Approved OMB No. 0704-0188

1. REPORT DATE **30 SEP 2006**	2. REPORT TYPE	3. DATES COVERED **00-00-2006 to 00-00-2006**
4. TITLE AND SUBTITLE **Coastal Ocean Observing System Modeling: Data Assimilation and Adaptive Sampling Design**		5a. CONTRACT NUMBER 5b. GRANT NUMBER 5c. PROGRAM ELEMENT NUMBER
6. AUTHOR(S)		5d. PROJECT NUMBER 5e. TASK NUMBER 5f. WORK UNIT NUMBER
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) **Rutgers University,Institute of Marine and Coastal Sciences,71 Dudley Road,New Brunswick,NJ,08901**		8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)		10. SPONSOR/MONITOR'S ACRONYM(S) 11. SPONSOR/MONITOR'S REPORT NUMBER(S)
12. DISTRIBUTION/AVAILABILITY STATEMENT **Approved for public release; distribution unlimited**		
13. SUPPLEMENTARY NOTES		
14. ABSTRACT		
15. SUBJECT TERMS		

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT **unclassified**	b. ABSTRACT **unclassified**	c. THIS PAGE **unclassified**	**Same as Report (SAR)**	**5**	

Standard Form 298 (Rev. 8-98)
Prescribed by ANSI Std Z39-18

(ii) Integrate model and observations using 4-dimensional variational data assimilation

(iii) Utilize the analysis tools underpinned by ROMS' tangent linear and adjoint codes to explore predictability, sensitivity, and adaptive sampling methodologies

(iv) Evaluate model skill by comparison to a set of appropriately crafted model metrics.

(v) Transition model results, capabilities and lessons to complementary observational studies in the Mid-Atlantic Bight; principally ONR's Shallow Water Acoustics 2006 (SW06) program.

APPROACH

We will use ROMS (the Regional Ocean Modeling System), a split-explicit free surface primitive equations ocean model well suited to regional simulation applications from the basin to coastal and estuarine scales. ROMS' numerical algorithms (Shchepetkin and McWilliams 2005) offer efficiency, stability and accuracy in coastal applications with both steep bathymetry and/or shallow water. Vertical turbulence closure options (Warner et al. 2005) enable accurate simulation of boundary layer dynamics. Paramount among the ROMS features suited to a modern nowcast/forecast system are the recently developed adjoint and tangent linear codes and 4-dimensional variational (4DVar) data assimilation scheme. Variational assimilation seeks the model hindcast that minimizes a cost function measuring the model/observation differences over the analysis time period. The adjoint provides the cost function gradient with respect to a set of chosen model control variables such as the initial or boundary conditions, or surface forcing. A gradient-descent algorithm iteratively improves the control variables to achieve the best correspondence of model and observations. At the end of the analysis period, the model state represents the best nowcast. The model can then be integrated forward in a forecast mode using forecast surface and lateral boundary conditions. In Incremental Strong Constraint 4DVar (IS4DVAR) (Weaver et al. 2003), adjustment of the control variables (in our implementation the initial conditions for each forecast cycle) proceeds while assuming the model is error free over the analysis cycle, i.e. the model physics enter as a strong constraint because the forward model conservations equations are satisfied exactly.

The implementation of the ROMS IS4DVAR algorithm implementation for realistic hindcast applications is being undertaken by H. Arango and J. Zavala-Garay. Adapting the model configuration to the Mid-Atlantic Bight domain for SW06 is being conducted by J. Wilkin and J. Levin. Forcing and assimilation input data are prepared by G. Foti and N. Fleming. Running the assimilation system in real-time is coordinated by H. Arango, W.G. Zhang, and J. Evans. All these participants are based at IMCS, Rutgers University.

WORK COMPLETED

Progress by the ROMS Developers during 2006 succeeded in completed a full implementation of the IS4DVAR algorithm for geographically realistic applications. In light of this, our Regional Ocean Prediction grouped chose to attempt operational prediction of the ocean state during SW06, drawing on in situ and satellite data sets available in real-time from the Rutgers University Coastal Ocean Observation Laboratory.

The prototype system implemented for SW06 was a 5-km horizontal resolution, 30-level model with IS4DVAR assimilation of all glider observations (from RU COOL), shipboard CTDs and XBTs of opportunity on research vessel transit legs from Woods Hole to the SW06 site, Scanfish profiles from

RV Endeavor (Gawarkiewicz), underway thermosalinograph data from the first two RV Knorr legs, daily composite SST (RU COOL) and gridded altimeter SSH anomalies (AVISO). Initial conditions were the Linder and Gawarkiewicz New Jersey shelf climatology adjusted by simple relaxation to the kinematic constraints of the model domain. Meteorological forcing was NCEP/NAM 12-km 3-hourly forecast data. Hudson River discharge data was from daily average USGS gauge observations. Tide boundary conditions were from the Oregon State OTPS harmonic analysis. We assimilated data over 2-day intervals iterating the initial conditions to minimize the model-data misfit over each cycle. Each 2-day cycle begins with first guess initial conditions being the conclusion of the preceding interval. Plots from the full hindcast sequence can be viewed at: http://marine.rutgers.edu/po/sw06/roms.

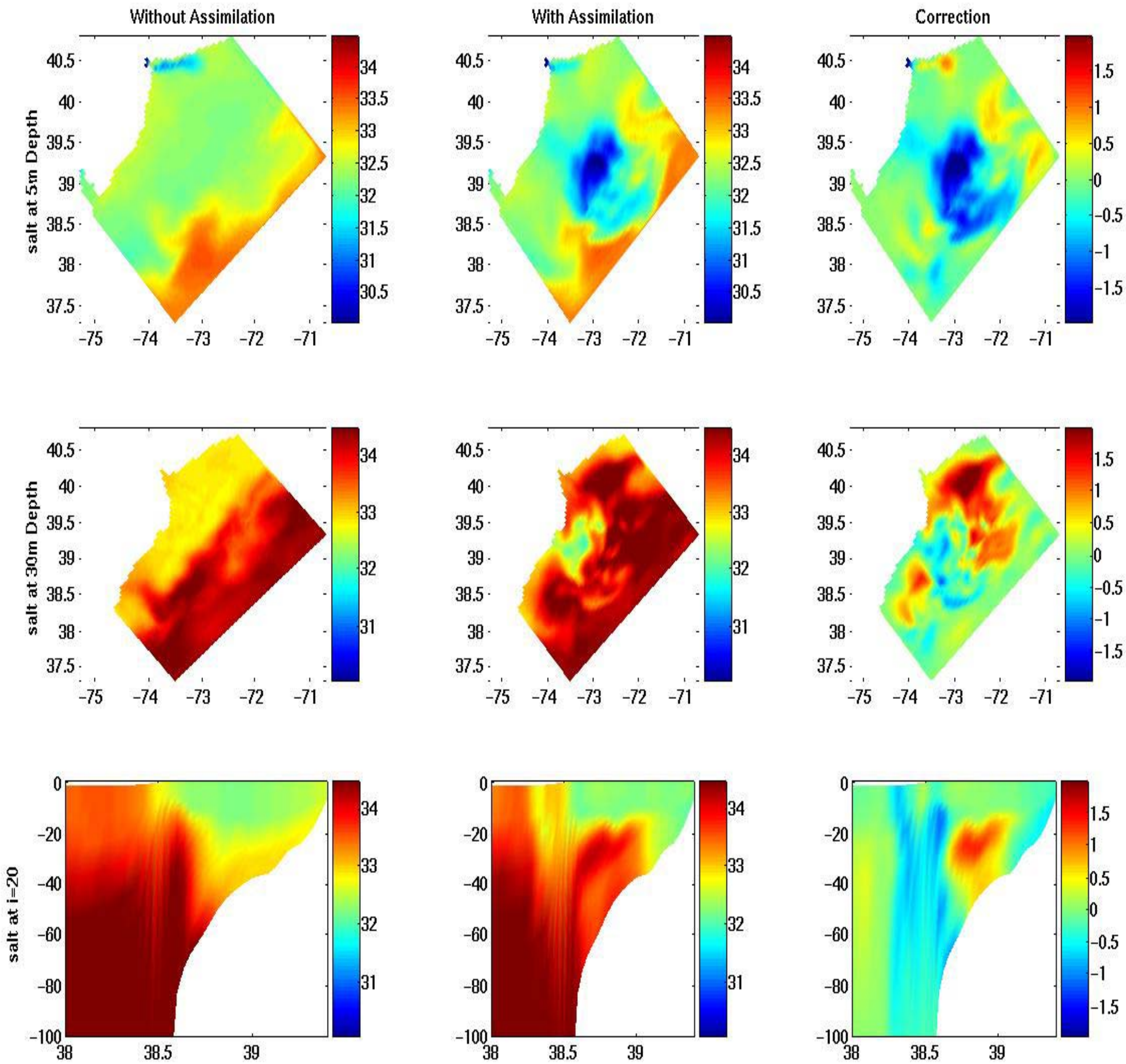

Figure 1: Example ROMS model salinity and temperature results at 30-m depth for the SW06 region. Left: prediction without assimilation. Right: With assimilation of data from gliders and XBTs the salinity is adjusted significantly within the scope of the observations.

RESULTS

Climatology was a poor estimator of the initial state in 2006 given the extreme precipitation that occurred in the Hudson River watershed during mid-July. Assimilation results (Figure 1) show the model quickly adjusts the salinity in the central SW06 region in response to low salinity observations by the gliders. However, in the absence of other data in the far field, the adjustment is local.

As the model simulation proceeded, the salinity-corrected region advanced slowly northward and eastward consistent with the adjoint model propagating the model-data misfit information upstream. The barotropic transport of the shelf/slope front was not well constrained by the assimilation of predominantly temperature and salinity data from gliders, ships and satellites, arguing in favor of the value of complementary observing systems (CODAR, ship ADCP, moored current meters) to constrain ocean velocities. The introduction of a low salinity core in the region of intensive observations generates a weak, unrealistic, anticyclonic circulation that will need to be corrected in future re-analyses by adopting initial conditions that better reflect the shelf-wide anomalously low salinity (with respect to climatology) in summer 2006.

IMPACT/APPLICATIONS

Future work will include all SW06 field data (CODAR; in situ data from mooring and ships) in a re-analysis of the submesoscale ocean state during SW06. The inclusion of velocity observations is expected to significantly constrain the null space in the ocean velocity field that arises when only tracer data are assimilated. Choices made in implementing the IS4DVAR algorithm for this region (length scales, model and data error estimates, assimilation cycle length) will be explored further to seek more appropriate definitions of the background error covariance statistics that controls the unobserved null space. Ensemble predictions generated using singular vectors of the tangent linear model will be used to quantify forecast predictability.

These efforts will increase the skill of the SW06 hindcasts to provide the best estimate of the submesoscale state for the acoustics and internal wave investigators in the program, and will demonstrate the capabilities of an integrated observation-modeling system to deliver coastal ocean analyses in other regions and for other applications.

RELATED PROJECTS

This project has strong synergies with ONR's NLIWI and AWACS DRIs that are companion to the SW06 program, and the recently commended Mid-Atlantic Bight shelf-wide MURI on Coastal Ocean Modeling, Observation and Prediction. For the MURI we will introduce new componenets to ROMS is enable the inclusion of ocean bio-optics data in the assimilation procedure.

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