Development of an operational analysis/forecast system for the Mid Atlantic Bight

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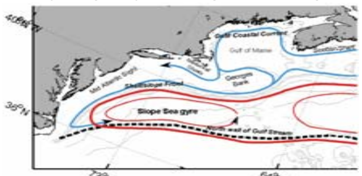
Abstract

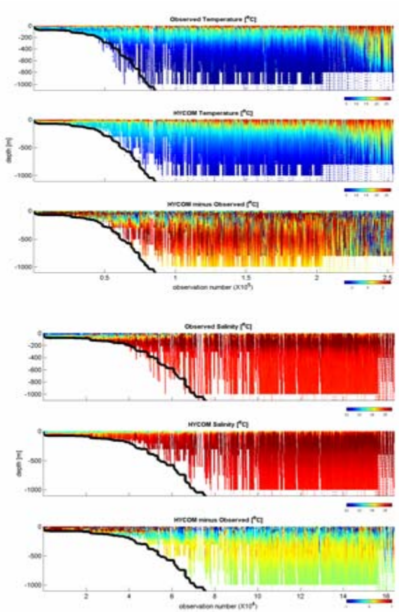
This work describes the development of an analysis and forecast system for the Mid-Atlantic Bight shelf-wide MURI Experimental System for Predicting Shelf and Slope Optics (ESPreSSO). ESPreSSO resolves mesoscale and sub-mesoscale process in a coastal transition region (mid-shelf to adjacent deep sea) by integrating a high-resolution 3-dimensional coastal model (ROMS; the Regional Ocean Modeling System) with numerous different observations using Incremental Strong-constraint 4-Dimensional Variational [1] (IS4DVAR) data assimilation. The system has been successfully prototyped to assimilate satellite Sea Surface Temperature (SST), along-track altimeter Sea Surface Height Anomaly (SSHA), HF radar surface currents, and hydrographic data (CTD, XBT and glider observations). Preliminary comparison to withheld in-situ temperature and salinity observations indicates that ESPreSSO can provide good estimates of observed hydrographic data when just satellite information (SST and SSHA) is assimilated. The skill seems to be superior to that from operational HyCOM+NCODA and French Mercator global analysis systems. We attribute the ESPreSSO added skill to the inclusion of climatological information in the assimilation procedure to correct for biases, and the projection of observed SST and SSHA to the subsurface by the adjoint model in the variational assimilation method.

The Mid Atlantic Bight (MAB)

- wide shallow shelf separated from Gulf Stream by the Slope Sea
- Shelf/Slope Front (~0.3 m/s) at shelf edge
- Gulf Stream rings frequently enter Slope Sea and impact shelf

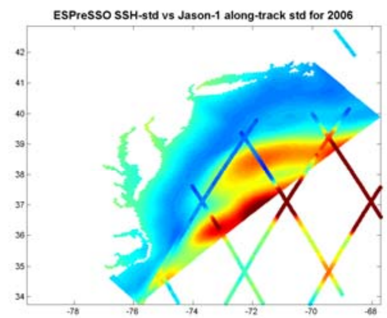


Current data-assimilative models for the area have very poor skill in hindcasting the observed temperature and salinity. Here is an example for the HYCOM+NCODA product:



Model and Assimilation Methodology

We use the Regional Ocean Modeling System (ROMS; www.myroms.org) forced by a shelf-scale circulation model for the MAB and Gulf of Maine [2] (MABGOM) that is forced by the operational data assimilative North Atlantic HyCOM (hycom.rsmas.miami.edu) at the boundaries, and by the North American Regional Reanalysis [3] at the surface. Without assimilation the model reproduces reasonably well the seasonal cycle but fails in predicting the mesoscale activity, notably the SSH variability:



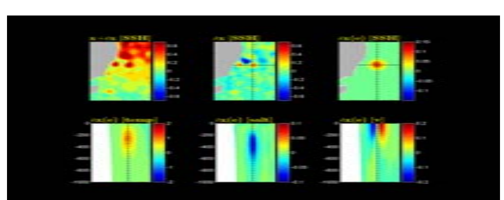
Variational data assimilation is a very attractive methodology to correct for these deficiencies as it exploits the property of the adjoint model to transfer efficiently information from observed variables (e.g., satellite data) to unobserved variables (e.g. subsurface temperature, salinity, and currents).

For a single observation (e.g. SSH at one grid point) the increment is given by:

$$\delta x = c\,B\,M^T e$$

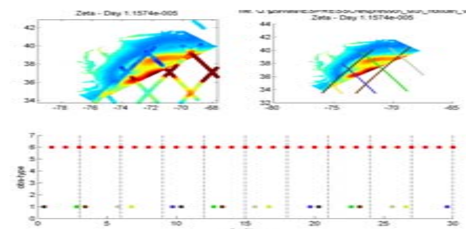
Where B is the analysis covariance matrix, and M^T is the adjoint model acting on the delta function e that targets the observation grid-point. Therefore there are two ways of transferring information between the variables:
1) Through the action of the adjoint model, and
2) through the specification of the off-diagonal elements of B.

Here is an example for a single observation of SSH in the East Australia Current using a block diagonal B, and therefore all the information to other variables is transferred through the adjoint model used in IS4DVAR:



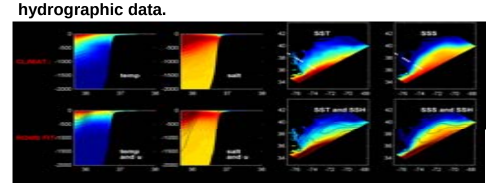
In IS4DVAR the control variable of the assimilation system are the initial conditions of each assimilation window, and the model trajectory through each interval is deemed the best-estimate of the estate of the ocean given the available observations, and can be used for a subsequent forecast.

ISD4DVAR data assimilation of Jason-1 along-track SSH and daily SST is applied in a sequential way during 2006 using an assimilation window (AW) of 3 days. The state at the end of each AW is the first guess for the next assimilation cycle.



Practical considerations for variational assimilation of along-track data

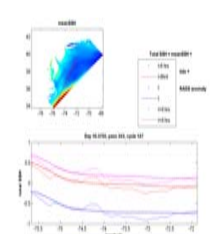
ROMS assimilates total SSH which is the sum of the mean SSH (or dynamic topography) plus the SSH anomaly due to mesoscale activity plus the tides. The Mean Dynamic Topography (MDT) is computed by IS4DVAR analysis of a regional 3-D T-S climatology computed from historical hydrographic data.



ROMS includes high frequency variability typically removed in altimeter processing (tides, storm surge). The IS4DVAR cost function, *J*, samples this high frequency variability, so it must be either (a) removed from the model or (b) included in the data. Our approach is to remove the tide in the observed SSH and add the model tide (computed via harmonic analysis of a forward run).

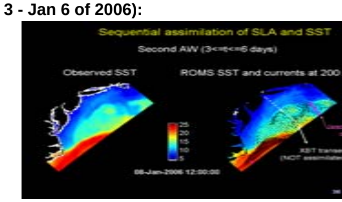
The adjoint model can erroneously accommodate too much of the SSH model-data misfit in the barotropic mode, which sends gravity wave at speed $(gh)^{1/2}$ along the model perimeter.

We therefore acknowledge the temporal correlation of the sub-tidal altimeter SSH data by repeating (duplicating) the altimeter SSH observations at $t = -6$ *hour*, $t=0$ and $t = +6$ *hour*, but with appropriate time lags in the added tide signal. These data cannot easily be matched by a barotropic wave.

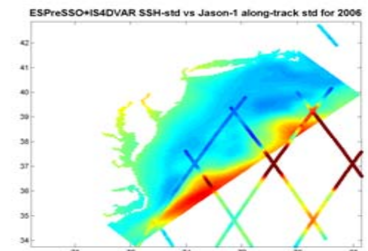


Preliminary Results

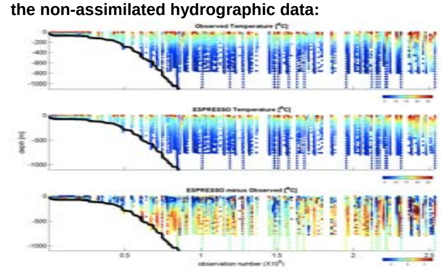
Here is an example of the ROMS fit during the second AW (Jan 3 - Jan 6 of 2006):



And the mesoscale SSH now agrees better with that of the along-track data:



And there is great improvement in the prediction of the non-assimilated hydrographic data:



Future work

- •Operational Prediction (prototype already in place, assimilating along-track Jason-2 SSHA and blended (microwave plus infrared) SST).
- •Near coast along-track data reprocessing
- •Include other observations (HF radar surface currents, CTD, XBT, glider data)
- •Inclusion and assessment of impact of reprocessed data
- •Observing System Simulation Experiments (OSSE)

Acknowledgments: SST product kindly provided by Remote Sensing Systems and served by NOAA CoastWatch (http://las.pfeg.noaa.gov/oceanWatch/oceanwatch.php)

References:

[1] P. Courtier, J. N. Thepaut, and A. Hollingsworth. A strategy for operational implementation of 4D-Var, using an incremental approach. Q. J. R. Meteorol. Soc. 120:1367-1387, 1994.
[2] R. He and K. Chen. Investigation of the Northeastern North America Costal Circulation Using a Regional-scale Ocean Model. Submitted to JGR. 2009.
[3] F. Mesinger, et al. North American Regional Reanalysis. Bulletin of the American Met. Soc. 87:343-360, 2006.