A National Oceanographic Partnership Program Award

HYCOM Consortium for Data Assimilative Modeling

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Long-Term Goals

The goal of the project is to make HYCOM (HYbrid Coordinate Ocean Model) a state of the art community ocean model with data assimilation capability of sea surface height from altimetry, sea surface temperature from MCSST and in-situ data. The ultimate goal is to have an eddy-resolving assimilative fully global nowcast/forecast system running in real time.

Objectives

Development and validation of global and basin scale ocean prediction systems which includes assimilation of available data, e.g. satellite altimetry, MCSST and in-situ data. This is a 5-year (FY00-04) National Ocean Partnership Program (NOPP) project and is a collaborative effort between several research groups with Eric Chassignet as the overall lead project PI. The focus will be on an eddy resolving Atlantic domain (with 7 km resolution at mid latitudes) and a coarser resolution global domain.

Approach

Many aspects of ocean modeling are included in this project. The modeling components are described in details in other HYCOM related ONR reports. This report will focus on some of the assimilation components of the project.

The approach is to implement several different assimilation techniques starting with simple incremental updating. Sophisticated algorithms such as the parameter matrix objective analysis (PMOA, Mariano and Brown, 1992), the singular evolutive extended Kalman filter (SEEK, Pham et al., 1998), the Markov random field information filter (MRFIF, Chin et al.1999) and the ensemble Kalman filter (Evensen, 1994) will also be implemented by the HYCOM/NOPP consortium. Different vertical projections of the surface information to the deep ocean will be evaluated for the simple techniques, (e.g. Hurlburt et al. 1990, Cooper and Haines, 1996 and Gavart and De Mey, 1996). Synthetic temperature and salinity profiles from the Modular Ocean Data Assimilation System (MODAS) (Fox et al. 2002) will also be tested as an alternative vertical projection technique. The assimilation techniques will be evaluated as a function of computational efficiency and prediction accuracy. The computational requirements will be an

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important part of the comparison. A real time system will have a limited amount of computer time available and the model with the data assimilation will have to run within this time limit. The validation of the results from the assimilation experiments is an important part of the project. Data not being assimilated will be used to validate the model solution. A suite of software to do model validation has been developed and is currently being used with the 1/16° global NRL Layered Ocean Model (NLOM) which is running in real time at the Naval Oceanographic Office (NAVOCEANO), see the NLOM web page http://www.ocean.nrlssc.navy.mil/global_nlom.

Work Completed

Two meetings of the HYCOM/NOPP partnership were held (November 2001 and February 2002) to review progress and update plans and milestones, technical issues and responsibilities of the participants.

The first baseline assimilation scheme has been successfully implemented in the HYCOM model in cooperation with Remy Baraille (LEGOS/BRESM). It presently consists of the assimilation of analyzed sea surface height (SSH) fields and a vertical projection of the surface observations using the Cooper and Haines technique, (Cooper and Haines, 1996). The assimilation was initially implemented in a 1/6° Japan-East Sea (JES) version of HYCOM. Several identical twin experiments were run with this model to test the performance of the assimilation technique.

As a prototype system, a 1/3° data assimilative Atlantic version of HYCOM was set up using the assimilation technique described above. The operational MODAS analysis of available satellite altimeter observations is used in the assimilation. It is currently running in near-real time (once a week) and the results are displayed on an internal web page. The web page that has been developed follows the same layout as the web page currently being used by NAVOCEANO's operational 1/16° global NLOM, see the NLOM web page for details. It includes comparisons to unassimilated observations, e.g. an independent frontal analysis of high resolution MCSST data performed by NAVOCEANO and observations of sea surface temperature (SST) and temperature profiles from buoys.

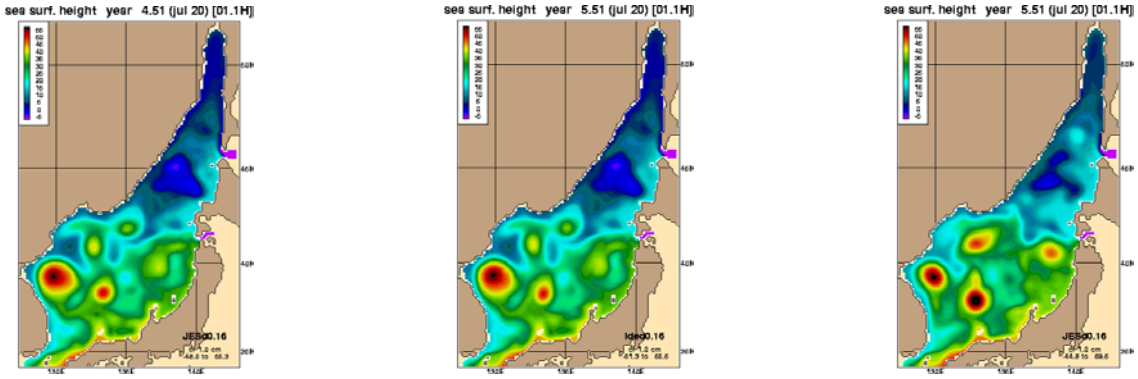
A major goal of the goals of the HYCOM project is to have a data assimilative 1/12° (~ 7 km mid-latitude resolution) eddy-resolving Atlantic Ocean model with data assimilation. During FY02 this model was spun up and run through July 2002 (see separate NOPP/HYCOM/NRL report). A data assimilative system with the 1/12° Atlantic model has also been set up. This system will be run in near real time starting in October 2002, replacing the 1/3° system.

Results

A baseline assimilation system has been implemented in HYCOM. A 1/6° JES version of HYCOM was used to test the performance of the assimilation. Several identical twin experiments were performed to make sure the technique worked. The model was spun up for several years forced with the European Centre for Medium Range Weather Forecasts (ECMWF) atmospheric forcing. The initial conditions for the control and assimilation run were from the same model simulation but taken one year apart. Figure 1 and 2 show the results from one of the identical twin experiments. The plots show the results after 30 days of assimilating the daily SSH fields from the control run. The success of the assimilation in reproducing the SSH field can clearly be seen, figure 1a and b. The SSH field from the model run without assimilation is shown

in figure 1c. The vertical projection of the surface information is done via the Cooper and Haines technique. Figure 2a-c show a vertical cross section along 135.2°E. The top panels show the u velocity component in the upper 1000 meters while the bottom panels show the vertical temperature profile along the section. The interface depths are overlaid on the velocity and temperature sections. The vertical projection of the surface observations has produced a vertical profile close to the "observed" field in the control run.

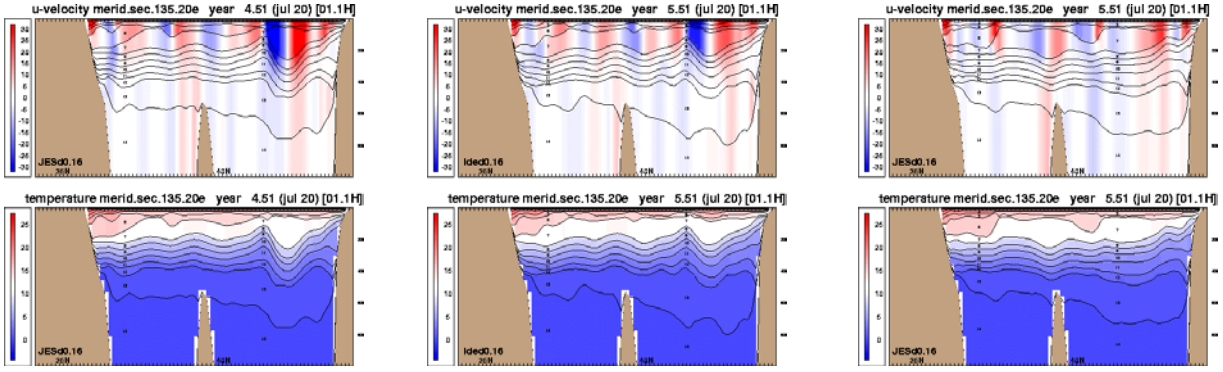
Control run | Assimilation | No assimilation



(a) **(b)** **(c)**

FIGURE 1 The sea surface height from the identical twin experiment with the 1/6° Japan-East-Sea HYCOM model. The model was forced with ECMWF atmospheric forcing. (a) Show the SSH from the control run corresponding to day 30 of the assimilation, (b) the corresponding SSH from the assimilation run and (c) the SSH from a run without assimilation.

Control run | Assimilation | No assimilation



(a) **(b)** **(c)**

FIGURE 2 Vertical section of meridional velocity and temperature from the identical twin experiment with the Japan-East-Sea HYCOM model. (a) Show the u velocity (top panels) and temperature (bottom panels) from the control run corresponding to day 30 of the assimilation. (b) Show the corresponding velocity and temperature from the assimilation run. (c) Show the velocity and temperature from a run without assimilation. The interface depths are overlaid on the sections.

In addition to the identical twin experiments with the JES model, a data assimilative 1/3° Atlantic version of HYCOM has been set up and is currently being run in near real time. This system assimilates the daily MODAS SSH anomaly analysis of available real time satellite data. In order to assimilate these anomalies a mean SSH must be used. Our results from last year showed that the mean from the 1/12° MICOM experiment forced with ECMWF atmospheric forcing had a realistic Gulf Stream pathway that was in good agreement with independent observations. We are currently using this mean in the assimilation experiments with real altimeter observations. The mean SSH in the Gulf Stream region can be seen in figure 3a. The atmospheric forcing of the near real time system comes from the Fleet Numerical Meteorology and Oceanography Center (FNMOC) Navy Operational Global Atmospheric Prediction System (NOGAPS). The current assimilation system is computationally very efficient. It increases the run time of the model by only a few percent compared to the model run without assimilation.

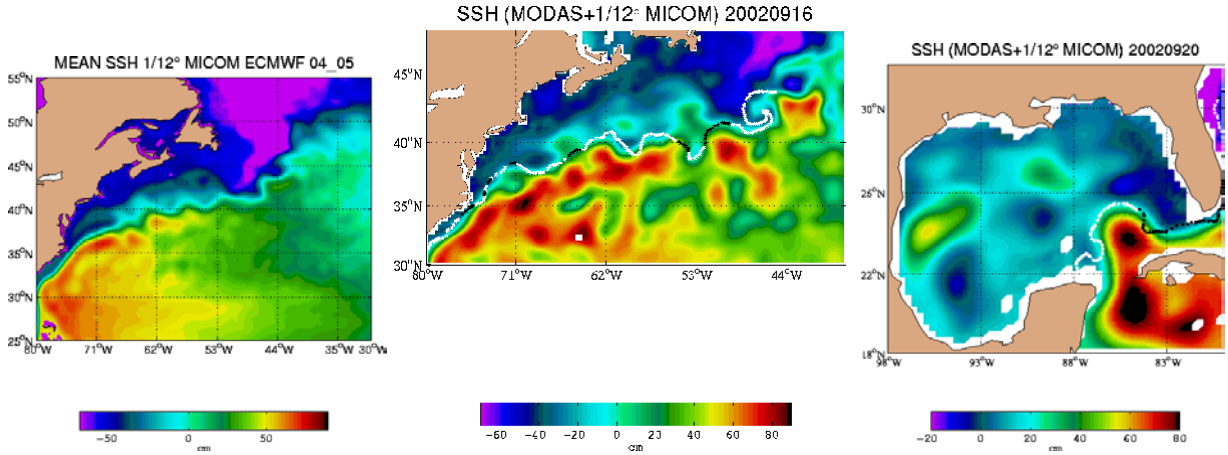


FIGURE 3 (a) Mean sea surface height from the 1/12° Atlantic MICOM with ECMWF atmospheric forcing in the Gulf Stream region. This mean is used in the 1/3° Atlantic HYCOM assimilation. (b) The sea surface height from the 1/3° Atlantic HYCOM in the Gulf of Mexico region on 20 September 2002 and (c) the sea surface height in the Gulf Stream region on 16 September 2002. Overlaid is an independent frontal analysis of MCSST observation performed at NAVOCEANO. The frontal position is marked in black if the observations are more than 2 days old.

Examples of the results from the 1/3° Atlantic model can be seen in figure 3b and c. The figures show the model SSH for the Gulf of Mexico region on 20 September 2002, figure 3b, and the Gulf Stream region on 16 September 2002, figure 3c. Overlaid on the SSH is an independent frontal analysis of MCSST data performed at NAVOCEANO. The agreement between the model and the independent observations is good. The 1/3° model is only a prototype system on the way to an eddy-resolving ocean model. Preliminary tests have started with the 1/12° Atlantic version of HYCOM. The data assimilative system has been set up and this system will replace the 1/3° system starting in October 2002.

An internal web page has been developed to display the results from the near real time system. It presently includes plots of nine different regions of the Atlantic domain. The regions plots are of SSH, SST and surface currents. The plan is to perform regular forecasts with the model and these results are shown on the web page as well. The forecasts validation includes the RMS error, anomaly correlation and the climatological skill score. Several vertical sections from the model is also included as well as comparison to observed time series of SST from buoys in the equatorial Atlantic, the Gulf of Mexico and the Gulf Stream region.

Impact and Applications

The intended impact of the HYCOM/NOPP project is the development of a next generation hybrid coordinate ocean model which will have a greater range of applicability than traditional single coordinate ocean models. The coordinate system design and its implications are discussed in the FY02 HYCOM ONR reports. The project is well on its way to the goals, including the first near real-time 1/12° HYCOM Atlantic nowcast/forecast system with a web page that will soon be released to the public. The ultimate goal is (via follow on projects) an eddy-resolving global ocean prediction system with 1/12° (~7 km mid-latitude) resolution running by the end of FY06 and 1/25° (3-4 km mid-latitude) resolution by the end of the decade including an embedded ice model and the capability to host nested littoral models with even higher resolution. The HYCOM consortium is participating in the Global Ocean Data Assimilation Experiment (GODAE) (2000-2007) and is contributing to the GODAE goal of helping to justify a permanent global ocean observing system by demonstrating real-time global ocean products with a customer base.

National Security

National security applications include anti submarine warfare and surveillance, mine warfare, tactical planning, inputs to tactical decision aids and amphibious operations, some of these via boundary and initial conditions to littoral models**.**

Economic Development

The results from the project can be used for fisheries monitoring and fishing forecasts as well as monitoring and prediction of eddies and currents that may impact deep ocean structures such as oil rigs and other offshore oil company operations.

Quality of Life

Applications under quality of life include pollution and tracer tracking such as oil spills..

Transitions

None

Related Projects

The results described here are a part of a HYCOM/NOPP project with participation from several different research groups. The groups include E.P. Chassignet (Coordinator), A. Mariano and G. Halliwell (University of Miami), T.M. Chin (JPL/University of Miami), R. Bleck (LANL), H. Hurlburt, P. Hogan, R. Rhodes, C. Barron, A. Wallcraft and G. Jacobs (Naval Research Laboratory), O.M. Smedstad and B. Lunde (Planning Systems Inc.), W.C. Thacker (NOAA/AOML).

References

Fox, D.N, W.J. Teague, C.N. Barron, M.R. Carnes and C.M. Lee, 2002: The Modular Ocean Data Assimilation System, Journal of Atmospheric and Oceanic Technology. 19, 240-252.

Chin, T.M., A.J. Mariano and E.P. Chassignet, 1999: Spatial regression with Markov Random Fields for Kalman filter approximation in least-squares solution of oceanic data assimilation problems. Journal of Geophysical Research, 104, 7991-8014.

Cooper, M. and K. Haines, 1996: Altimetric assimilation with water property conservation. Journal of Geophysical Research, 101, 1059-1077

Evensen, G. 1994: Sequential data assimilation with a nonlinear quasi-geostrophic model using Monte Carlo methods to forecast error statistics. Journal of Geophysical Research, 99, 10143-10162.

Gavart, M. and P. De Mey, 1996: Isopycnal EOFs in the Azores Current Region: A statistical tool for Dynamical Analysis and Data Assimilation, Journal of Physical Oceanography, 27, 2146-2157

Hurlburt, H. E., D. N. Fox and E. J. Metzger, 1990: Statistical inference of weakly-correlated subthermocline fields from satellite altimeter data. Journal of Geophysical Research, 95, 11375-11409.

Mariano, A.J. and O.B. Brown, 1992: Efficient objective analysis of dynamically heterogeneous and nonstationary fields via the parameter matrix. Deep-Sea Research, 39 (7/8), 1255-1271.

Pham, D.T., J. Verron and M.C. Roubaud, 1998: A singular extended filter for data assimilation in oceanography. Journal of Marine Systems, 16, 323-340.