Develop a Hybrid Coordinate Ocean Model with Data Assimilation Capabilities

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LONG-TERM GOALS

To develop data-assimilating capability for HYCOM, the hybrid version of University of Miami's Isopycnic Coordinate Ocean Model. This project is one component of the NOPP consortium for developing a data-assimilating ocean model based on a hybrid vertical coordinate. The focus of this component has been on the assimilation of in situ hydrographic data to correct the model state.

OBJECTIVES

a) To develop a methodology for assimilating temperature profiles from XBTs that accommodates the peculiarities of the hybrid system of vertical coordinates, allowing density to be corrected at fixed pressure levels where the coordinate is pressure-like, allowing interface pressures to be corrected when the coordinate is density-like, and allowing both to be corrected in the transition zone.

b) To compare the model-state to observations and to infer error statistics and influence functions.

c) To develop codes for implementing this methodology.

d) To prepare a HYCOM-based reanalysis of archived XBT data.

e) To provide the framework for a HYCOM-based oceanic forecast system.

APPROACH

Companion salinity profiles are to be estimated and used to estimate density profiles from which data for layer-interface pressures and layer potential-densities can be obtained. At first, error-statistics, which govern the nature of the data-based corrections to the model state, are to be postulated so that assimilation codes can be made functional; later, they are to be based on model-data comparisons. The method is to be sufficiently flexible to allow for incorporation of other types of data, in particular those from satellite-based observations.

WORK COMPLETED

a) The design for the data-assimilation methodology exists and is being tested and improved.

b) The preprocessing system to estimate companion salinity profiles and layer/interface values has been implemented. Biases have been identified as being caused by use of climatological salinity. Efforts are underway to obtain the Navy's climatology of temperature-salinity relationships, which should offer improvement by allowing departures from climatological salinity to be estimated from observed departures from climatological temperature.

c) Initial estimates of model and data errors have been improved, but more work is needed in this area.

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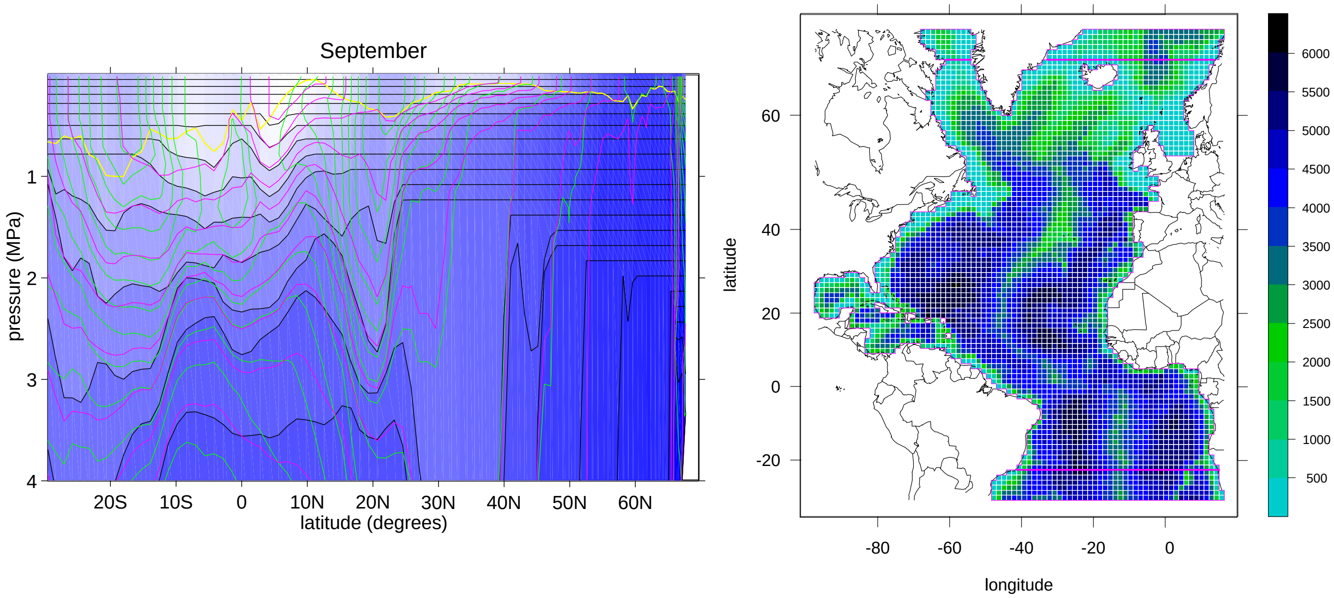

Figure 1: Left: Upper 400 meters along 31°W for 1972 from the Atlantic 1.4° HYCOM model without data assimilation. Shade of blue indicates potential density; black curves, interface pressure; magenta, potential temperature (2°C spacing); green, salinity (0.2 psu spacing); yellow, bottom of the mixed layer. Right: Mercator projection of grid with map overlay and with colors indicating basin depths of up to 6000 meters.

d) Need to identify water type and relationship of data to locations of fronts and eddies has been recognized as being important for making intelligent use of the data.

e) A paper describing the problem of model-data-error compatibility has been submitted for publication.

f) A preliminary reanalysis of Atlantic XBT data for the twenty-year interval 1972–1991 has been completed and a paper describing the results is in preparation.

RESULTS

HYCOM has layers that are density-like (specified potential density) at depths where the ocean is stratified and pressure-like (specified thickness) where it is well mixed, smoothly changing from one aspect to the other (left panel, figure 1); the Atlantic model with 1.4-degree resolution (right panel, figure 1) provides the context for development. The seasonal cycle of the mixed layer and upper thermocline requires that the nature of the layers change both with time and with location. While this formulation offers advantages for modeling, it also imposes challenges for data assimilation. We must determine the nature of the layers from data in order to know how the model state needs to be corrected.

The focus of this sub-project has been on the use of XBT data, because they comprise the bulk of the in situ data and because they provide the most direct information about the vertical structure of the ocean and thus about the nature of the hybrid layers. The design that has been developed addresses this issue directly. The XBT data are from AOML's Global Ocean Observing System (GOOS) Center (left panel, figure 2). The ultimate goal is to use all types of data, combining the horizontal information provided by satellite-based observations with the information about vertical structure from in situ soundings.

Unfortunately, density is not directly observed, nor is salinity, which together with temperature determines density. To infer where layer interfaces should be, a salinity strategy is necessary. For expediency, so that other aspects of the project can progress, salinity is being estimated from the climatological mean conditions for the location and time of year. Such estimates fail to account for the co-variability of salinity with temperature and can cause significant errors in the estimated depth at which the model's potential-density layers should be situated. Efforts are underway to obtain the Navy's TS climatology so that the salinity estimates can be improved (right panel, figure 2). Still better estimates might be achieved (Hansen and Thacker, 1999) but to do so would require a separate project.

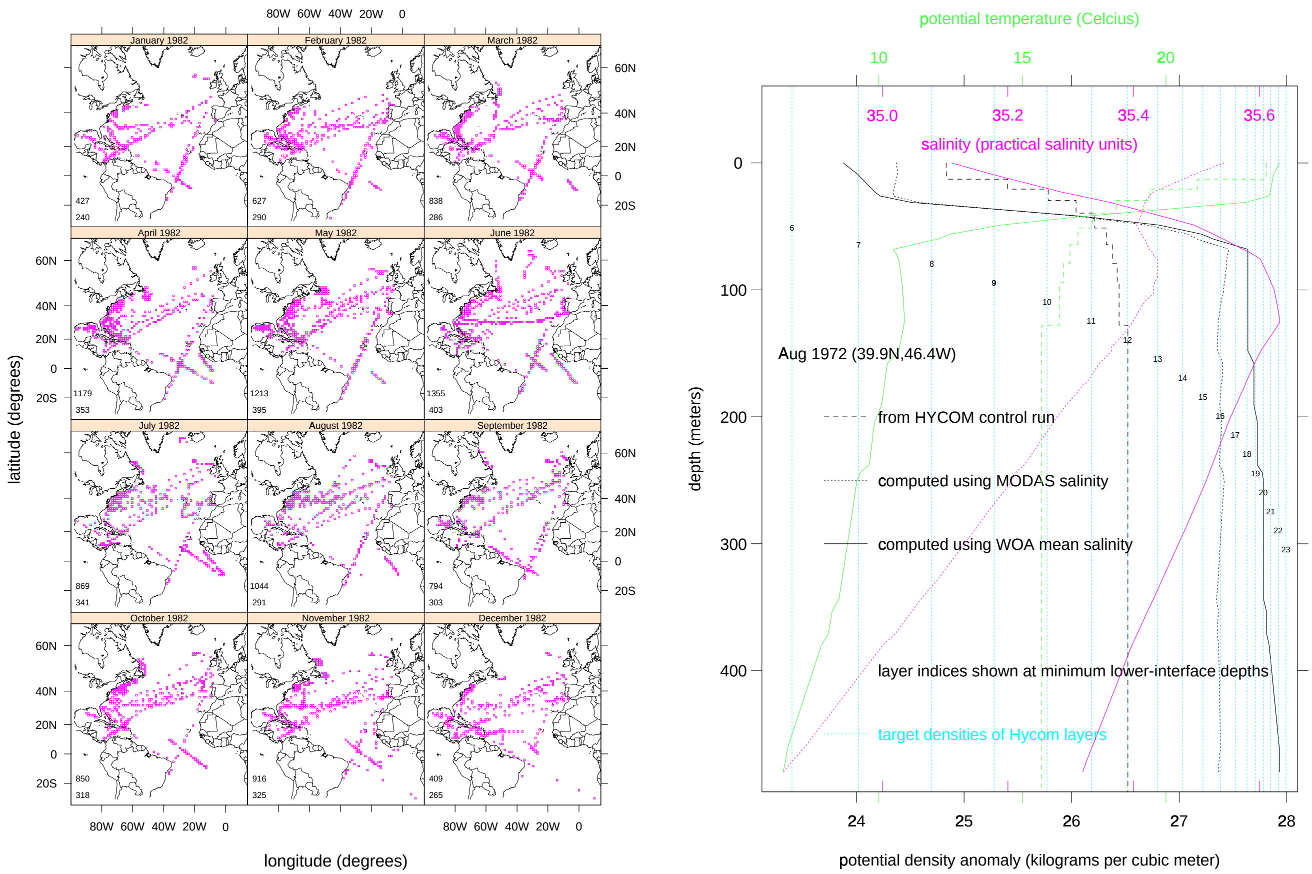

Figure 2: Left: Magenta squares mark locations of grid cells with data to be assimilated by month for the year 1982. Number of casts for the month and the number of cells sampled are indicated in the southwest corner of each panel. Right:Different estimates of salinity can strongly influence the inference of layer depth from XBT data. Solid green curve indicates unusually cold conditions for grid cell centered at 39.9°N, 46.4°W; broken green curve indicates excessively warm control-run counterparts. Solid magenta curve is climatological mean salinity for that location; dotted magenta curve is salinity estimated by MODAS using climatological TS relationships. Solid black curve is potential-density anomaly estimated from climatological salinity; dotted black curve, estimated from MODAS salinity; broken black curve, potential density from HYCOM control run. Vertical cyan lines indicate target values of potential-density anomaly for the model layers; layer indices are show at the minimum depths of the layers' lower interfaces.

The data within the domain of the 1.4° Atlantic HYCOM domain (30S to 70N) have been pre-processed to give model-relevant values: depths and thicknesses of the model's layers and layer-averaged potential densities and potential temperatures. A variety of techniques (see, for example, Malanotte-Rizzoli, 1996), most of which are based on the error statistics of the model state, can be used to assimilate the data. The approach taken here is to maintain flexibility, using simple, easy to implement methods in the

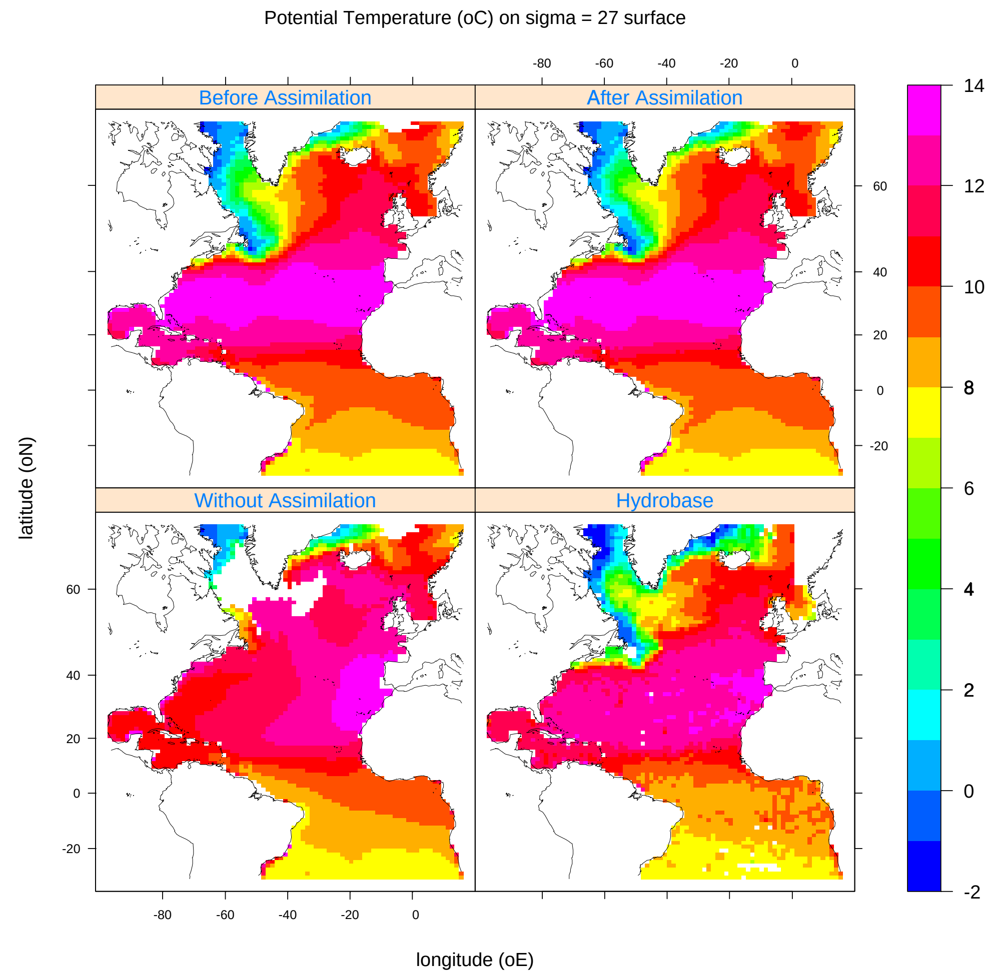

Figure 3: Climatological potential temperature (C) for $\sigma_0 = 27$ kg/m^3: from HYCOM simulation without data assimilation (lower left); average conditions immediately before assimilating data (upper left); immediately after assimilating data (upper right); from Hydrobase climatology (lower right). The color bar at the right indicates the color-coded values of potential temperature on the maps; white indicates absence of the $\sigma_0 = 27$ kg/m^3 surface for the entire 20-year simulation or for the entire data record.

beginning while allowing for increasing sophistication in the future. Codes implementing sequential optimal interpolation have been prepared to assimilate these data at monthly intervals, as the objective is to provide a model-based analysis of the month-to-month evolution of the state of the ocean. Because early simulations have focused more on getting the hybrid model working than on model-data comparisons, details of the error covariances are not yet suited to inferring influence functions for spreading the corrections away from the observations. As the project progresses, more emphasis will be placed on the statistical basis of the corrections. The immediate need is to assess the impact of the corrections on the model state and to determine whether any alterations are needed in the design concept.

The Atlantic XBT data for 1972–1991 have been assimilated into the model and provide a significant correction (figure 3). The data void near Greenland in the lower-left panel indicates that, the $\sigma_0 = 27$ kg/m^3 potential-density surface is not present in the HYCOM simulation at any time of year without assimilation; however assimilation (upper panels) brings the simulation into much closer agreement with the Hydrobase isopycnic climatology. Similarity of the two upper panels indicates that, between monthly assimilations, there is little tendency for the model to regress toward the uncorrected mean conditions. The assimilated XBT data cause the model temperature to be a bit warmer than climatology.

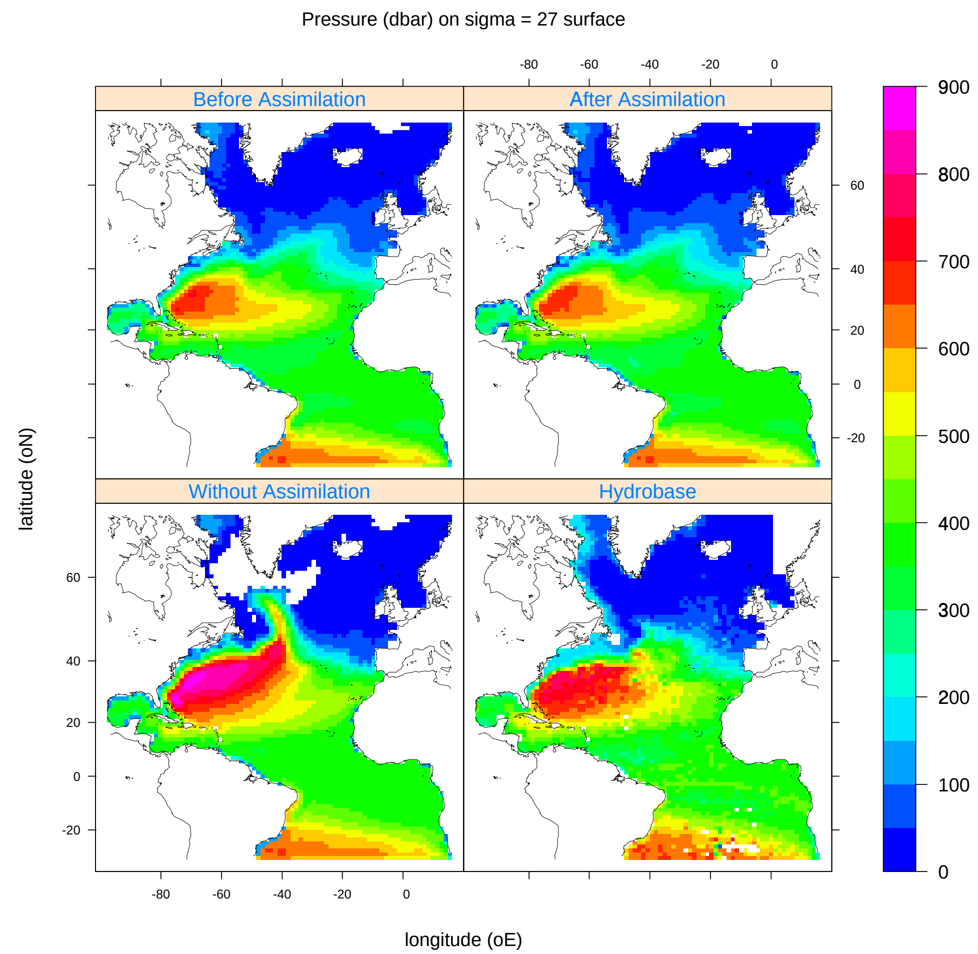

Figure 4: Climatological pressure (MPa) for $\sigma_0 = 27$ kg/m^3: from simulation without data assimilation (lower left); average conditions immediately before assimilating data (upper left); immediately after assimilating data (upper right); from Hydrobase climatology (lower right).

This difference is due to differences in the temperature-salinity (TS) make-up of the $\sigma_0 = 27$ kg/m^3 water, which are most likely caused by failure to preserve the TS relationship during assimilation (figure 2 right). This conclusion is supported by the fact that the corrected $\sigma_0 = 27$ kg/m^3 surface is a bit too shallow in comparison with Hydrobase climatology (figure 4), suggesting that the companion salinity profiles should be somewhat fresher, as this would make the density less, putting the $\sigma_0 = 27$ kg/m^3 surface deeper. Correcting the salinity estimates will be a focus of future work.

IMPACT/APPLICATIONS

This research should lead to a facility for producing model-based analyses of hydrographic data. Low-resolution analyses can be used to provide initial conditions for high-resolution models and for studying climate. At high resolution, this approach can be extended to incorporate detailed horizontal information provided by satellite-based observations.

TRANSITIONS

The assimilation codes that are under development will be made available to the wider oceanographic community as a part of the HYCOM modeling facility.

RELATED PROJECTS

This project is one component of the NOPP consortium for developing a data-assimilating ocean model based on a hybrid vertical coordinate.

REFERENCES

Bleck, R., and E.P. Chassignet, 1994: Simulating the oceanic circulation with isopycnic coordinate models. *The Oceans: Physiochemical Dynamics and Resources*. The Pennsylvania Academy of Science, 17-39.

Hansen, D. V., and W. C. Thacker 1999: On estimation of salinity profiles in the upper ocean. *Journal of Geophysical Research*, **104**, 7921–7933.

Malanotte-Rizzoli, P., editor 1996: *Modern Approaches to Data Assimilation in Ocean Modeling*. Elsevier, Amsterdam.

PUBLICATIONS

Thacker, W. C. and O. E. Esenkov 2002: Assimilating XBT data into HYCOM. *Journal of Atmospheric and Oceanic Technology*, **19**, 709–724.

Thacker, W. C. 2002: Data-model-error compatibility. Submitted to Ocean Modelling.

Thacker, W. C. 2002: Constrained optimality. Submitted to Tellus.

Thacker, W. C., S.-K. Lee, and G. R. Halliwell, Jr., 2002: Constraining HYCOM: Twenty years of Atlantic XBT data. In preparation.