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-coordinate version of University of Miami's Isopycnic Coordinate Ocean Model.

OBJECTIVES

- To develop a methodology for assimilating temperature and salinity profiles from XBT, CTD, and ARGO float data that accommodates the peculiarities of HYCOM's hybrid 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.
- To estimate salinity profiles for XBT data, so that density can be estimated for determining the nature of HYCOM's hybrid layers.
- To compare the model state to observations and infer error statistics and influence functions.
- To give an evolving view of the ocean over the recent past.

APPROACH

Temperature and salinity profiles are to be 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

- The design for the data-assimilation methodology exists and is being tested.
- Work is underway to estimate salinity from XBT temperature profiles. Much of the preprocessing system to estimate layer/interface values has been implemented, although additional software engineering is needed.

- Initial efforts have been made toward developing procedures for comparing model to data and inferring influence functions from error statistics. A paper on compatibility of model, data, and their error estimates has been published.
- Preliminary results have been published for dynamically re-analyzing archived XBT data for the Atlantic using HYCOM.

RESULTS

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.

The model's objective is to exploit the fact that the ocean is stratified and thus can largely be viewed as consisting of layers of water that move to preserve their densities (Bleck and Chassignet, 1994). However, near the surface where mixing is important, this description breaks down and density is less useful as a coordinate. The idea of a hybrid coordinate model is to have 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 (figure 1). 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. The bulk of the data available for assimilation pertain to the upper ocean. XBT casts, which comprise the bulk of the in situ data, span the pressure-like, transition, and density-like regions. Similarly, altimetric data from satellites reflect the thicknesses of layers in all three regions. In the pressure-like layers, density must be inferred from the observations to correct the model, while layer thicknesses must be inferred when the layers correspond to specified densities. The data-assimilating methodology must determine the nature of the layers from observations in order to know to what extent the model state needs to be corrected. The design that has been developed addresses this issue directly. Fig. 1 shows results on the $\Phi=27$ potential-density surface, which cuts through several of the model's layers and which is not present year round in some regions.

Central both to dynamics and to HYCOM's formulation is the ocean's density field, which requires knowledge of salinity as well as temperature. Thus, the XBT data must be supplemented by estimates of salinity. For expediency, so that other aspects of the project can progress, salinity has been estimated from the climatological mean conditions for the location and time of year. This appears to be the weakest aspect of the assimilation scheme at this point in its development. In particular, in regions of strong fronts, it is particularly important to account for the correlation between temperature and salinity, in order to get reasonable estimates of the depths of the model's layers. Consequently, the task of developing better salinity estimates (Fig. 2) has been undertaken as part of this project.
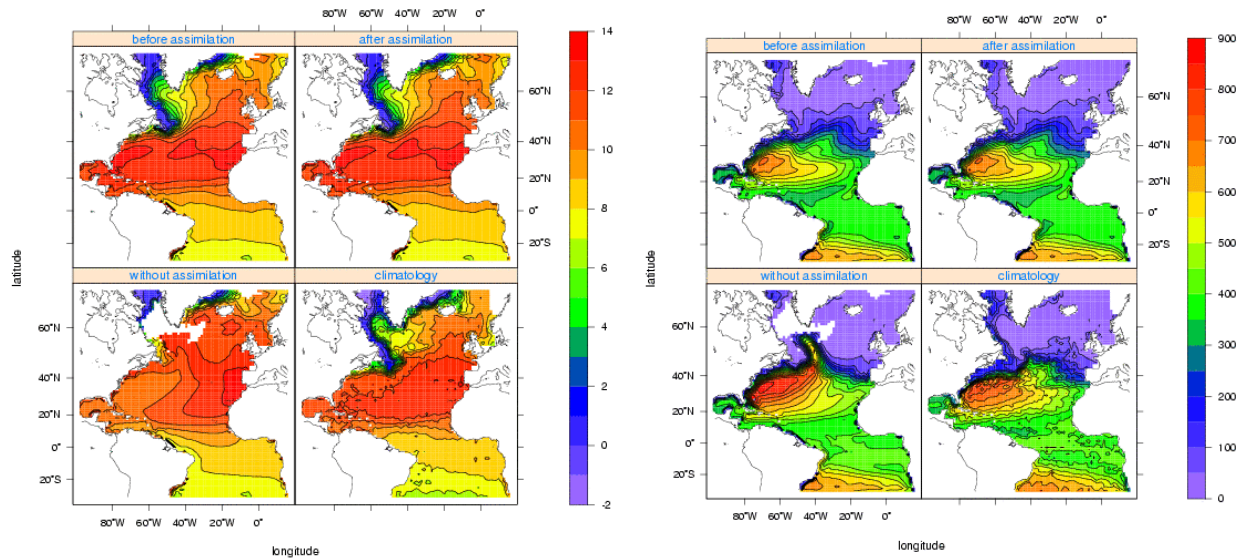
Fig. 1. *Contours of 20-year average of mid-month potential temperature (left) and pressure (right) on the Φ=27 potential-density surface for simulation without XBT data assimilated, for simulation with data assimilated with 20-year average computed just before and just after monthly assimilation, and Hydrobase 20-year climatology. Assimilating XBT data clearly brings the model simulation into better agreement with climatology, and the absence of significant differences between the averages computed before and after the monthly assimilation shows there is little tendency to revert to the uncorrected state.*

Another important concern is data quality (Fig. 3). Both the archived XBT data to be assimilated, for which companion salinity profiles are to be estimated, and the CTD data, from which the empirical relationships between salinity and temperature are to be inferred, include profiles that are obviously bad. The task of recognizing and removing bad data from the archives is quite tedious and time consuming. A supporting quality-control project is needed, so that the data that are to be processed for assimilation can be used without reservation.

Once the data have been pre-processed to give model-relevant values, they can be used to correct the model state. A variety of techniques are available (Malanotte-Rizzoli, 1996), most of which are based on the error statistics of the model state. The approach taken here is to maintain flexibility, using simple, easy to implement methods in the beginning while allowing for increasing sophistication in the future. 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.

Other partners in this NOPP project are focusing on assimilating altimetric data from satellites using a variety of techniques, some of which are quite sophisticated and computationally intensive. This profile-data effort is to be integrated with these approaches, so that the high resolution of horizontal variability from space can be combined with the sub-surface information from profiles to determine both the horizontal influence of the sparse profile data and the vertical projection of the surface information from the altimeters.
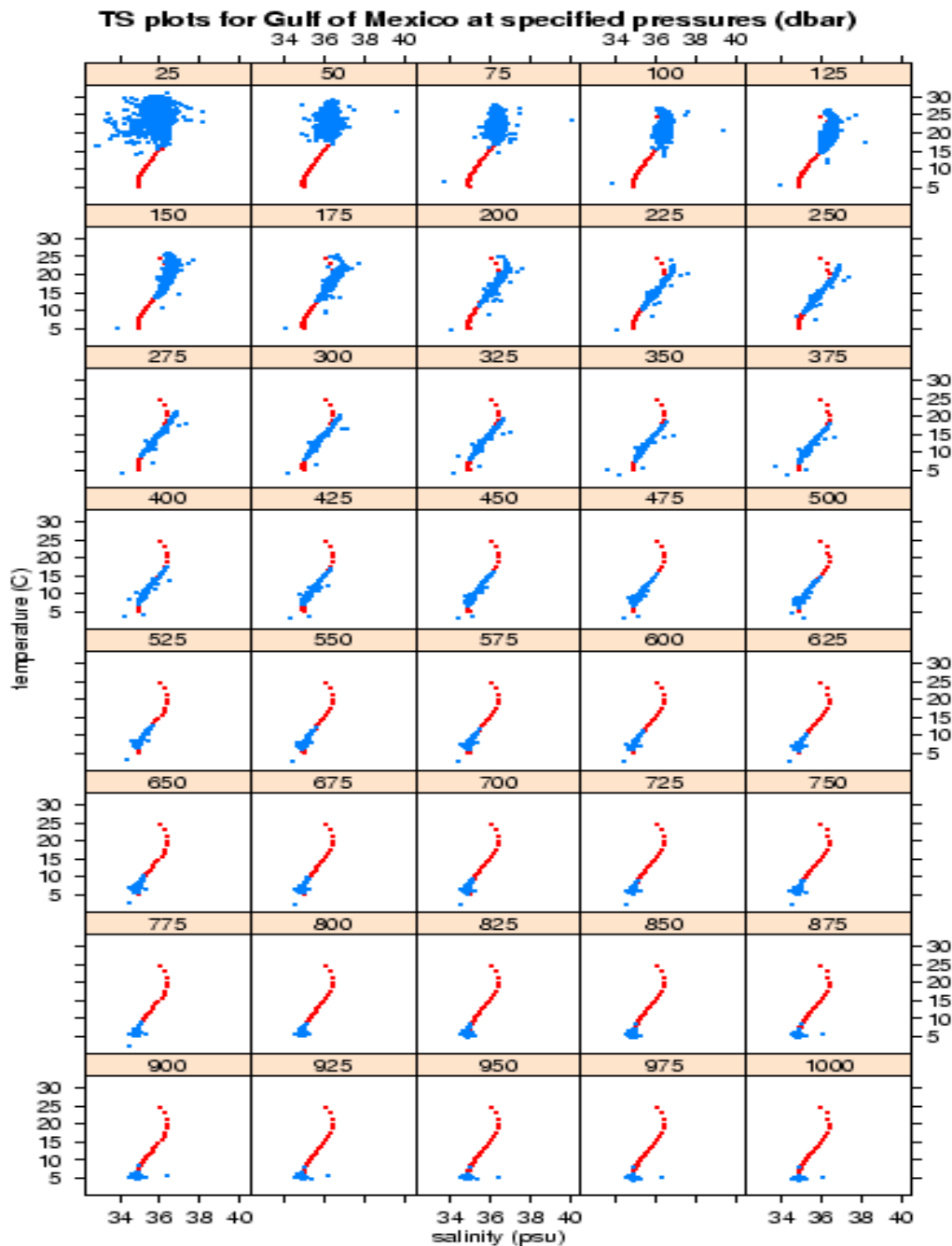
Fig.2. Plots of temperature vs. salinity at 25 dbar intervals for CTD data from the Gulf of Mexico. The red dots, which are the same on all panels, show the mean T and S at each pressure level, while the blue dots show the data for the pressure indicated on the panel label. Although most of the bad data were removed before plotting, some were missed and can be seen as outliers. While the mean TS curve can be used to estimate salinity between 350 dbar and 650 dbar, it would miss warm anomalies in the vicinity of 250 dbar. Above 150 dbar and below 650 dbar, there is little correlation between temperature and salinity, so climatology must be used unless another predictor can be identified (Hansen and Thacker, 1999).
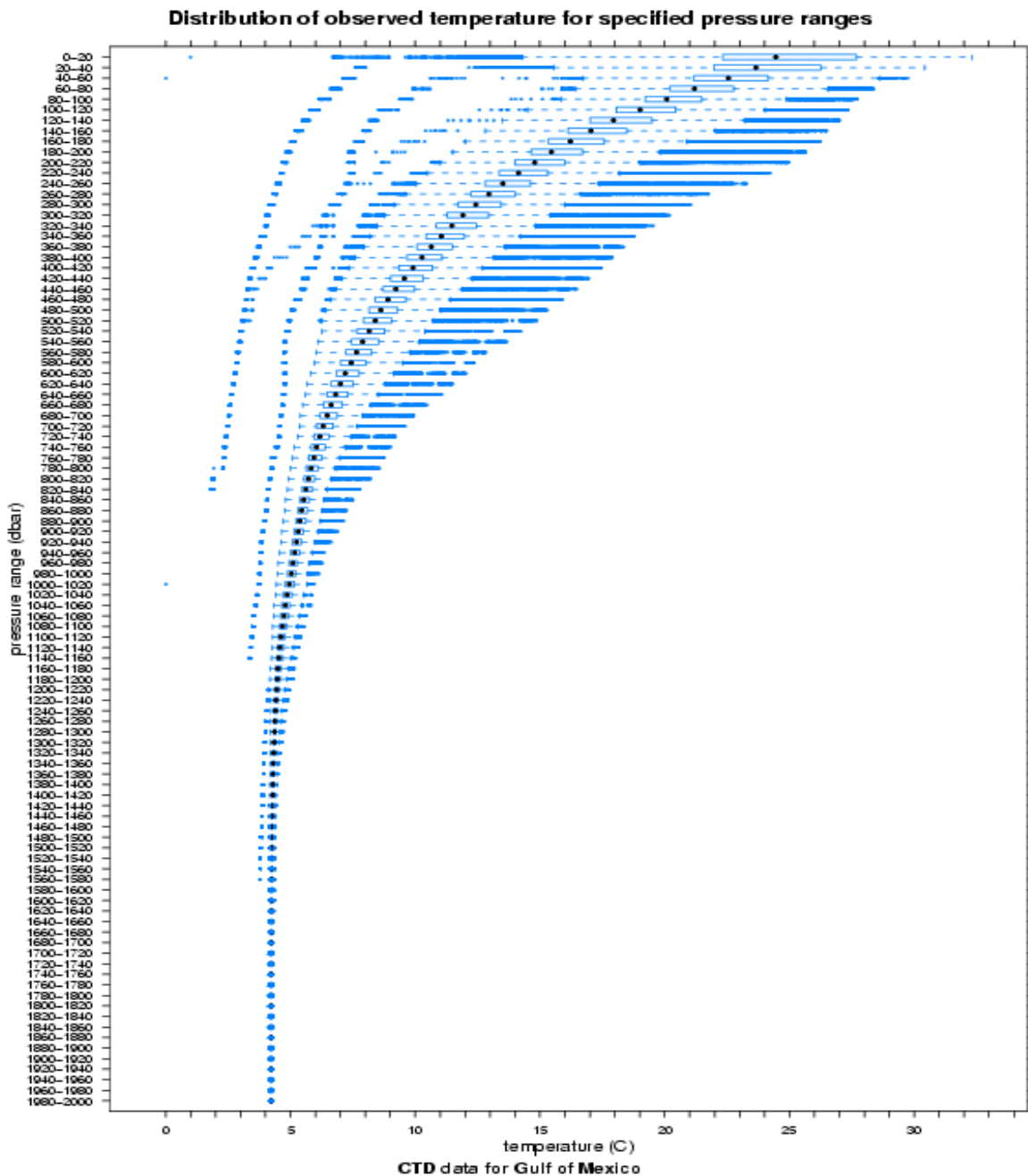
Fig.3. Distribution of CTD observations of temperature within 20 dbar pressure intervals for the Gulf of Mexico. The black dots indicate the median values, while the central boxes extend from the first quartile to the third quartile, indicating the range of the central half of the data within each pressure range. The dashed lines extend 1.5 times the length of inter-quartile range to indicate the span of expected measurements if the data are normal. Outliers are indicated as dots. Clearly, many of the outliers are bad data. Some of the warm outliers are consistent with loop-current data.

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.

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