EXTENSION OF THE NAVY LAYERED OCEAN MODEL TO SHALLOW SEAS: A HYBRID COORDINATE APPROACH

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Award #: N00014-97-1-0096

LONG-TERM GOALS

This work extends the geographic range of applicability of isopycnic coordinate circulation models, such as the Miami Isopycnic Coordinate Ocean Model and the Navy Layered Ocean Model, toward shallow coastal seas and unstratified parts of the world ocean. The numerical innovation making this extension possible is the "hybrid" (mixed isopycnic/terrain following) vertical coordinate.

OBJECTIVES

(a) Demonstrate the feasibility of the hybrid coordinate approach in an ocean basin encompassing both deep and shallow regions, as well as an annual heating/cooling cycle. Take advantage of the high near-surface vertical resolution afforded by this coordinate in developing alternatives to the Kraus-Turner mixed-layer formulation used in present-day isopycnic models.

(b) Port the algorithm to the NLOM.

APPROACH

A *hybrid* coordinate, in the context of the present work, is one that is *isopycnal* in the open, stratified ocean but smoothly reverts to a *sigma* (terrain-following) coordinate in shallow coastal and/or unstratified seas. The theoretical foundation for implementing such a coordinate was laid in papers published by the PI in 1981 and 1993 (Bleck and Boudra, 1981; Bleck and Benjamin, 1993).

In a hybrid model, each grid point is assigned a reference isopycnal. The model continually checks whether grid points lie on their reference isopycnals and, if not, tries to move them vertically toward the latter. However, grid points are not allowed to migrate if this would lead to excessive crowding of coordinate surfaces. Thus, in shallow water, grid points are geometrically constrained and stay in place while in deep water they are allowed to join and follow their reference isopycnals. The hybrid model therefore behaves like a conventional sigma model in very shallow and/or unstratified oceanic regions, whereas it behaves like an isopycnic coordinate model in halo- or thermoclinic regions. In doing so, the model combines the advantages of either type of coordinate in optimally simulating coastal and open-ocean circulation features.

Report Documentation Page

Form Approved
OMB No. 0704-0188

1. REPORT DATE **1998**	2. REPORT TYPE	3. DATES COVERED **00-00-1998 to 00-00-1998**

4. TITLE AND SUBTITLE **Extension of the Navy Layered Ocean Model to Shallow Seas: A Hybrid Coordinate Approach**	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) **University of Miami,Rosenstiel School of Marine and Atmospheric Science,4600 Rickenbacker Causeway,Miami,FL,33149**	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
See also ADM002252.

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)**	**4**	

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

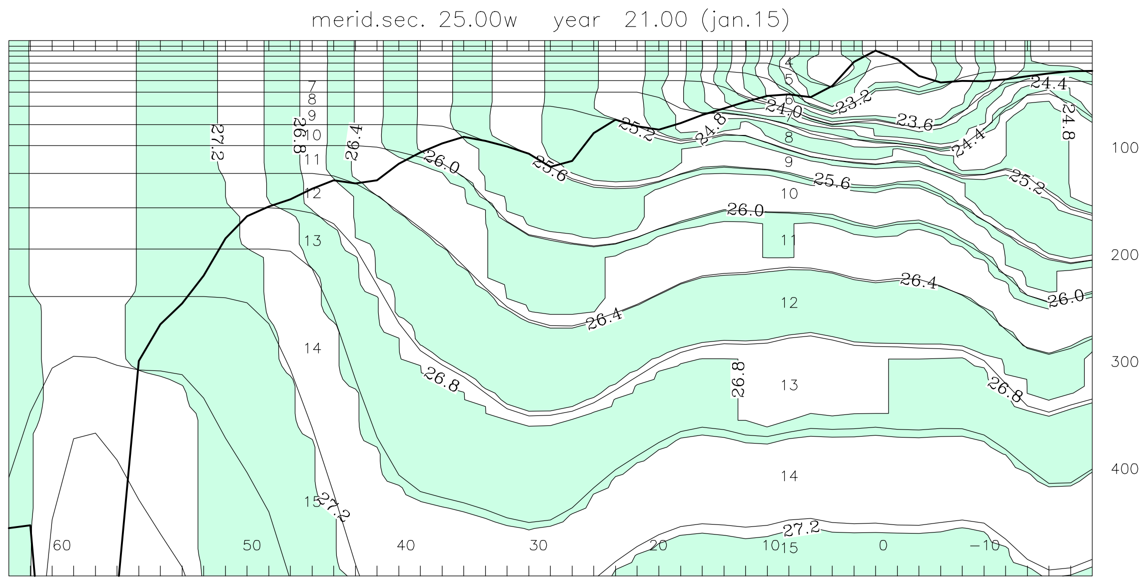

Figure 1: Vertical section through model fields at 25°W in January of year 21. Striped fields: density. Thin solid lines; layer interfaces. Thick line: mixed-layer depth. Depth range: 500 m. Numbers along bottom indicate latitude.Tick marks indicate horizontal mesh size. Also shown: coordinate layer index. The stairsteps in the density field result from trying to contour a piecewise constant field.

Model equations must be formulated in a way that makes no assumption about whether a particular grid point lies on its reference isopycnal. Care must be exercised in maintaining a smooth horizontal transition between isopycnic-coordinate and sigma-coordinate domains.

WORK COMPLETED

A North Atlantic basin version of the hybrid MICOM was completed in early 1998 and is now undergoing extensive testing. With the help of Dr. George Halliwell, we have successfully converted MICOM's original Kraus-Turner mixed layer code for use in a hybrid framework. In a series of multi-decadal simulations, the basin model equipped with the KT mixed layer has performed well both in terms of numerical stability and physical realism.

Early in this project, agreement was reached with the NLOM group to make the Gulf of Mexico with its extensive shelf areas the testbed for a prototype hybrid model. A reliable open-boundary version of MICOM (in the traditional nonhybrid configuration) did not exist at that time and had to be prepared. This work was completed in 1997.

RESULTS

Two vertical cross sections through hybrid model fields, depicting winter and

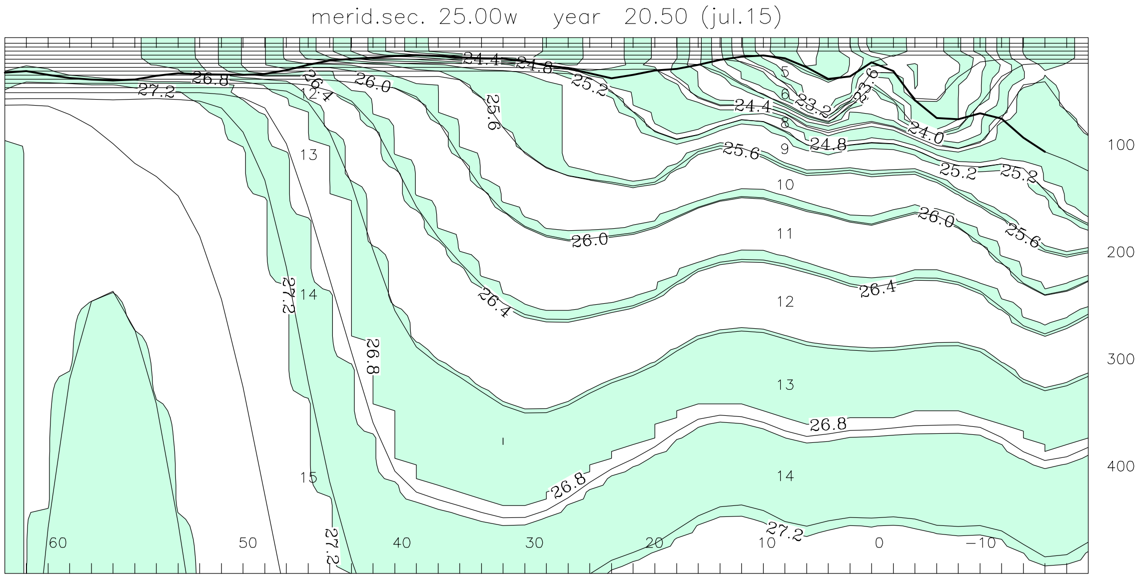

Figure 2: As in Fig. 1, but for July of year 21.

summer conditions respectively, will be used here to elucidate the structure of the hybrid model and the properties of the solutions obtained with it. Emphasis at present is on the model's handling of seasonal changes in the thermocline, judged to be the "Achilles heel" of hybrid coordinate modeling.

Fig. 1 shows the stratification of the model ocean along a 500 m deep meridional section in the eastern Atlantic in winter. Features to note are the coincidence of layer interfaces and isopycnals in the stratified interior, the vertical orientation of isopycnals in the mixed layer (a feature dictated by the KT paradigm), and the transition of layer interfaces to constant-depth surfaces near the point where they enter the mixed layer. The flattening of the interfaces well below the mixed-layer bottom near 45°N illustrates the point that the minimum layer-thickness constraint overrides the tendency of a coordinate surface to remain attached to its reference isopycnal.

Fig. 2 shows conditions along the same meridional section in summer. At this time, the seasonal thermocline extends upwards to within a few 10s of meters of the surface. This allows several coordinate surfaces at mid to high latitudes, which in Fig. 1 are shown to reside in the sigma domain, to attach themselves to their reference isopycnals. In order to extend the isopycnal coordinate domain upward during the warm season, we allow the minimum layer thickness to be smaller in summer than in winter.

There is a temptation to prevent near-surface crowding of sigma surfaces in unstratified water columns by scaling their position by the mixed-layer depth. This turned out to be disadvantageous for two reasons: (a) in deep mixed layers adjacent to the continental margin, coordinate surfaces would have to climb steeply to reach their assigned position on the shelf, a configuration known to lead to serious numerical problems in pure sigma models; (b) the large temporal fluctuations in mixed layer depth would cause constant up and down movement of coordinate surfaces, also undesirable for numerical reasons.

IMPACT/APPLICATIONS

Initiation of the MICOM/NLOM hybridization project was announced at the February 1997 MICOM users' workshop. Judging from the number of inquiries the PI has received since then, a hybrid model is eagerly anticipated by the community, given the emphasis placed in recent years on modeling of coastal phenomena, and in particular on the control exerted on these by the offshore circulation.

Of particular interest to the Navy will be a streamlining of the present cumbersome procedure of driving coastal models with output from a basin-scale isopycnic model. Differences in coordinate architecture – near-shore models invariably use fixed grids while NLOM-like models allow coordinate surfaces to migrate freely in the vertical – render this coupling difficult at present. The hybrid model will solve a major part of this problem by "delivering" at its near-shore boundary the required data at fixed depth intervals.

According to information available to the PI, the NLOM group has decided to adopt the hybrid coordinate approach developed in this project.

TRANSITIONS

The open-boundary MICOM version has been made available to the community. The PI is aware of at least five projects so far involving this model or its output.

RELATED PROJECTS

The hybridization work is firmly embedded in the MICOM development effort carried out at RSMAS. The freedom to adjust the vertical spacing of coordinate surfaces is expected to simplify the numerical implementation of some physical processes (mixed layer detrainment, convective adjustment, sea ice modeling, ...) without robbing the model of its basic layer architecture.

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