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# Parameterizations in High Resolution Isopycnal Wind-Driven Ocean Models

Progress Report

for Period January 1, 1993 through December 31, 1993

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## 1. Introduction

For our CHAMMP project, we proposed to develop a new multi-layer ocean model, based on the hydrodynamic FSU Indian Ocean model Jensen, (1991). The new model will include prognostic temperature and salinity and will be coded for massively parallel machines. Other specific objectives for the proposed research were:

- incorporate a oceanic mixed layer on top of the isopycnal deep layers.
- implement positive definite scheme for advection (e.g., Arakawa and Hsu, 1990) ;
- determine effects of islands on large scale flow;
- investigate lateral boundary conditions for boundary layer currents.

The mixed layer model is proposed to be of a bulk type with prognostic equations for temperature and salinity, similar to, but more general, than the model used by McCreary and Kundu, 1989. Development of parallel code will be done in cooperation with other CHAMMP participants, mainly the ocean modelling group at LANL.

The main objective is model development, while the application is to determine the influence and parameterization of narrow flows along continents and through chains of small islands on the large scale oceanic circulation. Test runs with artificial wind stress and heat flux will be used to determine model stability, performance and optimization for the new model configuration. Tests will include western boundary currents, coastal upwelling and equatorial dynamics.

During the first 6 months of the project (Aug 1 - Dec 31, 1992), a 1.5 layer reduced gravity model (that is a single moving layer over an infinitely deep ocean at rest) was implemented and tested on the CM-200 at LANL. A simple box model with prognostic temperature and salinity was being developed and used to test various numerical schemes as described in last years report.

## 2. Accomplishments since January 1, 1993

Our most important objective for 1993 was to include irregular geometry in the new thermodynamic version of the model. This goal has essentially been completed in 1993. The code make use of c-compiler directives and consists of many modules (61 subroutines and 33 include files to date) that make global changes easy and the compiled code more efficient. In addition to prognostic temperature and salinity, the model is prepared for any number of other tracers.

The first investigations of boundary layer flow along a coast has been done. Since the horizontal resolution in OGCMs is so coarse that the boundary current is not resolved, it has been argued whether the usual no-slip BC is appropiate. Some investigators imply that a free slip condition is (at least numerically) more consistent. In the experiment a low-latitude western boundary current crosses the equator and cause instability waves (Fig. 1). We found that in order to get the same separation latitude using a coarse grid, 0.5° by 0.5°, as in the case where the boundary layer was well resolved (0.1° by 0.1°), we needed to increase the transfer of vorticity from the boundary to the flow. Traditionally this is done by increasing the lateral friction, i.e. widening the boundary layer. However, it also decreases the amplitude of the instability waves in the interior. As an alternative, we simply increased the vorticity transfer along the boundary using a 'super drag' formulation. It is accomplished using a mirror point with a value equal to Z times the value for tangential flow component near the boundary. For no slip Z=-1, while free slip Z=0. For 'super drag', we simply use Z < -1. These model results will be presented at the Fifth Symposium on Global Change Studies in Nashville, Tennesee, January 1994 at a special CHAMMP session.

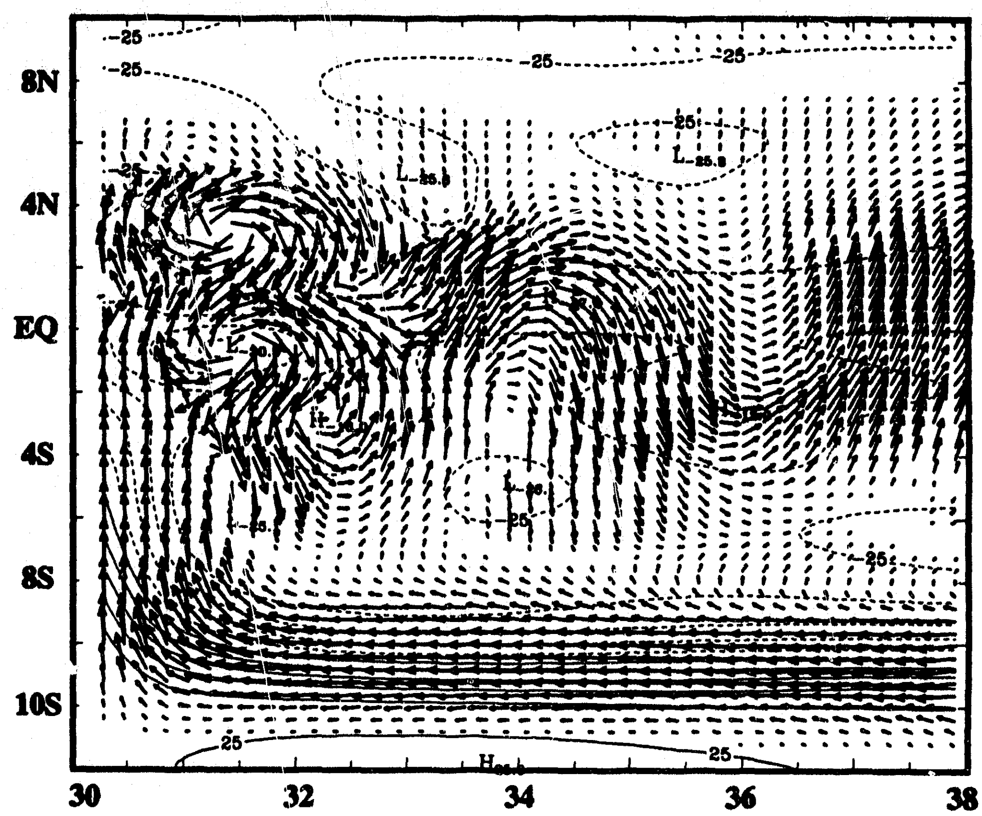


Fig 1. Western boundary current forced by discontinuity in potential energy at 9°S. Model resolution is 0.1°. Vectors for currents larger than 15 cm/s are truncated.

Results from CM-200/CM-5 model of the Indian Ocean were published (Jensen, 1993). A 21 year run with a 3.5 layer CRAY version of the model, forced by seasonal climatological wind stress, showed that the ratio of semi-annual transports to annual transports along the equator was 2 or larger. However, the ratio of semi-annual to annual zonal wind stress is about 0.5. The CM-200 version of the model (with one active layer, 1/3° by 1/3° resolution) was used to demonstrate that equatorial Kelvin and Rossby waves may combine to a standing mode with large amplitude when the period of the forcing, T, the internal gravity wave speed, c, and the width, L, of the ocean basin is related through

$$T = 4L/mc, \; m = 1,2,3,...$$

Cane and Moore, (1981) had found this relation analytically for a linear model of a rectangular β-plane ocean, but speculated that the effect would be unlikely to be of importance in an ocean with irregular coastlines, realistic wind forcing and strong non-linear effects. Our study demonstrated that the resonant equatorial basin mode does exist in the Indian Ocean. Further details ares given in the enclosed reprint.

At the CHAMMP meeting in Monterey, the first testruns of the model with prognostic temperature and salinity in an irregular geometry was shown. The color plate (Fig. 2) shows a test run from this model (one active layer, 1/3° resolution). The initial temperature decreases linearly poleward from 29°C at the equator as shown in the bottom panel. The initial upper layer depth also decreases from the equator, so the upper layer has a constant mass to be consistent with the reduced gravity model assumption. Associated with the meridional temperature gradient is an unbalanced pressure gradient, which will force currents until a geostrophic balance is established. In Fig.2 (top panel) the upper layer depth anomalies are due to equatorial waves and coastal Kelvin waves, the latter moving counter-clockwise around islands (southern hemisphere). Note that the temperature field is little affected by the currents generated by these waves. The main point using a model with material layer is to avoid vertical diffusion associated with these waves. Testruns with 9 moving layers for other cases were done in order to assure that model internal waves had upward phase propagation and downward phase propagation as observed.

## 3. Plans for 1994

One of our most important objectives for 1994 is to improve the mixed layer physics. Tommy Jensen has been invited to visit the International Research Centre for Computational Hydrodynamics (ICCH), Denmark, for several months to work jointly with other researchers on numerical methods to include turbulent mixing in stratified ocean flows. The visit will be funded by ICCH. The main advantage is that work on testing mixed layer representations and associated physical processes in stratified flow (e.g., entrainment,convection, TKE, thermocline erosion), which is part of the proposed work for the DOE, can be done in cooperation with researchers who work on similar problems for 3-D coastal ocean models. They have also worked extensively with alternative finite difference schemes for advection-diffusion in ocean models. The visit is an opportunity to get new ideas and get more experience in these areas of the proposed work.

We anticipate that the first versions of a 2.5 layer global model will be ready in 1994. The land mask will be the same as used by the CSU AGCM , usually 5° by 4° resolution in lon and lat, but the actual grid resolution for the interior ocean will be 1° by 1° or finer. The model will be initialized using the Levitus data set for T and S, and driven by fluxes of heat, precipitation and wind stress from history tapes from the CSU GCM.

Finally, work on a more efficient implementation of the thermodynamic code on the CM-5 at LANL will continue.



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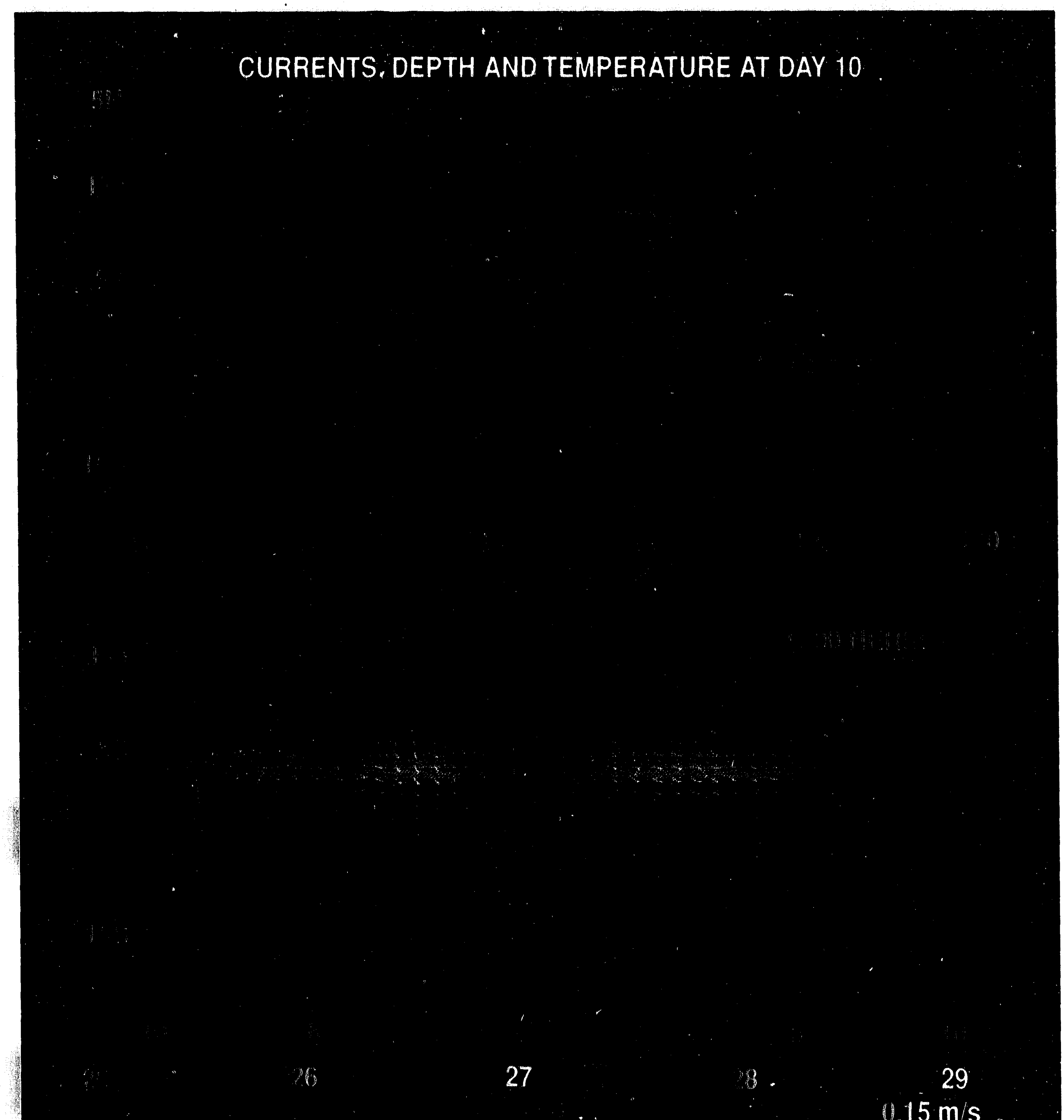


Fig. 2 Test run of thermodynamic Indian Ocean model.

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