HYCOM Overview

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General Remarks

The HYbrid Coordinate Ocean Model (HYCOM; (Halliwell *et al.*, 1998; 2000; Bleck, 2001) is a primitive equation ocean general circulation model that evolved from the Miami Isopycnic-Coordinate Ocean Model (MICOM) developed by Rainer Bleck and colleagues. MICOM has become one of the premier ocean circulation models, having been subjected to validation studies (e.g. Chassignet *et al*., 1996; Roberts *et al*., 1996; Marsh *et al*., 1996) and used in numerous ocean climate studies (e.g., New and Bleck, 1995; New et al., 1995; Hu, 1996, 1997; Halliwell, 1997, 1998; Bleck 1998 and references therein). HYCOM was developed to address known shortcomings of the MICOM vertical coordinate scheme. MICOM vertical coordinates are isopycnic except for model layer 1, which is a non-isopycnic slab mixed layer. This leads to two significant problems: First, slab models must be used to govern mixed layer entrainment and detrainment. MICOM was equipped with a Kraus-Turner type model as described in Niiler and Kraus (1977), but using the modified turbulent kinetic energy balance parameterization of Gaspar (1988). Second, vertical coordinates are "wasted" because all model layers less dense than the mixed layer (layer 1) exist as zero-thickness layers at the mixed layer base. Although MICOM has produced good scientific results, improvements in the representation of vertical mixing, and the representation of oceanic flow in shallow-water and weakly stratified regions are constrained by these vertical coordinate limitations.

Vertical coordinates in HYCOM remain isopycnic in the open, stratified ocean. However, they smoothly transition to z coordinates in the weakly-stratified upper-ocean mixed layer, to terrain-following sigma coordinate in shallow water regions, and back to level coordinates in very shallow water. The latter transition prevents layers from becoming too thin where the water is very shallow. The vertical coordinates that were "wasted" in MICOM are used to provide vertical resolution within the surface mixed layer. This enables the use of more sophisticated non-slab closure schemes. One important goal for HYCOM is to provide the capability of selecting among several different vertical mixing schemes for both the surface mixed layer and the comparatively weak interior diapycnal mixing. No vertical mixing algorithm can provide a perfect representation of ocean mixing and its influence on ocean circulation and climate. When using an ocean model to study processes sensitive to vertical mixing, it is a good idea to run simulations with different mixing algorithms to quantify the sensitivity of scientific results to the mixing parameterizations. One specific example is the use of coupled ocean-atmosphere models to quantify global warming rates expected from greenhouse gas increases. This warming is likely to be sensitive to the parameterization of vertical mixing in the ocean model. HYCOM is designed to easily test these sensitivities whether used alone or in a coupled system. Sensitivity of ocean mixing to other factors such as the vertical structure and resolution of the vertical grid can also be readily tested.

The the K-Profile Parameterization (KPP, Large et al., 1994; 1997) algorithm was included as the first non-slab mixed layer model for several reasons. It provides mixing throughout the water column with an abrupt but smooth transition between the vigorous mixing in the surface boundary layer and the relatively weak diapycnal mixing in the ocean interior. It works on a relatively coarse and unevenly spaced vertical grid. It parameterizes the influence of a larger suite of physical processes than other commonly used mixing schemes. In the ocean interior, the contribution of background internal wave breaking, shear instability mixing, and double diffusion (both salt fingering and diffusive instability) are parameterized. In the surface boundary layer, the influences of wind-driven mixing, surface buoyancy fluxes, and convective instability are parameterized. The KPP algorithm also parameterizes the influence of nonlocal mixing of T and S, which permits the development of countergradient fluxes. The Kraus-Turner slab model has also been included in HYCOM. With the release of HYCOM version 2.1, two additional mixed layer models have been included: the dynamical instability model of Price *et al.* (1986), and the Mellor-Yamada level 2.5 turbulence closure used in the Princeton Ocean Model (Mellor and Yamada, 1982; Mellor, 1998). Other mixed layer models will be included in the near future, such as the model developed recently by Canuto (2000).

HYCOM versions 1.0 and 2.0 have already been released, with development the result of collaborative efforts between the University of Miami, the Los Alamos National Laboratory, and the Naval Research Laboratory. The present set of documents describes algorithms contained in HYCOM version 2.1. The user has control over setting up the model domain, generating the forcing fields, and generating either climatology fields or output fields from other model simulations to use for boundary and interior relaxation. The model is fully parallellized, and it is designed to be portable among all UNIX-based systems. It is equipped with inert tracer code, which has been significantly improved from the inert tracer code originally included in HYCOM. The tracer is now a full-fledged prognostic scalar that is carried at both leapfrog time steps. As in MICOM, surface values of the tracer are maintained at a value of 1.0.

Ongoing HYCOM research has been funded under the National Oceanographic Partnership Program (NOPP) and the Office of Naval Research (ONR) to develop it for use in a global ocean data assimilation system and as the ocean component of a coupled ocean-atmosphere model.

HYCOM Documentation

The HYCOM documentation listed here describes algorithms contained in version 2.1. Detailed descriptions of HYCOM algorithms are provided in the following summaries:

advdiff.pdf (horizontal advection/diffusion)
boundary.pdf (boundary conditions)
diapycnal.pdf (three interior diapycnal mixing algorithms)
float.pdf (synthetic floats/drifters/moorings)
hybrid.pdf (hybrid vertical coordinate adjustment)
ice.pdf (energy loan ice model)
KPP.pdf (K-Profile Parameterization vertical mixing)
KT.pdf (three Kraus-Turner mixed layer models)
mesh.pdf (horizontal mesh)
momentum.pdf (momentum equation, including pressure gradient force)
MY.pdf (Mellor-Yamada level 2.5 turbulence closure vertical mixing)

PWP.pdf (Price-Weller-Pinkel dynamical instability vertical mixing)
state.pdf (equation of state, including cabbeling and thermobaricity)
surface.pdf (surface fluxes, including penetrating shortwave radiation)
vdiff.pdf (solution of vertical diffusion equation)

These documents focus on algorithms that are unique to HYCOM or that have been significantly modified from MICOM. The user should consult MICOM documentation for information on other algorithms such as the continuity equation, barotropic momentum equation, advection algorithm, and vertical mode splitting.

These documents do not provide information on how to set up and run the model, and do not provide information on computer issues such as parallelization and file formats. This information is provided on README files provided with the model code.

Initial results from HYCOM simulations emphasizing model development and validation are presented in three complementary papers. Rainer Bleck conducts basic tests of HYCOM performance, in particular the vertical coordinate adjustment algorithm (Bleck, 2001). George Halliwell evaluates the performance of different vertical mixing algorithms in conjunction with the vertical coordinate adjustment algorithm in a low-resolution simulation of the Atlantic Ocean (Halliwell, 2001). Finally, Chassignet et al. (2001) evaluate the vertical coordinate algorithm in conjunction with model resolution, reference density, and thermobaricity.

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