HYCOM Equation of State and Related Issues

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This note summarizes three aspects of HYCOM 1.0/2.0 thermodynamics: the equation of state, cabbeling, and thermobaric compressibility.

The equation of state embedded in HYCOM is the approximation to the UNESCO equation of state described by Brydon *et al*. (2001). At a given reference pressure level p, the density in sigma units is given by a seven term polynomial function cubic in potential temperature q and linear in salinity S:

$$s\,(q,S,p) = C_1(p) + C_2(p)q + C_3(p)S + C_4(p)q^2 + C_5(p)Sq + C_6(p)q^3 + C_7(p)Sq^2.$$

One advantage of this simple polynomial representation is that it can be inverted to calculate $q(s,S,p)$ and $S(s,q,p)$.

Three sets of coefficients are provided in HYCOM for reference pressures of 0, 20, and 40 Mpa. The sigma values calculated with these sets of coefficients are referred to as s_0, s_2, and s_4, respectively. If the user selects s_0 to represent model vertical coordinates, the density structure will be represented reasonably well in the upper ocean. In the deep ocean, however, regions will exist where s_0 does not increase monotonically with depth, causing model vertical coordinate interfaces to fold over. The user must consider this problem in choosing the proper set of density coordinates for model simulations.

Cabbeling is not an issue when HYCOM is run in MICOM mode since there is no penetrating shortwave radiation, and since salinity alone is advected and diffused within isopycnic layers. When HYCOM is run with hybrid vertical coordinates, however, cabbeling is an issue because temperature and salinity are always mixed in the vertical and shortwave radiation can penetrate into the isopycnic coordinate domain. Horizontal advection and diffusion of temperature and salinity, and fluxes of temperature and salinity across vertical coordinates relocated by the hybrid coordinate algorithm can also contribute to cabbeling. When HYCOM is run with hybrid vertical coordinates, reliance is placed on the hybrid vertical coordinate adjustment algorithm to restore and maintain isopycnic conditions.

There are two ways by which the user can reduce the influence of cabbeling. HYCOM contains the option of horizontally advecting and diffusing salinity and density, or temperature and density, instead of temperature and salinity. HYCOM also has the option to flux salinity and density, or temperature and density, instead of temperature and salinity, across vertical coordinates relocated by the hybrid coordinate algorithm. For further information on the problems that can be caused by cabbeling, refer to the documentation of the HYCOM horizontal advection/diffusion algorithms and the HYCOM hybrid vertical.

HYCOM 1.0/2.0 is equipped with the algorithm of Sun *et al.* (1999) to account for the dynamical influence of thermobaric compressibility, or thermobaricity.

References

Brydon, D., S. Sun, and R. Bleck, 2001: A new approximation of the equation of state for seawater, suitable for numerical models.

Sun, S., R. Bleck, C. Rooth, J. Dukowicz, E. Chassignet, and P. Killworth, 1999: Inclusion of thermobaricity in isopycnic-coordinate ocean models, *J. Phys. Oceanogr.*, **29**, 2719-2729.