Ocean Science Discussions, 2, S136–S141, 2005
www.ocean-science.net/osd/2/S136/
European Geosciences Union

Ocean Science Discussions

Interactive comment on "Formulation of an ocean model for global climate simulations" *by* S. M. Griffies et al.

S. M. Griffies et al.

Received and published: 2 August 2005

- Horizontal friction

  The transition in OM3.0 between the tropical viscosity to middle latitudes is large. Our motivation for using this large middle latitude viscosity was, unfortunately, due to problems with the atmospheric model's winds. We describe this issue in the manuscript. It represents one of the least satisfying aspect of OM3.0. We tried unsuccessfully a few times to reduce the friction, but had problems with drift in the North Atlantic heat transport.

- Appendix: Is is needed?

  The appendix was added to the manuscript in response comments from informal reviewers. Its purpose is to summarize the model equations and numerical methods forming the basis for the MOM4.0 code. This summary is perhaps not as necessary for those already familiar with MOM. Nonetheless, we feel it necessary to provide details of the model equations, general assumptions, and brief description of methods not covered in the main text. We point to many of the equations in the appendix throughout the main text. Absent this appendix, much of its material would need to be incorporated into the main text. Separating the material into an appendix allows for more streamlined discussions in the main text. We therefore feel that this appendix serves the paper well.

- Advective metric frequency

  The so-called *advective metric frequency* $\mathcal{M}$ appears in the thickness weighted velocity equation as $[\,\partial_t + (\mathcal{M} + f)\,\hat{z}\times\,]\,(h\,u)$. It therefore has the *same* dimensions as the Coriolis parameter f, and so can be measured in cycles per second if one chooses.

  As detailed in Section 4.4.1 of [Griffies(2004)], $\mathcal{M}$ arises when expressing the material time derivative of velocity on a sphere. Two terms arise in this derivative: the familiar divergence term also occurring in flat space with Cartesian coordinates, plus the *advective metric frequency*. Hence, our choice for the name of this term is motivated because it (1) is associated with the advection of velocity, (2) arises from velocity advection on a sphere, (3) has units of a frequency. Note that when choosing spherical coordinates, this term takes the form

  $$\mathcal{M} = (u/R)\,\tan\phi. \tag{1}$$

  This is the form that appears in most treatments of the primitive ocean equations (e.g., [Bryan(1969)]). We chose to be more general, however, since MOM4 is written using generalized orthogonal coordinates.

- Stability of the Coriolis force

  We agree with the reviewer's analysis. We have corrected our discussion, and raised the issues of phase and amplitude errors associated with the trapezoidal or semi-implicit treatment of the Coriolis force.

References

[Bentsen et al.(1999)] Bentsen, M., Evensen, G., Drange, H., and Jenkins, A.: Coordinate Transformation on a Sphere Using Conformal Mapping, Monthly Weather Review, 1267, 2733–2740, 1999.

[Bryan(1969)] Bryan, K.: A numerical method for the study of the circulation of the world ocean, Journal of Computational Physics, 4, 347–376, 1969.

[Bryan and Cox(1972)] Bryan, K. and Cox, M. D.: An approximate equation of state for numerical models of the ocean circulation, Journal of Physical Oceanography, 4, 510–514, 1972.

[Campin et al.(2004)] Campin, J.-M., Adcroft, A., Hill, C., and Marshall, J.: Conservation of properties in a free-surface model, Ocean Modelling, 6, 221–244, 2004.

[Coward et al.(1994)] Coward, A., Killworth, P., and Blundell, J.: Tests of a two-grid world ocean model, Journal of Geophysical Research, 99, 22 725–22 735, 1994.

[Deleersnijder et al.(1993)] Deleersnijder, E., Van Ypersele, J.-P., and Campin, J.-M.: An orthogonal curvilinear coordinate system for a world ocean model, Ocean Modelling, 100, 7–10, 1993.

[Durran(1999)] Durran, D. R.: Numerical Methods for Wave Equations in Geophysical Fluid Dynamics, Springer Verlag, Berlin, 470 pp, 1999.

[Eby and Holloway(1994)] Eby, M. and Holloway, G.: Grid transformation for incorporating the Arctic in a global ocean model, Climate Dynamics, 10, 241–247, 1994.

[Gnanadesikan et al.(2005)] Gnanadesikan, A., Dixon, K. W., Griffies, S. M., Balaji, V., Beesley, J. A., Cooke, W. F., Delworth, T. L., Gerdes, R., Harrison, M. J., Held, I. M., Hurlin, W. J., Lee, H.-C., Liang, Z., Nong, G., Pacanowski, R. C., Rosati, A., Russell, J., Samuels, B. L., Song, S. M., Spelman, M. J., Stouffer, R. J., Sweeney, C. O., Vecchi, G., Winton, M., Wittenberg, A. T., Zeng, F., and Zhang, R.: GFDL's CM2 Global Coupled Climate Models-Part 2: The Baseline Ocean Simulation, Journal of Climate, submitted, 2005.

[Griffies(2004)] Griffies, S. M.: Fundamentals of ocean climate models, Princeton University Press, Princeton, USA, 496 pages, 2004.

[Griffies et al.(2000)] Griffies, S. M., Pacanowski, R. C., and Hallberg, R. W.: Spurious diapycnal mixing associated with advection in a z-coordinate ocean model, Monthly Weather Review, 128, 538–564, 2000.

[Hallberg(1997)] Hallberg, R. W.: Stable split time stepping schemes for large-scale ocean modeling, Journal of Computational Physics, 135, 54–65, 1997.

[Haltiner and Williams(1980)] Haltiner, G. T. and Williams, R. T.: Numerical Prediction and Dynamic Meteorology, John Wiley and Sons, New York, USA, 1980.

[Latif et al.(1998)] Latif, M., Anderson, D., Barnett, T., Cane, M., Kleeman, R., Leetmaa, A., O'Brien, J., Rosati, A., and Schneider, E.: A review of the predictability and prediction of ENSO, Journal of Geophysical Research, 103, 14 375–14 393, 1998.

[Madec and Imbard(1996)] Madec, G. and Imbard, M.: A global ocean mesh to overcome the North Pole singularity, CD, 12, 381–388, 1996.

[Marshall et al.(1997)] Marshall, J., Hill, C., Perelman, L., and Adcroft, A.: Hydrostatic, quasi-hydrostatic, and nonhydrostatic ocean modeling, Journal of Geophysical Research, 102, 5733–5752, 1997.

[Marsland et al.(2003)] Marsland, S., Haak, H., Jungclaus, J., Latif, M., and Röske, F.: The Max-Planck-Institute global ocean/sea ice model with orthogonal curvilinear coordinates, Ocean Modelling, 5, 91–127, 2003.

[McDougall et al.(2003)] McDougall, T. J., Jackett, D. R., Wright, D. G., and Feistel, R.: Accurate and computationally efficient algorithms for potential temperature and density of seawater., Journal of Atmospheric and Oceanic Technology, 20, 730–741, 2003.

[Meehl et al.(2001)] Meehl, G., Gent, P. R., Arblaster, J., Otto-Bliesner, B., Brady, E., and Craig, A.: Factors that affect the amplitude of El Niño in global coupled climate models, Climate Dynamics, 17, 515–526, 2001.

[Mesinger and Arakawa(1976)] Mesinger, F. and Arakawa, A.: Numerical Methods used in Atmospheric Models, in GARP Publication Series, vol. 1, p. 66 pages, 1976.

[Murray(1996)] Murray, R. J.: Explicit generation of orthogonal grids for ocean models, Journal of Computational Physics, 126, 251–273, 1996.

[Murray and Reason(2002)] Murray, R. J. and Reason, C. J. C.: A curvilinear version of the Bryan-Cox ocean model, Journal of Computational Physics, 171, 1–46, 2002.

[Roberts et al.(2005)] Roberts, J., Heil, P., Murray, R., Holloway, D., and Bindoff, N.: Pole relocation for an orthogonal grid: an analytic method, Ocean Modelling, accepted, 2005.

[Russell et al.(2005)] Russell, J., Stouffer, R., and Dixon, K.: Intercomparison of the Southern Ocean Circulations in the IPCC Coupled Model Control Simulations, Journal of Climate, submitted, 2005.

[Schneider et al.(2003)] Schneider, E., DeWitt, D., Rosati, A., Kirtman, B., Link, J., and Tribbia, J.: Retrospective ENSO forecasts: sensitivity to atmospheric model and ocean resolution, Monthly Weather Review, 131, 3038–3060, 2003.

[Smith et al.(1995)] Smith, R. D., Kortas, S., and Meltz, B.: Curvilinear coordinates for global ocean models, Los Alamos preprint, LA-UR-95-1146, 1995.

[Wittenberg et al.(2005)] Wittenberg, A., Rosati, A., Lau, G., and Ploshay, J.: Tropical simulations with the recent GFDL coupled climate model, Journal of Climate, submitted, 2005.

Interactive comment on Ocean Science Discussions, 2, 165, 2005.