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The role of tracer advection formulation on diapycnal mixing in geopotential coordinate eddying ocean models.

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We report on an examination of how advection operator formulation for active tracers can significantly reduce spurious mixing across isopycnals for eddying ocean models which use height as their vertical coordinate. Simulations in which the ocean mesoscale eddy field is partially resolved are becoming increasingly prevalent due to increases in available computer resources. Numerical studies [e.g. Griffies et al 2000] find that using a vertical coordinate that does not align with isopycnals in an eddying model introduces an artificial background diffusion across isopycnal surfaces as high as, $6 \times 10^{-4} m^2 s^{-1}$; a factor of sixty greater than the actual background diapycnal mixing measured in the open-ocean during deliberate tracer release field experiments [Ledwell et al. 1993]. Surprisingly the numerical studies found excess diapycnal mixing initially increases with higher resolution in eddying regimes. Eventually spurious mixing does fall, but at resolutions in the kilometer range which still remain computationally challenging for large scale models.

The work we present examines whether improved formulation of advection of active tracers can address the spurious mixing issue for eddying models at reasonable resolutions. We consider idealized eddying flow in a periodic zonal channel forced by an along channel wind stress and a cross channel heat flux gradient with a linear equation of state in temperature (so that temperature and density surfaces are equivalent). The system is integrated to a statistical equilibrium in which an overturning cell counters the differential heating with eddies fluxing heat laterally. For this equilibrated state we examine (i) the overturning cell in temperature coordinates and (ii) effective diapyncnal diffusivity diagnosed from the rate of change of temperature distribution and from diapycnal mixing of an injected tracer. We diagnose these quantities for a range of spatial resolutions and with two different advection schemes (1) a high-order flux limited scheme [Darau and Tenaud, 2004] and (2) a finite-volume, general orthogonal curvilinear coordinate implementation of the second-order moment scheme of Prather [Prather, 1986]. We find that the third order scheme behaves in accord with previous studies i.e the temperature coordinate overturning cell shows interior fluxes across isotherms and the diagnosed diapycnal mixing is large for moderately resolved eddying solutions. In contrast, the Prather scheme produces an equlibrated solution in which temperature coordinate overturning is along isotherms in the interior and the diagnosed diapycnal mixing is close to observed values.

The Prather scheme requires more computation per timestep and requires more information to be carried at each model grid cell. However, it can reduce spurious mixing by more than an order of magnitude. For a practical eddying resolution it lowers background numerical diapycnal mixing to levels that are comparble to observed background mixing. We believe that, in many situations, this more than compensates for the enhanced computational cost that the second-order moment scheme entails. To illustrate this point we will show results from a preliminary application of the Prather scheme to a fully global eddying ocean circulation model.