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# Sensitivity of numerical ocean models to the choice of isopycnal mixing directions in rotated diffusion tensors

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Despite considerable advances over the past 30 years, numerical ocean models still exhibit a number of systematic biases in their simulated properties even after their adjustable parameters have been optimally tuned to reduce discrepancies with observations, for instance by using an adjoint model as done by the MIT group. Optimization exercises carried out so far, however, all take it for granted that the isopycnal mixing directions in rotated diffusion tensors should be aligned with the so-called neutral directions. The physical basis for doing so, however, has never been satisfactorily explained from first principles. While it is generally agreed that neutral rotated diffusion succeeds in eliminating some of the spurious diapycnal mixing exhibited by early numerical ocean models mixing separately in the horizontal and vertical directions, there is little understanding of whether the use of the neutral directions is actually optimal to eliminate all unphysical diapycnal mixing. To shed light on the issue, this work examines the impact of the choice of isopycnal mixing directions on available potential energy (APE) and background gravitational potential energy (GPEr). In order to demonstrate its usefulness, we will first show that this approach succeeds in demonstrating the benefits of moving from a purely diffusive tensor mixing separately in the horizontal and vertical directions to a neutral rotated diffusion tensor combined with a eddy-induced parameterization. Prior such a move, APE was dissipated entirely by diabatic mixing, whereas in modern ocean models, APE is now primarily dissipated adiabatically by eddy-induced advection. The main effect of neutral rotated diffusion was to significantly reduce the diabatic dissipation of APE, as well as the diabatic generation of GPEr. Our work shows, however, that the neutral directions are not optimal to reduce these. The physics of these alternative mixing directions and implications for ocean modelling will be discussed.