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The geography of numerical mixing in a suite of global ocean models

Ryan Holmes[1,2], Jan Zika[2], Stephen Griffies[3], Andrew Hogg[4], Andrew Kiss[4], and Matthew England[1]
[1]Climate Change Research Centre and ARC Centre of Excellence for Climate Extremes, University of New South Wales, Sydney, Australia
[2]School of Mathematics and Statistics, University of New South Wales, Sydney, Australia
[3]NOAA Geophysical fluid dynamics laboratory and Princeton University Program in Atmospheric and Oceanic Sciences, Princeton, New Jersey, USA
[4]Research School of Earth Sciences and ARC Centre of Excellence for Climate Extremes, Australian National University, Canberra, Australia

Numerical mixing, the physically spurious diffusion of tracers due to the numerical discretization of advection, is known to contribute to biases in ocean circulation models. However, quantifying numerical mixing is non-trivial, with most studies utilizing specifically targeted experiments in idealized settings. Here, we present a precise method based on water-mass transformation for quantifying numerical mixing, including its spatial structure, that can be applied to any conserved variable in global general circulation ocean models. The method is applied to a suite of global MOM5 ocean-sea ice model simulations with differing grid spacings and sub-grid scale parameterizations. In all configurations numerical mixing drives across-isotherm heat transport of comparable magnitude to that associated with explicitly-parameterized mixing. Numerical mixing is prominent at warm temperatures in the tropical thermocline, where it is sensitive to the vertical diffusivity and resolution. At colder temperatures, numerical mixing is sensitive to the presence of explicit neutral diffusion, suggesting that much of the numerical mixing in these regions acts as a proxy for neutral diffusion when it is explicitly absent. Comparison of equivalent (with respect to vertical resolution and explicit mixing parameters) 1/4-degree and 1/10-degree horizontal resolution configurations shows only a modest enhancement in numerical mixing at the eddy-permitting 1/4-degree resolution. Our results provide a detailed view of numerical mixing in ocean models and pave the way for future improvements in numerical methods.