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The sensitivity of the convective circulation in a rectangular ocean basin to entrainment into slope currents and interior vertical mixing

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In recently published work (Hughes & Griffiths, Ocean Modelling 12, 46–79, 2006), we develop a model of the convective overturning circulation in a box ocean. We describe the high-latitude sinking regions as dense, entraining slope currents. The consequent highly-localized boundary mixing and heat transport is then coupled with a Munk-like vertical advection-diffusion heat balance throughout the box interior. We obtain a steady solution in which the buoyancy flux by interior vertical mixing at any depth balances the buoyancy flux carried through that depth by the sinking regions. In order to apply the model most simply to the global ocean, we assume a single dominant sinking plume (which is the outflow from the Weddell Sea) and a heat transport of 2 PW as previously estimated for each hemisphere. The solution successfully predicts the observed overturning mass flux, the top-to-bottom density difference, the thermocline depth, and the measured vertical diffusivity (of order 10^{-5} m^{2}s^{-1}).

We focus here on the sensitivity of this steady solution to both the rate of entrainment into the slope current and the rate of interior vertical mixing. We find that the predicted sensitivity to the vertical diffusivity compares very well with scalings based on non-rotating and geostrophic theories and on results obtained from GCMs. Importantly, this analysis also indicates that models with insufficient mixing in the sinking regions require a very substantial increase in the interior vertical diffusivity, if the results are to satisfy observational constraints on the overturning mass flux and the top-to-bottom density difference. As most climate and ocean numerical models are unable to resolve the sinking regions, our results illustrate the imperative for the development of better entrainment parameterizations for use in computations.