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Absorption of Ocean Heat Along and Across Isopycnals in HadCM3

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Anthropogenic warming added to the climate system accumulates mostly in the ocean interior and discrepancies in how this is modelled contribute to uncertainties in predicting sea level rise. Temperature changes are partitioned between excess, due to perturbed surface heat fluxes, and redistribution, that arises from the changing circulation and perturbations to mixing. In a model (HadCM3) with realistic historical forcing (anthropogenic and natural) from 1960 to 2011, we firstly compare this excess-redistribution partitioning with the spice and heave decomposition, in which ocean interior temperature anomalies occur along or across isopycnals, respectively. This comparison reveals that in subtropical gyres (except in the North Atlantic) heave mostly captures excess warming in the top 2000 m, as expected from Ekman pumping, whereas spice captures redistributive cooling. At high-latitudes and in the subtropical Atlantic, however, spice predicts excess warming at the winter mixed layer whereas below this layer, spice represents redistributive warming in southern high latitudes.

Secondly, we use Eulerian heat budgets of the ocean interior to identify the process responsible for excess and redistributive warming. In southern high latitudes, spice warming results from reduced convective cooling and increased warming by isopycnal diffusion, which account for the deep redistributive and shallow excess warming, respectively. In the North Atlantic, excess warming due to advection contains both cross-isopycnal warming (heave found in subtropical gyres) and along-isopycnal warming (spice). Finally, projections of heat budgets —coupled with salinity budgets— into thermohaline and spiciness-density coordinates inform us about how water mass formation occurs with varying T-S slopes. Such formation happens preferentially along isopycnal surfaces at high-latitudes and along isospiciness surfaces at mid-latitudes, and along both coordinates in the subtropical Atlantic. Because spice and heave depend only on temperature and salinity, our study suggests a method to detect excess warming in observations.