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Rapid short-circuiting of the Meridional Overturning Circulation in the Antarctic Circumpolar Current

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The currently favoured paradigm of the Meridional Overturning Circulation (MOC) in the Southern Ocean is based on residual mean models of the zonal-average overturning across the Antarctic Circumpolar Current (ACC). Those models portray the Southern Ocean overturning as a residual circulation arising from an approximate balance between a wind-driven Ekman cell, which tends to steepen isopycnals, and an opposing eddy-driven cell acting to flatten isopycnals. Implicit in this paradigm are the assertions that isopycnal mixing by mesoscale eddies is downgradient with a diffusivity in the region of 500-1500 m^2 s^{-1}, and that diapycnal mixing is negligibly weak in the ocean interior with a diffusivity of $\sim 10^{-5}$ m^2 s^{-1}. The resulting MOC closure expressed by the residual mean models is one in which mesoscale eddies drive upwelling along the mid-depth ACC isopycnals with an average vertical velocity of $\sim 10^{-1}$ m d^{-1}, while compensatory sinking at a similar rate occurs in the Southern Ocean both north and south of the ACC. The near-impermeability of density surfaces in the ocean interior inherent to the assumption of weak diapycnal mixing implies that there is little interaction between water parcels upwelling along different isopycnals, or indeed between the upwelling and downwelling limbs of the Southern Ocean overturning. Accordingly, transitions between different levels of the MOC must occur either at the Southern Ocean surface or at depth in the oceans to the north, so relatively long transit paths and residence times in the deep ocean are implied for water parcels participating in the overturning.

Here, we put this paradigm to the test by taking advantage of a serendipitous tracer release experiment that enables us to measure the rates of mixing and upwelling in the intermediate layers of the ACC, averaged over a large sector spanning nearly one tenth of the current's circumpolar path. The experiment takes the form of an injection of primordial helium, issued by submarine volcanoes in the South Pacific, into the northern ACC upstream of Drake Passage. The dispersion of the tracer reveals that mesoscale eddies mix tracers isopycnically at roughly the assumed rate and, as expected, play a leading role in promoting deep water upwelling along isopycnals. Surprisingly, this eddy-driven upwelling is much too rapid (~ 1 m d^{-1}) to fit the residual mean paradigm and occurs in conjunction with strikingly intense mid-depth diapycnal mixing (at a rate of $\sim 10^{-4}$ m^2 s^{-1}). Using an energetics-based argument, we propose that these two unexpected features of the Southern Ocean overturning are interrelated, backing the emergence of a revised MOC paradigm in which deep water pathways along and across density surfaces intensify and intertwine as the ACC flows over complex topography. A vigorous short-circuiting of the MOC in these regions is implied that is absent from the present residual mean paradigm.