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Closing the meridional overturning circulation of the Indian Ocean: the mixing perspective

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The Indian Ocean is a region of paramount importance in the global thermohaline circulation (GTC). Cold deep water from the Southern Ocean is thought to flow northward across the southern boundary of the Indian Ocean, to be transformed into warm upper waters by turbulent mixing and return southward as part of the return path for the GTC. The strength and vertical structure of this overturning are currently one of the most contentious issues in physical oceanography. Available estimates, based on ocean general circulation models and inversions of transoceanic hydrographic sections, yield overturning circulation strengths ranging from 2 to 28 Sv with widely different vertical distributions. Here we tackle the problem from a new angle by quantifying turbulent mixing in the Indian Ocean and mapping its spatial distribution from CTD / LADCP measurements collected during the World Ocean Circulation Experiment and a recent trans-Indian section along 32 S. We achieve this by using a technique that enables us to infer the intensity of the mixing from observations of the density and velocity signatures of the internal waves driving the turbulence.

We find that the Indian Ocean overturning closure is zonally asymmetric, a consequence of the breaking of internal tides over the rough topography of the western basins. This asymmetry appears to be maintained by a system of deep zonal jets reversing direction with depth, which communicate the multiple basins via which deep water enters and leaves the Indian Ocean with the localised regions of intense diapycnal transformation. The overturning has a large vertical extent compared to most past estimates and peaks at 13 Sv near 3000 m, representing around a third of the global upwelling required to close the GTC. The compatibility of this estimate with those of other studies is examined in the light of the energetics of the GTC.