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Does lateral stirring really take place along neutral surfaces in double-diffusive regions of the oceans?

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Potential temperature/salinity (theta/S) characteristics of water masses in the ocean interior can often be traced back over long distances to their source regions. In practice, understanding how water masses are altered by interior mixing and stirring requires a detailed understanding of the interior pathways linking fluid parcels to their source regions. So far, oceanographers have generally assumed that these pathways are strongly constrained to take place on potential density surfaces of some kind, of which the most commonly employed have been the Jackett and McDougall neutral density variable and sigma2, the potential density referenced to 2000 dbar. Because sigma2 is a somewhat ad-hoc and artificial construct, the more physically-based neutral density variable has been widely assumed to represent the most accurate variable to describe interior pathways, but the analysis of van Sebille et al. (2011) intriguingly suggests otherwise. In order to shed light on the issue, this work hypothesizes that if neutral surfaces were optimal to describe lateral stirring in the ocean, they should be the surfaces along which the observed spread in potential temperature and salinity anomalies should be minimum, since lateral stirring is about 7 orders of magnitude more vigorous in the lateral directions than perpendicular to them. Surprisingly, it is found that this is actually never the case in ocean regions with positive density ratios, traditionally associated with double-diffusive regimes. In those regions, indeed, it is always possible to find material surfaces, not necessarily definable in terms of potential density, along which the spread is reduced for both potential temperature and salinity compared to that over neutral surfaces. In doubly-stable regions, on the other hand, it is not possible to find material variables able to simultaneously reduce both the spread in potential temperature and salinity compared to that over neutral surfaces. Given the widespread nature of double-diffusive regimes in the world oceans, especially in the Atlantic Ocean, these results have strong implications for the ability of ocean climate models to accurately simulate water masses, as it is unclear how to maintain water masses properties by mixing vigorously along directions along which the spread in theta/S is far from its minimum.