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Dynamics of downwelling and overturning in an eddying marginal sea: contrasting the Eulerian and the isopycnal perspective

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In the marginal seas of the North Atlantic, intense net downward motions connect the upper northward branch and the lower southward branch of the Atlantic Meridional Overturning Circulation (AMOC). The sinking of dense water masses in the North Atlantic has often been associated with deep convection in these marginal seas. However, earlier studies have pointed out that deep convection is not associated with intense net vertical transports and that strong sinking can only occur close to lateral boundaries where ageostrophic processes play a role.
Using an idealized model configuration of an eddying marginal sea subject to a strong surface heat loss, we demonstrate that intense Eulerian sinking indeed only occurs near the boundary, and peaks in regions with strong eddy activity. Notably, the net near-boundary sinking is directed across the mean isopycnals (suggesting diapycnal mixing) even though it occurs well below the mixed layer in the stratified boundary current, i.e. at a depth where diapycnal processes are assumed to be small. So while it is well known that a substantial diapycnal mass flux occurs in marginal seas, it is questionable if this occurs in the region with intense Eulerian sinking.

To address this issue, we explore the sinking from a Eulerian as well as an isopycnal perspective, to assess where the diapycnal mass flux actually takes place, to explore the pathways of dense water masses, and to elucidate the role of eddies in the system. By evaluating the instantaneous diapycnal flow, we confirm that the region where intense Eulerian sinking takes place is not associated with a diapycnal mass flux. Rather, the latter takes place in the interior and elsewhere in the boundary current.
An analysis of the export routes of dense water masses towards the North Atlantic reveals two routes, governed by different processes:
1) A direct route with water masses that are directly transformed within the upper part of the boundary current and advected out of the basin, and
2) An indirect route associated with denser water masses in the lower part of the boundary current; these are formed in the interior and steered towards the boundary by the intense eddy activity in the basin.

This study thus reveals a complex three-dimensional view on the downwelling and overturning in a marginal sea, in which interactions between water mass transformation in the boundary current and in the interior and the eddy activity play a prominent role. It motivates to rethink the connection between sinking, water mass transformation, and overturning in the North Atlantic Ocean.