A model-based seasonal assessment of the North Atlantic net downwelling

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Net downwelling in the boundaries

Most of sinking occurs in the North Atlantic near the boundaries (Figure 1-top), due to buoyancy loss and sharp topography [1]. This sinking is proportional to the alongshore density gradient and eddies may play an important role in the densification of waters [2].

We use a high resolution model to answer the following questions:

a) What is the seasonal variation of sinking in the North Atlantic?

b) How sinking spreads over the different North Atlantic marginal seas?

Model configuration & dataset

- Parallel Ocean Program (POP) model. Curvilinear coordinates.
- Nominal horizontal resolution 0.1 deg. at the equator & 42 z-levels.
- Normal (climatological) year forcing of wind and heat fluxes. Including river run-off.
- Results are based on 15 years monthly mean fields of 3D velocity fields and potential density. Employed fields (years 260 to 274) are part of a longer simulation [3]. The region of study is defined in Figure 1-bottom.

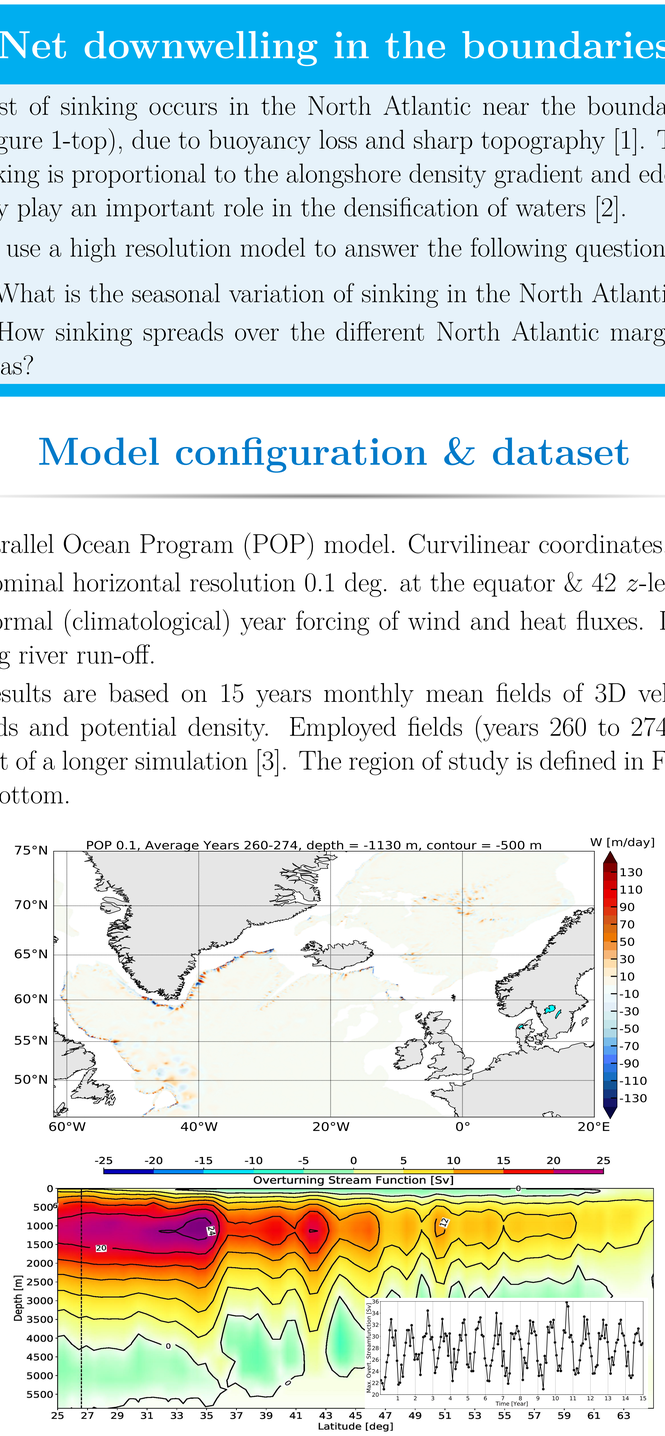

Figure 1. (top) Mean vertical velocity at 1130 m for the period of study. (bottom) Model-based mean overturning streamfunction for the North Atlantic. CI is 4 Sv. The inset figure shows the time-series of maximum overturning streamfunction (black line).

Seasonal variability of net downwelling

- Time-mean maximum overturning (net downwelling/sinking), defined as $\mathrm{W}(z)\,\Delta x\,\Delta y$, is found at a depth of 1130 m (Figure 2-left) with a mean value of ~ -14 Sv (negative sign denotes sinking), in good agreement with the max. overturning streamfunction at 45° (Figure 1-bottom).
- Stronger(weaker) overturning occurs in summer(winter), which matches with a stronger(weaker) overturning streamfunction (Figure 1-bottom, inset), with a seasonal variability of ~ 10 Sv.

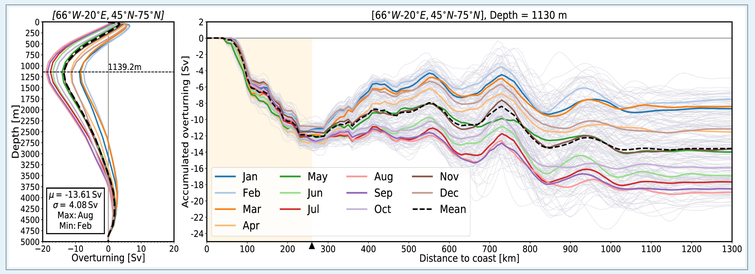

Figure 2. (left) Total mean (black line) and monthly mean (color lines) overturning profiles (see legend Figure 2-right) for the whole study area (Figure 1-top). The horizontal line indicates the depth of maximum overturning. (right) Accumulated mean (black line) and monthly mean (color lines) net downwelling respect to the distance to the coast. The yellow shading highlights the accumulated sinking within the first 260 km (also indicated with a black triangle).

Regional variability of net downwelling

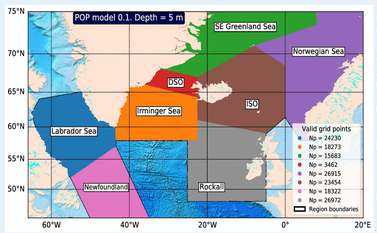

Figure 3. Study area divided in 8 regions. DSO and ISO refer to Denmark Strait and Iceland-Scotland Ridge overflow regions respectively.

- **Magnitude and depth of max. sinking is different for each region.**
- **30% of sinking occurs in overflow regions (DSO and ISO).**

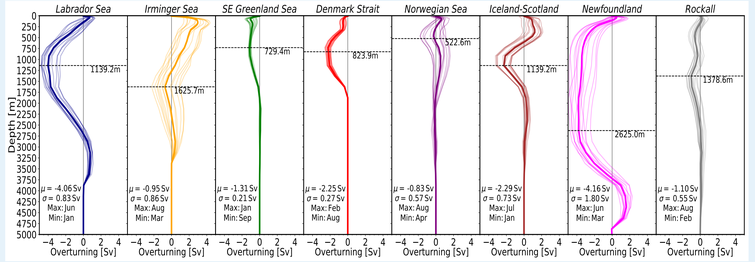

Figure 4. Mean (thick line) and monthly-mean (thin lines) profiles of net sinking for regions of Figure 3. μ = mean, σ = standard deviation, max and min refer to the months with maximum and minimum sinking.

A first-look at water-mass transformation

- Deepest mixed layer develops in late winter/early spring, with the greatest convection occurring in Labrador and Greenland Seas (Figure 5-top).
- All sub-regions of Figure 3 show a densification of waters in spring, which suggests the importance of diapycnal mixing (Figure 5-bottom).
- The highest relative changes in potential density occur in the Labrador Sea and in the Denmark Strait (Figure 5-bottom).
- The connection between the maximum overturning and the densification of waters during spring in the Labrador Sea is further discussed in the poster of [4].

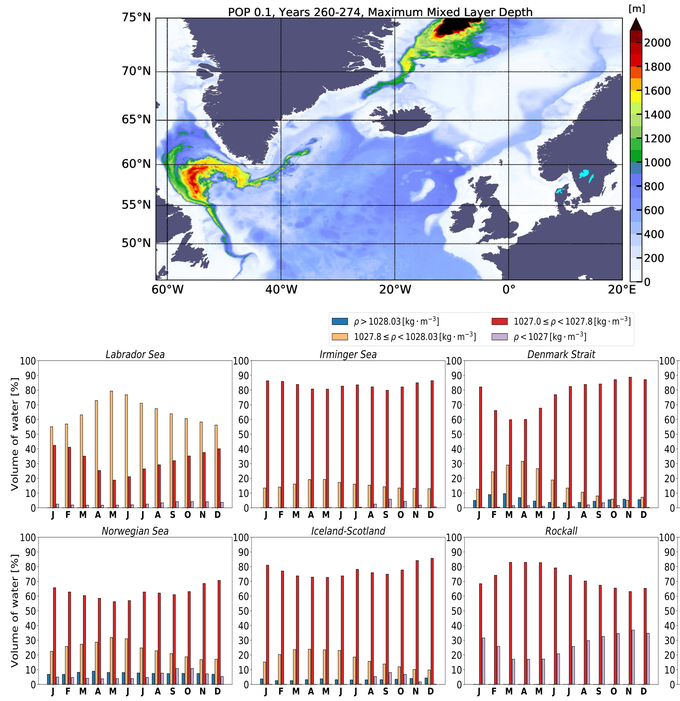

Figure 5. (top) Map of maximum mixed layer depth for the study period (years 260-274). (bottom) Monthly mean percentage of volume of water for four density classes: $\geq 1028.03\,\mathrm{kg\cdot m^{-3}}$ (blue), $[1027.8,\ 1028.03)\,\mathrm{kg\cdot m^{-3}}$ (orange), $[1027,\ 1027.8)\,\mathrm{kg\cdot m^{-3}}$ (red) and $< 1027\,\mathrm{kg\cdot m^{-3}}$ (light purple). The total volume for each basin is based on the maximum mixed layer depth shown in Figure 5-top. Each panel corresponds to one of the regions defined in Figure 3.

References

[1] M. A. Spall and R. S. Pickart, "Where Does Dense Water Sink? A Subpolar Gyre Example," *Journal of Physical Oceanography*, vol. 31, no. 3, pp. 810–826, 2001.

[2] C. Katsman, S. S. Drijfhout, H. A. Dijkstra, and M. A. Spall, "Sinking of Dense North Atlantic Waters in a Global Ocean Model: Location and Controls," *Journal of Geophysical Research: Oceans*, vol. 123, no. 5, pp. 3563–3576, 2018.

[3] S. E. Brunnabend and H. A. Dijkstra, "Asymmetric response of the atlantic meridional ocean circulation to freshwater anomalies in a strongly-eddying global ocean model," *Tellus A: Dynamic Meteorology and Oceanography*, vol. 69, no. 1, p. 1299283, 2017.

[4] S. Georgiou et al., "The impact of changing eddy pathways on deep convection and downwelling in the Labrador Sea," in *International AMOC Science Meeting*, (Coconut Grove, Florida), Jul. 24-27 2018.