Mixing Processes in the Labrador Sea: Simulations at Resolutions Consistent with Coupled Climate Models

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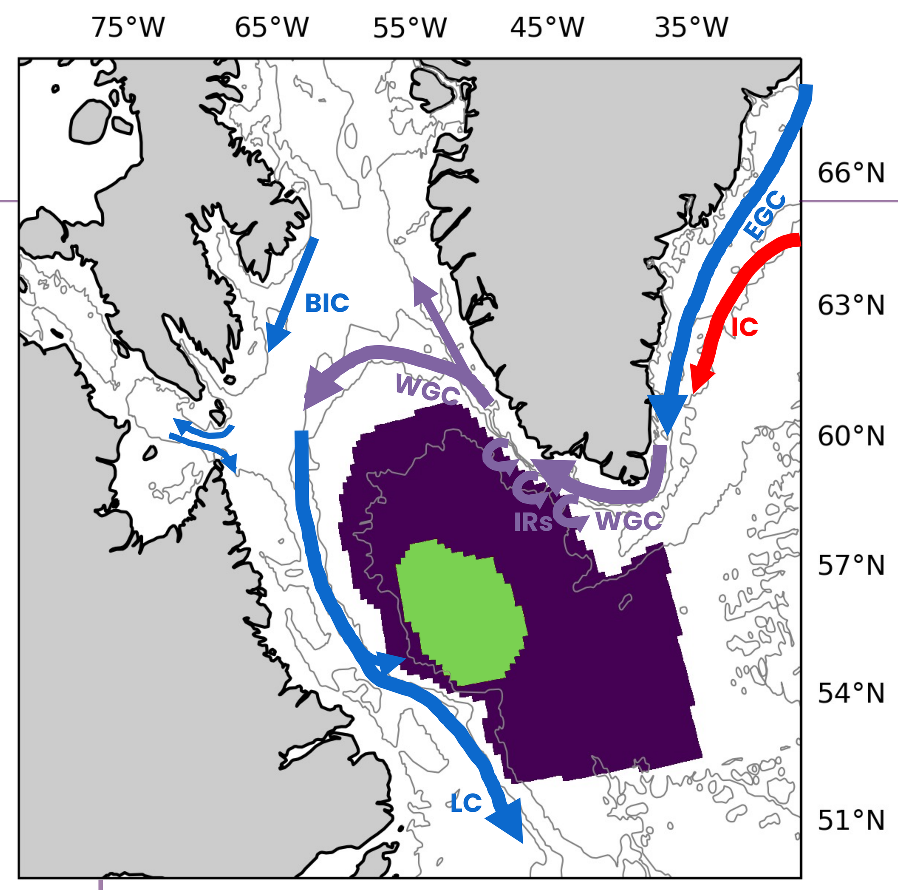


The Labrador Sea and its boundary currents, with the "typical" convection region in green and our mask (following the 3000 m isobath) in purple.

01 Introduction

- The Labrador Sea experiences deep convection, supplementing and densifying the AMOC [1]. It is modulated by fluxes of heat and freshwater from its boundary currents.
- Most global coupled climate models have low ocean resolutions—i.e., under 1/4°—and do not capture important mesoscale and submesoscale features [2].
- This results in MLD biases, which are often unrealistically deep [3], with implications for the magnitude of AMOC estimations.

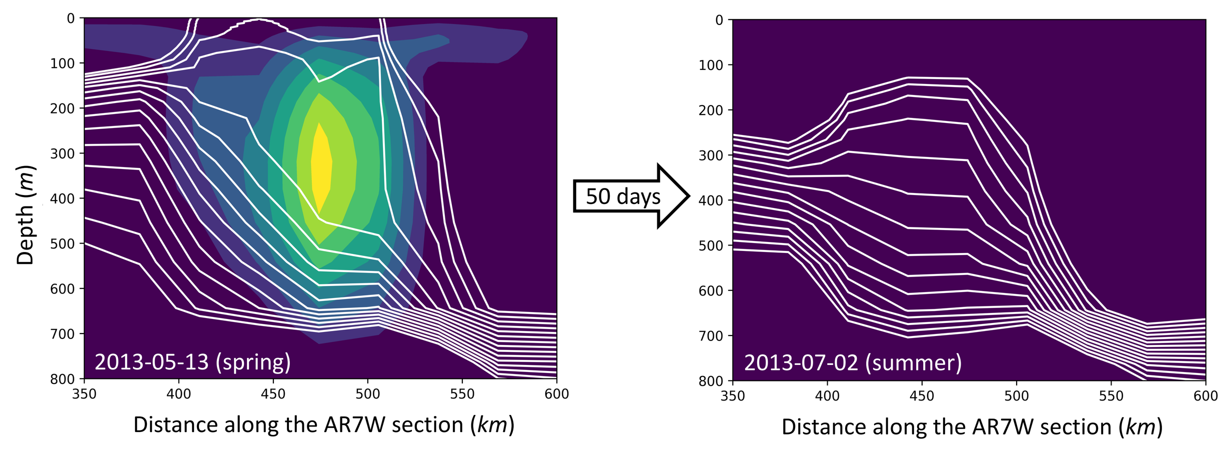
02 SMLEs

- Submesoscale mixed layer eddies (SMLEs) are baroclinic instabilities in the mixed layer that overturn fronts and restore stratification.
- SMLEs can be parameterized in NEMO based on the stream function from Fox-Kemper et al. [4],

$$\mathbf{\Psi} = C_e \frac{\Delta s}{L_f} \frac{H^2 \nabla \bar{b} \times \hat{\mathbf{z}}}{\sqrt{f^2 + \tau^{-2}}} \mu\left(\frac{z}{H}\right),$$

where an updated formulation of the typical width of a mixed layer front is used,

$$L_f = \frac{NH}{\sqrt{f^2 + \tau^{-2}}}.$$



Color denotes the magnitude of $\mathbf{\Psi}$, and white lines denote isopycnals between 1027.71 and 1027.73 kg/m^3.

03 Tidal forcing

- Barotropic tidal forcing can be represented by additional terms in the momentum equation.
- We use 9 constituents; $M_2, M_4, k_1, k_2, N_2, O_1, P_1, Q_1$, and S_2.
- In the North Atlantic and the Labrador Sea, the M_2 tide dominates.
- At 1/4°, the lowest mode internal tides are likely represented [5], but tidal mixing must still be parameterized.

RESEARCH QUESTION

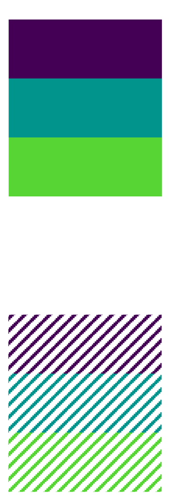
Can the SMLE parameterization and/or tidal forcing be used to improve the representation of MLDs in the Labrador Sea?

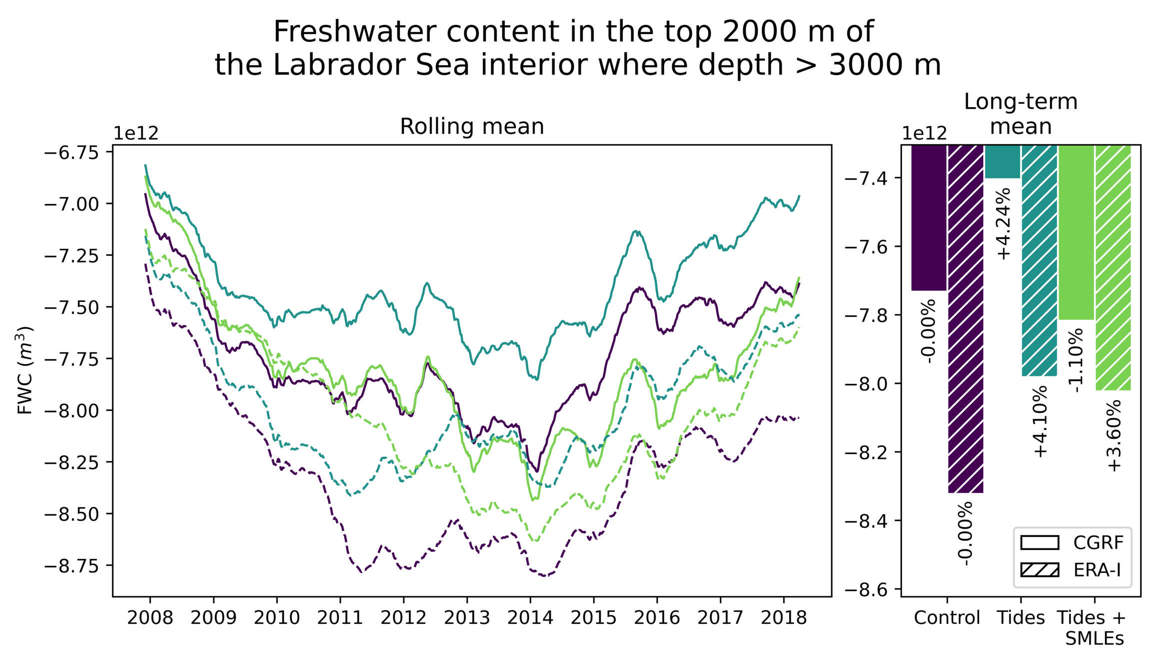
04 Methodology and analysis

- ANHA4: A configuration of NEMO v3.6 coupled with the LIM2 ice model, with a domain encompassing the **A**rctic and **N**orthern **H**emisphere **A**tlantic at 1/4° resolution.
- Six runs are analyzed:

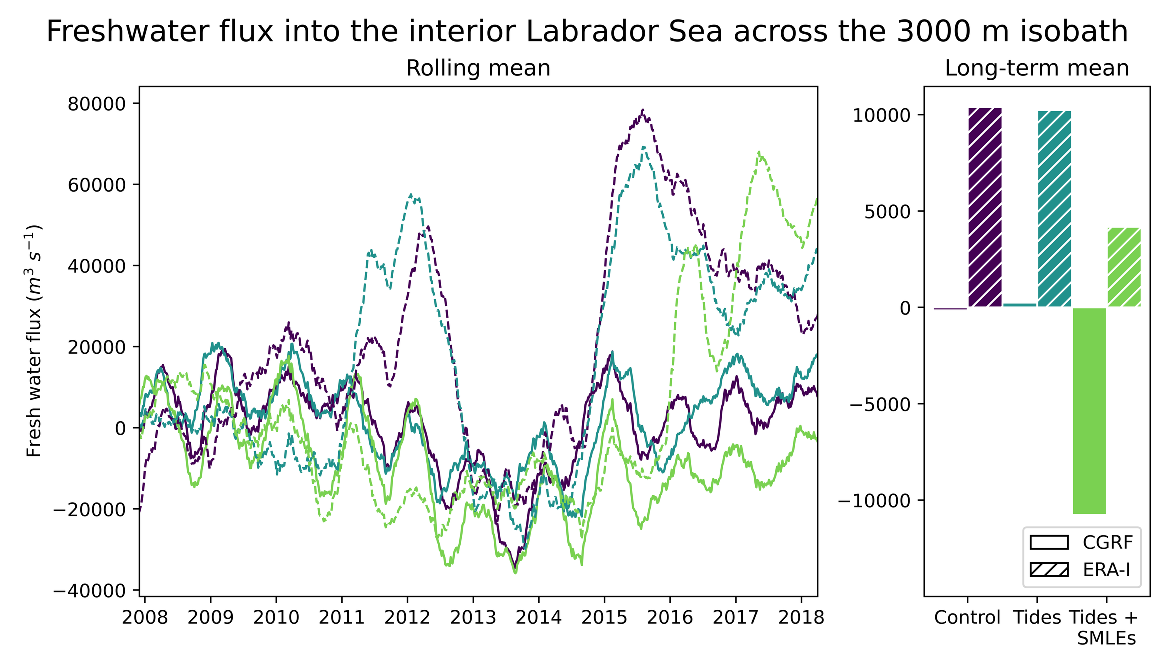
CGRF forcing
1. Control (no tides, SMLEs)
2. Include tides
3. Include tides, SMLEs

ERA-I forcing
4. Control (no tides, SMLEs)
5. Include tides
6. Include tides, SMLEs

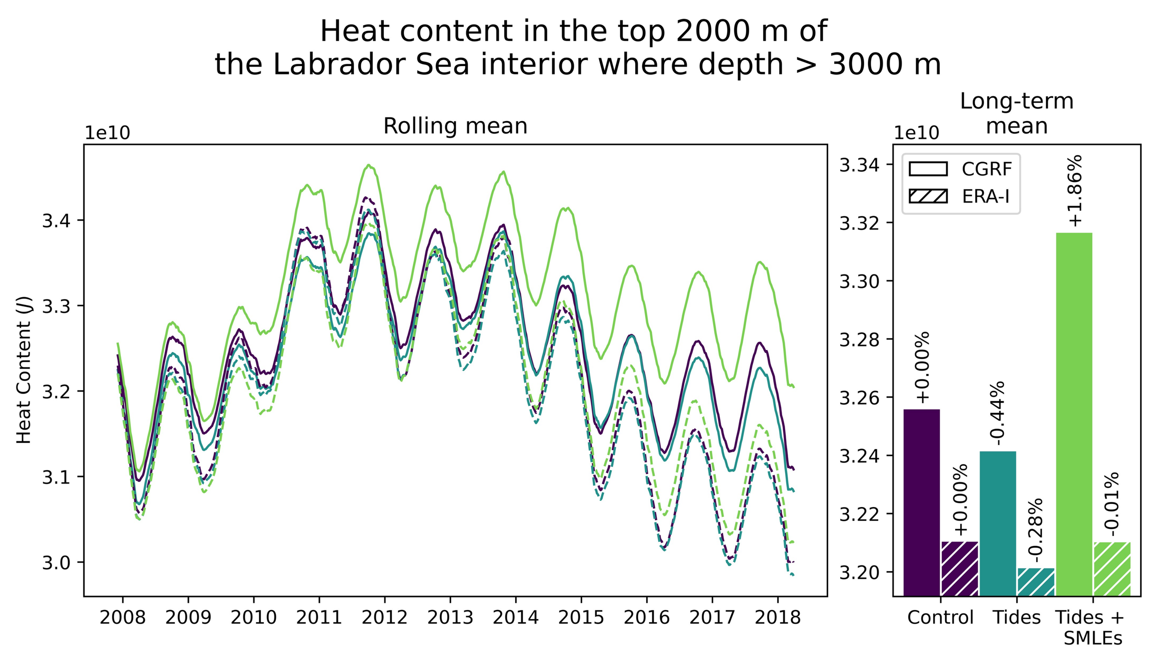




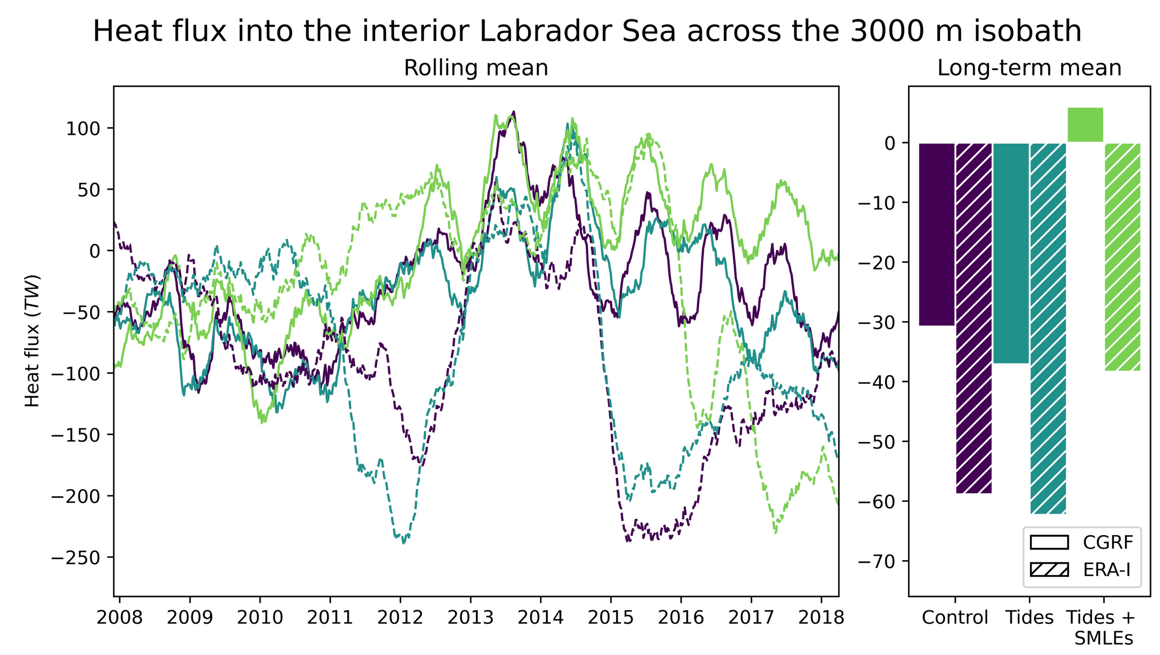
Tides increase FWC for both forcing products, while the SMLE parameterization has either little effect (with ERA-I) or it reduces FWC (with CGRF).



ERA-I forcing causes stronger freshwater flux compared to CGRF. Long-term means show that the SMLE parameterization dominates tides, strongly reducing the freshwater flux for both forcing products.



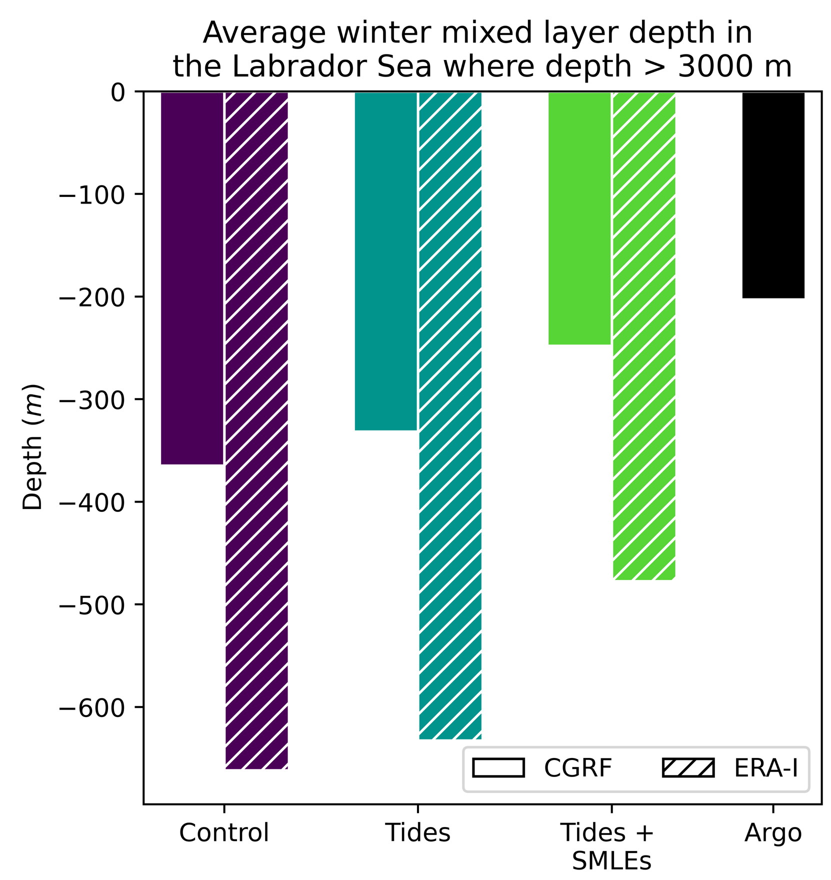
The SMLE parameterization dominates with CGRF forcing, significantly increasing heat content, while it is comparable in magnitude to the effects of tides with ERA-I forcing.



Results mirror those above; the SMLE parameterization dominates, leading to increased heat flux, while tidal forcing has less effect.

05 Results

- Mean model wintertime MLDs are shown (right) compared to observations from Argo floats during 2007–2018. For both forcing products, MLD biases are reduced by both the SMLE parameterization and tidal forcing.
- We hypothesize that the SMLE parameterization can overturn fronts in the boundary currents, thereby reducing fluxes due to baroclinic instabilities and leading to (relatively) increased heat flux and strengthened interior stratification. It also enhances post-convection restratification, weakening preconditioning for the subsequent winter.
- Conversely, tidal forcing has little overall effect on boundary-interior exchange, but still enhances stratification by increasing FWC—the exact mechanism by which it does this is an ongoing question. Tides also likely increase interior mixing, including numerical mixing, potentially accelerating the post-convection slumping of isopycnals.



06 Conclusion

- Within a 1/4° NEMO model, both the SMLE parameterization and tidal forcing are found to increase stratification in the Labrador Sea, either via increased FWC, increased heat content, or enhanced mixing in the interior. This reduces deep MLD biases compared to Argo observations.
- These results imply that both tidal forcing and the SMLE parameterization might be (relatively) inexpensive techniques for reducing MLD biases within global climate models, with the potential to improve their representation of the AMOC relative to its observed mean and variability.
- Going forward, we plan to investigate energetics associated with baroclinic vs. barotropic instabilities as well as conducting additional model runs to investigate the strengths of the tidal and SMLE-induced velocities.

References

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