How does imposing an observation-informed map of background mixing impact the modelled Arctic Ocean state?

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Context & Rationale

- mixing in the Arctic Ocean drives water mass transformations critical to how the Arctic Ocean functions, with consequences for the storage of heat and freshwater as well as the export of freshwater to the subpolar N. Atlantic
- our understanding of Arctic Ocean mixing variability is limited by a scarcity of observations; however, new estimates of mixing rates provided by autonomous instruments + turbulence parameterizations show that mixing is highly variable in space & time on a wide range of scales[1,2,3]
- these results motivate questions about the sensitivity of the Arctic Ocean state and its exports to mixing space-time geography, as well as the sensitivity of Arctic Ocean models to the prescription of mixing strength and space-time distribution

Study Objective

- here we explore the sensitivity of the modelled Arctic Ocean state & its exports to variation in the strength & geography of prescribed background mixing rates
- specifically we address the questions:
  1. "What are the effects of imposing a spatially-varying map of background vertical diffusivity with horizontal and vertical structure informed by observational estimates on the modelled Arctic Ocean state?"
  2. "How can these effects be understood in the context of the results of increasing and decreasing the diffusivity uniformly in space, and what does this understanding imply for the sensitivity of Arctic Ocean heat and freshwater budgets to changing Arctic Ocean mixing regimes?"

Methods

- we use an intermediate complexity regional model of the Arctic Ocean based on the MITgcm[4]
- we prescribe a map of background vertical diffusivity with horizontal & vertical variations informed by observational estimates[3] (Fig. 1) (the "OBS" model run)
- we compare to a control run ("CTL") with uniform diffusivity of 6×10^{-6} $m^2 s^{-1}$ (the value typically employed in the model) and to model runs with uniform background vertical diffusivities an order of magnitude larger and smaller than CTL ("HI" and "LO", respectively)

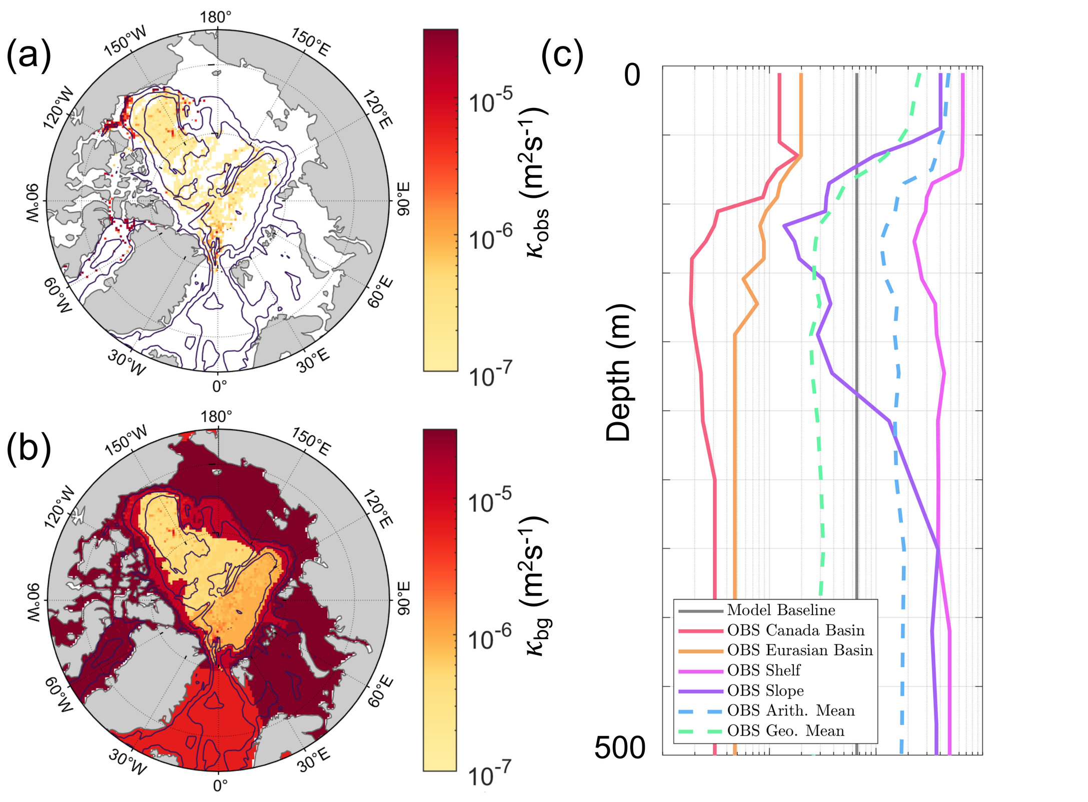
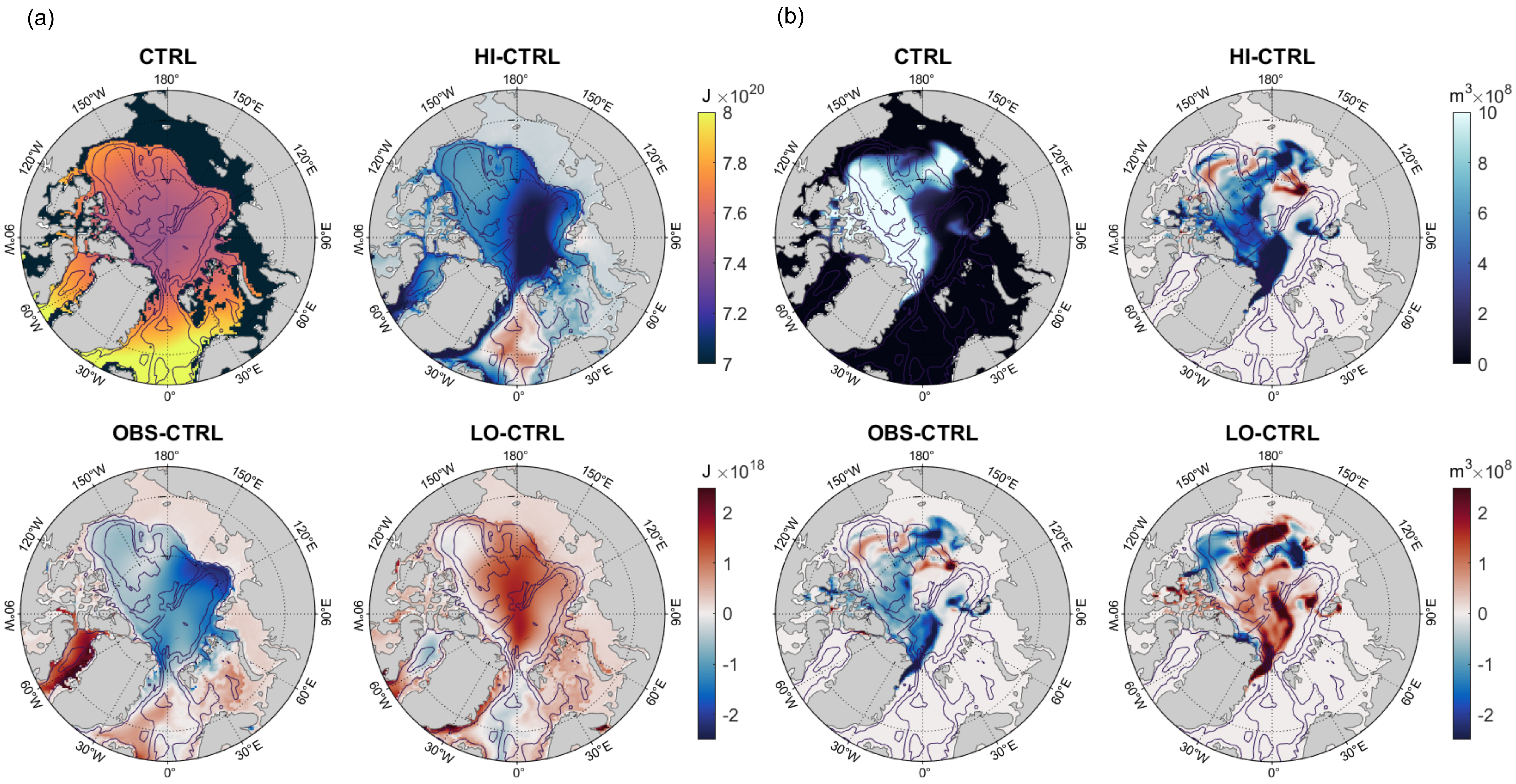


Fig. 1 *(a) Observational estimates of vertical diffusivity (shown here is the vertical mean in each grid cell) constructed from Ice-Tethered Profiler and shipboard CTD data and the finescale parameterization (see [4]). (b) The OBS distribution of background vertical diffusivity, κ_{bg} constructed from (a) and shelf, slope, Canada Basin and Eurasian basin mean values. (c) The regional mean vertical profiles of κ_{bg}.*



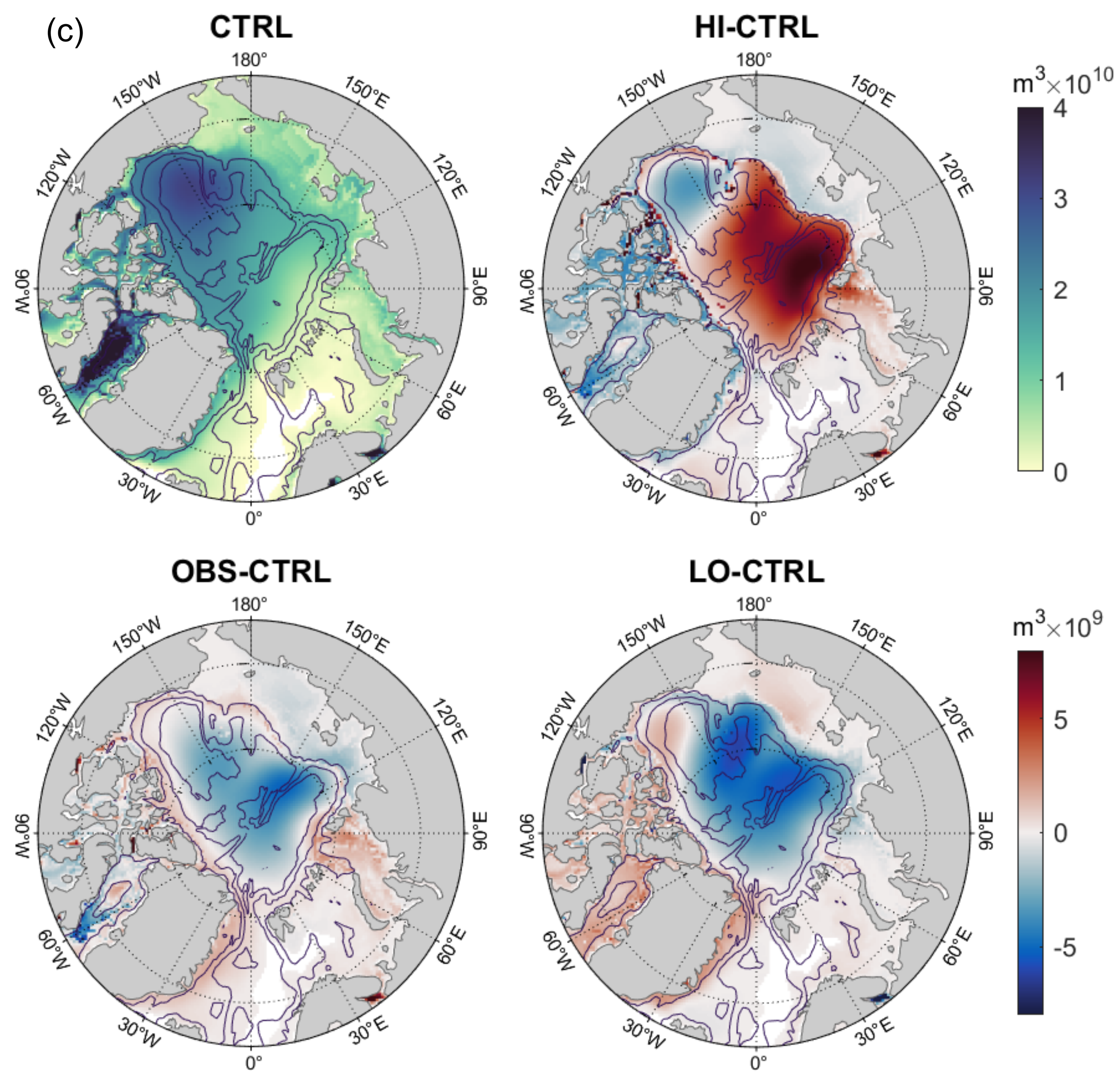


Fig. 2 *Distribution in the CTRL run (upper left) and anomalies from the CTRL run for OBS (lower left), HI (upper right) and LO (lower right) for (a) full water column heat content; (b) sea ice volume; and (c) full-depth freshwater content relative to 34.8.*

Key Results

- imposing a spatially-varying map of background vertical diffusivity based on observational estimates results in (relative to CTL):
  - less heat storage in the Arctic Ocean
  - a reduction in sea ice volume
  - less freshwater storage in the Arctic Ocean
  - more freshwater exported to the N. Atlantic
  - changing export pathways with more exported through Fram Strait and less exported through Davis Strait
- these responses look like:
  - the high mixing run for the case of heat storage & sea ice reductions
  - the low mixing run for the case of freshwater storage & export

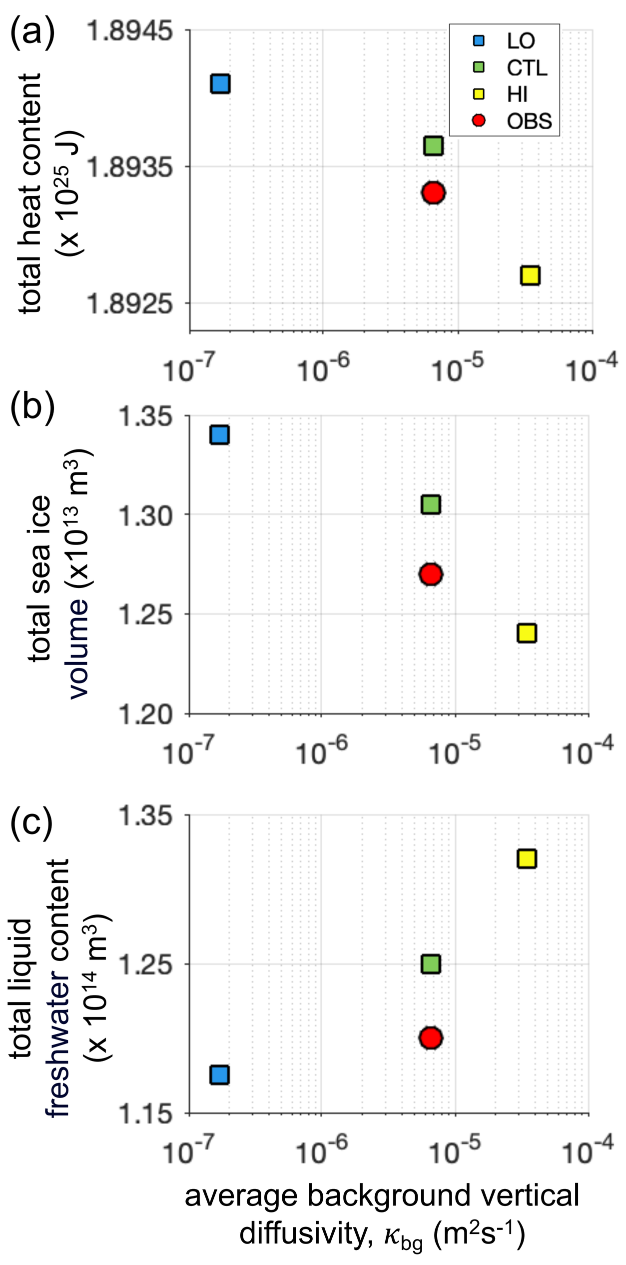


Fig. 3 *Total Arctic Ocean (a) heat content (b) sea ice volume and (c) liquid freshwater content integrated over the full water column and across the full Arctic Ocean domain for each model run (see legend). Values represent the average over 4 years. Metrics are shown as a function of the average prescribed background vertical diffusivity, κ_{bg} (x axis).*

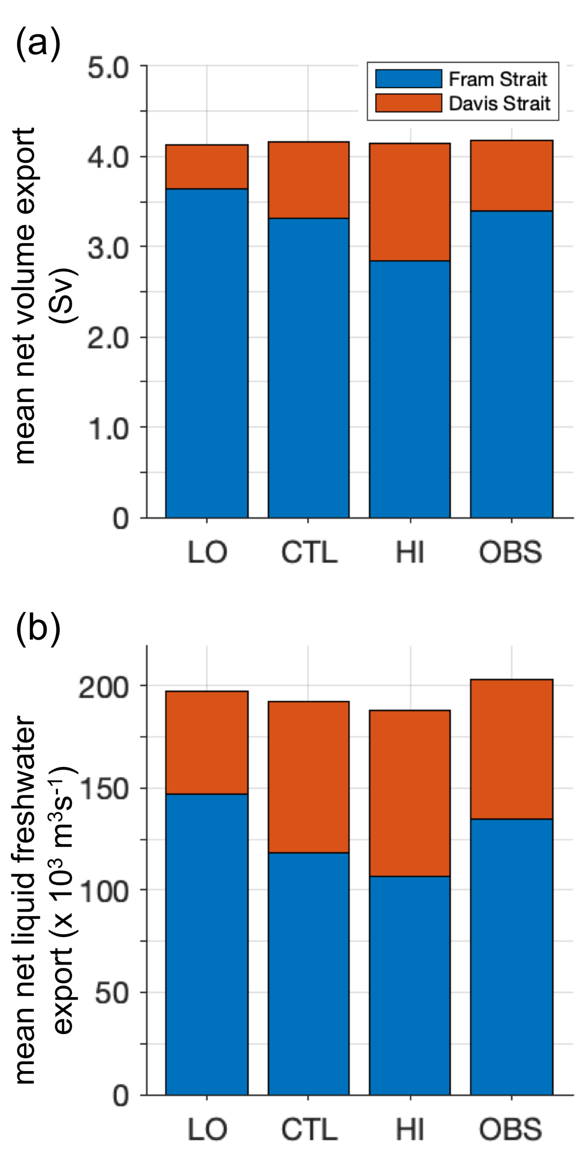


Fig. 4 *Mean net (a) volume flux and (b) liquid freshwater export flux for each model run. The total flux is partitioned into fluxes through Fram Strait (blue) and Davis Straight (orange). Values represent the average over 4 years.*

Summary & Discussion

- prescribing spatial variability in background vertical diffusivity that resembles observational estimates results in important changes in the modelled Arctic Ocean heat & freshwater budgets relative to the typical model configuration
- differing responses of heat vs. freshwater terms suggest the Arctic Ocean heat budget is more strongly influenced by mixing rates on the shelves (high in OBS), while the freshwater budget is more strongly influenced by mixing rates in the basins (low in OBS)
- sea ice loss couples the heat and freshwater systems
- mechanisms responsible for the distinct sensitivities to regional mixing rates are under investigation: the heat budget appears highly sensitive to mixing on the shelf (and in the Barents Sea in particular) because it dictates important ocean-to-atmosphere heat loss; the freshwater budget appears sensitive to mixing in the basins because it dictates basin stratification & circulation
- varied sensitivities to regional mixing rates have important implications for understanding the Arctic Ocean's response to ongoing & future changes in mixing rates & regimes which may be expected to have distinct regional dependencies

References: [1] Chanona, M., S. Waterman and Y. Gratton (2018). Variability of internal wave-driven mixing and stratification in Canadian Arctic shelf and shelf-slope waters. *J. Geophys. Res. Oceans*. 123, 9178-9195. [2] Chanona, M. and S. Waterman (2020). Temporal variability of internal wave-driven mixing in two distinct regions of the Arctic Ocean. *J. Geophys. Res. Oceans*. 125, e2020JC016181. [3] Scheifele, B., S. Waterman and J. Carpenter (2021). Turbulence and mixing in the Arctic Ocean's Amundsen Gulf. *J. Phys. Oceanogr*. 51, 169-186. [4] Dosser, H., M. Chanona, S. Waterman, N. Shibley and M.-L. Timmermans (2021). Changes in Internal Wave-Driven Mixing Across the Arctic Ocean: Finescale Estimates From an 18-Year Pan-Arctic Record. *Geophys. Res. Lett.,* 48, e2020GL091747. [5] Marshall, J., J. Scott, J. and A. Proshutinsky (2017). "Climate response functions" for the Arctic Ocean: A proposed coordinated modelling experiment. Geosci. Model Dev., 10, 2833–2848.