Exploring the impact of the rise of Greenland-Scotland Ridge on ocean circulation and climate

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Motivation

- Changes in land-sea configuration throughout Earth's history have had a profound effect on ocean circulation and climate. Reorganizations of continents and appearance of oceanic ridge alter the geometry of ocean basins and influences how the ocean circulation re-distributes heat around the globe.
- This work focuses on the **Greenland-Scotland Ridge (GSR)** and explore its role in shaping the *ocean circulation*, *heat transport* and *high latitude climate*. In particular, we seek to understand how the appearance of the GSR affects deep water formation and the Atlantic Meridional Overturning Circulation (AMOC).

Methods

MITgcm aquaplanet

Model configuration

- Coupled **ocean-atmosphere-sea ice** model with idealized topography
- Configured on cubed sphere grid at 2.8° resolution *(CS32)*
- 3,000 m deep and flat-bottomed **ocean** with 30 levels; Intermediate complexity **atmosphere** with 5 levels *(SPEEDY)*; 2.5 layer thermodynamic **sea-ice** model *(TH-SICE)*. No sea ice dynamics

Experimental design

A **ridge** with a sill depth of 500 m is introduced between 61°-65°N in the small basin mimicking the GSR. The model is integrated forward for 200 years.

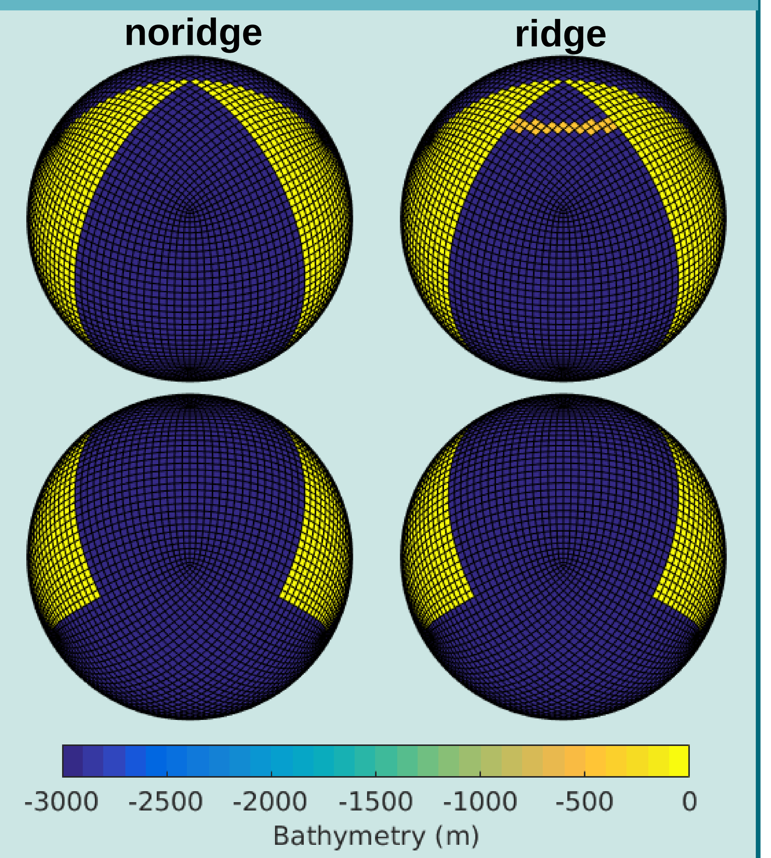
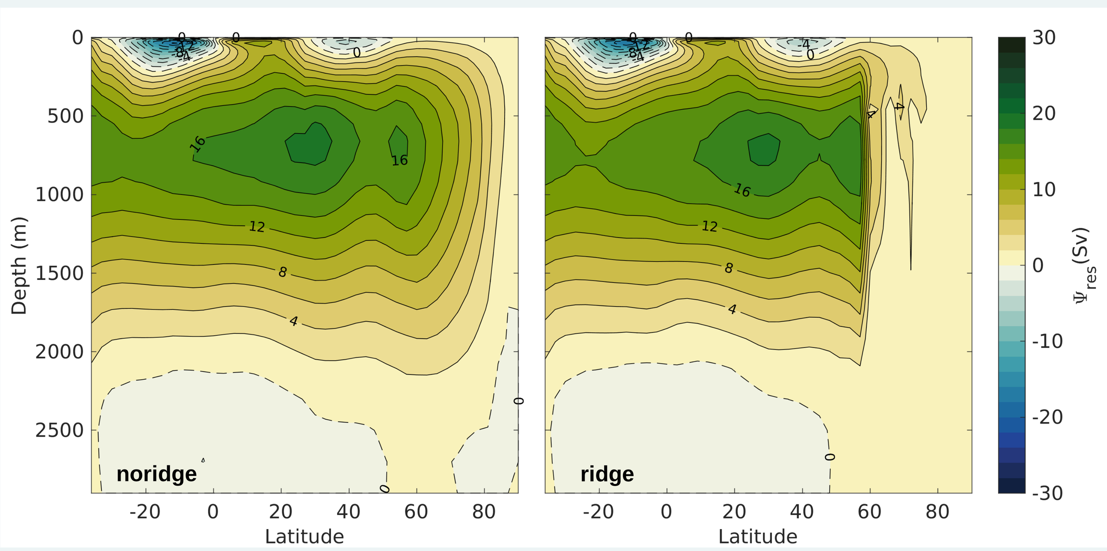
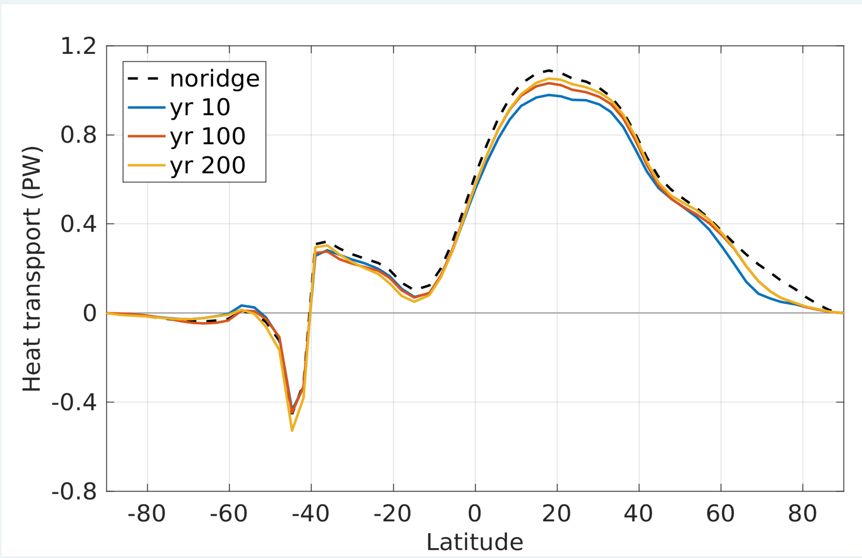


Figure 1 – Land-ocean configurations of the MITgcm Aquaplanet used in this study.

Results

Small basin MOC and heat transport

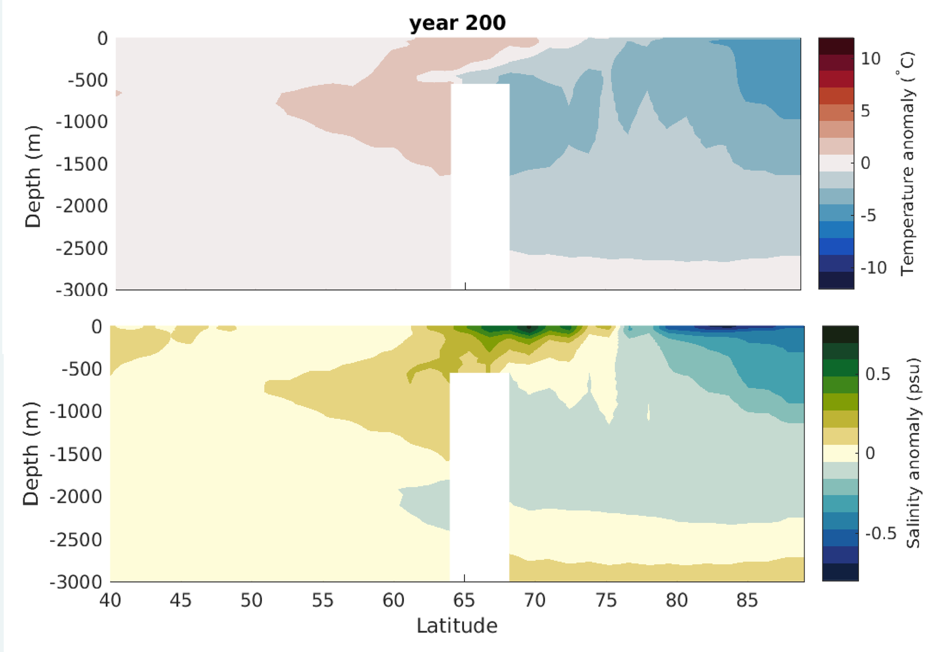




- Unrestricted northward flow of subpolar waters in *noridge* keeps northern high latitudes warm and ice-free
- The ridge partly blocs inflow of North Atlantic water and mid-to-high latitude OHT decreases by 0.2 PW (~36%)
- Downwelling shifts southwards with large structural changes in AMOC, but maximum strength is unchanged

Figure 2 – Small basin overturning streamfunction (Sv) for *noridge* (left) and *ridge* (right) and zonal mean ocean heat transport (PW) for years 10, 100 and 200 after the ridge is introduced. Dashed black lines corresponds to *noridge*.

Hydrographic changes in the small basin



Temperature and salinity anomalies

- *Cooling and freshening* north of the ridge, but *warmer and saltier* conditions south of ridge
- High latitudes become less ventilated

Figure 3 – Zonal mean anomalies of potential temperature (°C) and salinity (psu) in the small basin. Anomalies are relative to a 50-year average at the end of *noridge*.

Density changes

- Strong meridional density gradient develops across the ridge
- Dense water is formed north of the ridge
- Pressure gradient sets up zonal jet along the ridge

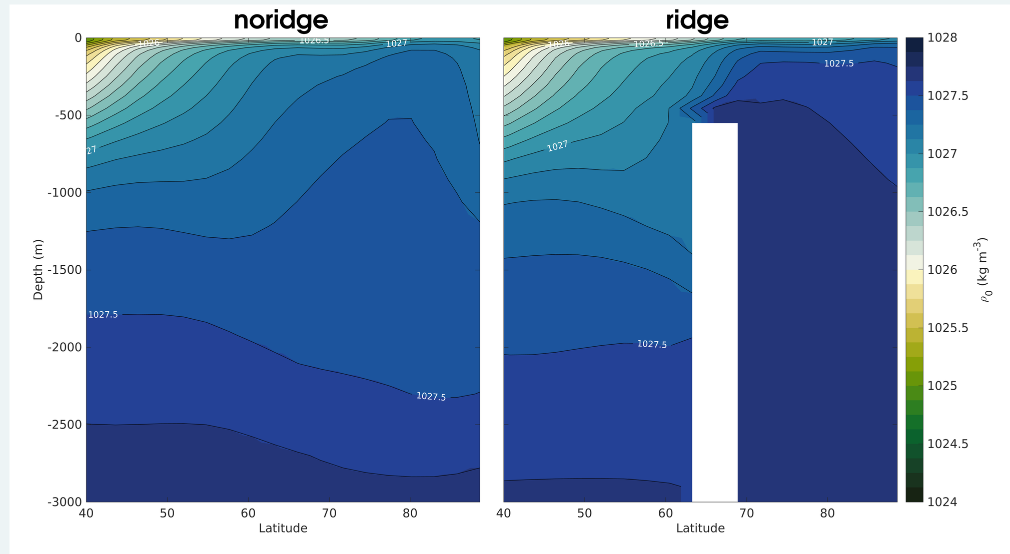
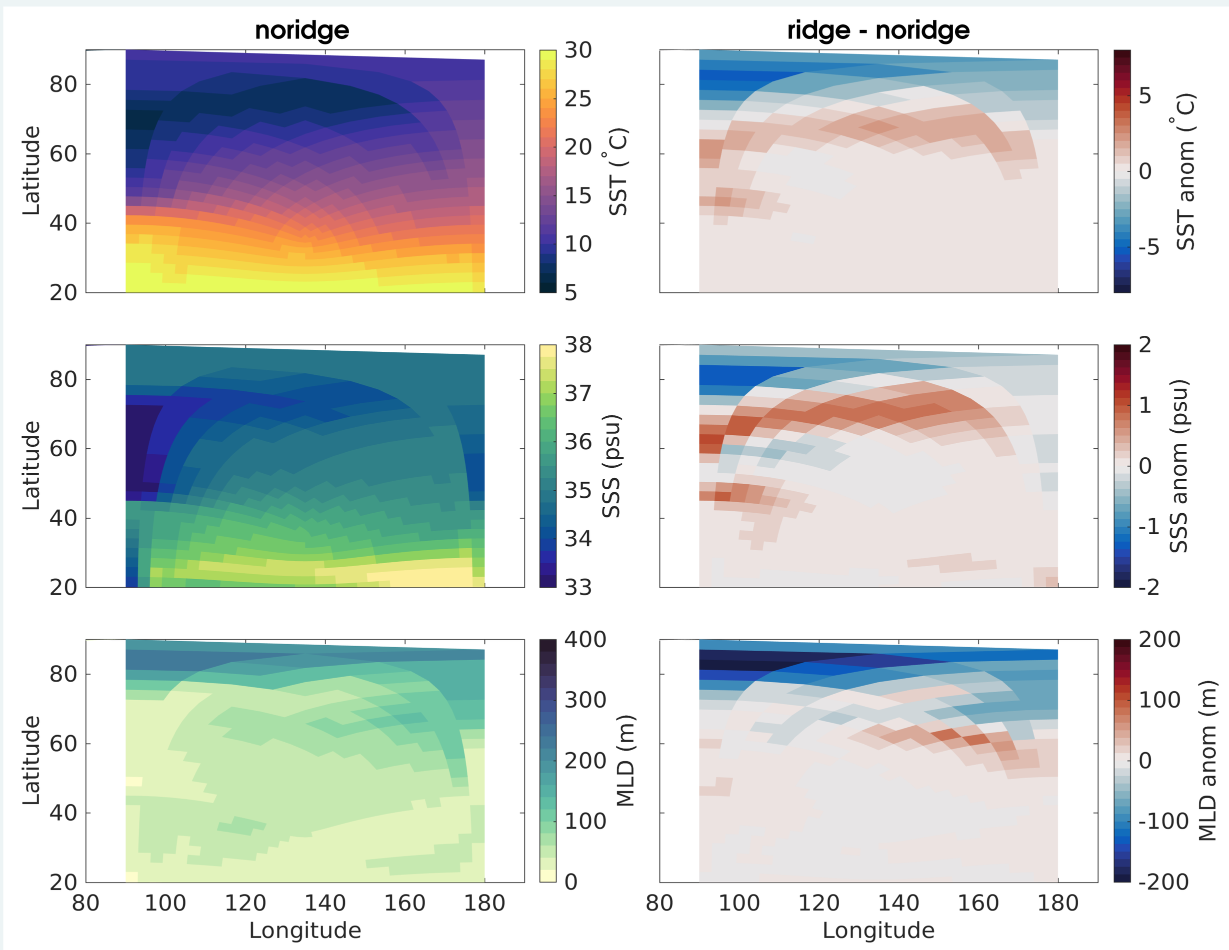


Figure 4 – Zonal mean potential density in the small basin for *noridge* (left) and *ridge* (right).

Surface climate response



SST / SSS / MLD

- Surface cooling and freshening at northern boundary
- ML shoals at northern boundary in *ridge*

Figure 5 – Left panel shows SST (°C; top), SSS (psu; middle) and mixed layer depth (m; bottom) in the small basin for *noridge*. Right panel shows anomalies for *ridge* relative to *noridge*.

Surface buoyancy fluxes

- Heat fluxes dominates surface buoyancy loss at subpolar and polar latitudes
- Reduced ocean heat loss at high northern latitudes weakens buoyancy loss in *ridge*

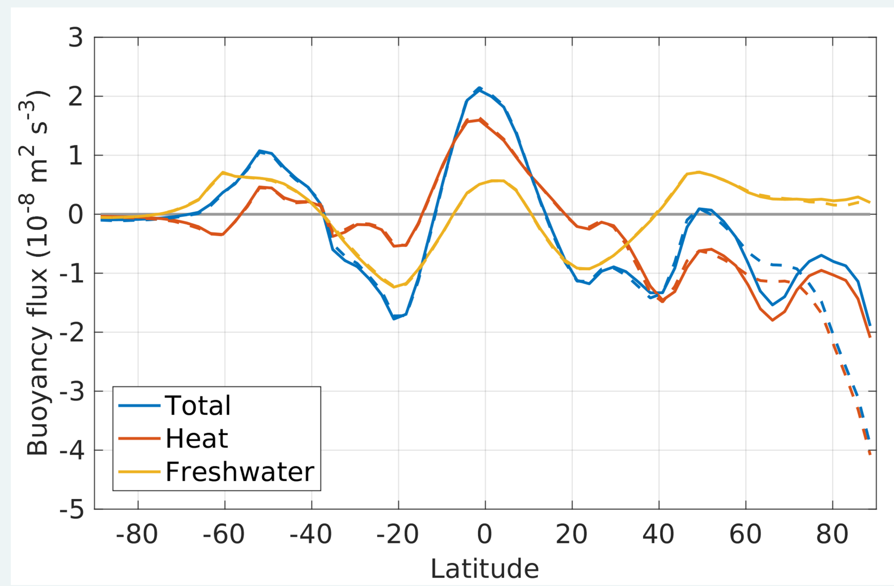


Figure 6 – Zonal mean surface buoyancy flux ($m^2\ s^{-3}$) in the small basin for *noridge* (dashed) and *ridge* (solid)

Localization of deep water formation

Water mass transformation by surface density fluxes [Walin (1982); Speer and Tziperman (1992)]

The transformation of surface waters to lighter or heavier density classes by buoyancy fluxes between outcropping isopycnals ρ and ρ+δρ, is equivalent to a diapycnal volume flux *F(ρ)* across the outcropping isopycnal:

$$F(\rho) = \frac{1}{\Delta T \Delta\rho}\int_{year} dt \iint_{area} dA\,\delta(\rho-\rho')D(x,y,t)$$

Surface density flux: $$D = D_{HF} + D_{FW} = -\frac{\alpha Q_{HF}}{c_p} + \beta S Q_{FW}$$

Density fluxes

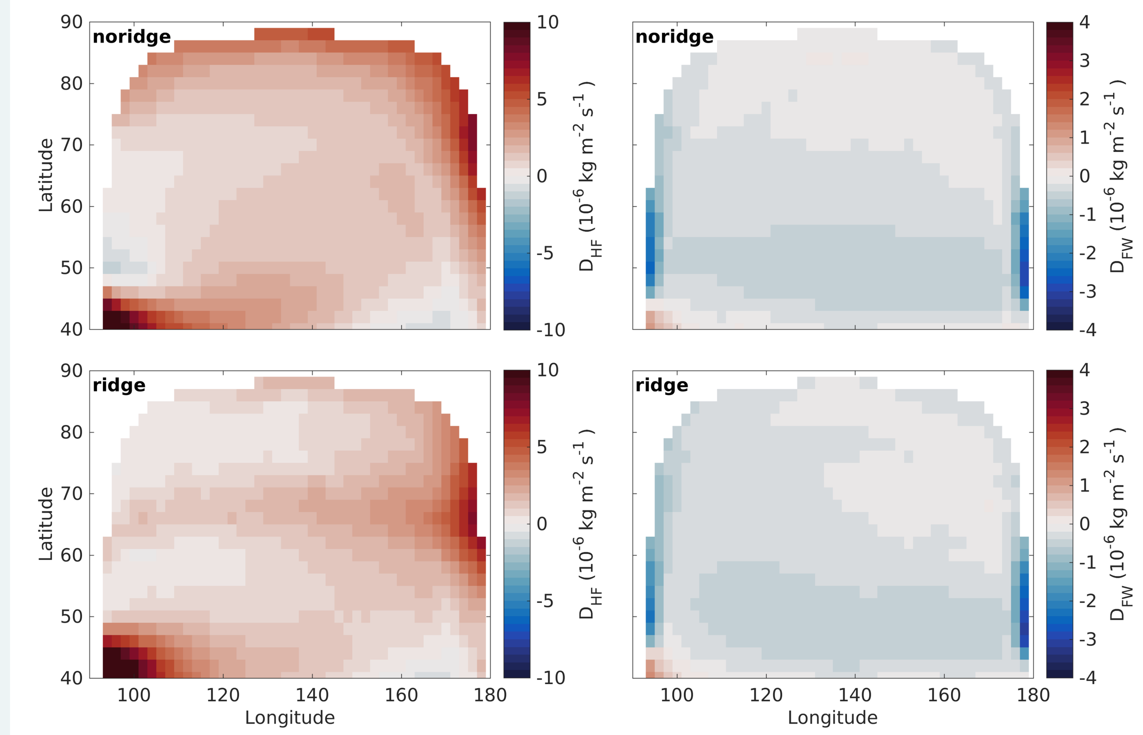


Figure 7 – Mean thermal (D_{HF}; left) and haline (D_{FW}; right) contribution to the surface density flux (10^{-6} kg m^{-2} s^{-1}) over a period of 10 years for noridge (top) and ridge (bottom). Positive values indicate densification.

Water mass transformation

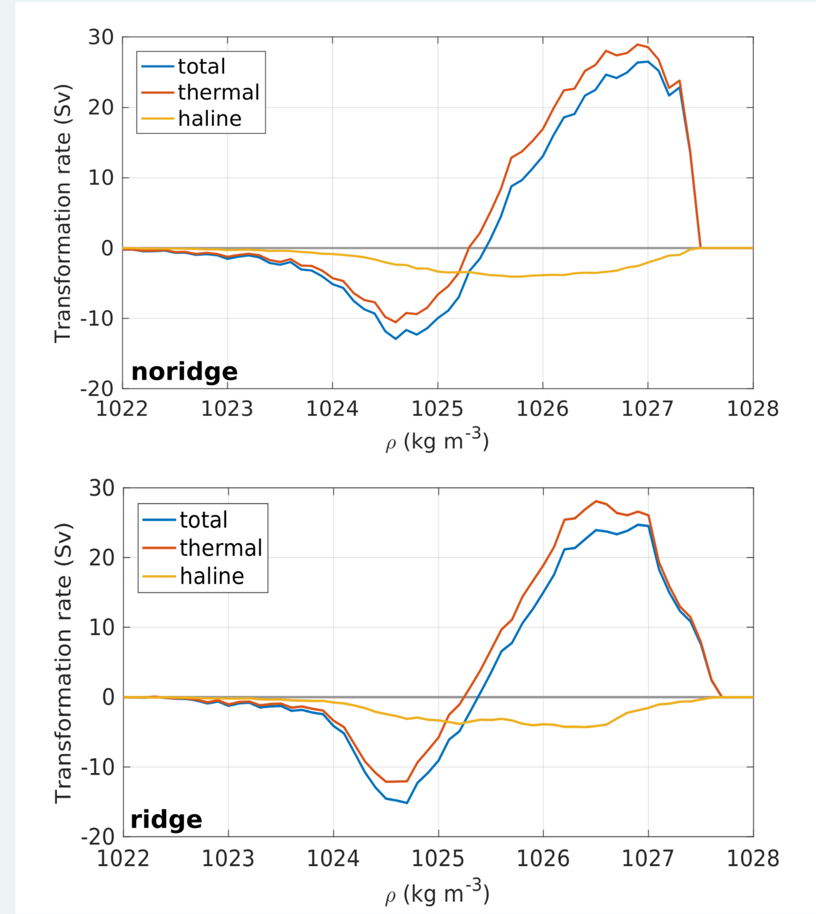


Figure 8 – Surface forced water mass transformation *F(ρ)* in Sverdrups (10^6 m^3 s^{-1}) for *noridge* (top) and *ridge* (bottom) over 10 years. *F(ρ)* is estimated from the spatial integral of the surface density flux *D* over the North Atlantic spanning the density range ρ = 1022-1028 kg m^{-3} with a density bin width of $\Delta\rho$=0.1. The total (blue) is decomposed into its thermal (red) and haline (yellow) contribution. Negative values imply a transformation of surface water to lower density classes, positive values indicate transformation to greater densities.

Conclusion

- Introducing the GSR restricts northward flow of subpolar waters by the upper overturning branch and OHT across 70°N decreases by 36%
- Convection shifts southward altering the structure of the AMOC, but the maximum does not change
- Arctic Basin cools and freshens while it gets warmer and saltier south of the ridge. Dense waters forms north of the ridge resulting in a large meridional density gradient between the Arctic Basin and North Atlantic
- Relatively modest surface climate response (SST/SSS/sea ice), but major changes in circulation suggests a potential disconnect between big AMOC changes and changes in Northern Hemisphere surface climate