The Interplay Between Wind Stress and Surface Buoyancy Fluxes in Driving Ocean Gyres

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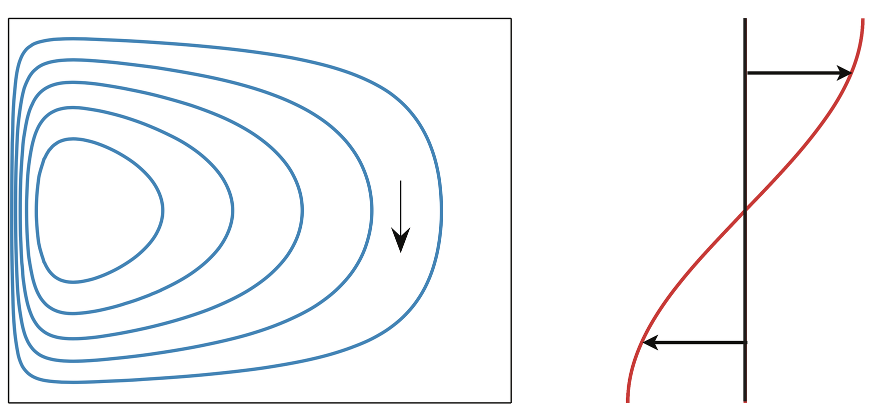
What are gyres and why do we care?

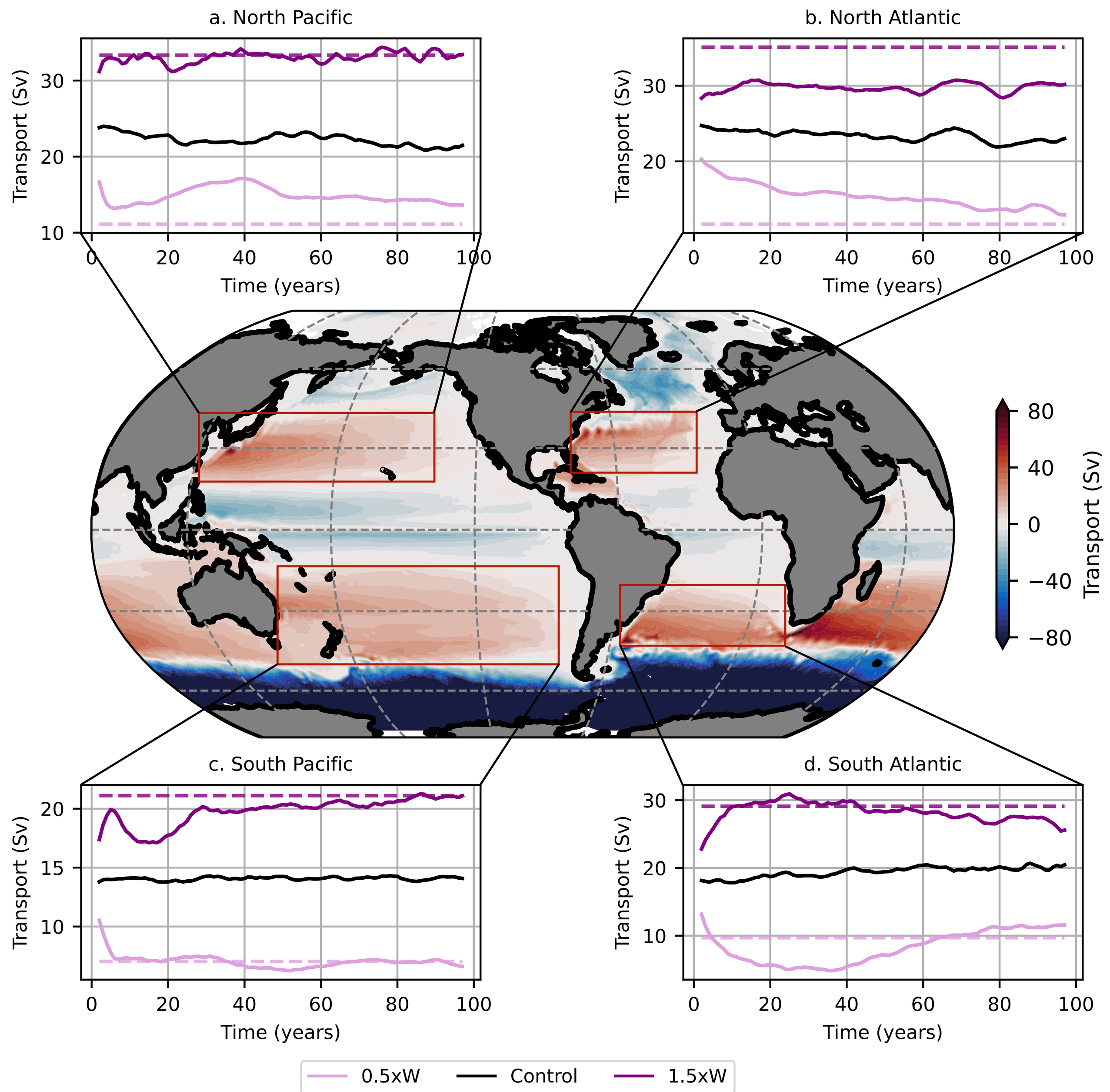
- Carry warm water as western boundary currents, making the adjacent coasts habitable.
- Promote carbon-dioxide exchange with the atmosphere at eastern boundaries.
- Assists migration of marine wildlife within and across ocean basins.

Sverdrup transport, a balance between wind stress curl and meridional transport, is a canonical theory explaining the existence of gyres:

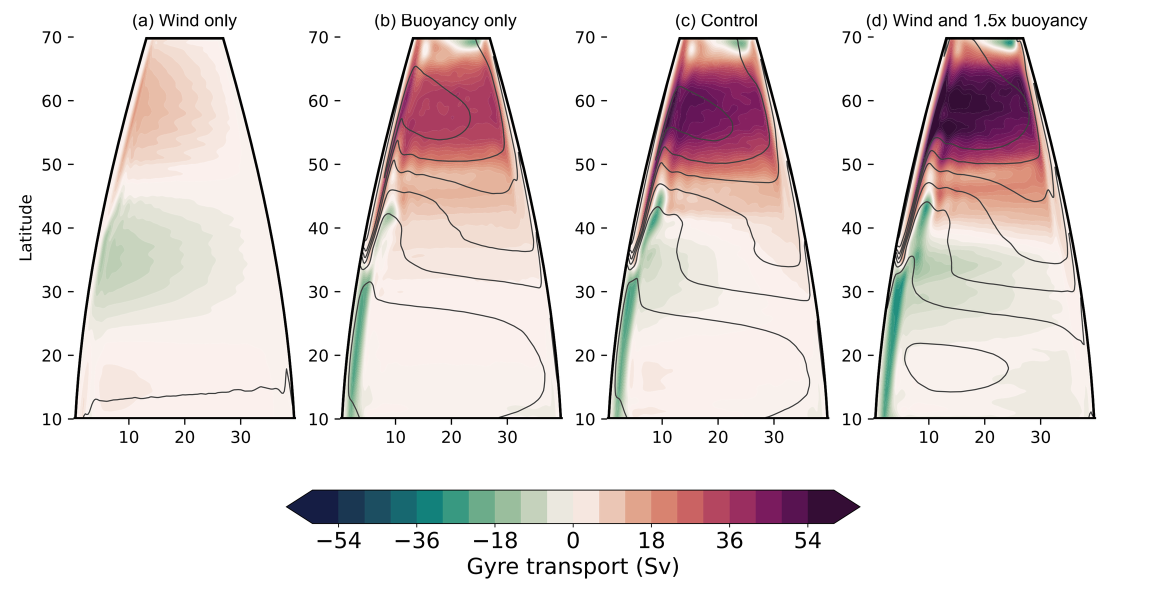
$$\beta V = \hat{\boldsymbol{k}} \cdot (\nabla \times \boldsymbol{\tau}), \qquad (1)$$



Greater the wind-stress curl, greater is the net meridional transport



Could gyres be driven by forcings other than wind stress?



Hogg and Gayen, 2020 (HG20): A restoring surface temperature profile is used as buoyancy forcing in MOM6.

- A zeroth-order balance between buoyancy flux and meridional transport, as given by HG20:

$$v = \frac{F_s}{h\frac{\partial b}{\partial y}} \qquad (2)$$

- Gyre strength increases with buoyancy forcing.
- The simulations indicate that a subtropical and subpolar gyre, along with an intense WBC, can be driven solely by buoyancy forcing.

Model setup for buoyancy-forced simulations

$$u = \frac{1}{\rho_0 f}(\hat{k} \times \nabla p) \qquad \frac{\partial p}{\partial z} = -g\rho$$

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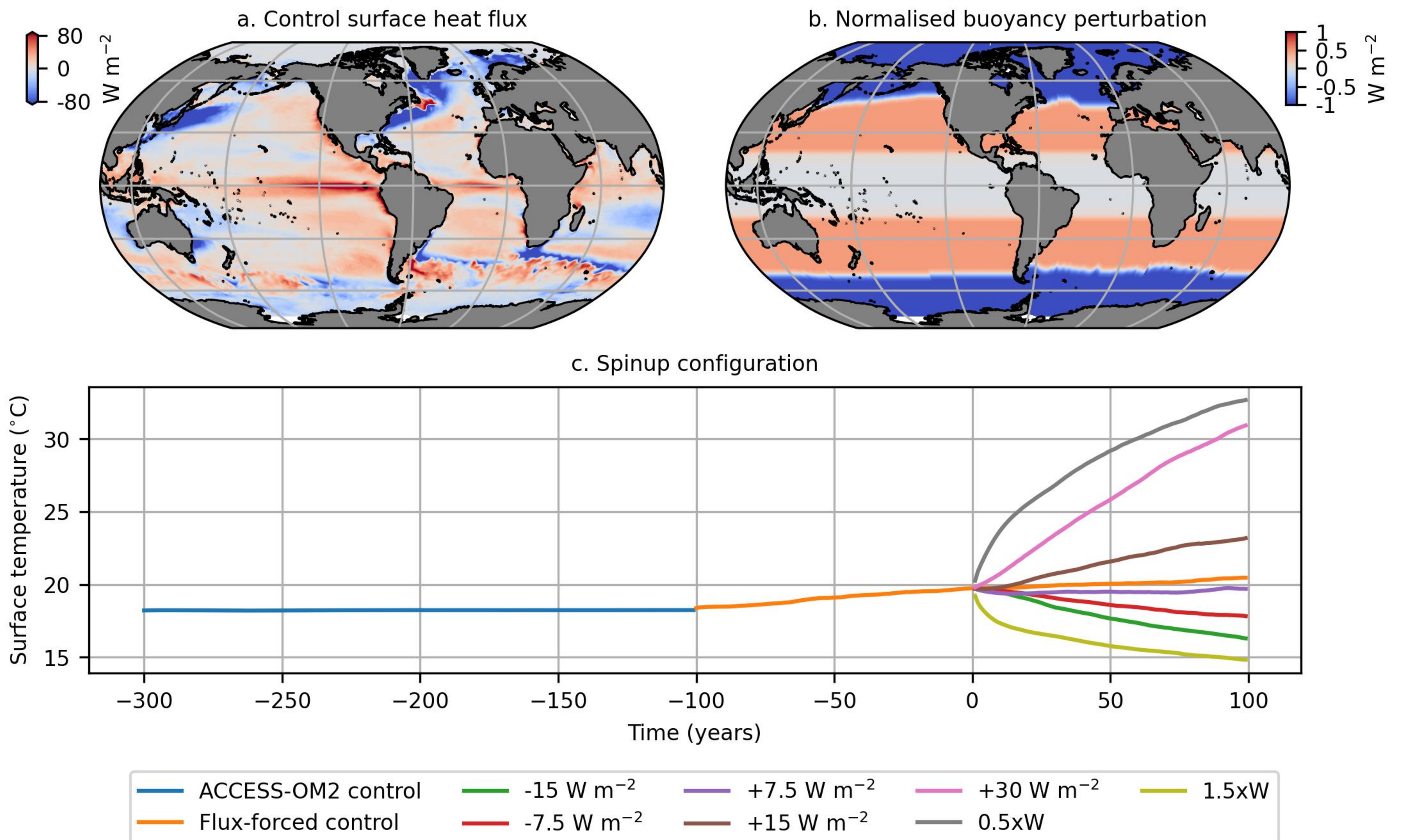
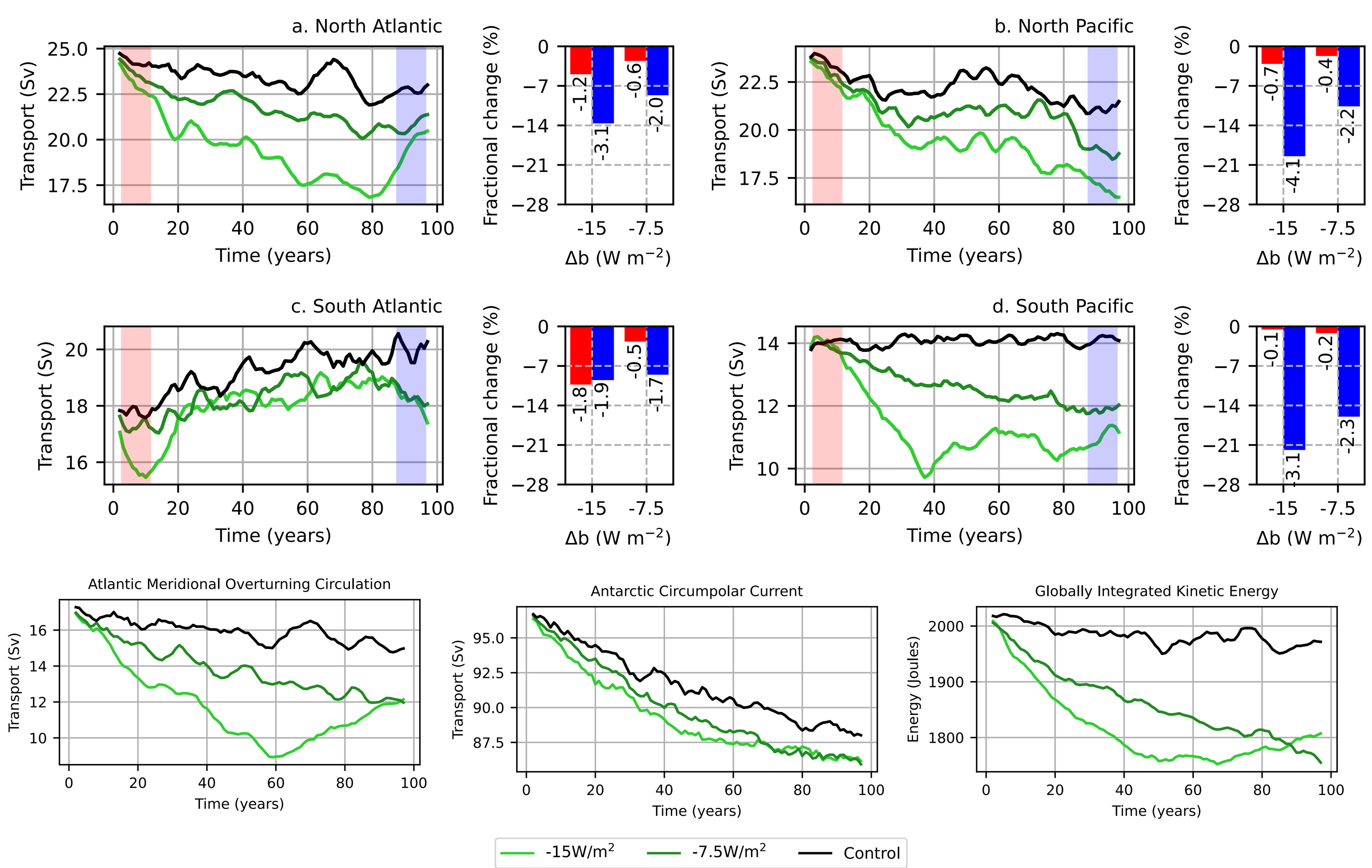
Thermal wind balance

$$\frac{\partial \boldsymbol{u}}{\partial z} = \frac{g}{\rho_0 f}(\nabla \rho \times \hat{\boldsymbol{k}})$$

- HG20's experiments are on conducted an idealised domain, so, fail to capture key aspects of ocean circulation.
- In Flux Forced Models (FFMs), a climatological forcing is applied to MoM5, therefore, all forcing are independent of each other, and the effect of one forcing on ocean circulation can be easily quantified.

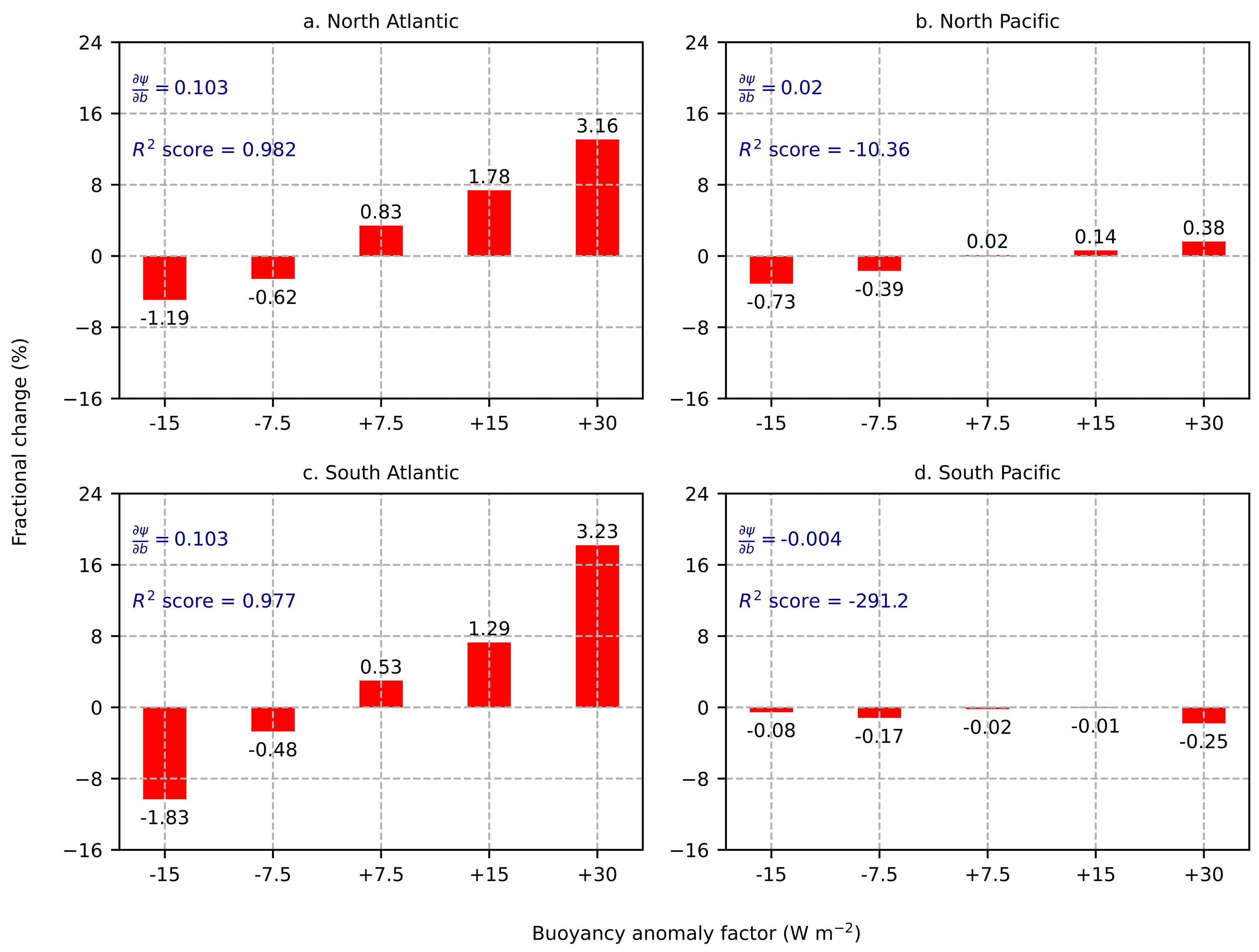


Reduced buoyancy contrast experiments



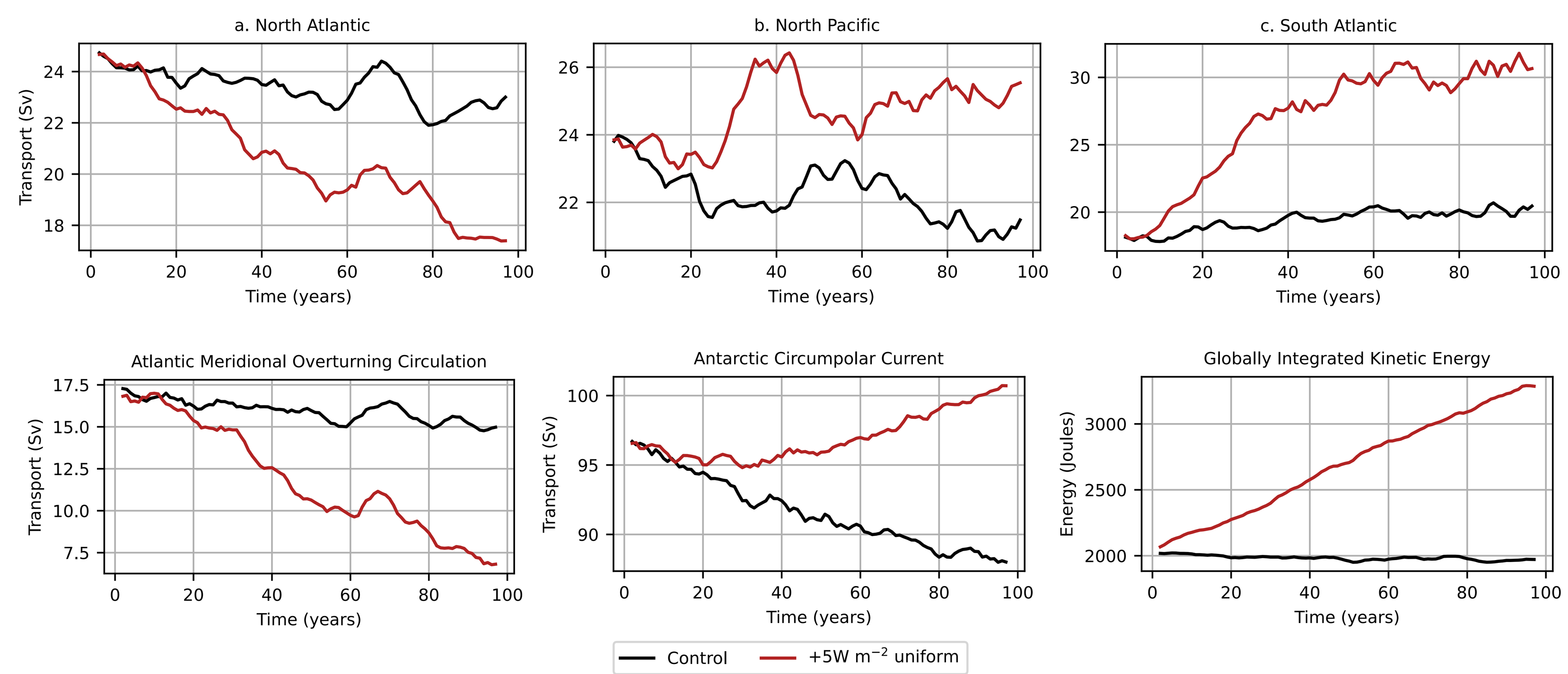
- Reducing meridional surface heat flux leads to a decline in subtropical gyre strength. The magnitude of reduction varies with gyres.
- North Atlantic Ocean's transient response is quicker than North Pacific Ocean.
- The MOC decreases for the first 60 years in -15 W/m2 experiment, followed by a systematic increase. This increase can be explained using potential density latitude-depth maps.

Increased buoyancy contrast experiments



- The Atlantic gyres spin-up by 1 Sv for every 10 W m^{-2} anomaly in the initial stages of the experiment.
- The MOC and North Atlantic gyre both show a highly non-linear response after 10-15 years of perturbation, with increased convection near western boundary.

A global warming experiment



- Subtropical gyres show a varied behaviour (intensification of North Pacific and South Atlantic, and slowdown of North Atlantic), and could be linked to spatial variations in mixed layer depths.
- KE significantly increases with an increase in surface heat flux gradient, suggesting a conversion from available potential energy to kinetic energy (Tailleux et al. 2009).

References

- Hughes, G. O., A. M. Hogg, and R. W. Griffiths, 2009: Available potential energy and irreversible mixing in the Meridional Overturning Circulation. Journal of Physical Oceanography, 39, 3130–3146.
- Morrison, A. K., A. M. Hogg, and M. L. Ward, 2011: Sensitivity of the Southern Ocean overturning circulation to surface buoyancy forcing. Geophysical Research Letters, 38.
- Yeager, S., 2015: Topographic coupling of the Atlantic overturning and gyre circulations. Journal of Physical Oceanography, 45, 1258– 1284.