How Are Changing Sea Ice Conditions Affecting the Spin-up of the Beaufort Gyre?

NATURAL ENVIRONMENT RESEARCH COUNCIL

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1. Introduction

- The Arctic Ocean is a massive reservoir of freshwater (FW) with contributions from river runoff, precipitation, sea ice melt and inflow of relatively fresh Pacific Water.
- FW storage far exceeds annual export (70,000 km^3 vs. 9000 km^3), with the majority stored in the Canadian Basin and the anticyclonic Beaufort Gyre.
- The Beaufort Gyre mechanically accumulates FW through Ekman Pumping (driven by anticyclonic winds), and has gained 8000 ± 2000 km^3 of FW since the 1990s.
- If this excess FW were to be released into the north Atlantic, it is likely to have significant impacts on deep convection and hence the climate of Northern Europe.

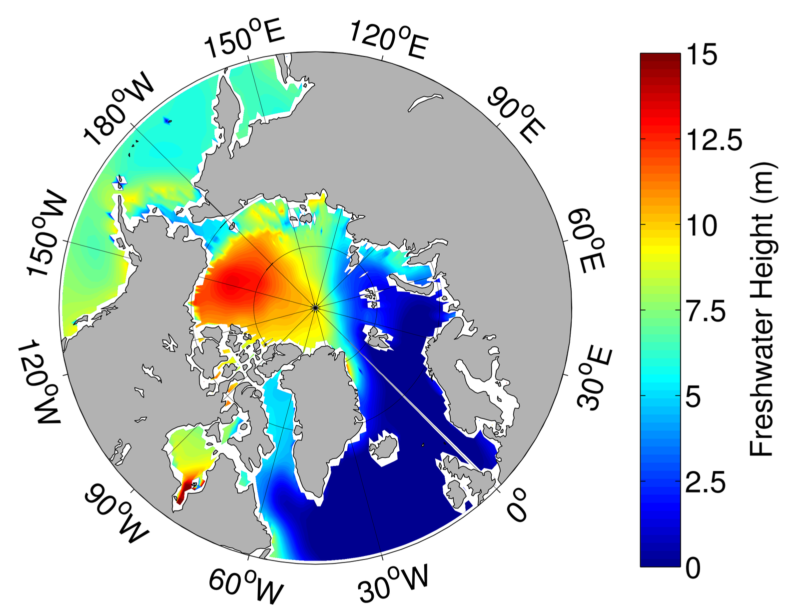


Figure 1: Arctic FW content from PHC 3.0 climatology

Since 2003, satellite observations have shown that the wind is becoming more effective at spinning up the Beaufort Gyre (Giles 2012), and this coincides with the dramatic reductions in sea ice. Therefore:

Can the increased spin up be related to the changing seasonality of Arctic sea ice cover, and the effect it has on the annual cycle in ocean stress?

2. Model Setup

- 1½ layer reduced gravity model: active halocline overlying stationary Atlantic layer. The halocline layer is initially 400m thick.
- Represents the Canadian Basin as a circular domain, with a single outflow region.
- The GM parameterisation is used to represent eddies, with κ_{GM} scaled by the stress, model dimensions and required steady state.

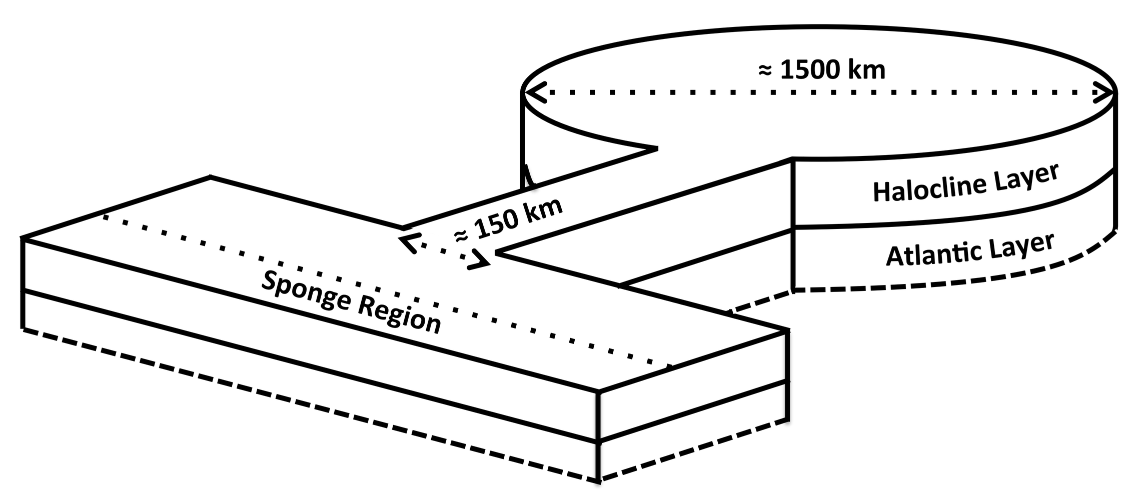


Figure 2: Schematic of the model domain, layer distribution, outflow and sponge region.

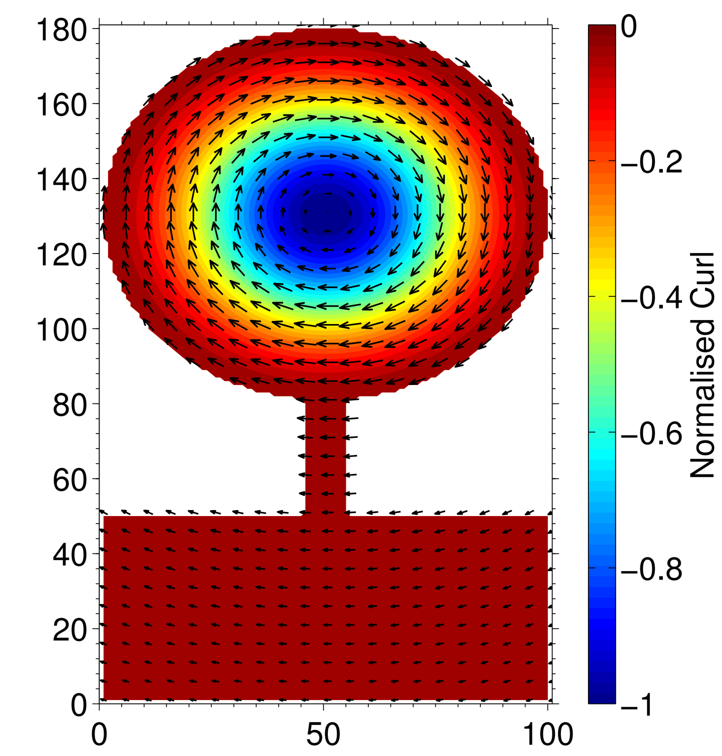


Figure 3: Model Forcing - Anticyclonic ocean stress with maximum curl (or Ekman pumping) in centre of domain.

- The response in the thickness of the halocline layer to the anticyclonic ocean stress mirrors the curl field, with the maximum thickening in the centre.

3. Experimental Design

- Initially forced with an annual cycle based of average conditions before the recent sea ice retreat.

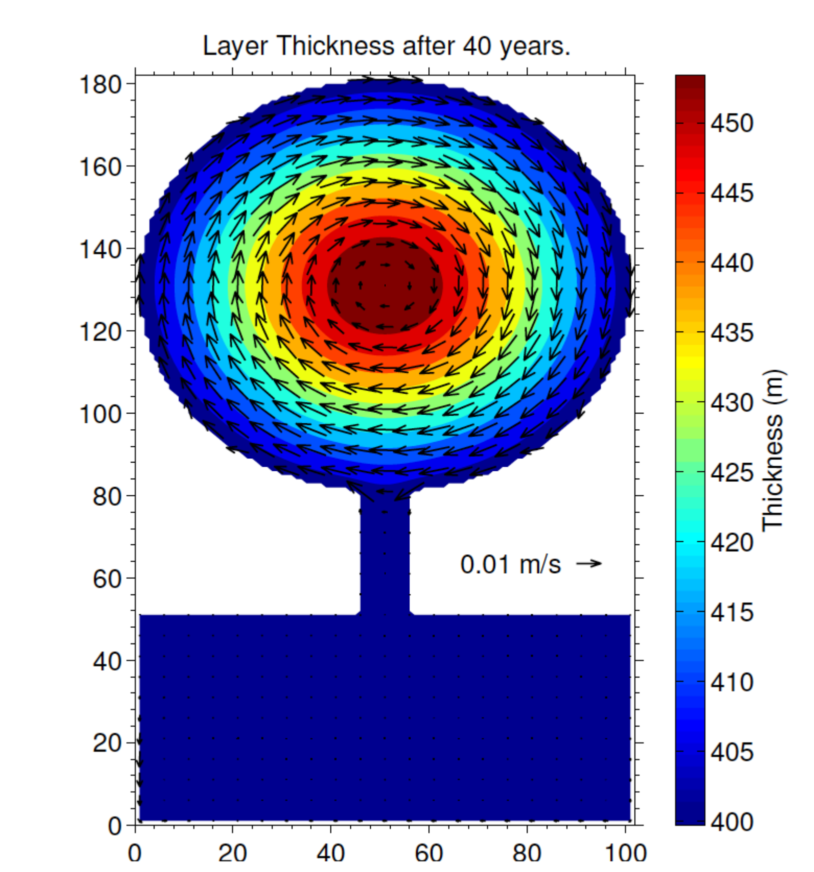
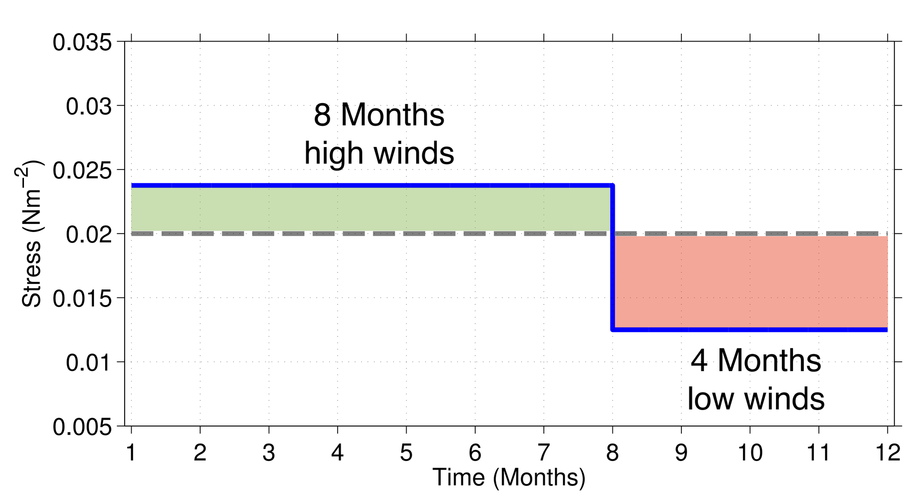


Figure 4: Snapshot of the initial steady state thickness and velocity field.

- As sea ice retreats further and for a longer period each year, form drag from melt ponds and ice floe edges increases the efficiency of momentum transfer into the ocean. This changes both the amplitude and timing of the seasonal cycle in ocean stress (i.e. its seasonality), as well as the annual mean ocean stress (or net forcing).



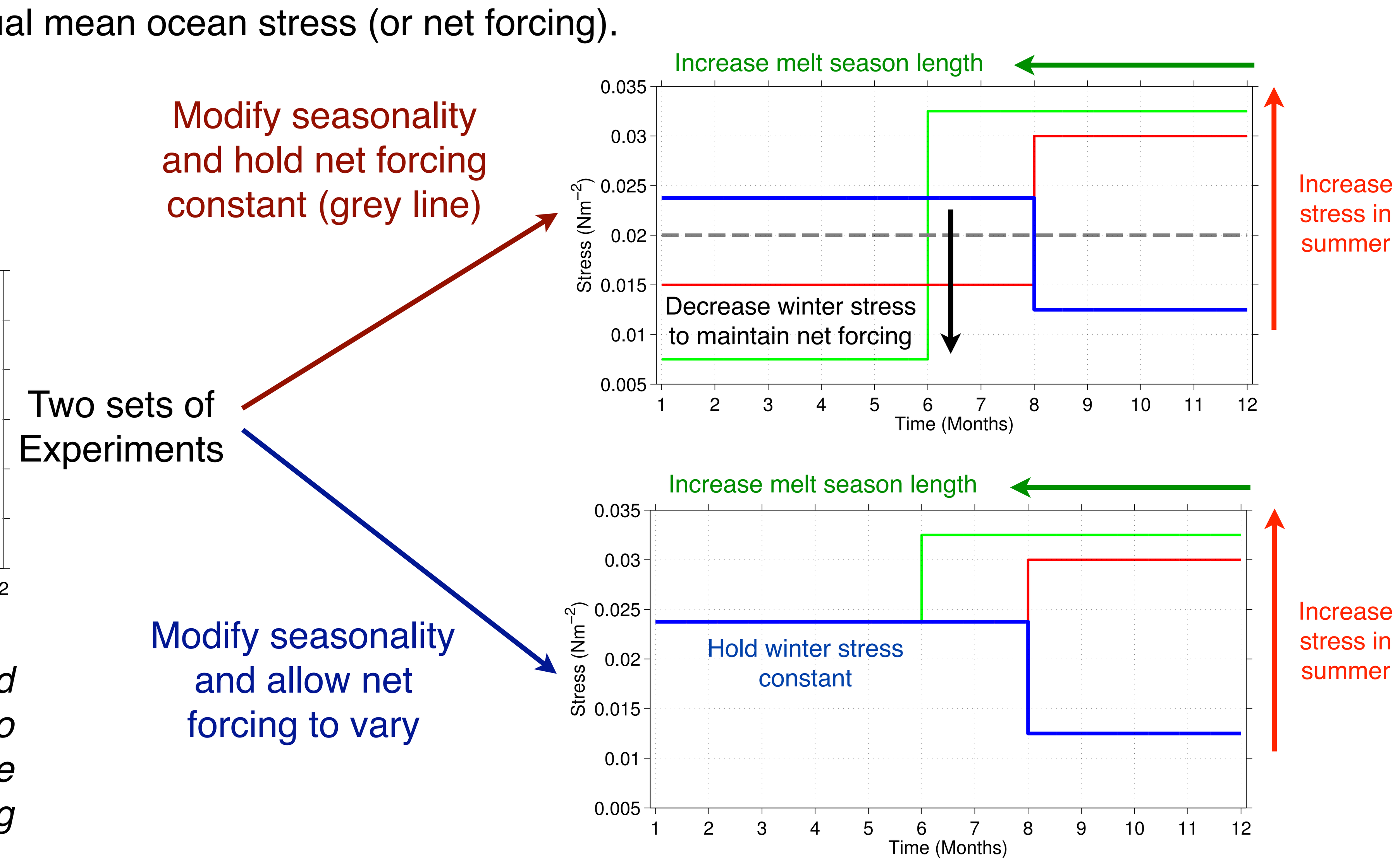
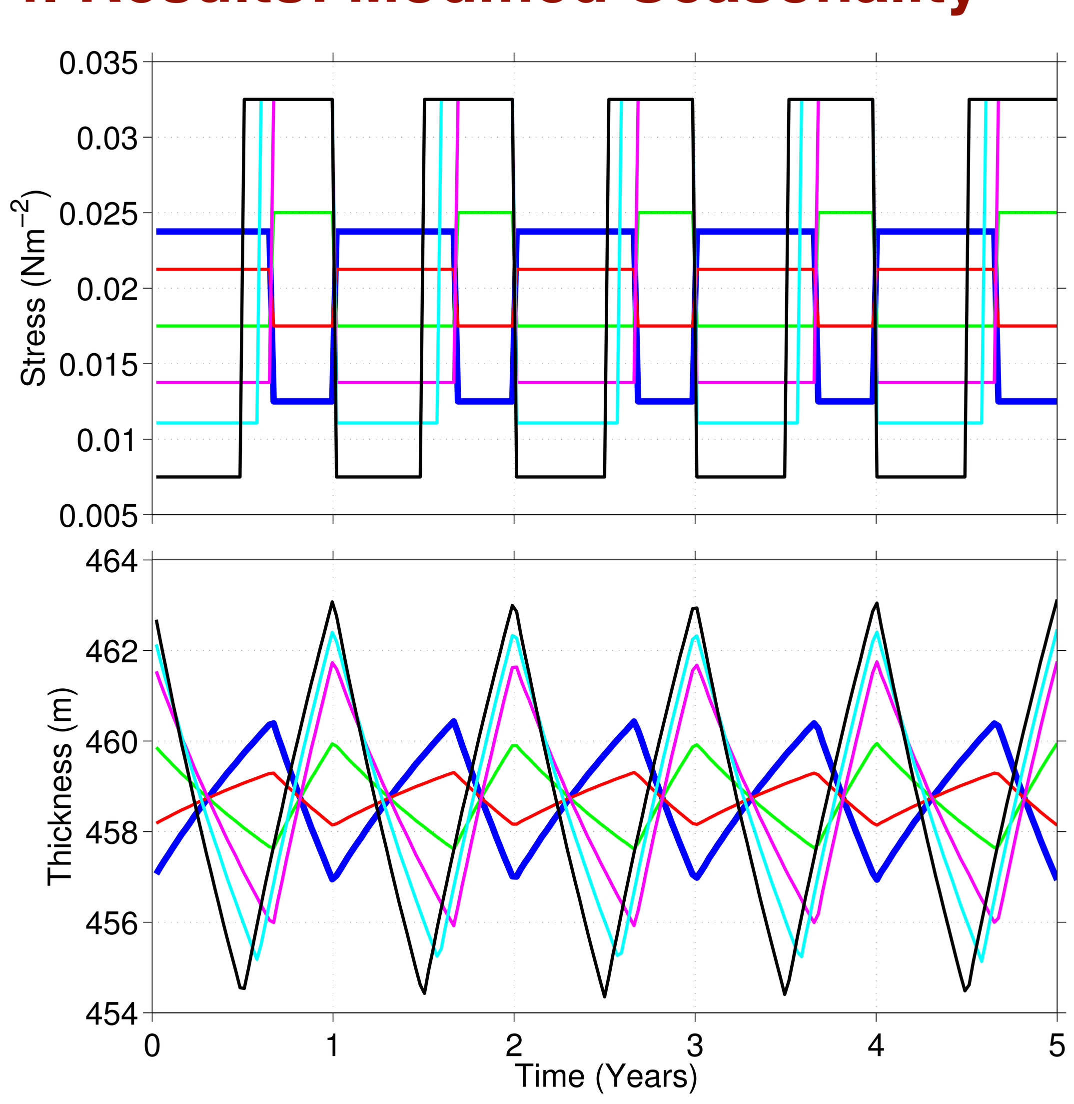


Figure 5: The initial annual cycle, and modifications made to the annual cycle to explore the effect of changing the seasonality in stress and the net forcing on the spin-up of the Beaufort Gyre.

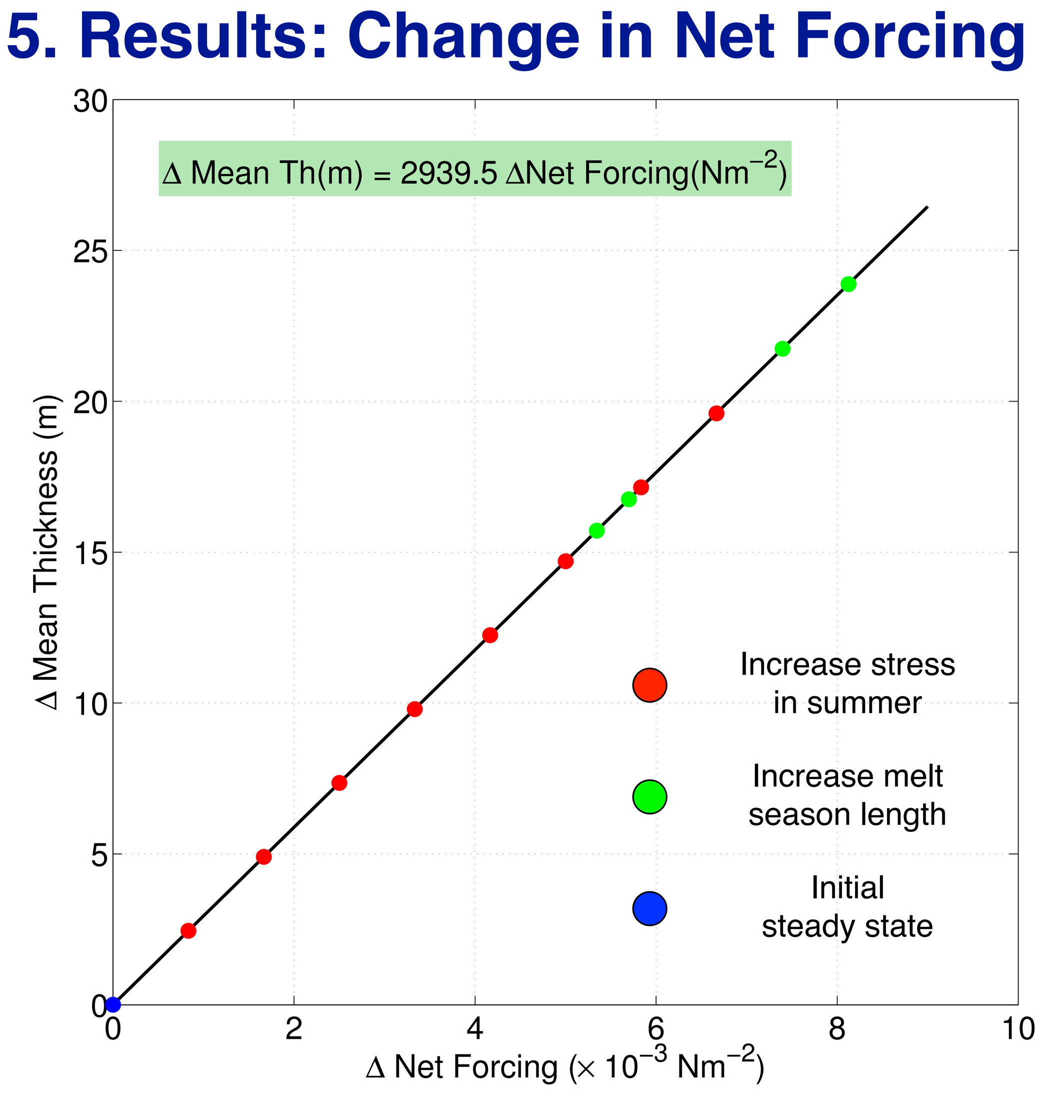
4. Results: Modified Seasonality



- Changing the seasonality whilst holding the net forcing constant does not cause the Beaufort Gyre to spin-up (all runs oscillate around the same mean).
- However, increasing the stress in summer both reverses the phase and increases the amplitude of the annual cycle in freshwater storage, whilst increasing the length of the melt season changes the timing of the minimum freshwater storage.

Figure 6: Thickness in the centre of the domain and forcing, against time in years

5. Results: Change in Net Forcing



- There is a clear linear relationship between the increase in net forcing and the increase in mean thickness for all modifications to the initial annual cycle.
- This suggests that the exact shape of the annual cycle is unimportant for the inter-annual variability, and the spin-up of the Beaufort Gyre is determined exclusively by the magnitude of the increase in net forcing.

Figure 7: Change in time mean thickness in center of domain, versus change in net forcing from the steady state.

6. Conclusions

- Changing the seasonality whilst holding the net forcing constant does not cause the Beaufort Gyre to spin-up. However, it reverses and phase, changes the timing and increases the amplitude of the annual cycle in freshwater storage.
- When the net forcing is increased, the Beaufort Gyre spins up with a linear dependence on the change in net forcing from the initial steady state.

7. References

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