Sensitivity of the Southern Ocean circulation to enhanced regional Antarctic meltwater input

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1. Introduction

- Emerging research suggests that retreat of the West Antarctic Ice Sheet (WAIS) in the Amundsen Sea may now be unstoppable.
- However, the effects of increasing Antarctic meltwater on Southern Ocean dynamics have not been fully explored, despite observations which suggest that changes may already be occurring.
- To explore potential feedbacks within the coupled ice–ocean system, we present climate model simulations driven by a range of scenarios representing the collapse of some or all of the WAIS.

2. Data and methods

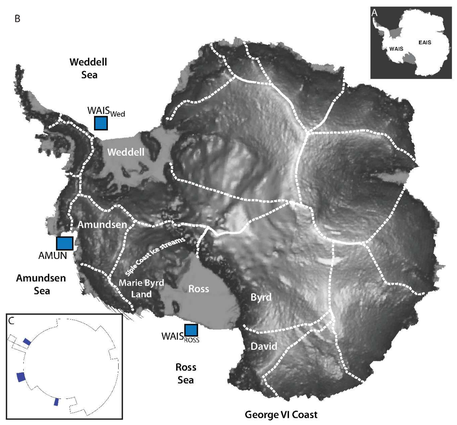

Figure 1. Modern ice divides and locations of meltwater input within the model.

- We use the CSIRO Mk3L climate system model, driven by three idealised Antarctic meltwater scenarios.
- AMUN reflects a hypothetical collapse of the Amundsen Sea sector, while $WAIS_{MAX}$ and $WAIS_{MIN}$ reflect hypothetical collapses of the entire WAIS.
- An ensemble modelling approach is employed, in which each experiment is run three times using different initial conditions.

Scenario	Sea level equiv. (m)	Time (years)	Freshwater flux (Sv)	Description
AMUN	1.2	200	0.069	Loss of Amundsen Sea sector over 200 years
$WAIS_{MAX}$	3.6	200 400	0.139 0.070	Loss of Amundsen Sea sector over 200 years, plus loss of Ross and Weddell Sea sectors over 400 years
$WAIS_{MIN}$	3.6	900 1000	0.044 0.028	Loss of Amundsen Sea sector over 900 years, plus loss of Ross and Weddell Sea sectors over 1000 years

Table 1. The idealised scenarios used to drive the climate model simulations.

3. Large-scale response

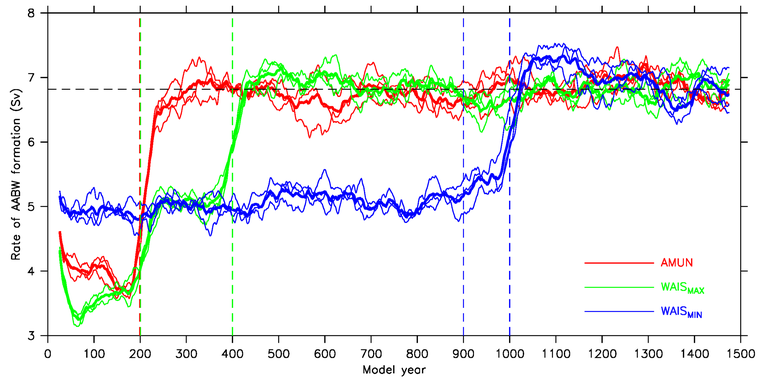

Figure 2. Changes in the rate of AABW formation (50-year running means). Thin lines show individual simulations; thick lines show the ensemble means. The horizontal dashed line shows the mean rate for a pre-industrial control simulation.

- The freshwater fluxes have a rapid impact on the Southern Ocean circulation, with the rate of Antarctic Bottom Water (AABW) formation decreasing by 25–50% within decades in all simulations.
- These impacts persist for as long as the freshwater flux is applied.

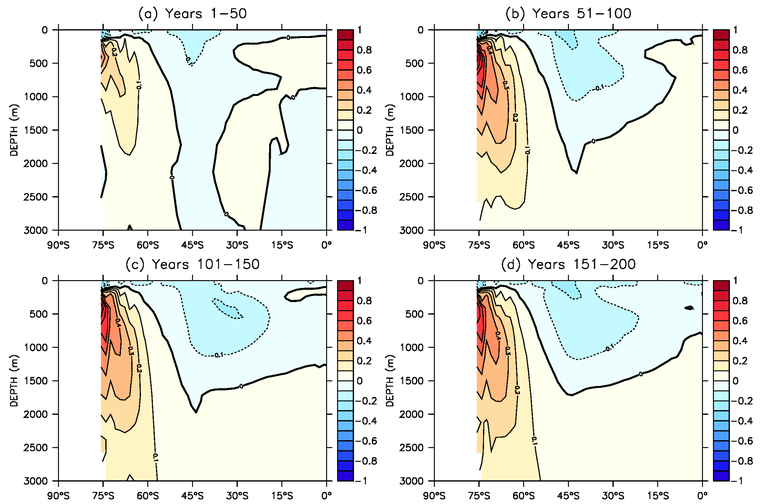

Figure 3. The evolution of the zonal-mean temperature anomaly (°C), relative to the control simulation, during the hosing stage of experiment AMUN.

- The reduced vertical mixing drives pronounced temperature changes throughout the water column, with cooling at the surface but rapid and pervasive warming at depth.
- The strongest warming occurs adjacent to the Antarctic continent and at depths of between 200 and 700 m; this coincides with the location of the grounding lines of the Antarctic ice sheets.

4. Regional response

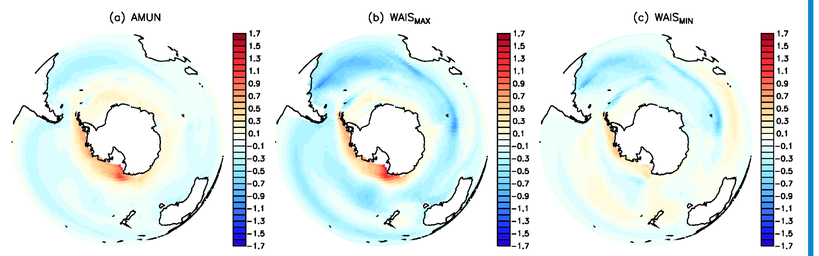

Figure 4. The mean temperature anomaly (°C) at a depth range of 400–700 m, relative to the control simulation, for years 101–200 of each experiment.

- Each experiment predicts warming around the entire continent at the depths of the grounding lines, with increases in the water temperature of up to 1.7°C in the Ross and Amundsen Sea sectors.
- The magnitude and spatial pattern of the warming is similar in experiments AMUN and $WAIS_{MAX}$, indicating that the Amundsen Sea is the critical location for freshwater input.

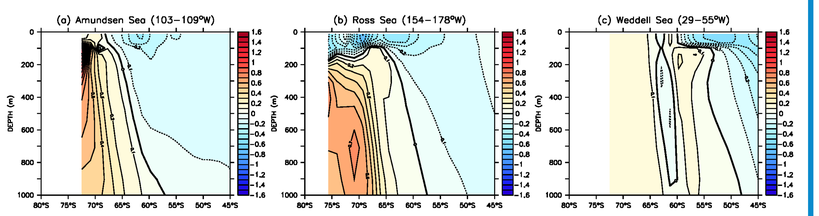

Figure 5. The mean temperature anomaly (°C) across the Amundsen, Ross and Weddell Seas, relative to the control simulation, for years 101–200 of experiment AMUN.

- Further examination of AMUN reveals the pervasive nature of the warming throughout the Amundsen and Ross Seas, key sectors of the WAIS that are sensitive to ocean-driven instability.

5. Conclusions

- Our findings demonstrate that Antarctic meltwater flux into the Southern Ocean drives warming at depth, creating a positive feedback that may enhance thermal erosion of grounding lines in key sectors of the Antarctic ice sheets.
- This provides an additional feedback mechanism that may further enhance the basal melting and thermally-driven grounding line retreat during the 21st century.

Reference

- Fogwill, C.J., S. J. Phipps, C. S. M. Turney and N. R. Golledge: Enhanced Southern Ocean warming driven by meltwater input in the Amundsen Sea, *Science Advances*, submitted.