



# Strange loops or vicious cycles? The impact of ice sheet melting on the circulation of the Southern Ocean

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# Context: Antarctica and the Southern Ocean

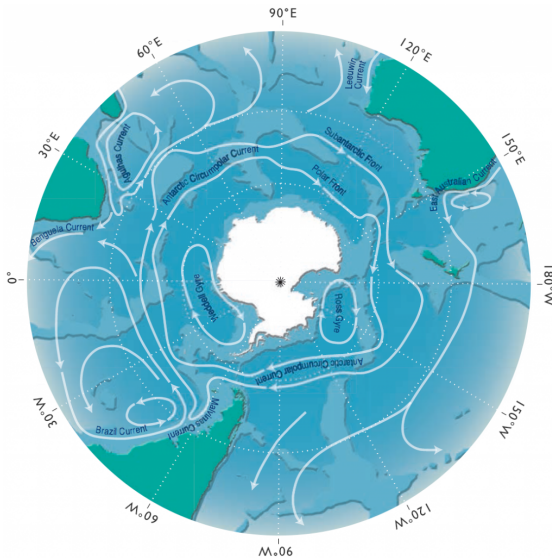
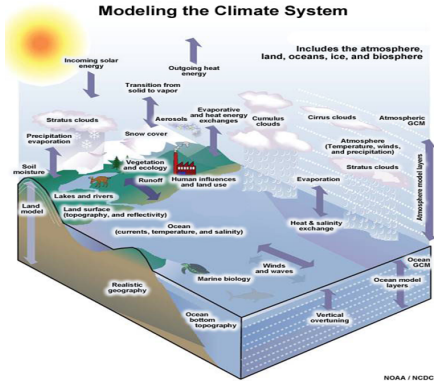


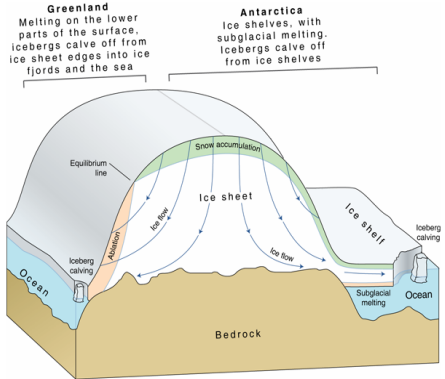
Image courtesy of Academic Press / de Vos Design

# Context: Climate and ice sheet modelling

## Climate model

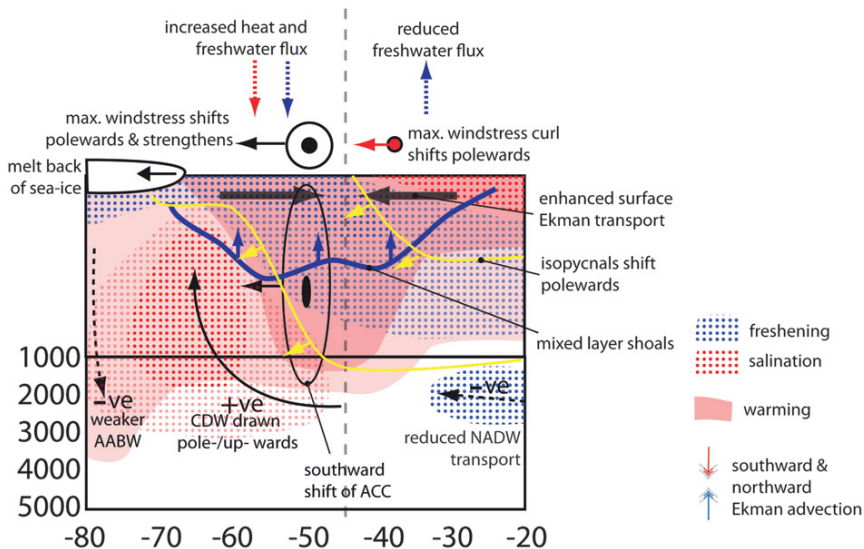


## Ice sheet model



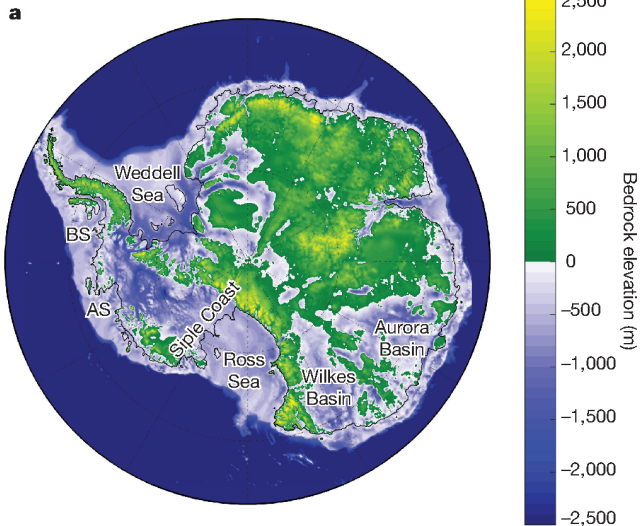
Images courtesy of NOAA/NCDC and NSIDC

# Context: Future changes in the Southern Ocean



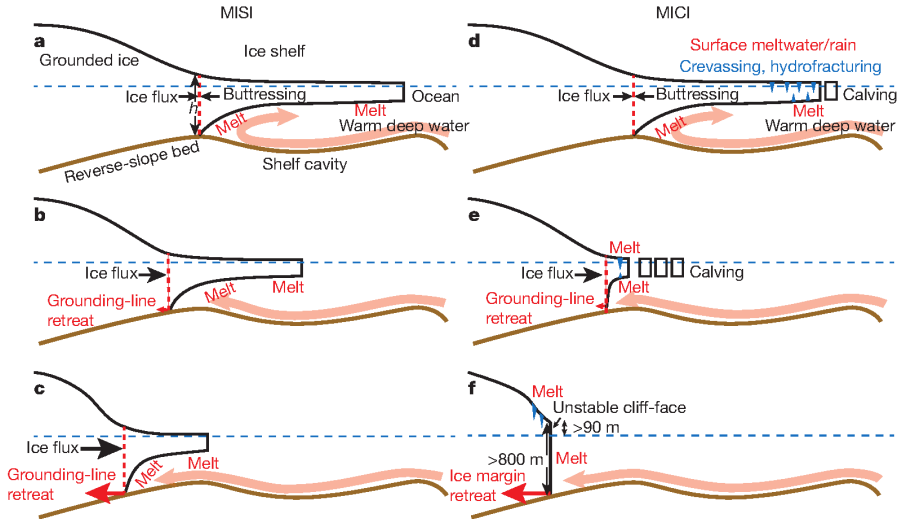
Sen Gupta et al. (2009), *Journal of Climate*

# Context: Marine ice sheet instability



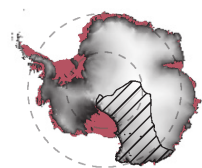
DeConto and Pollard (2016), *Nature*

# Context: Marine ice sheet instability



DeConto and Pollard (2016), *Nature*

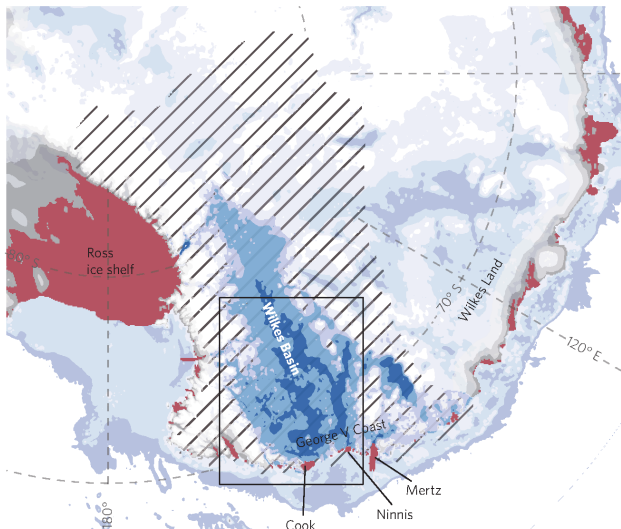
# Context: Marine ice sheet instability



Wilkes Basin  
subglacial topography

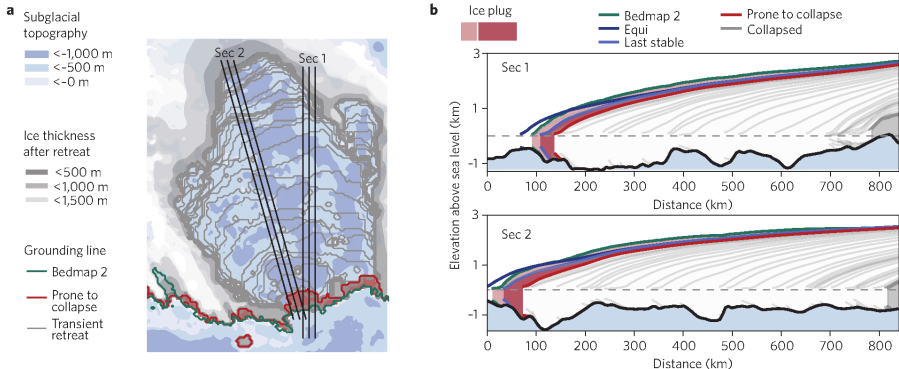


 Model domain



Mengel and Levermann (2014), *Nature Climate Change*

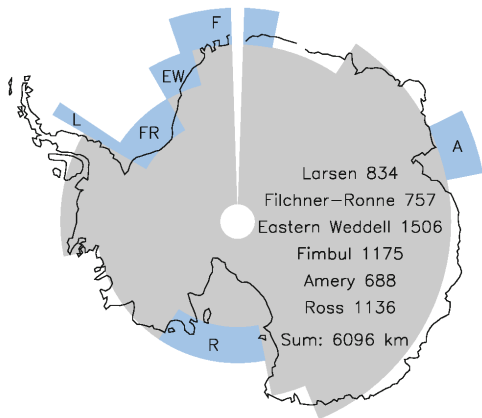
# Context: Marine ice sheet instability



Mengel and Levermann (2014), *Nature Climate Change*



# Ice sheet–ocean feedback loops

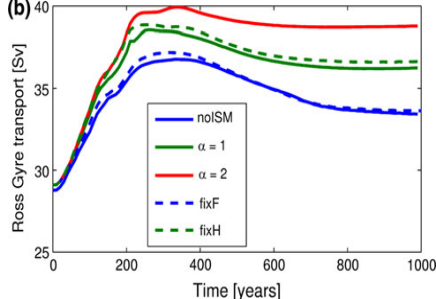
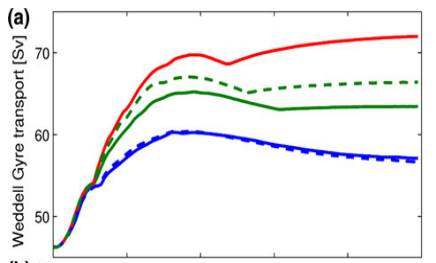
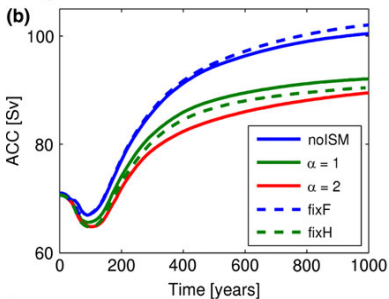
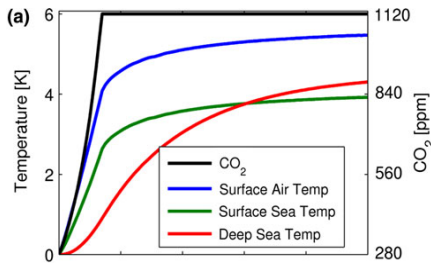


Climate model experiments:

- Intermediate complexity model CLIMBER-3 $\alpha$ .
- Parameterisation of ice shelf melting, based on Beckmann and Goosse (2003) and Holland et al. (2008).
- Quadrupling of CO<sub>2</sub> concentration over 140 years (at 1% per year).

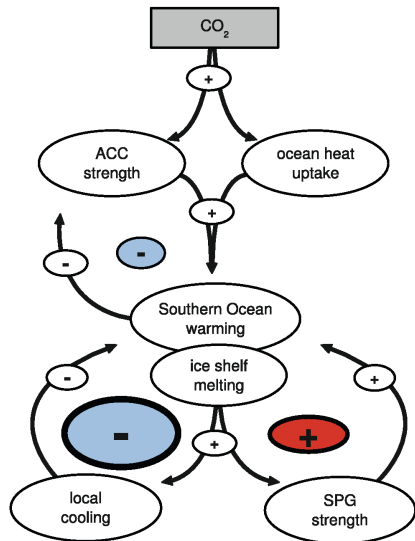
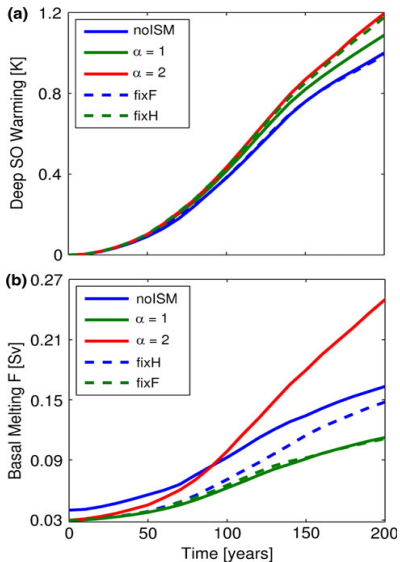
Hattermann and Levermann (2010), *Climate Dynamics*

# Ice sheet–ocean feedback loops



Hattermann and Levermann (2010), *Climate Dynamics*

# Ice sheet–ocean feedback loops



Hattermann and Levermann (2010), *Climate Dynamics*

# Modelling the collapse of the Wilkes Basin

Climate model experiments:

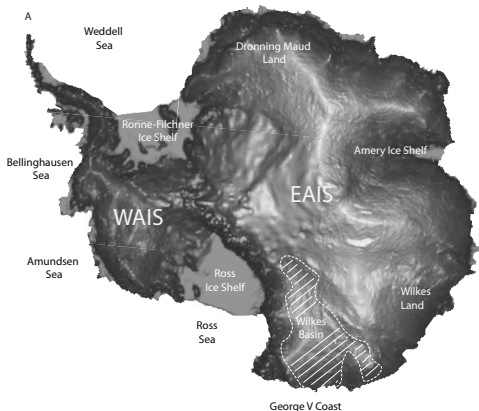
- CSIRO Mk3L climate system model.

WILKES:

- Freshwater pulse equal to collapse of Wilkes Basin over 900 years.

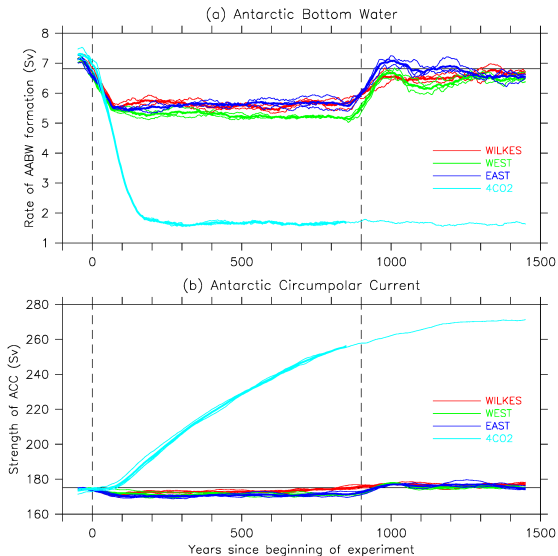
4CO<sub>2</sub>:

- Quadrupling of CO<sub>2</sub> concentration over 140 years (at 1% per year).



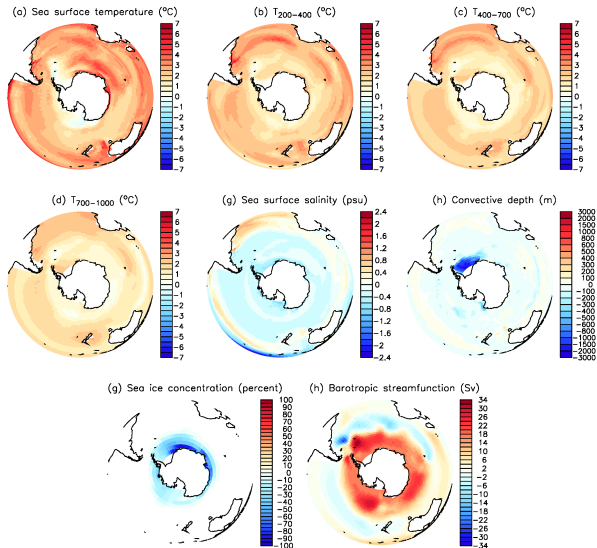
Phipps et al. (in revision), *The Cryosphere*

# Impacts on the circulation of the Southern Ocean



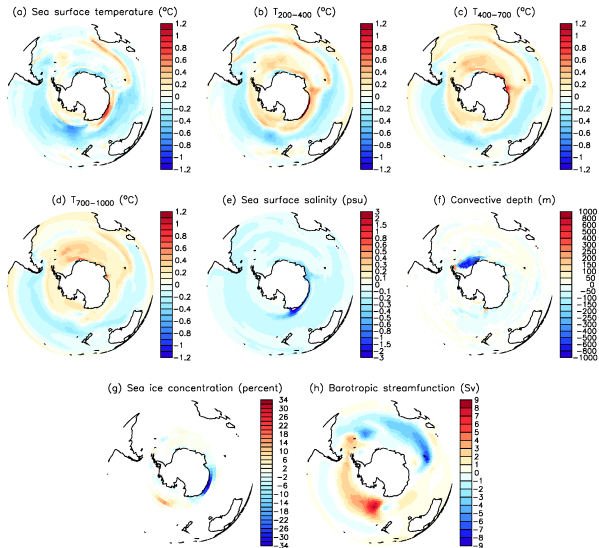
Phipps et al. (in revision), *The Cryosphere*

# Response to $4\times\text{CO}_2$



Phipps et al. (in revision), *The Cryosphere*

# Response to collapse of the Wilkes Basin



Phipps et al. (in revision), *The Cryosphere*

# Conclusions

- Climate models do not (generally) incorporate dynamic ice sheets.
- Projections of 21st century climate therefore do not (generally) take into account feedbacks between the Antarctic Ice Sheet and the Southern Ocean.
- Large sectors of the Antarctic Ice Sheet are vulnerable to marine ice sheet instability, and are therefore sensitive to anthropogenically-induced increases in ocean temperatures.
- Collapse of these sectors would generate large and prolonged fluxes of freshwater into the Southern Ocean.
- The resulting changes in the ocean circulation have the potential to amplify the anthropogenic warming signal around Antarctica.
- These feedback loops should be taken into account in 21st century climate projections, demonstrating a compelling need for coupled climate–ice sheet models.