



# Reducing uncertainties in projections of global sea level rise

Steven J. Phipps

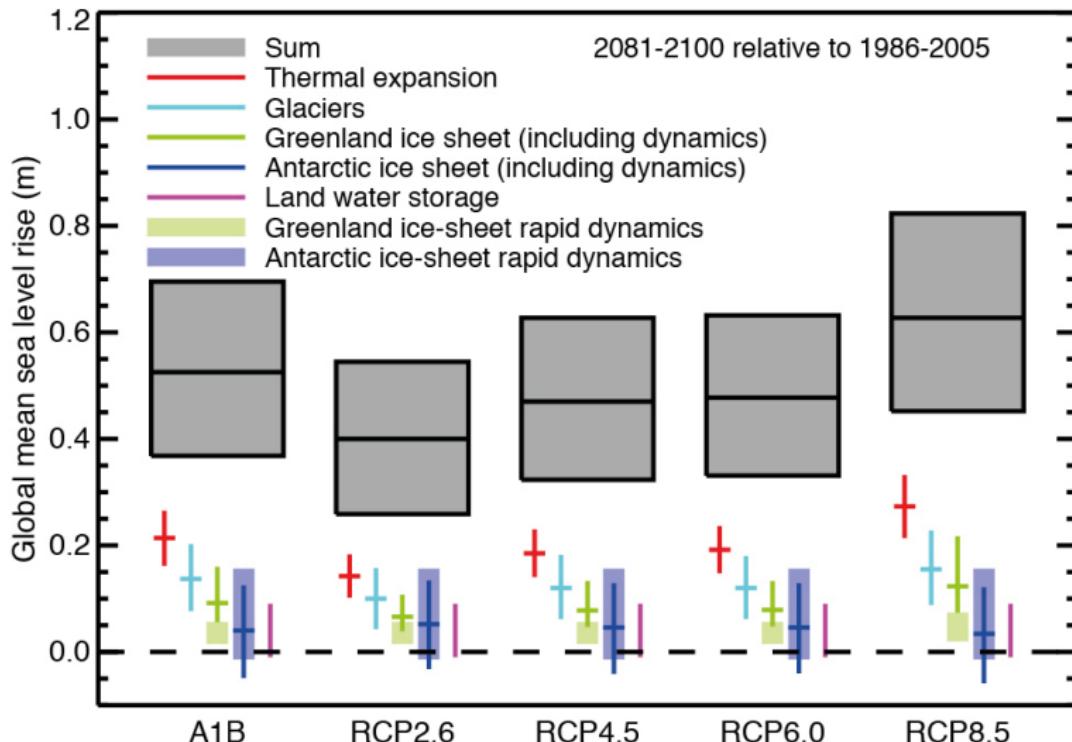
Institute for Marine and Antarctic Studies  
University of Tasmania

School of Geography, Geology and the Environment  
Keele University  
26 April 2018

A wide-angle photograph of a massive glacier. In the foreground, there's a rocky, debris-strewn area with patches of snow and ice. The middle ground shows a vast expanse of blue and white ice fields. The background features towering, steep mountains with dark, rocky ridges and patches of snow at their summits.

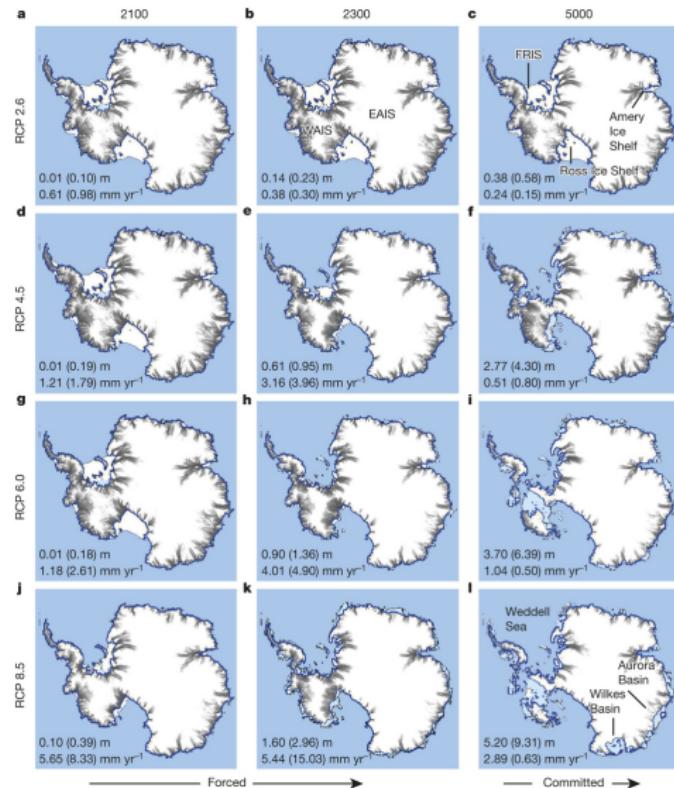
# Context

# Likely changes in global sea level by 2081–2100



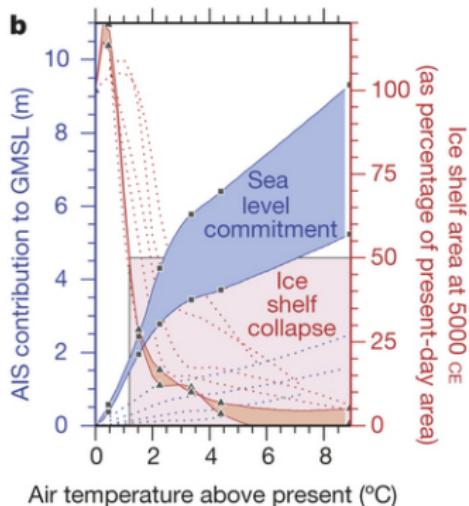
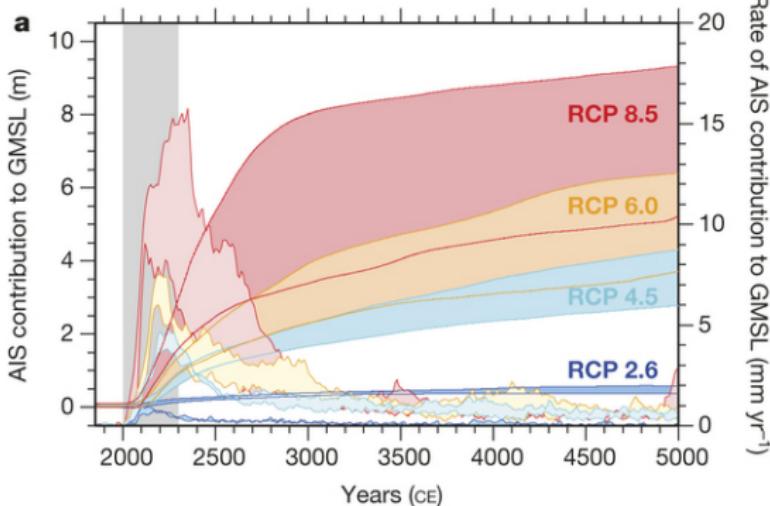
IPCC AR5 WG1 report (2013)

# Future Antarctic contribution to global sea level



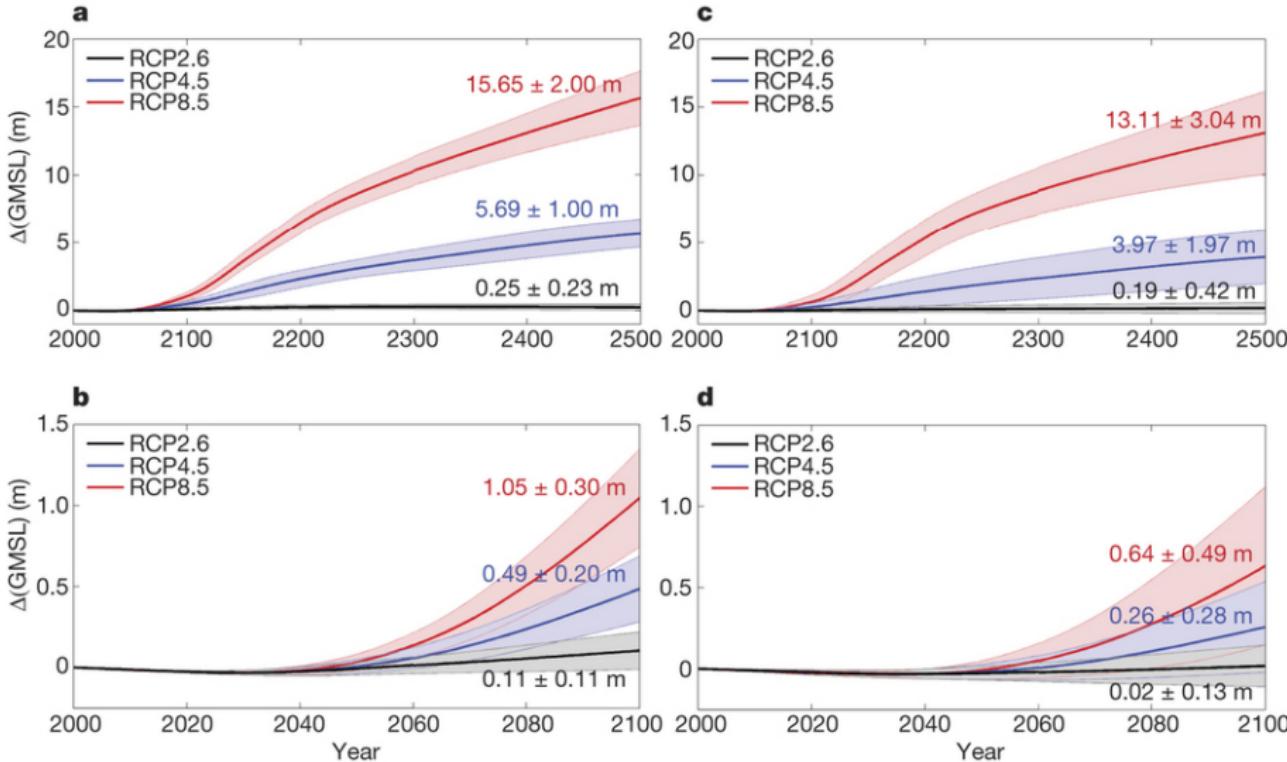
Golledge et al. (2015), *Nature*

# Future Antarctic contribution to global sea level



Golledge et al. (2015), *Nature*

# Future Antarctic contribution to global sea level



DeConto and Pollard (2016), *Nature*

# Are we facing an ice apocalypse?

COVER STORY

## Ice Apocalypse

Rapid collapse of Antarctic glaciers could flood coastal cities by the end of this century.

By Eric Holthaus on Nov 21, 2017

In a remote region of Antarctica known as Pine Island Bay, 2,500 miles from the tip of South America, two glaciers hold human civilization hostage.

Stretching across a frozen plain more than 150 miles long, these glaciers, named Pine Island and Thwaites, have marched steadily for millennia toward the Amundsen Sea, part of the vast Southern Ocean. Further inland, the glaciers widen into a two-mile-thick reserve of ice covering an area the size of Texas.

There's no doubt this ice will melt as the world warms. The vital question is when.

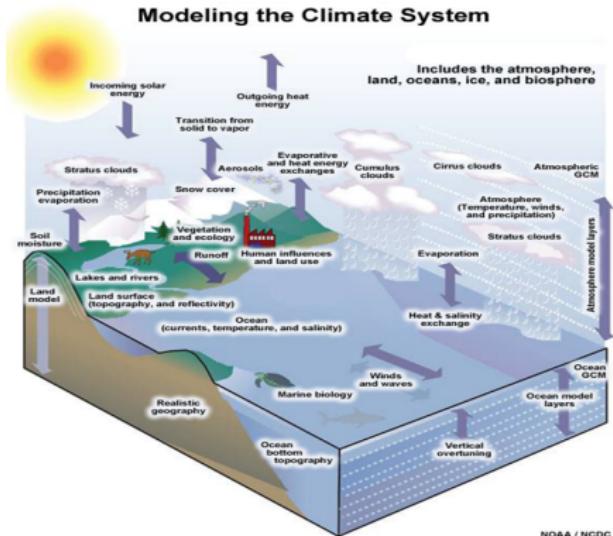
The glaciers of Pine Island Bay are two of the largest and fastest-melting in Antarctica. (A Rolling Stone feature earlier this year dubbed Thwaites "The Doomsday Glacier.") Together, they act as a plug holding back enough ice to pour 11 feet of sea-level rise into the world's oceans — an amount that would submerge every coastal city on the planet. For that reason, finding out how fast these glaciers will collapse is one of the most important scientific questions in the world today.

To figure that out, scientists have been looking back to the end of the last ice age, about 11,000 years ago, when global temperatures stood at roughly their current levels. The bad news? There's growing evidence that the Pine Island Bay glaciers collapsed rapidly back then, flooding the world's coastlines — partially the result of something called "marine ice-cliff instability."

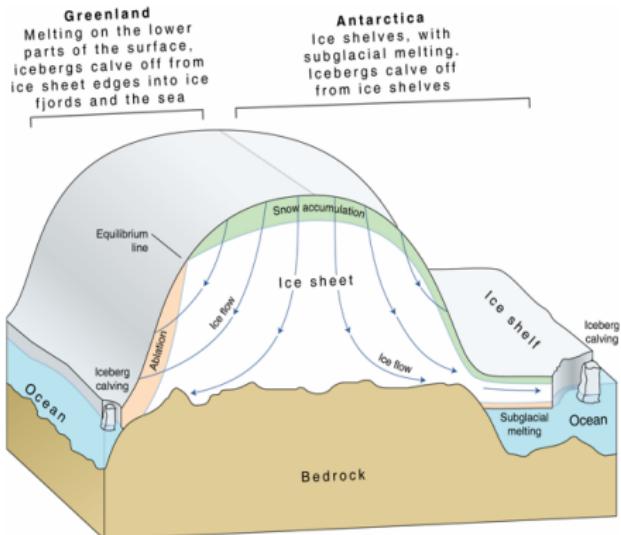


# Climate and ice sheet modelling

## Climate model



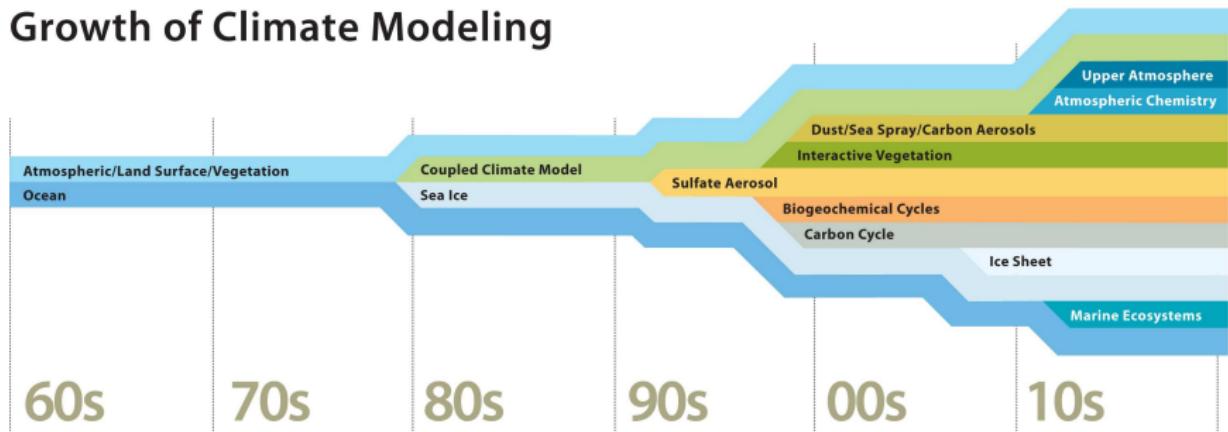
## Ice sheet model

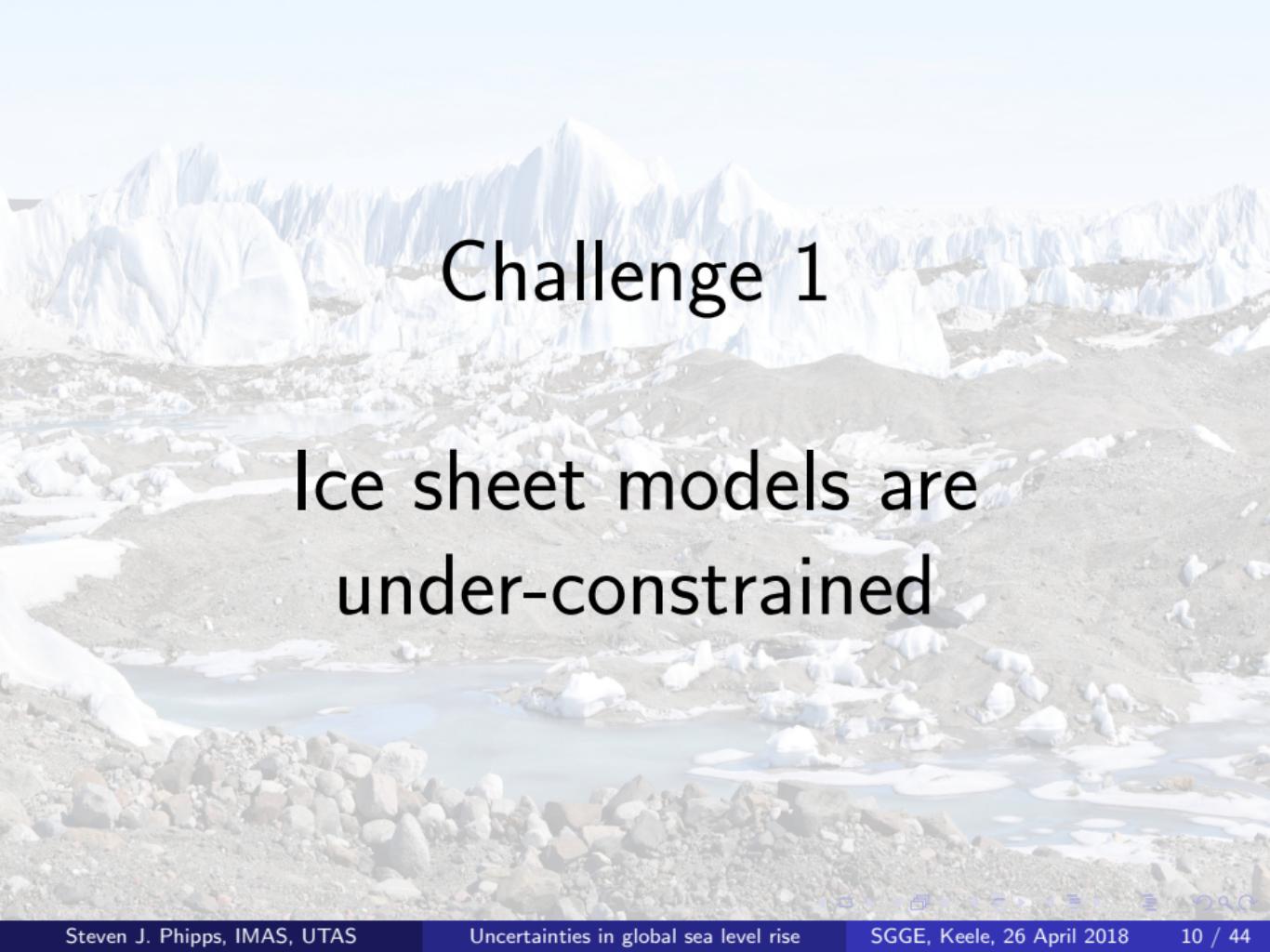


Images courtesy of NOAA/NCDC and NSIDC

# The development of coupled climate system models

## Growth of Climate Modeling



A photograph of a massive glacier with sharp, white peaks. In the foreground, there's a rocky, brownish slope with patches of snow and ice. The sky is overcast.

# Challenge 1

## Ice sheet models are under-constrained

# Challenge 1: Ice sheet models are under-constrained

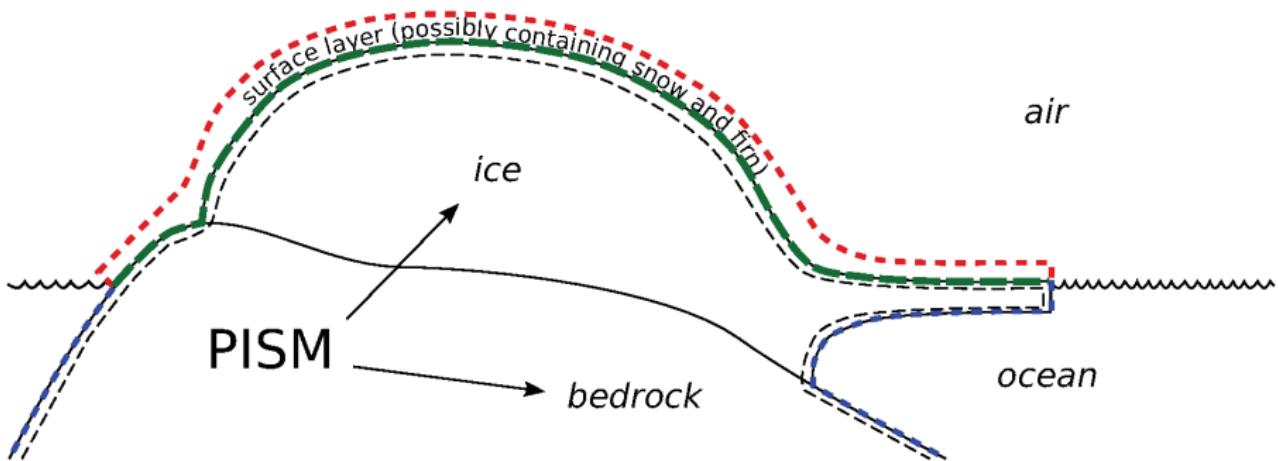


Figure 15: PISM's view of interfaces between an ice sheet and the outside world

# Challenge 1: Ice sheet models are under-constrained

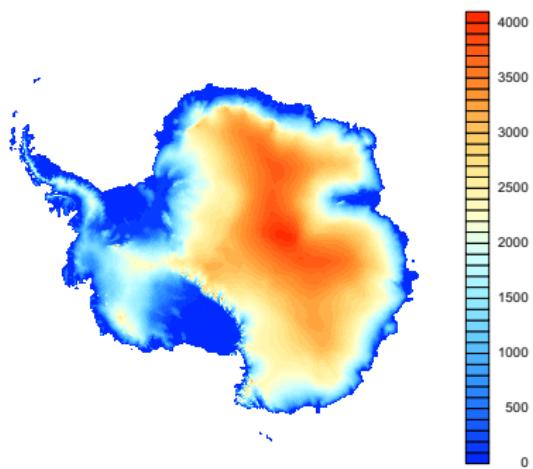
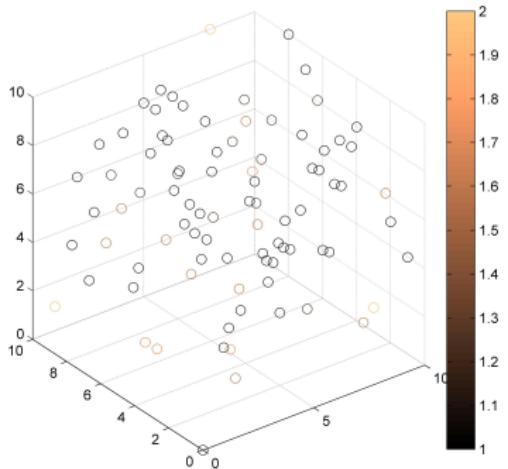
```
mpexec -n 4 pismr -skip -skip_max 10 -i nomass_20km.nc  
-sia_e 3.0 -atmosphere given -atmosphere_given_file  
pism_Antarctica_5km.nc -surface simple -ocean pik  
-meltfactor_pik 5e-3 -ssa_method fd -ssa_e 0.6 -pik -calving  
eigen_calving,thickness_calving -eigen_calving_K 2.0e18  
-thickness_calving_threshold 200.0 -stress_balance ssa+sia  
-hydrology null -pseudo_plastic -pseudo_plastic_q 0.25  
-till_effective_fraction_overburden 0.02  
-tauc_slippery_grounding_lines -topg_to_phi 15.0,40.0,  
-300.0,700.0 -ys 0 -y 100000 -ts_file ts_run_20km.nc  
-ts_times 0:1:100000 -extra_file extra_run_20km.nc  
-extra_times 0:1000:100000 -extra_vars thk,usurf,  
velbase_mag,velbar_mag,mask,diffusivity,tauc,bmelt,  
tillwat,tempabase,hardav,Href,gl_mask -o run_20km.nc  
-o_size big
```

# Challenge 1: Ice sheet models are under-constrained



# Constraining ice sheet model parameterisations

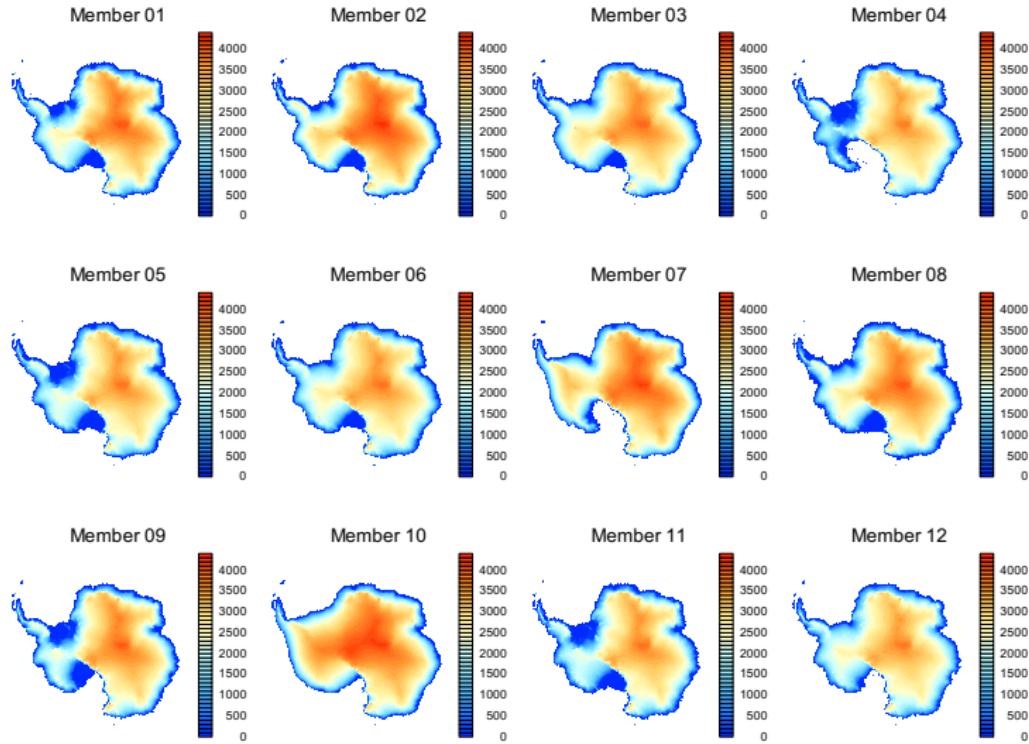
- Use PISM to simulate the past evolution of the Antarctic Ice Sheet.
- Run the model many times. Perturb the model physics each time, sampling as many different parameter combinations as possible.
- Identify the model configurations where the simulated evolution of the ice sheet agrees best with the known history.

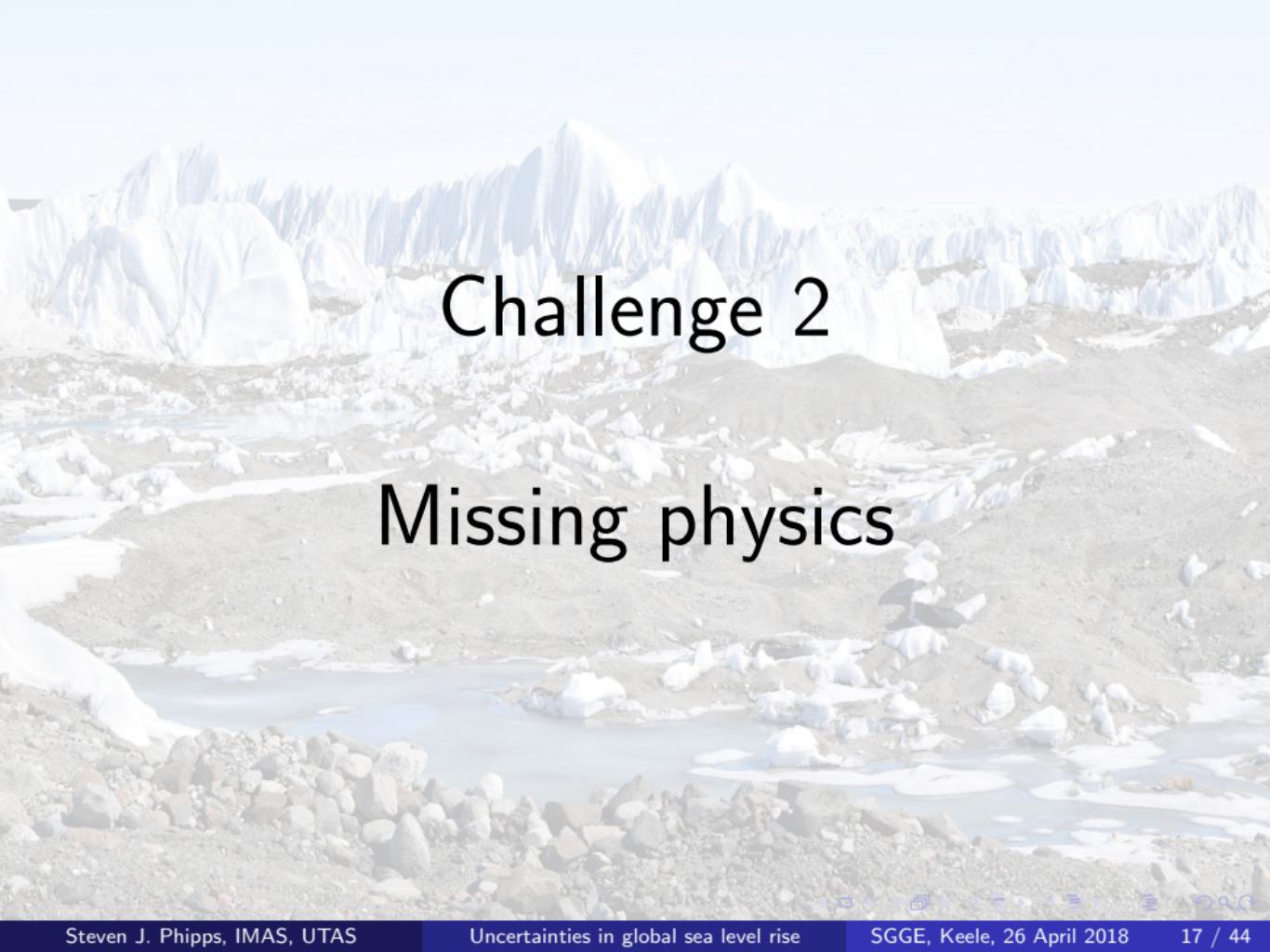


# “Tuning” an ice sheet model: Parameters

Parameter	Description	Minimum	Maximum
-sia_e	Shallow ice enhancement factor	1.0	4.5
-ssa_e	Shallow shelf enhancement factor	0.5	1.6
-pseudo_plastic_q	Exponent of basal resistance model	0.15	1.00
-till_effective_fraction_overburden	Effective till pressure scaling factor	0.01	0.04
-eigen_calving_K	Calving rate scaling factor	3.0e16	1.0e19
-thickness_calving_threshold	Minimum thickness of floating ice shelves	150.0	300.0

# Constraining ice sheet model parameterisations

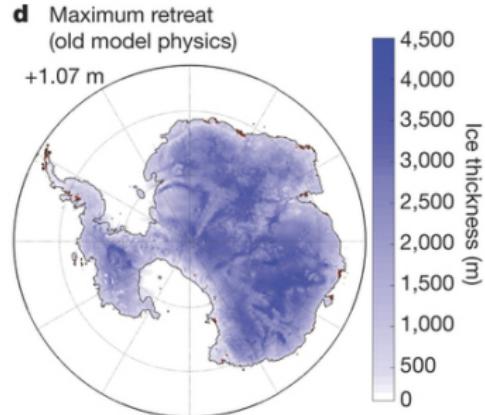
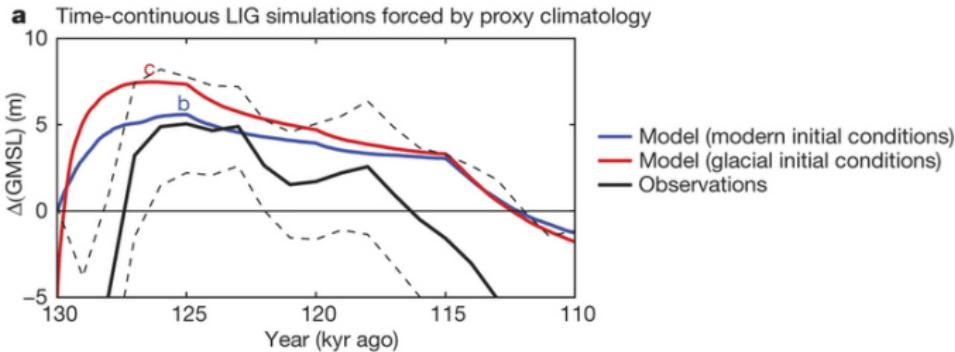


A photograph of a mountainous landscape. In the background, several large, jagged icebergs or glacial features are visible against a bright sky. The middle ground shows a rocky, brownish slope with patches of snow and ice. The foreground is a rocky, gravelly area with some small pools of water. The overall scene suggests a cold, arctic environment.

## Challenge 2

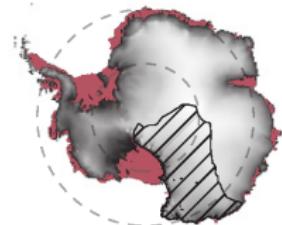
## Missing physics

# Challenge 2: The case of the ice that won't melt



DeConto and Pollard (2016), *Nature*

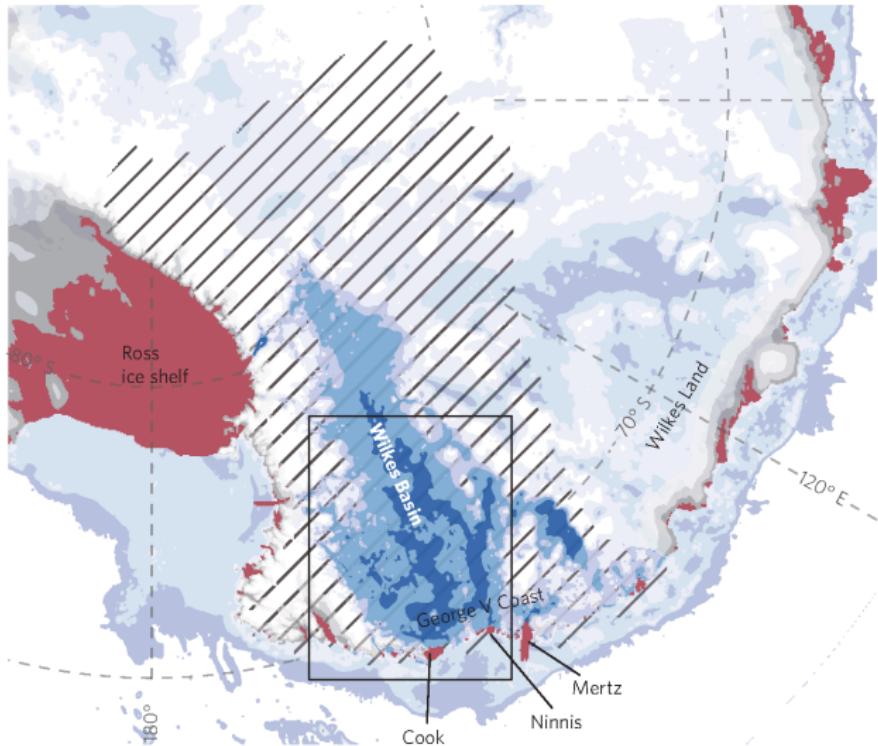
# Marine ice sheet instability (MISI)



Wilkes Basin  
subglacial topography

- <1,000 m
- <500 m
- <0 m

Model domain



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

# Marine ice sheet instability (MISI)

a Subglacial topography

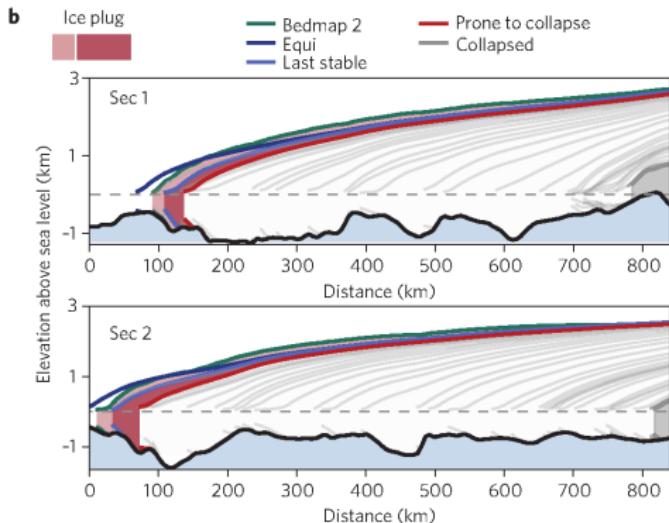
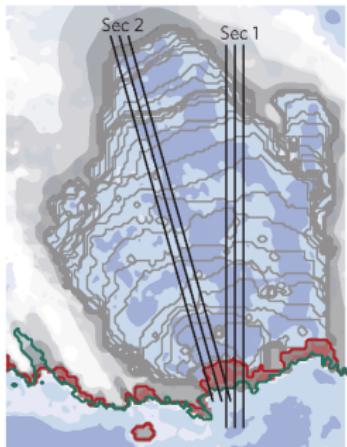
- < -1,000 m
- < -500 m
- < -0 m

Ice thickness after retreat

- < 500 m
- < 1,000 m
- < 1,500 m

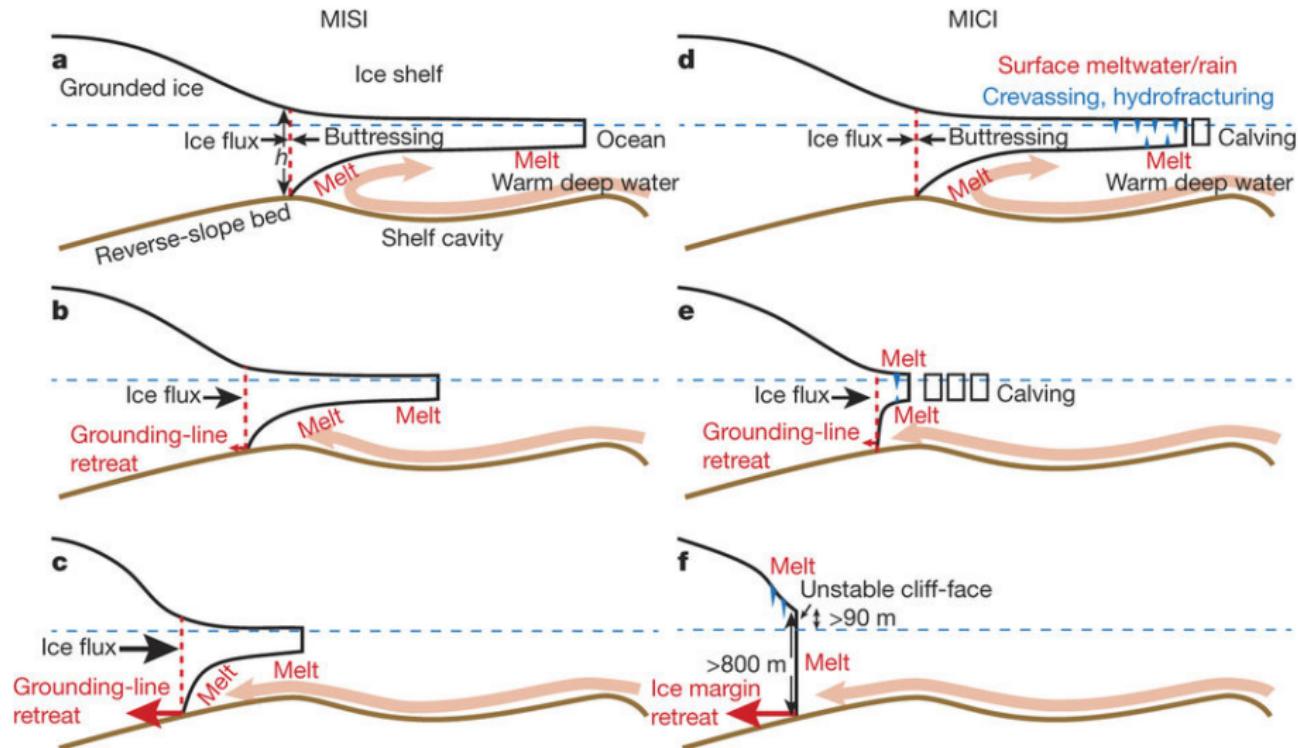
Grounding line

- Bedmap 2
- Prone to collapse
- Transient retreat



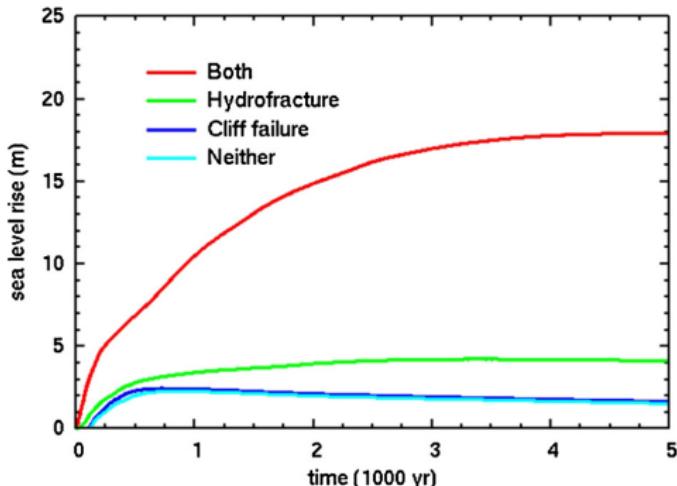
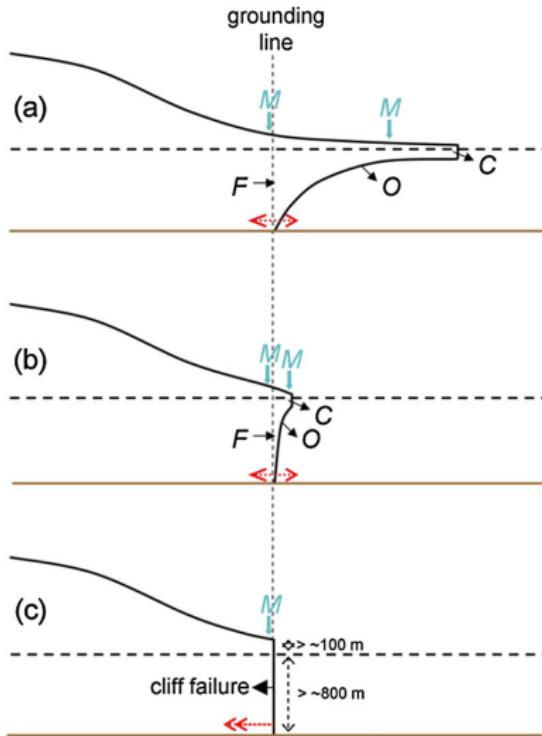
Mengel and Levermann (2014), *Nature Climate Change*

# Mechanisms of ice sheet instability



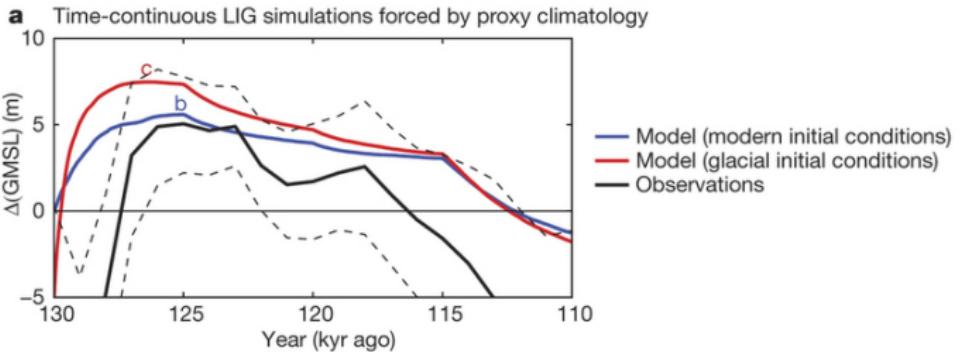
DeConto and Pollard (2016), *Nature*

# Hydrofracturing and ice cliff failure

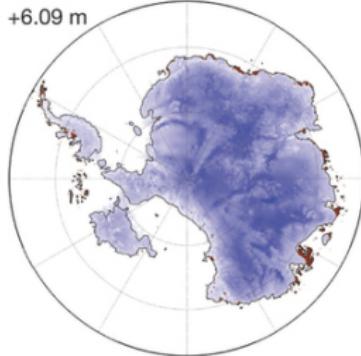


Pollard et al. (2015), *Earth and Planetary Science Letters*

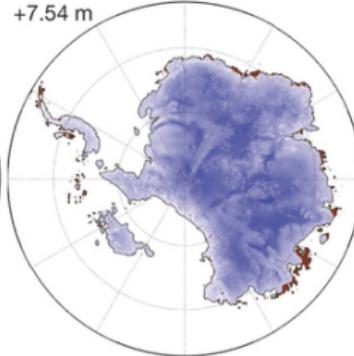
# Marine ice cliff instability (MICI)



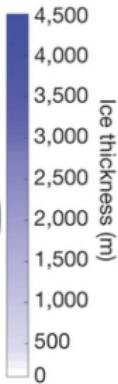
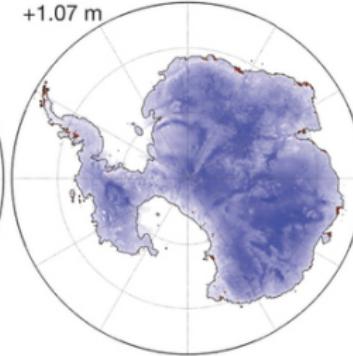
**b** Maximum retreat  
(modern initial conditions)



**c** Maximum retreat  
(glacial initial conditions)

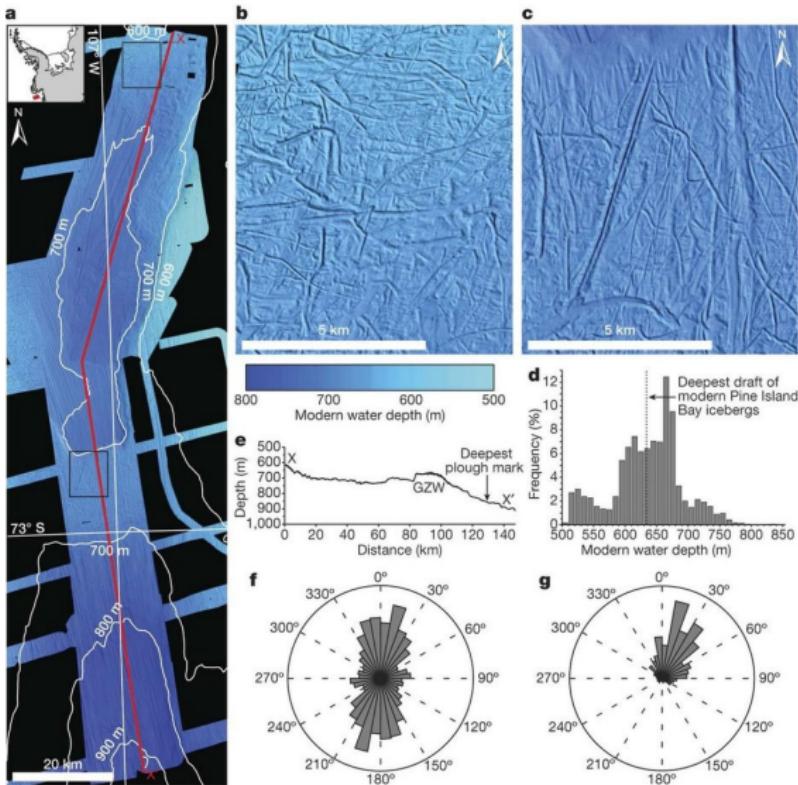


**d** Maximum retreat  
(old model physics)



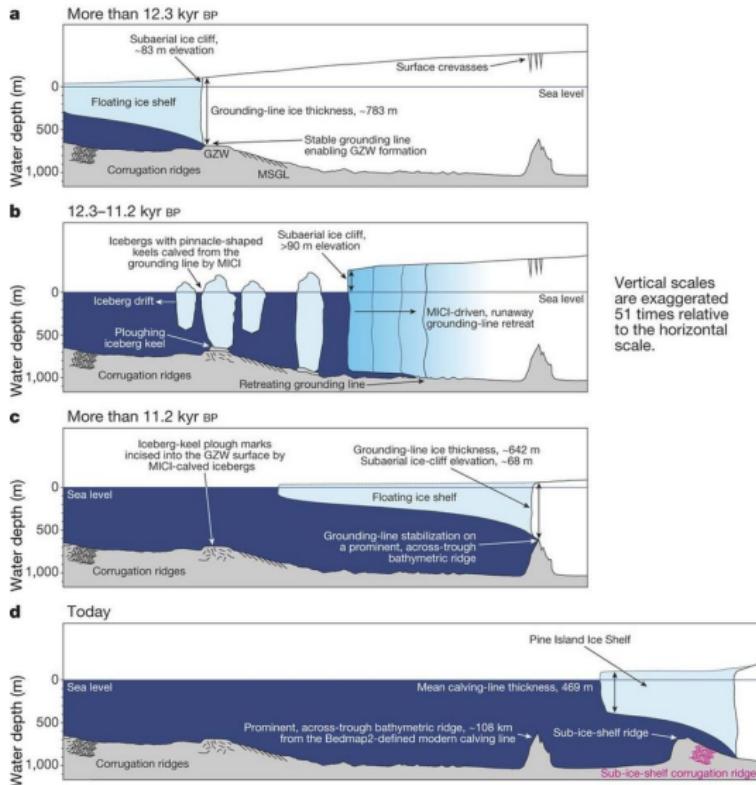
DeConto and Pollard (2016), *Nature*

# Marine ice cliff instability: observational evidence

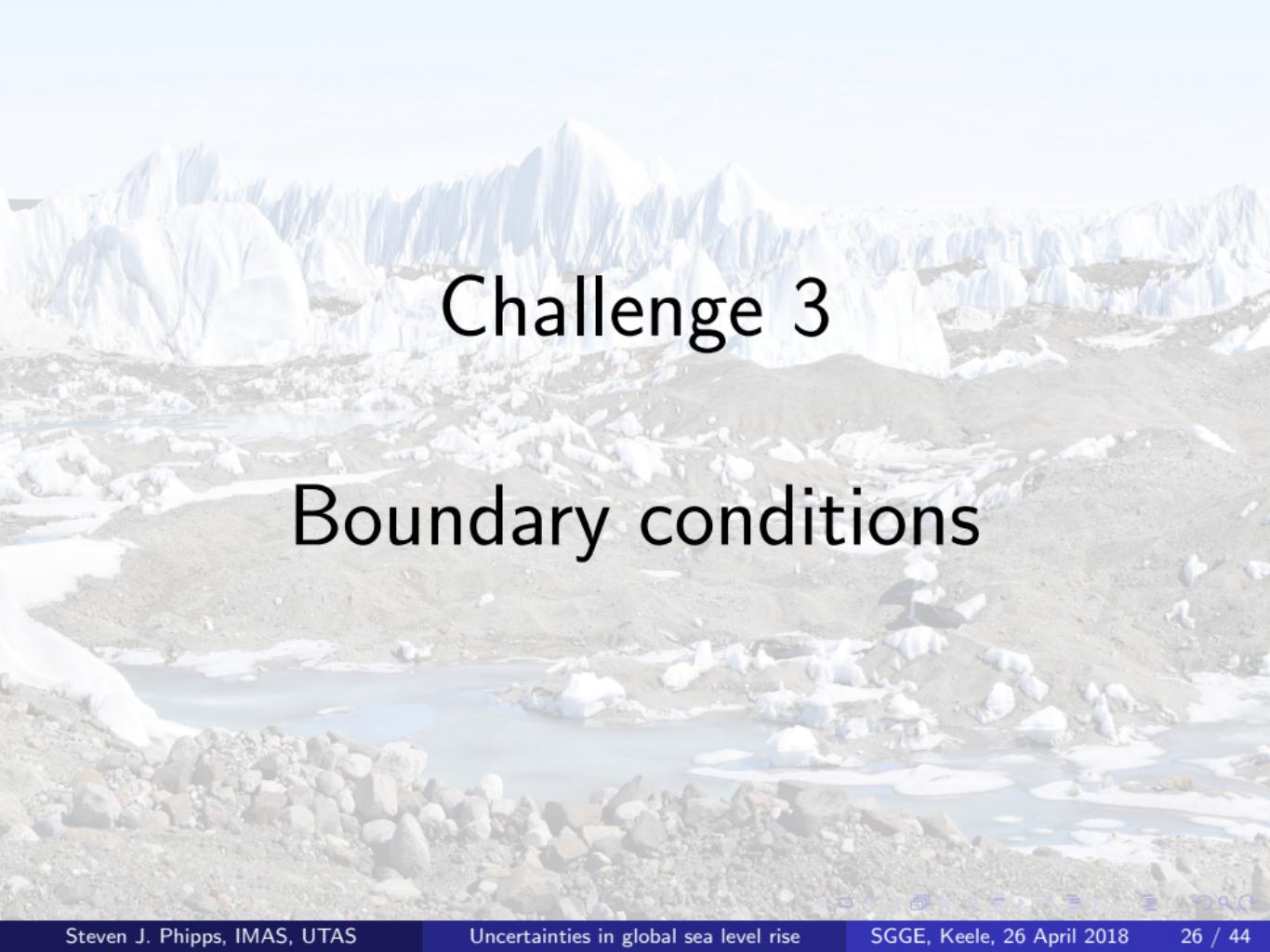


Wise et al. (2017), *Nature*

# Marine ice cliff instability: observational evidence



Wise et al. (2017), *Nature*

A photograph of a glacier landscape. In the background, several large, jagged icebergs are visible against a bright sky. The middle ground shows a rocky, uneven terrain covered with patches of snow and small streams of meltwater. The foreground is dominated by a rocky slope with some low-lying vegetation and more snow patches.

# Challenge 3

## Boundary conditions

## Challenge 3: Boundary conditions

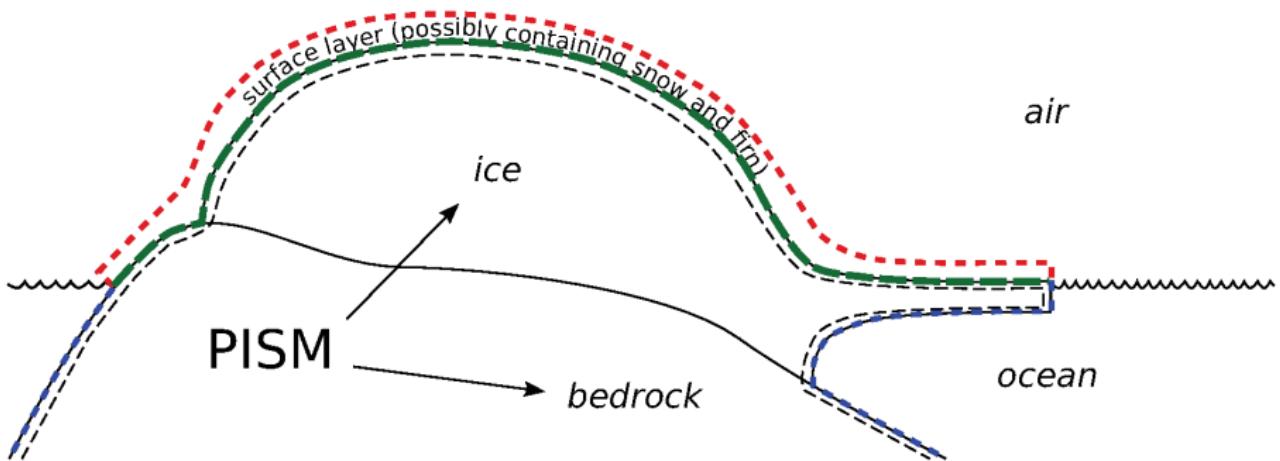
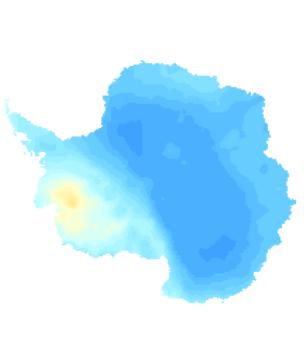


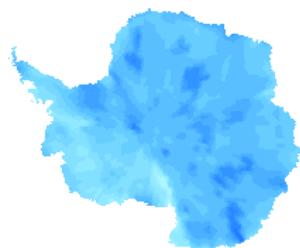
Figure 15: PISM's view of interfaces between an ice sheet and the outside world

# Uncertainty in boundary conditions

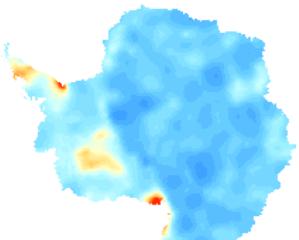
(a) Shapiro and Ritzwoller (2004)



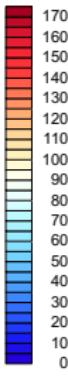
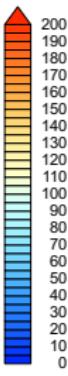
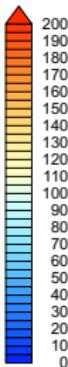
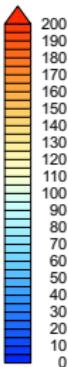
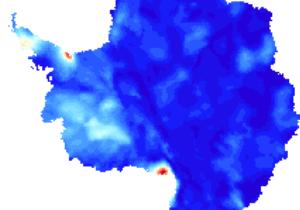
(b) An et al. (2015)



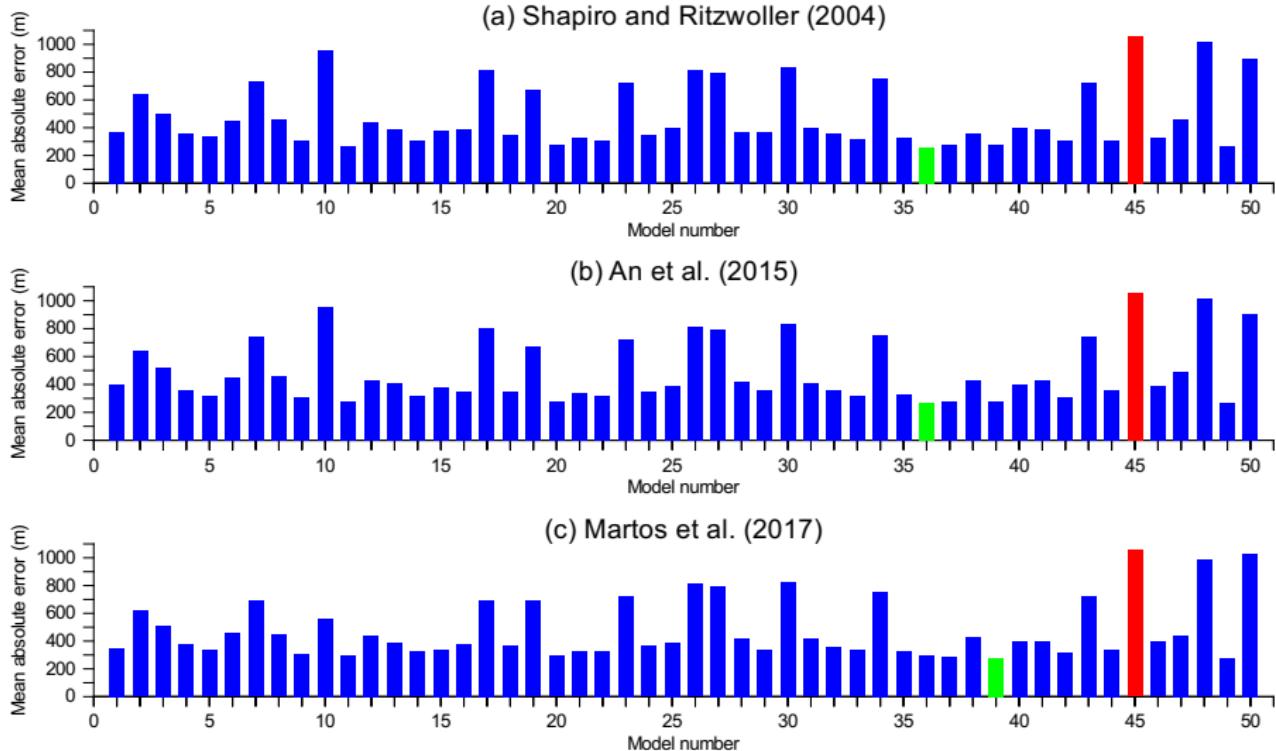
(c) Martos et al. (2017)



(d) Range

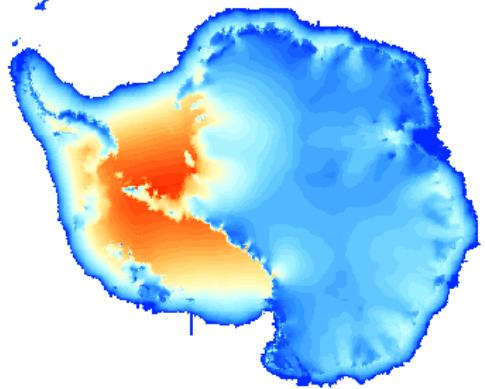


# Impact on “tuning” an ice sheet model

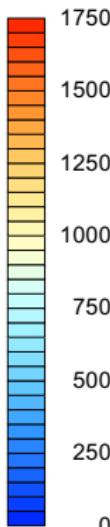
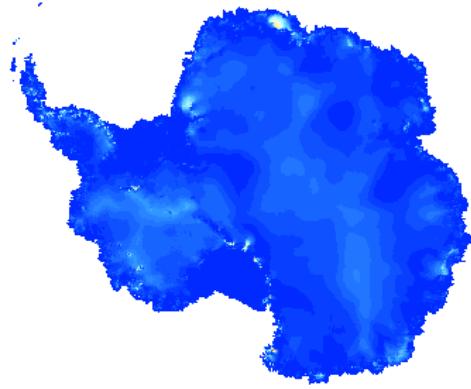


# “Tuning” an ice sheet model: Roles of physics and GHF

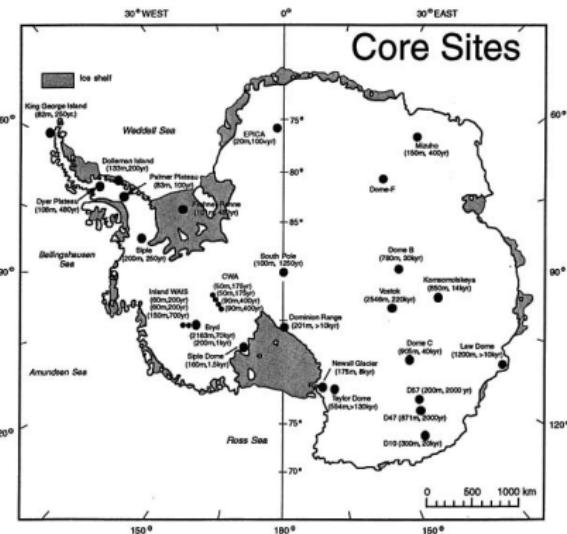
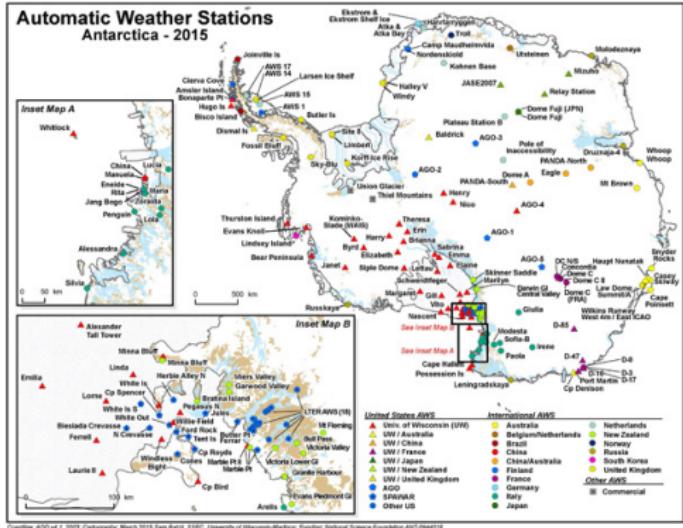
(a) Intra-ensemble range



(b) Inter-ensemble range



# Lack of observational data



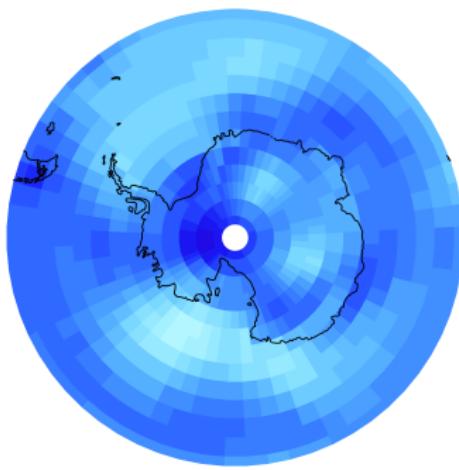
Source: AGO v1.2015, Cartography: March 2015 Sam Ball, NSIDC, University of Wisconsin-Madison, Funding: National Science Foundation, AGO-04012

Present

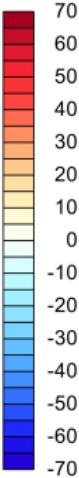
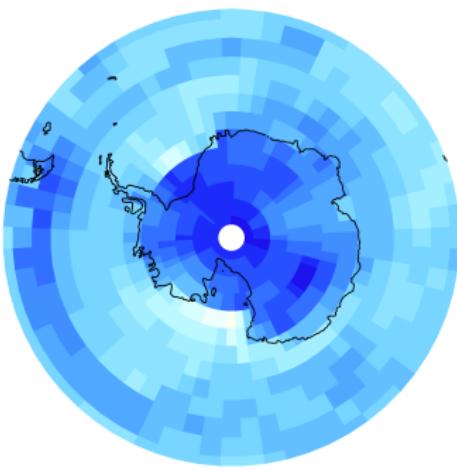
Past

# Using climate modelling to generate boundary conditions

Surface air temperature anomaly ( $^{\circ}\text{C}$ )

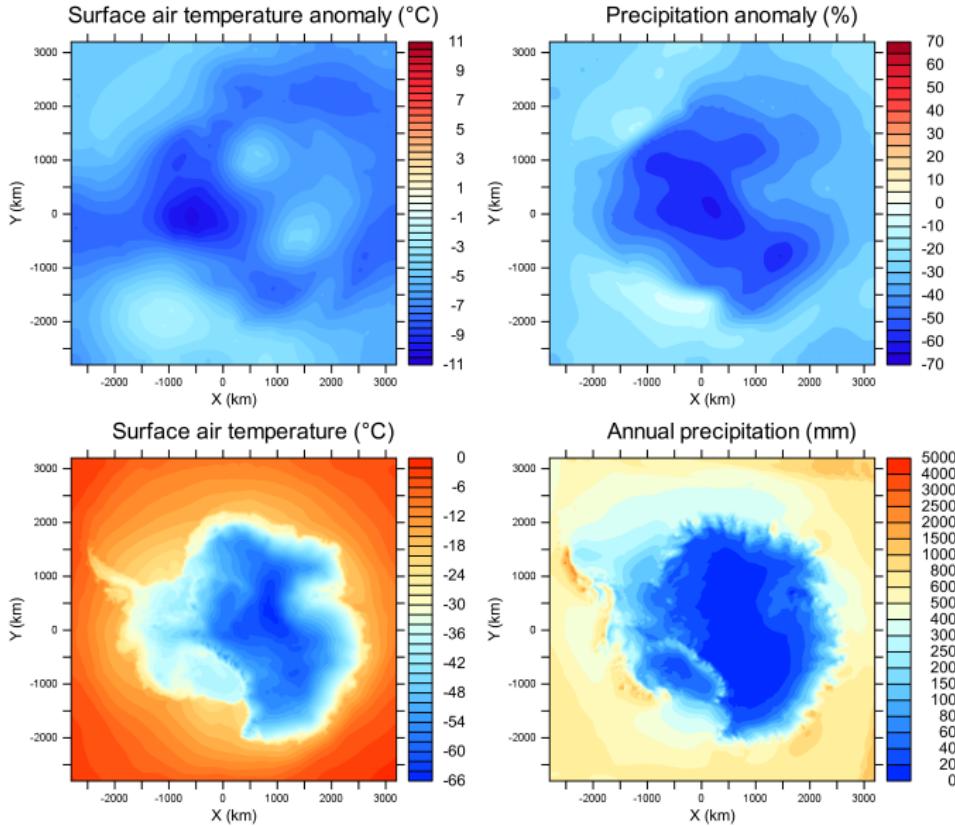


Precipitation anomaly (%)

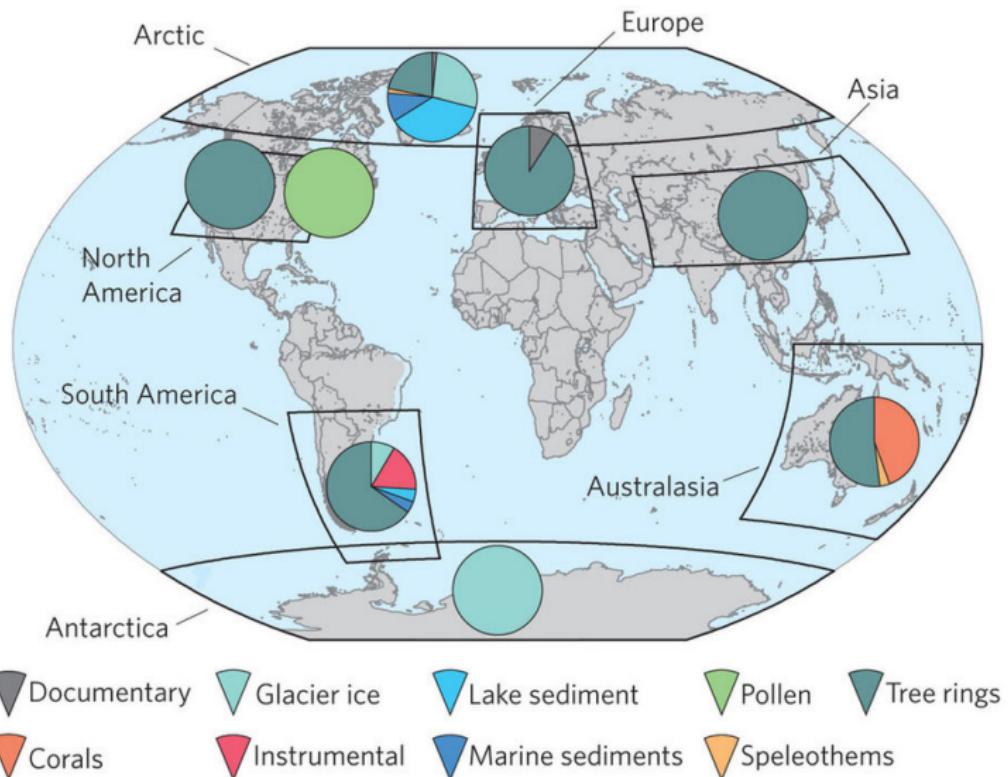


- Use the CSIRO Mk3L climate system model to simulate the period 56–0 ka, then 5,000 years into the future under the RCP8.5 scenario

# Using climate modelling to generate boundary conditions

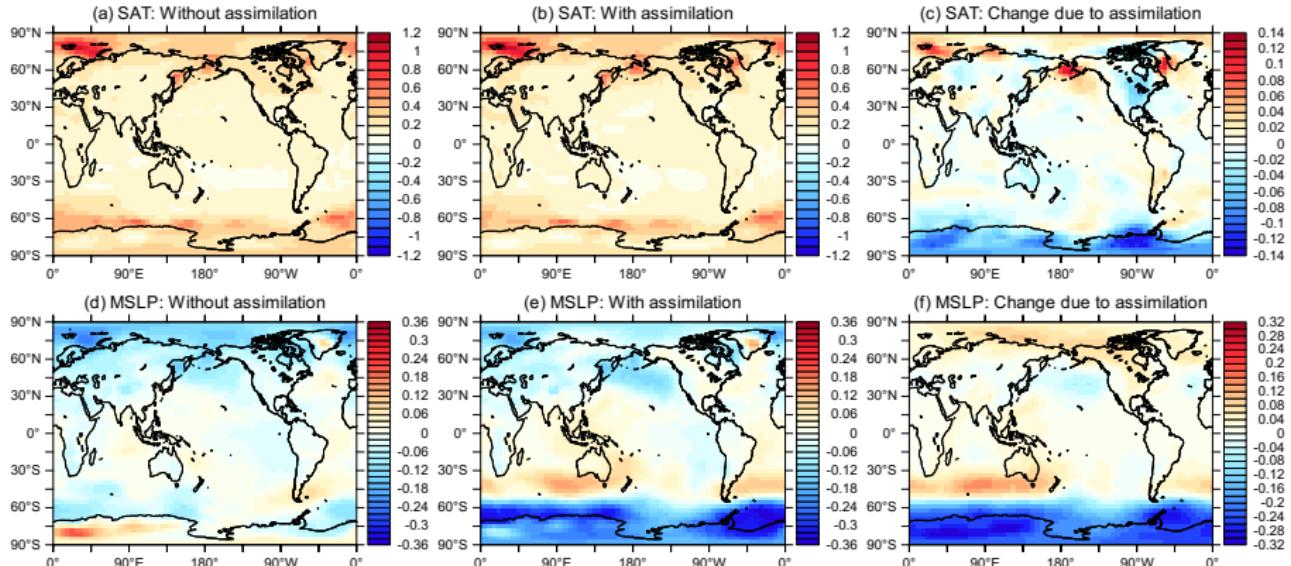


# Using data assimilation to incorporate proxy information

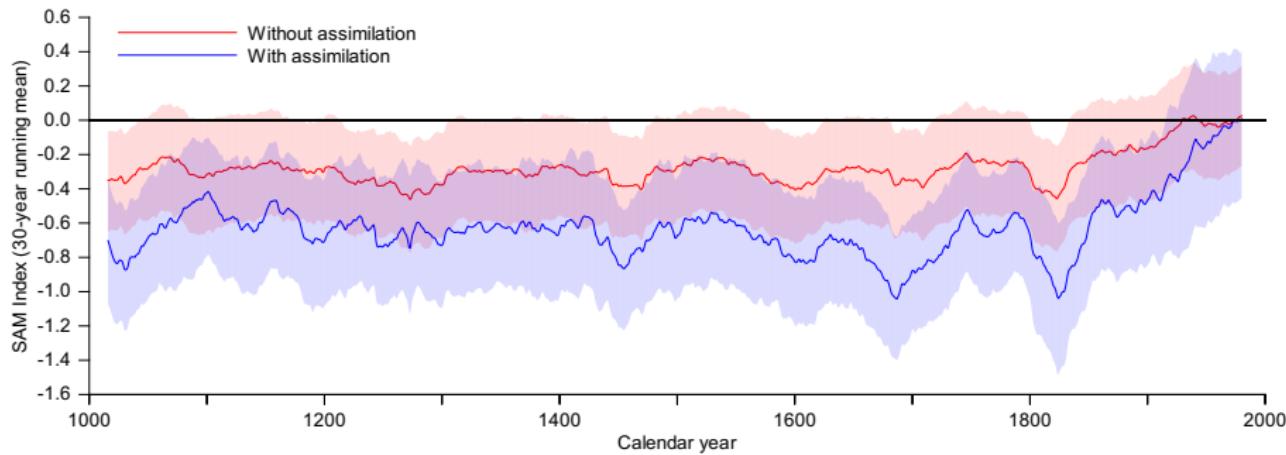


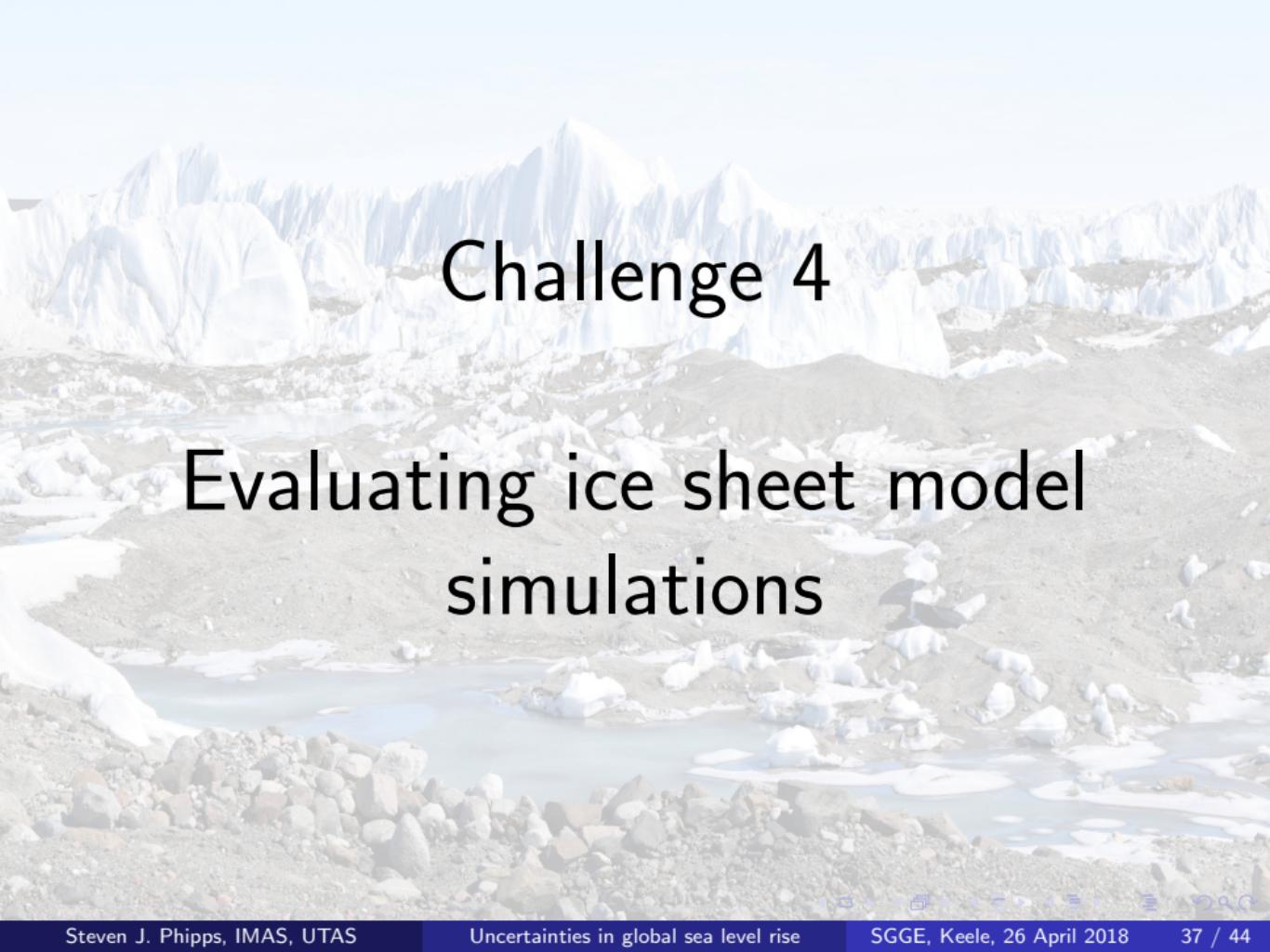
PAGES 2k Consortium (2013), *Nature Geoscience*

# Using data assimilation to incorporate proxy information



# Using data assimilation to incorporate proxy information

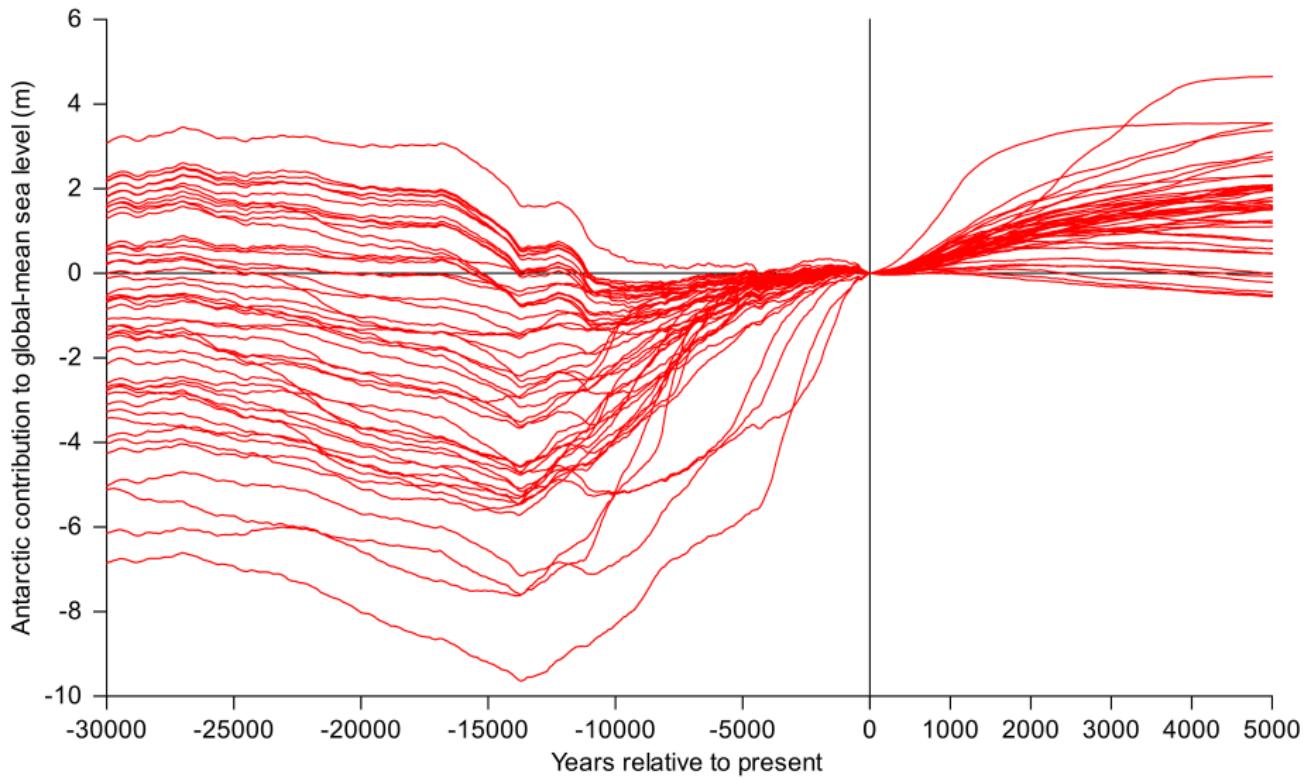


A photograph of a massive glacier with deep blue ice and white snow-capped mountain peaks in the distance. The foreground shows rocky ground and small pools of meltwater.

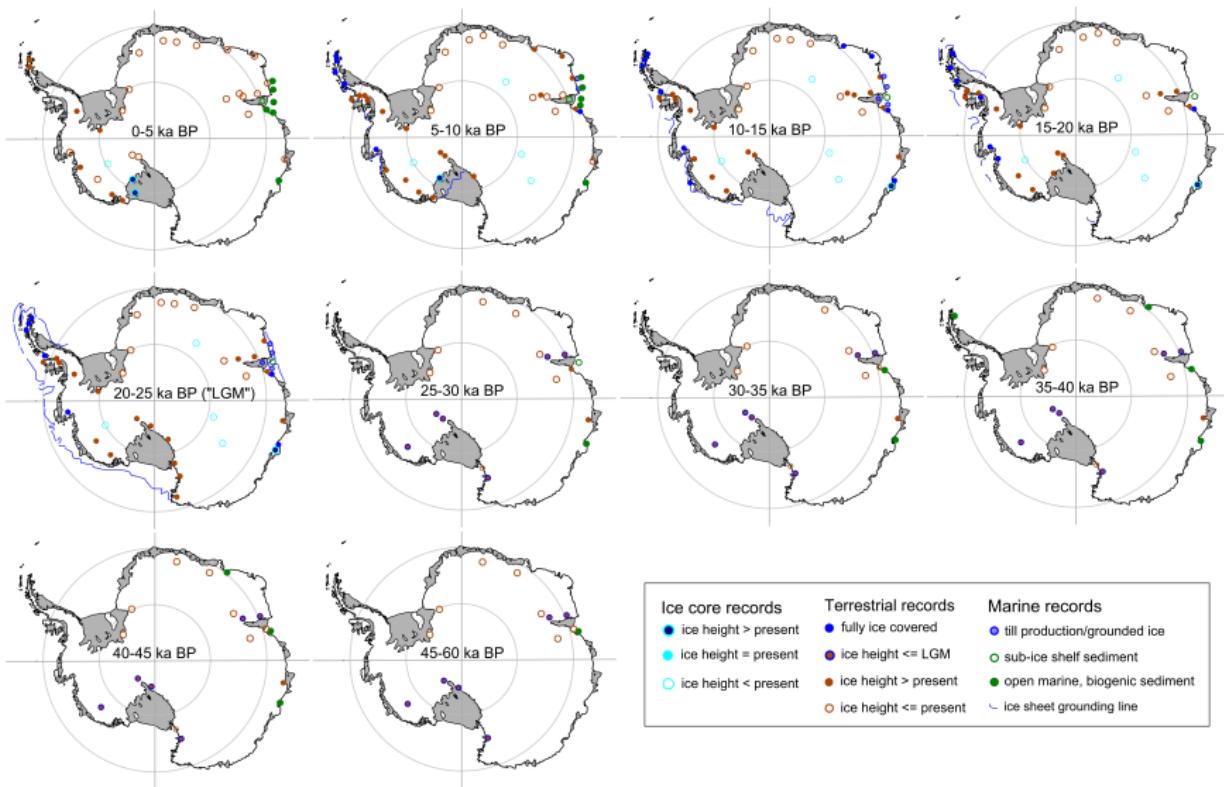
# Challenge 4

## Evaluating ice sheet model simulations

## Challenge 4: Evaluating ice sheet model simulations



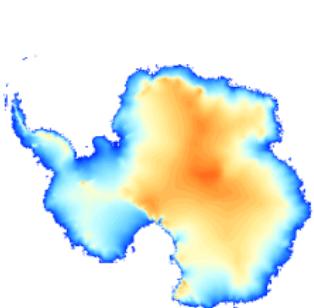
# The history of the Antarctic ice sheet (60–0 ka)



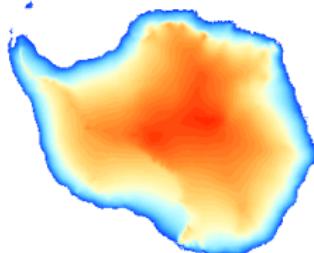
Duanne White/University of Canberra

# Constraining parameterisations: Using the past

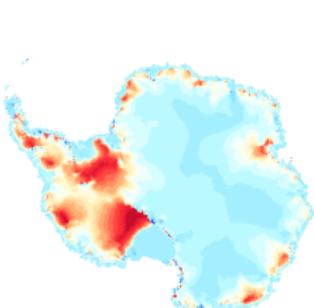
a. 20-25ka elevation (BEST)



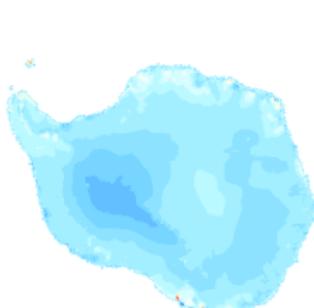
b. 20-25ka elevation (WORST)



c. 20-25ka anomaly (BEST)



d. 20-25ka anomaly (WORST)



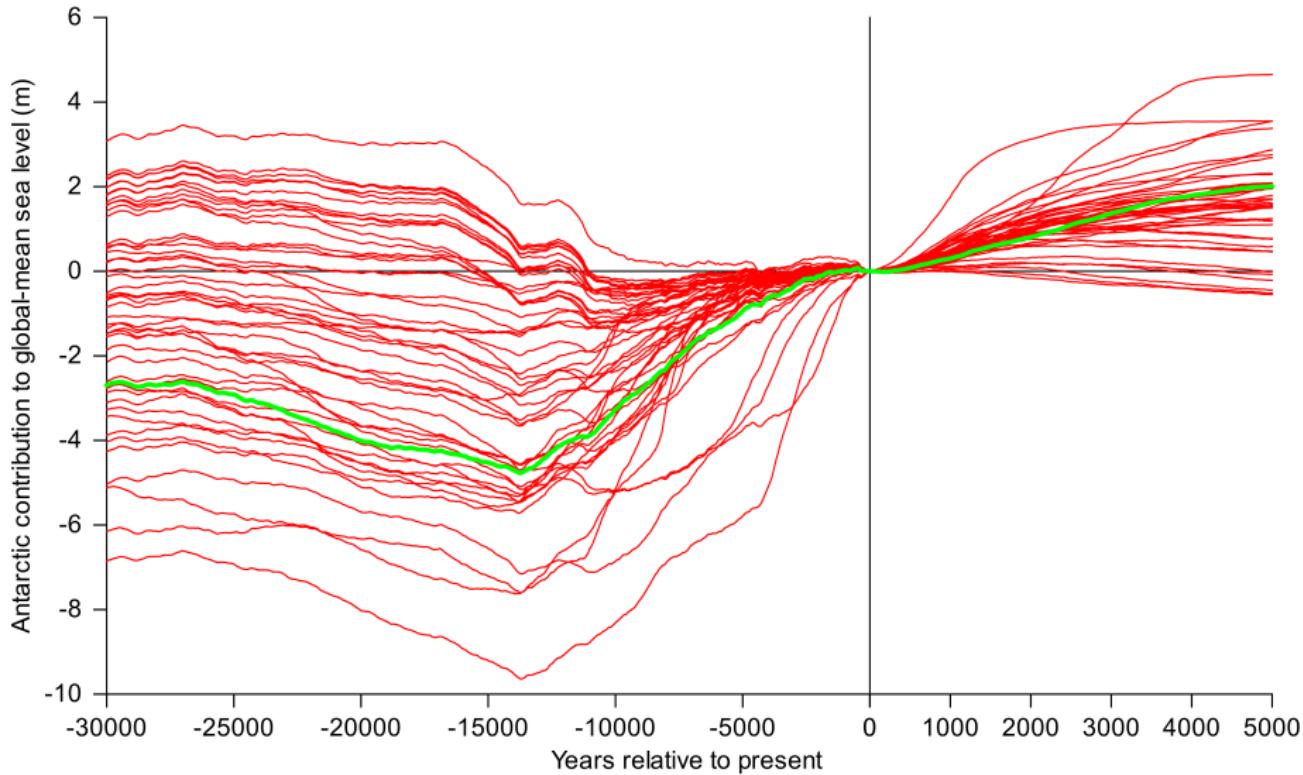
# We need more data!



A wide-angle photograph of a massive glacier. In the foreground, there's a rocky, debris-strewn slope leading down to a body of water. The middle ground is dominated by the glacier's surface, which is covered in white snow and dark, rocky scree. In the background, several snow-capped mountain peaks rise against a clear blue sky.

# Bringing it all together

# Using the past to inform the future



# Potential areas for collaboration

- Constraining ice sheet model parameterisations
  - Improving representations of known physical processes
  - Incorporation of hypothetical physical processes
- Simulating past and future changes in the atmosphere and ocean
  - Ensemble simulations using coupled atmosphere–sea ice–ocean general circulation models
  - Assimilation of Southern Hemisphere proxy data
  - Ice sheet–ocean coupling?
- Reconstructing past changes in the Antarctic ice sheet
  - Reconstructing past changes in ice thickness and extent
  - Using reconstructions to evaluate ice sheet model simulations