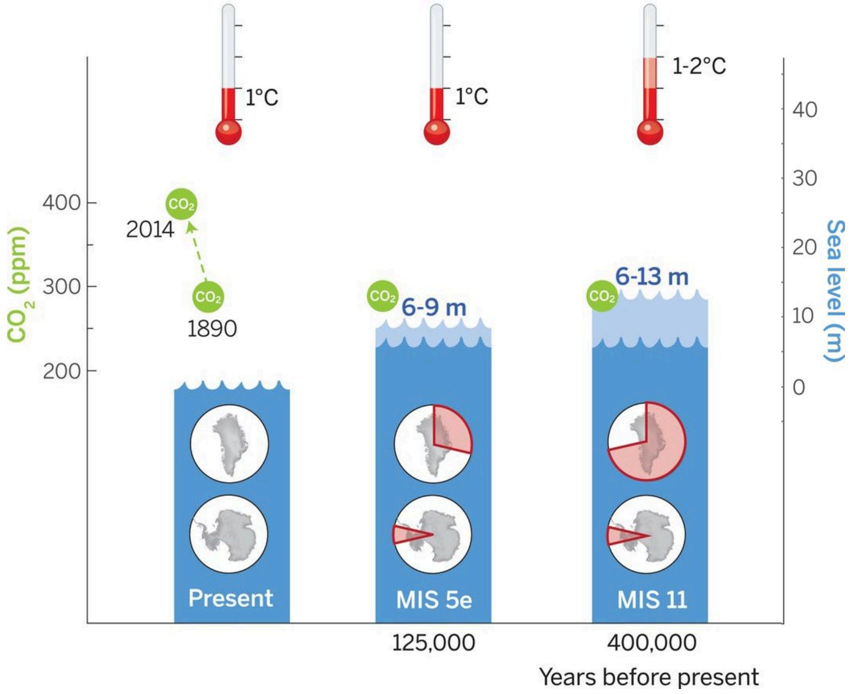
Searching for subglacial evidence of past West Antarctic Ice Sheet collapse

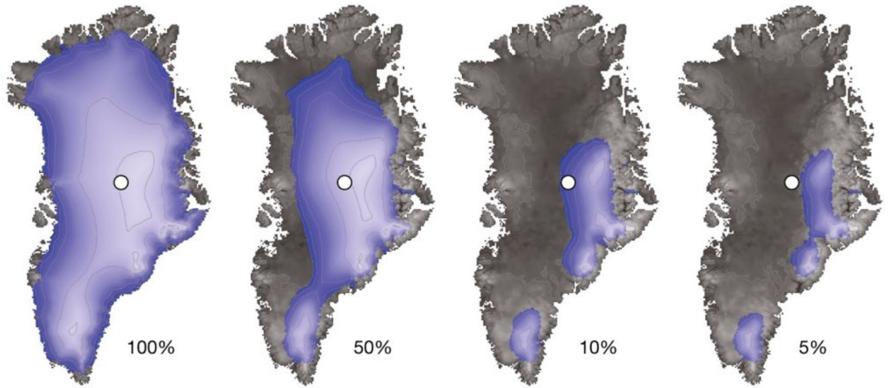
Trevor Hillebrand, Perry Spector, David Pollard, John Stone, Joel Gombiner

Pleistocene sea level records might not require West Antarctic Ice Sheet collapse



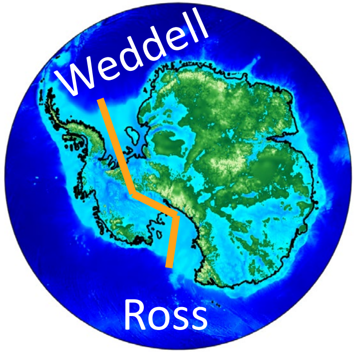
Dutton et al. (2015)

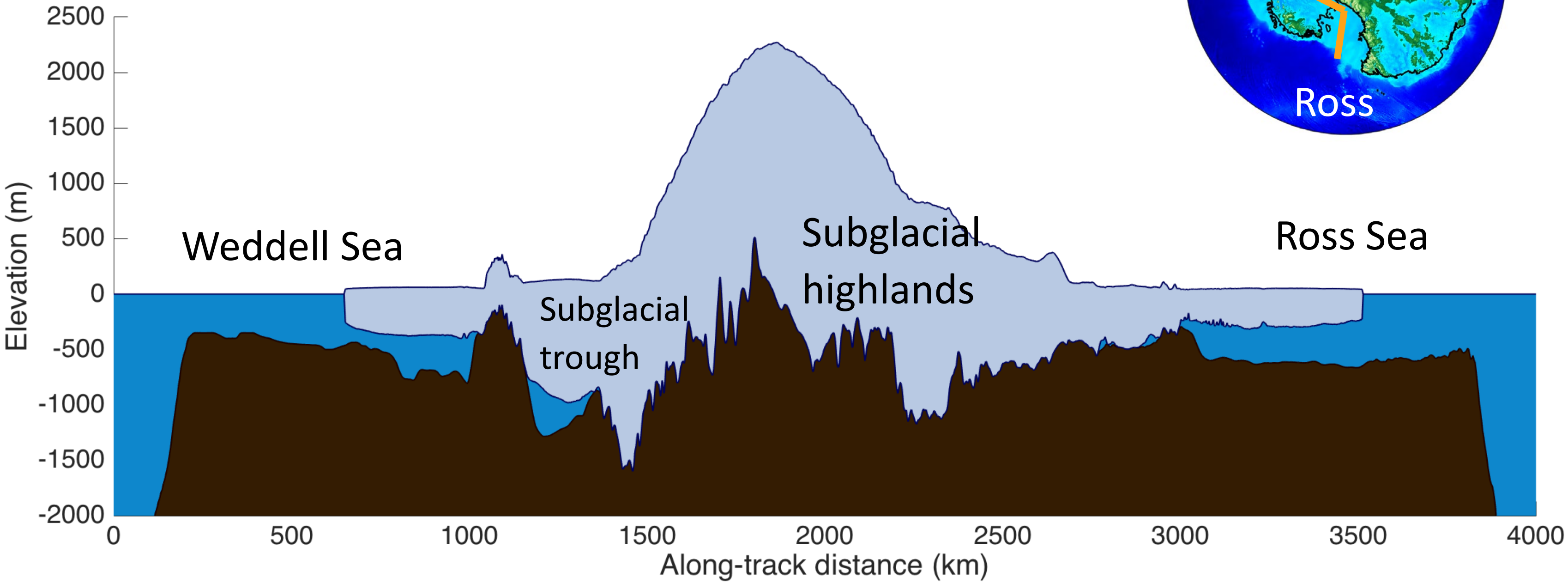
6 - 7 m sea level rise



Schaefer et al. (2016)

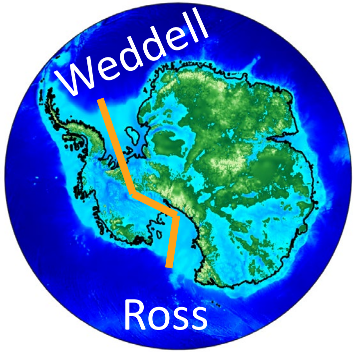
Has the West Antarctic Ice Sheet collapsed in the last few million years?

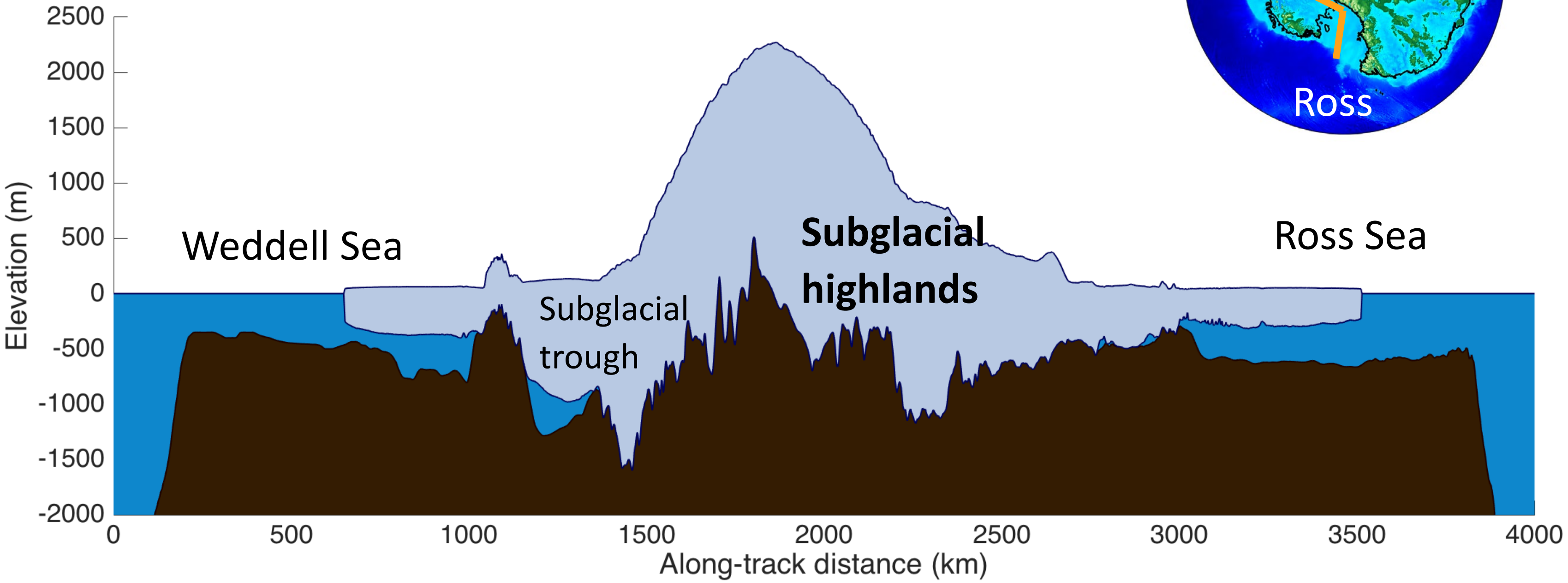




Greene et al. (2017)

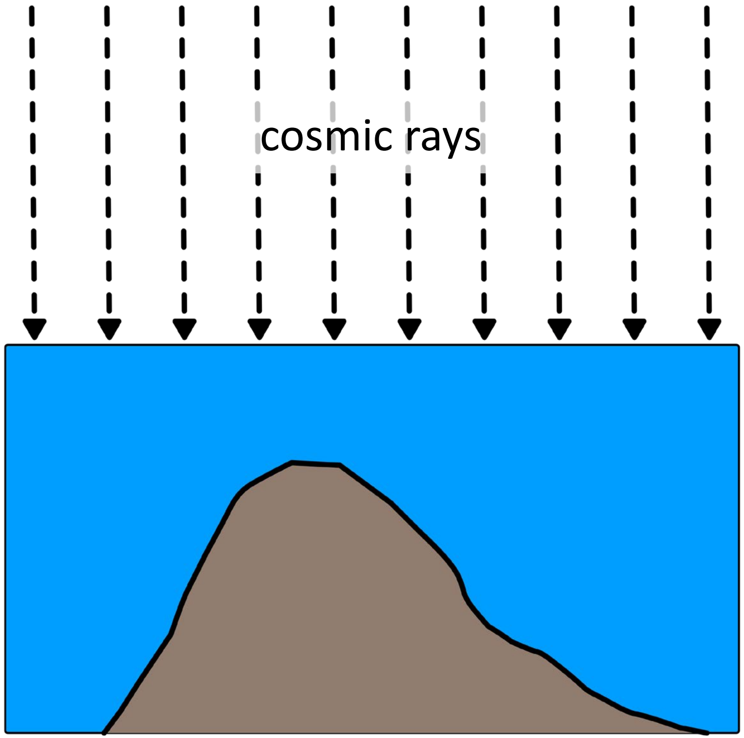
Evidence of past ice sheet collapse is likely to be buried under the ice.





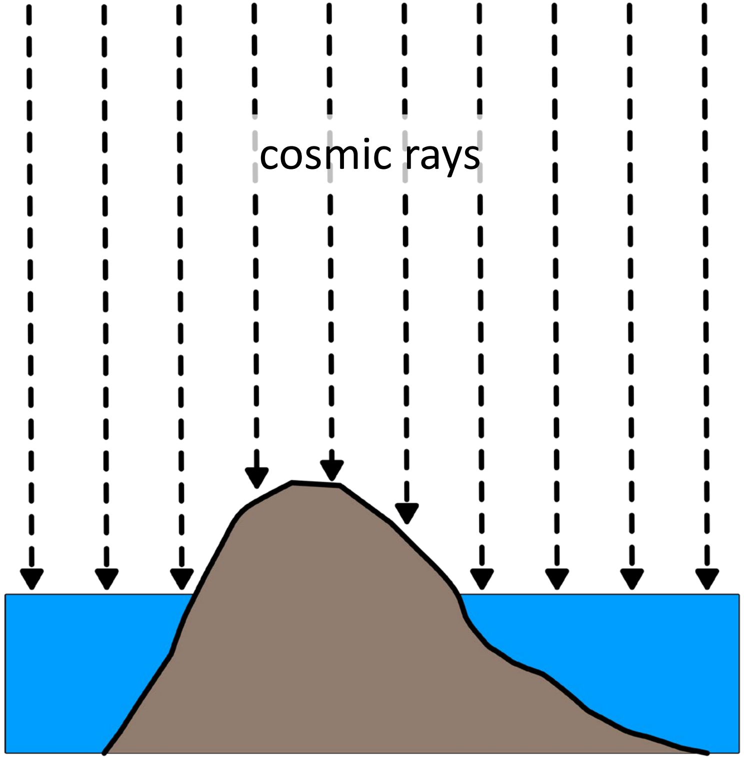
Greene et al. (2017)

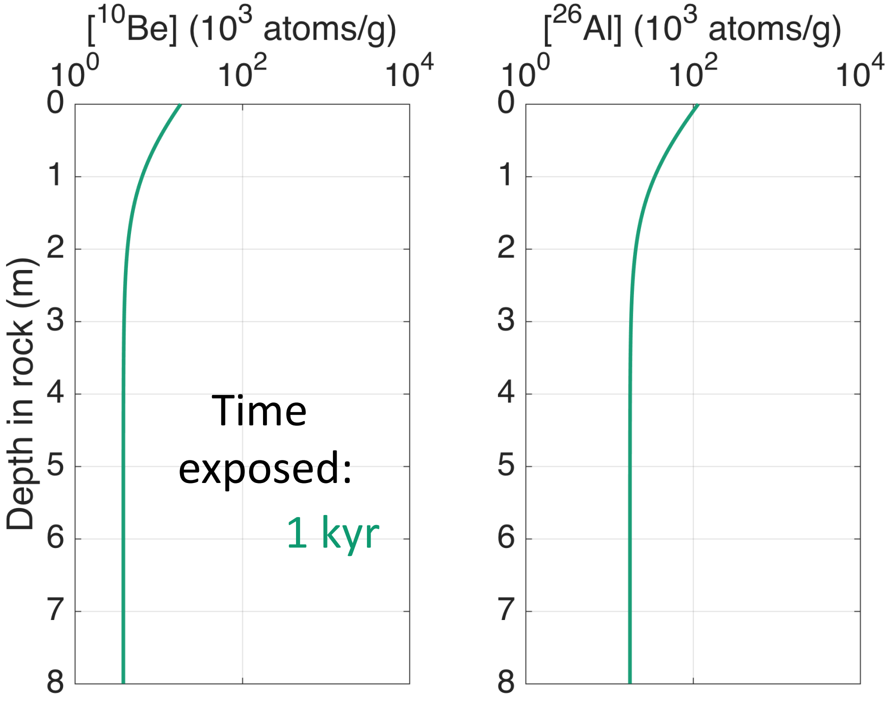
A binary test for ice-sheet drawdown



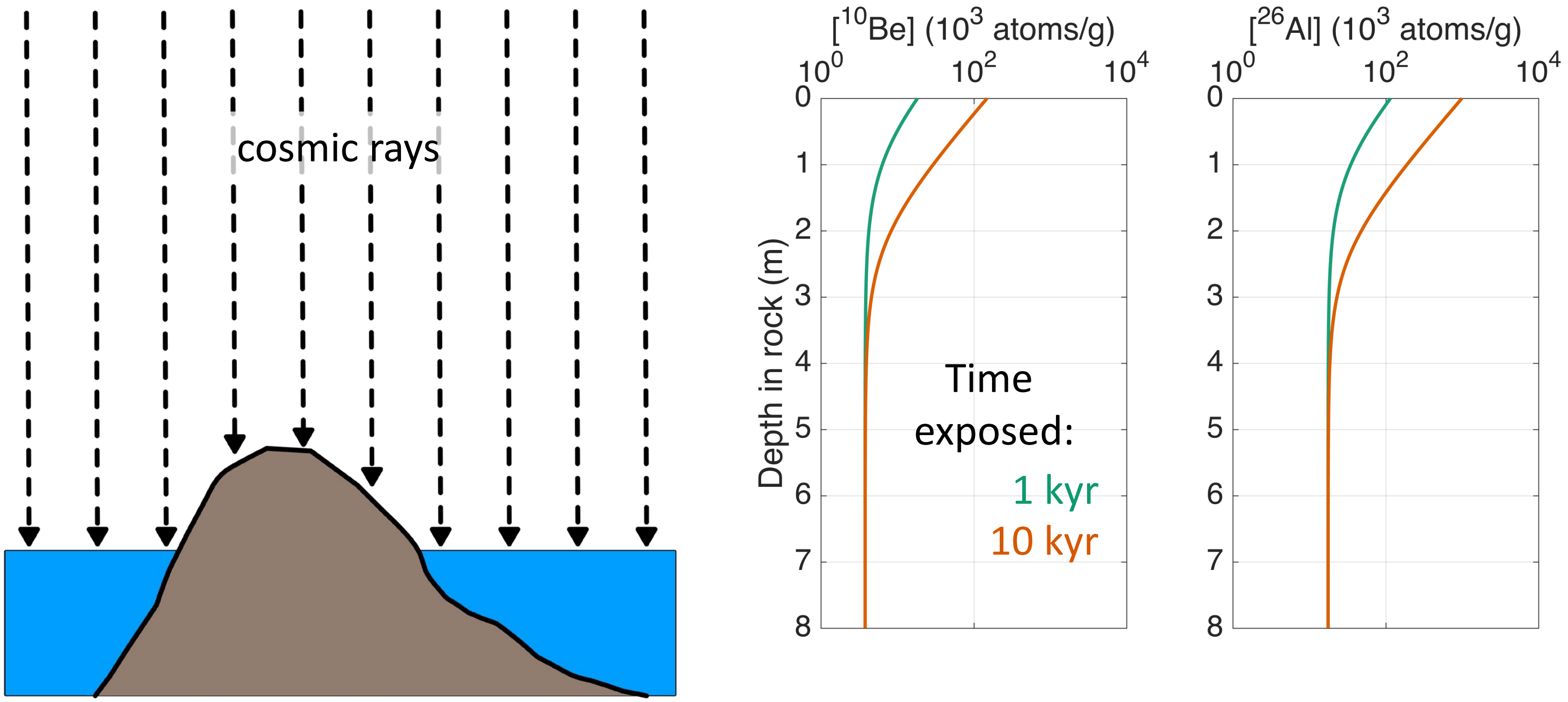
- We can test for past exposure of subglacial rock surfaces using the **cosmogenic nuclides** ^{10}Be and ^{26}Al.
- These are mainly produced by spallation reactions as cosmic rays break up Si and O nuclei in quartz.
- Most cosmic rays only penetrate a few meters into rock or ice.
- Rates of production and decay are known with high precision.

A binary test for ice-sheet drawdown

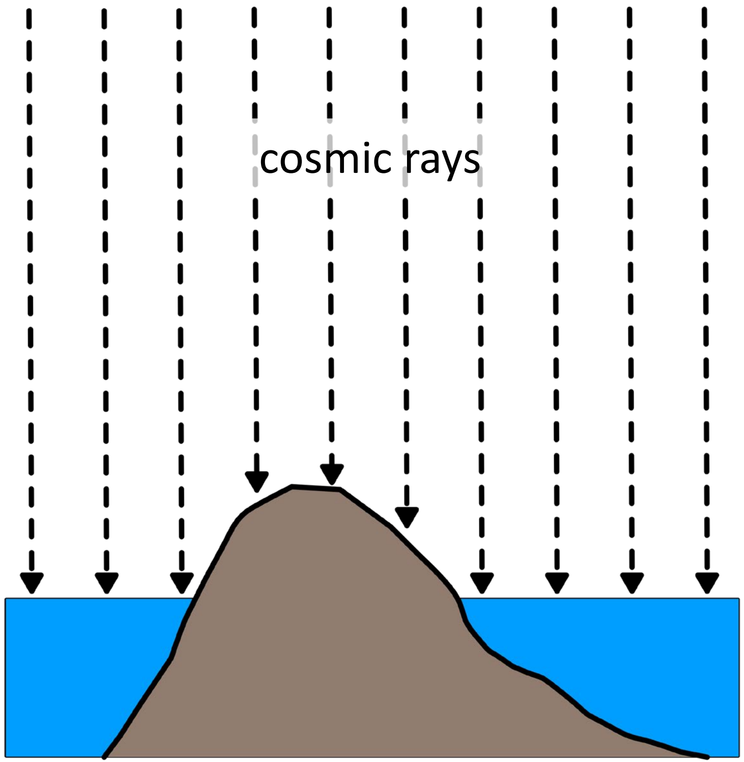


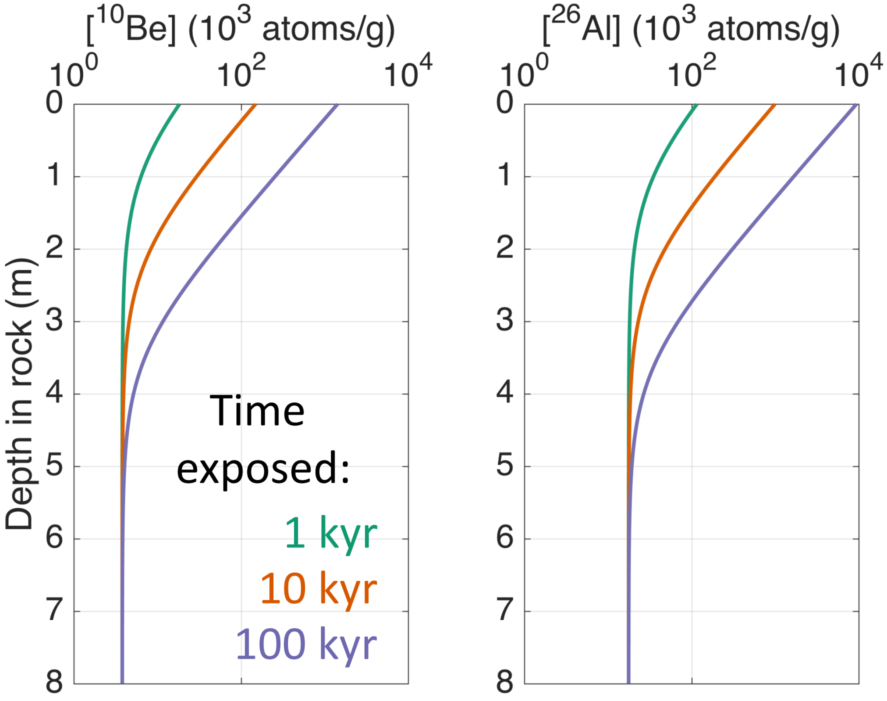


A binary test for ice-sheet drawdown

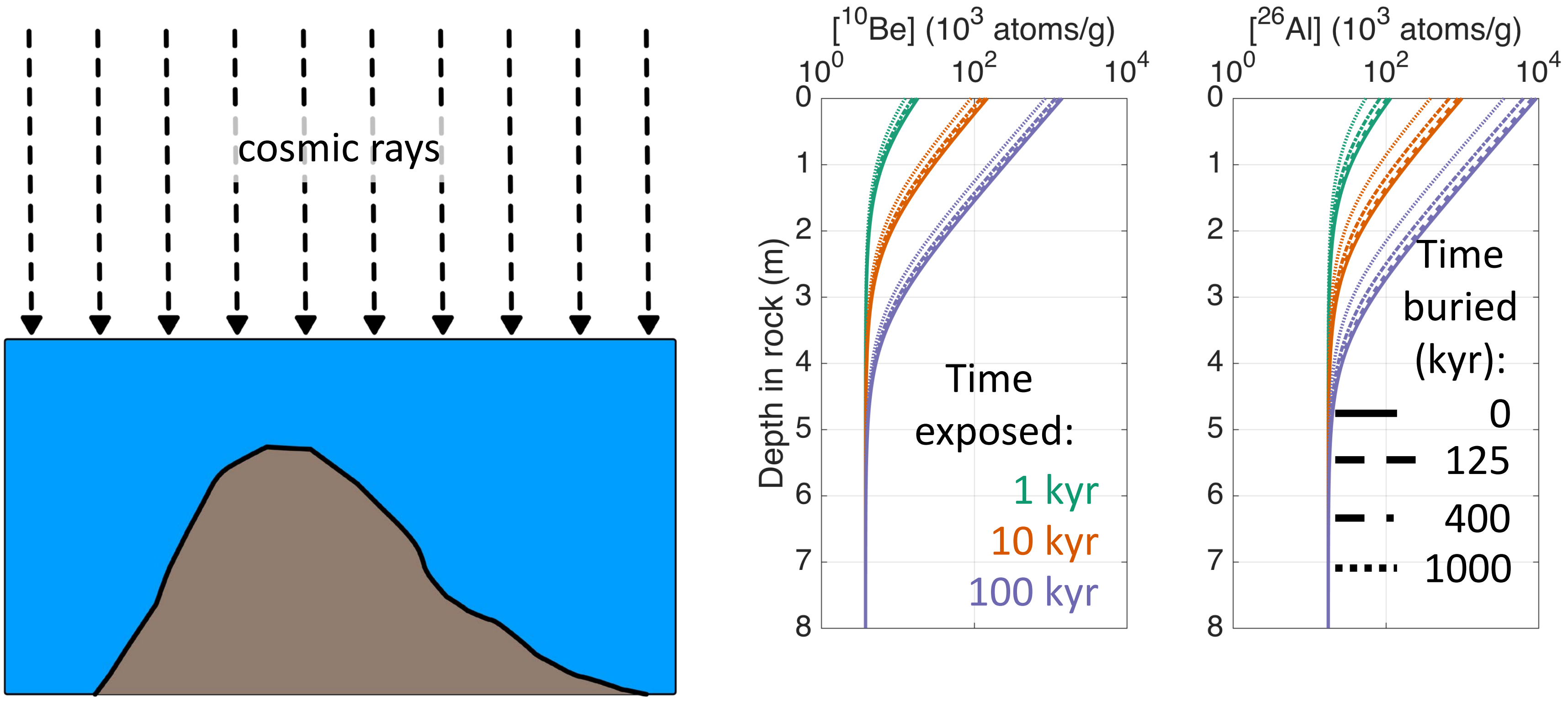


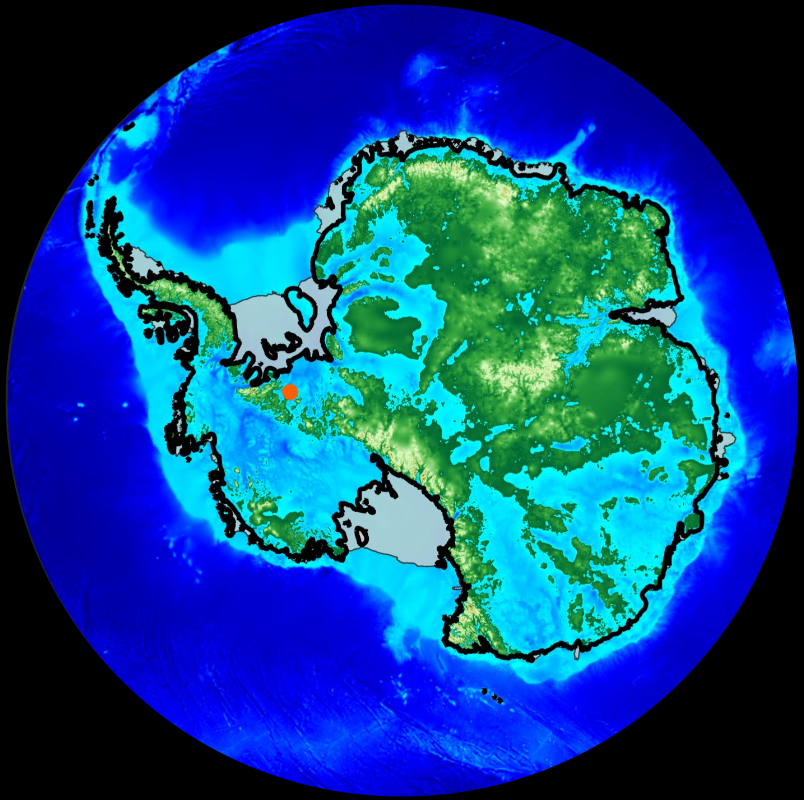
A binary test for ice-sheet drawdown

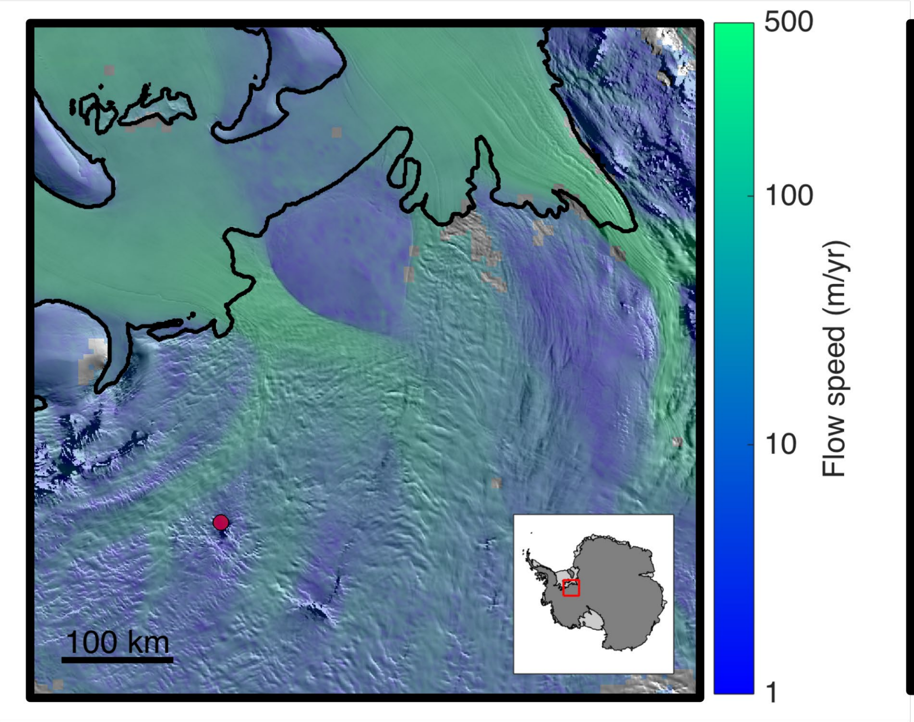




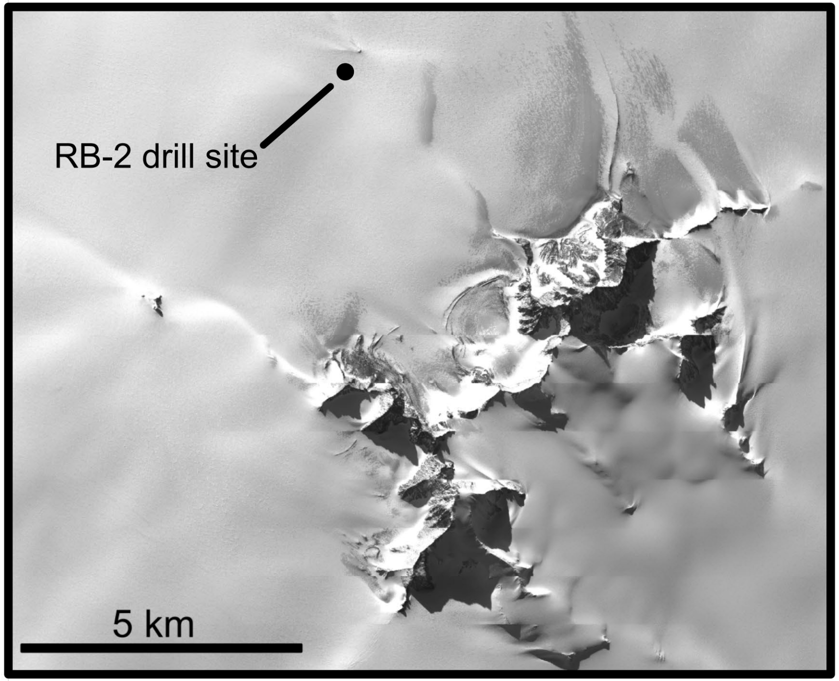
A binary test for ice-sheet drawdown



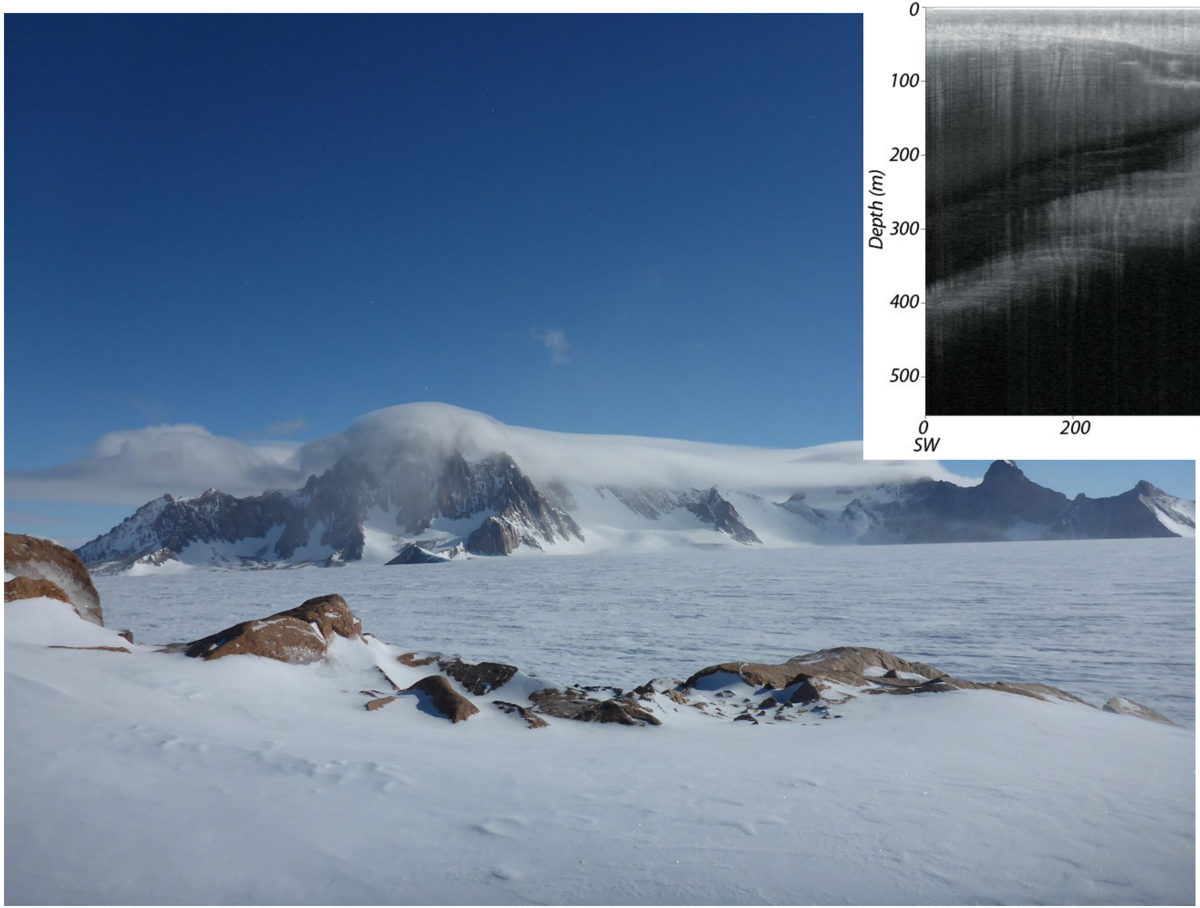


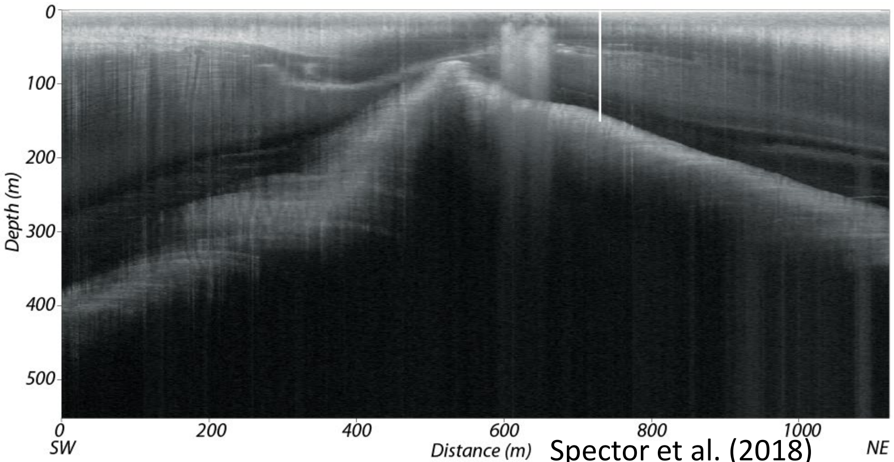


Rignot et al. (2011); Haran et al., (2014); Greene et al. (2017)



Worldview satellite image © DigitalGobe, Inc.

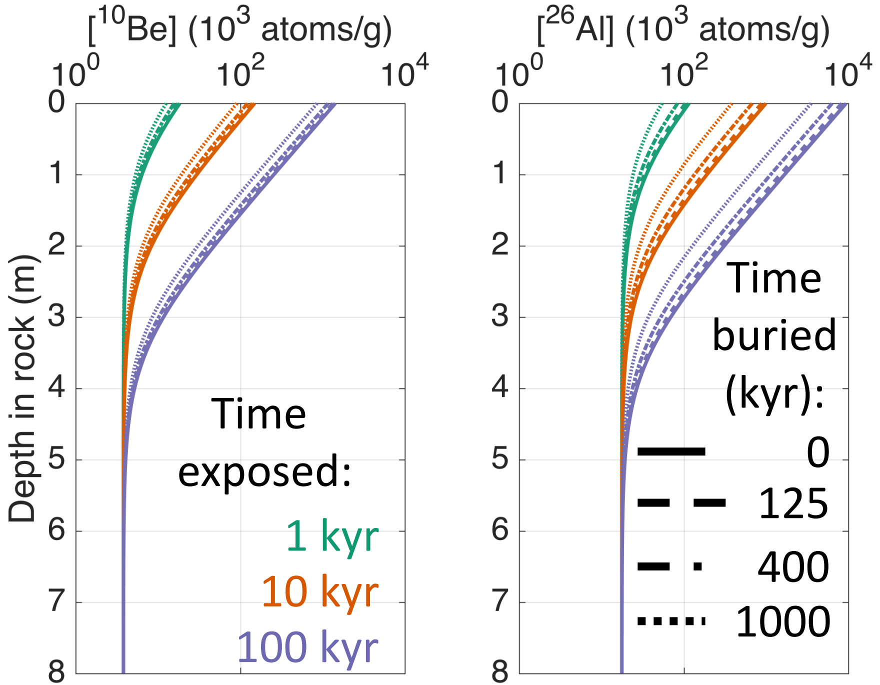




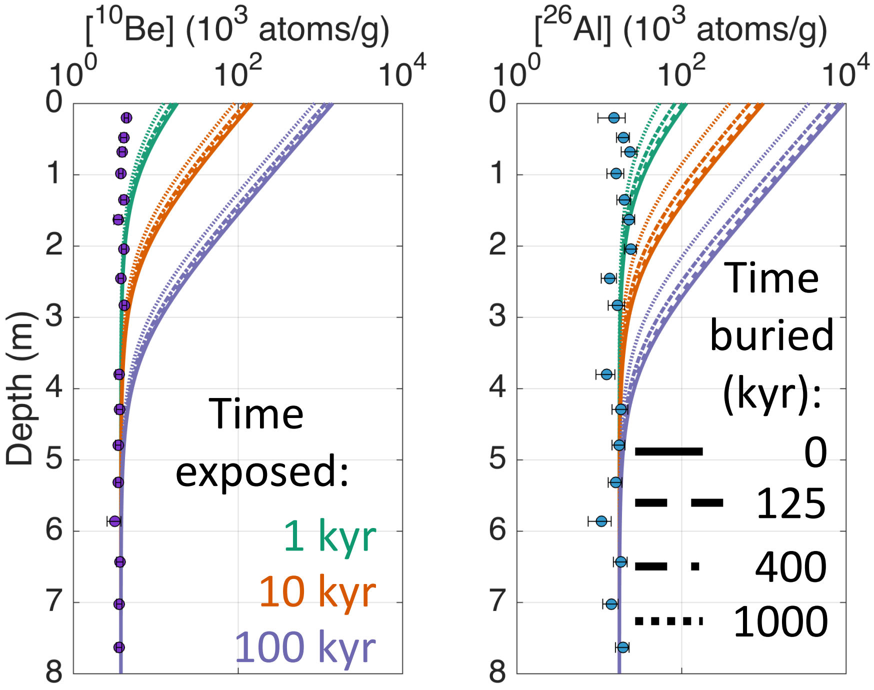
Spector et al. (2018)

Photos: J.O.H. Stone

Results:


[^{10}Be] (10^3 atoms/g)
10^0
10^2
10^4
Depth in rock (m)
0
1
2
3
4
5
6
7
8
Time exposed:
1 kyr
10 kyr
100 kyr
[^{26}Al] (10^3 atoms/g)
Time buried (kyr):
0
125
400
1000

Results:


[^{10}Be] (10^3 atoms/g)
[^{26}Al] (10^3 atoms/g)
10^0
10^2
10^4
Depth (m)
0
1
2
3
4
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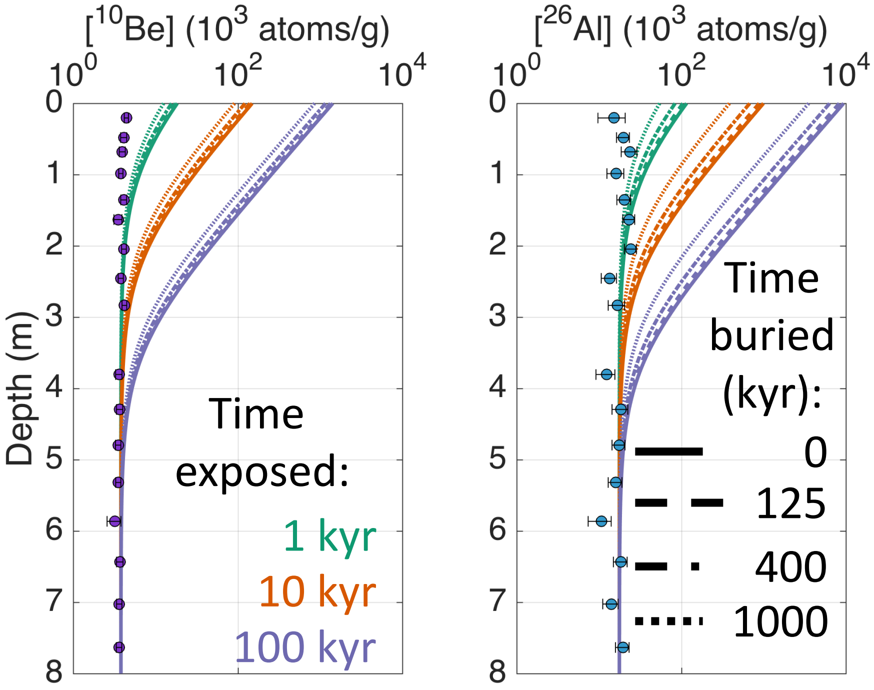
Time exposed:
1 kyr
10 kyr
100 kyr
Time buried (kyr):
0
125
400
1000

Results: Ice has not thinned by ≥150 m

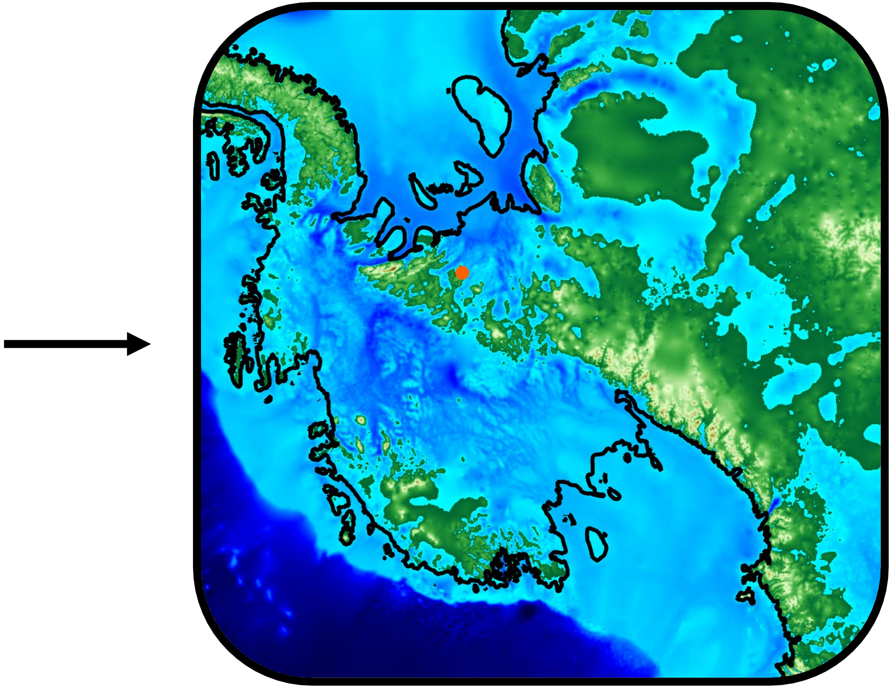


- Vertical profile consistent with millions of years of nuclide production under ~200 m of ice
  - → Average ice sheet is thicker than present

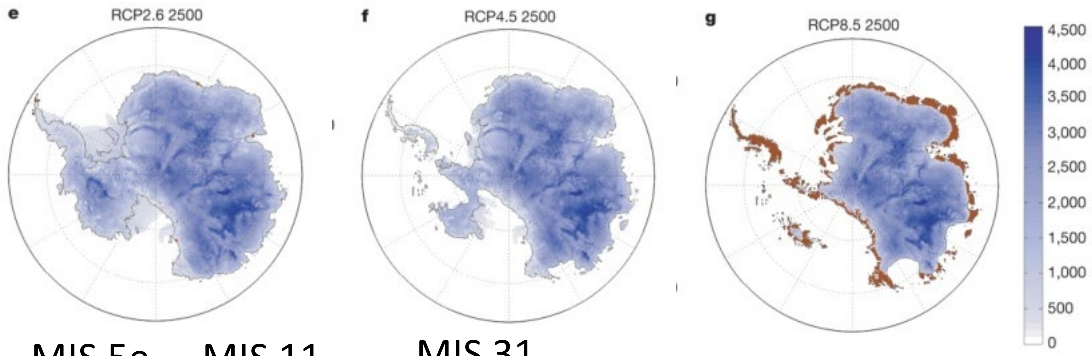
- **This rock has not been exposed at the surface in ≥ 2.5 million years.**

Ice around the Pirrit Hills has not thinned by ≥150 m during the Pleistocene.

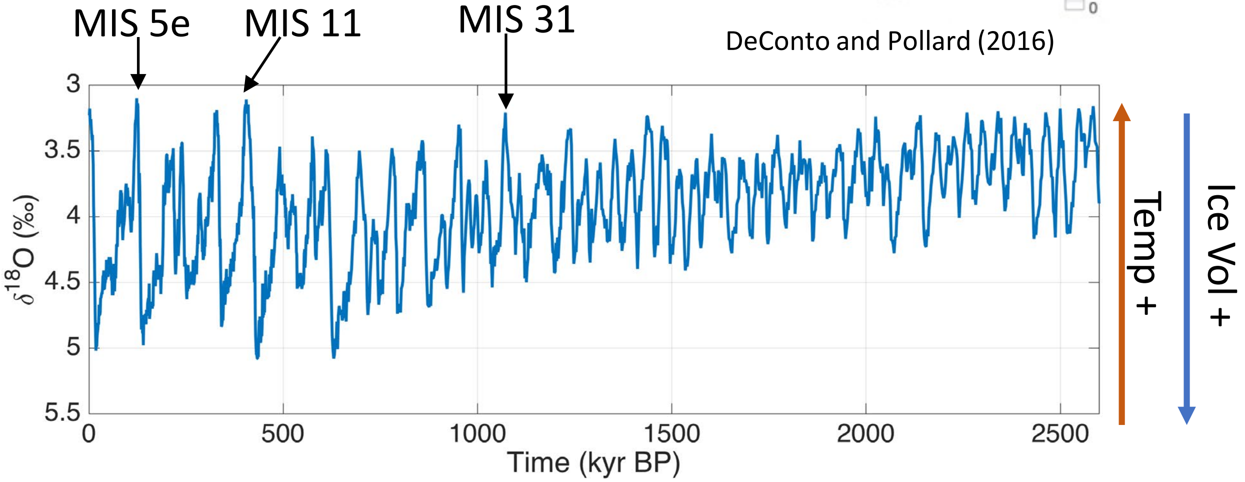
What does this mean for the West Antarctic Ice Sheet?



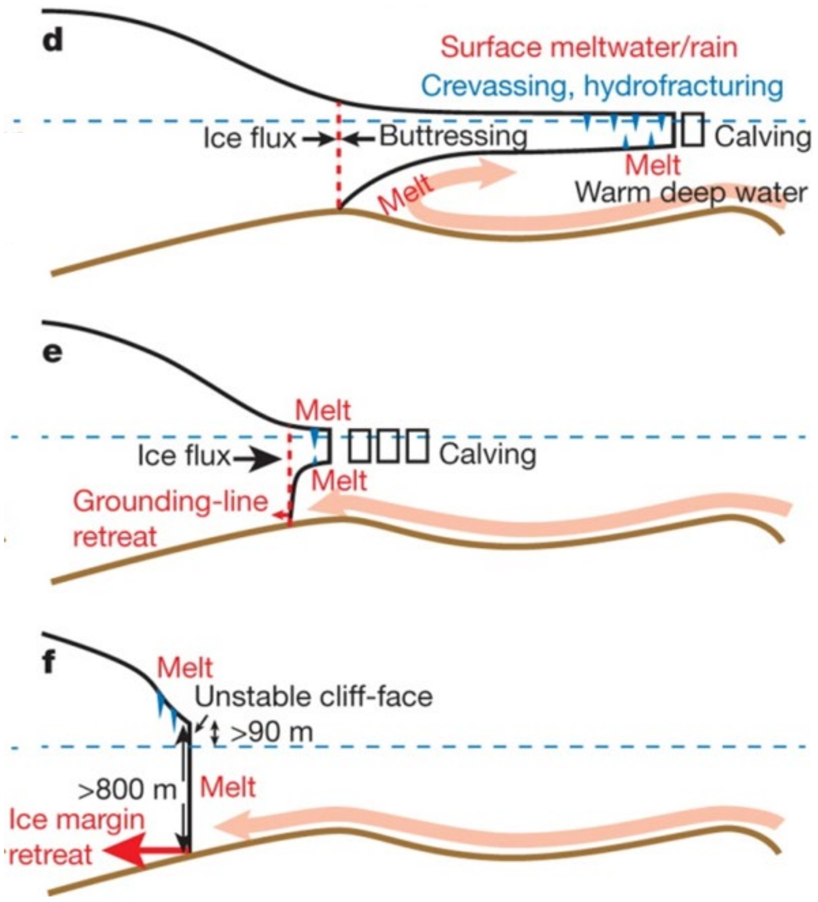
- Penn State ice sheet model
- 3 warm interglacial periods: Marine Isotope Stages 5e, 11, and 31
- 20 km WAIS ice sheet-shelf model, nested within 40 km continental runs
- 540 model runs (90 parameter combinations, 3 time-periods, 2 resolutions)
- Simple modification of LGM-to-present ocean and present atmosphere using benthic $\delta^{18}O$ and insolation



DeConto and Pollard (2016)



Lisiecki and Raymo (2005)

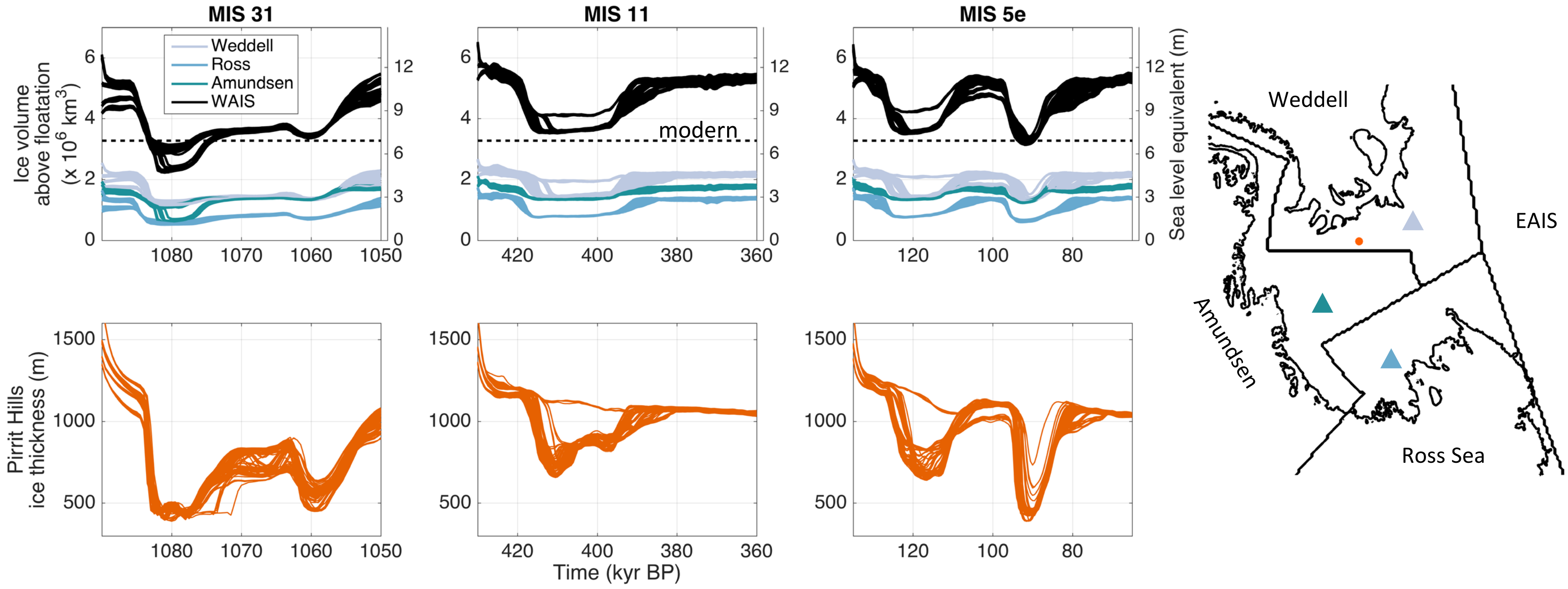


DeConto & Pollard (2016)

Model Ensemble

- 3 ice shelf hydro-fracture coefficients (including zero)
- 3 sub-shelf melt scalings
- 2 isostatic rebound timescales
  - 1,500 and 3,000 years
- 3 maximum cliff failure rates
  - 0, 3, 10 km/yr
- 3 values for basal sliding on modern seafloor
  - 10^{-4} (slippery), 10^{-5}, 10^{-6} (resistant)

Results: Pirrit Hills ice thickness and WAIS volume



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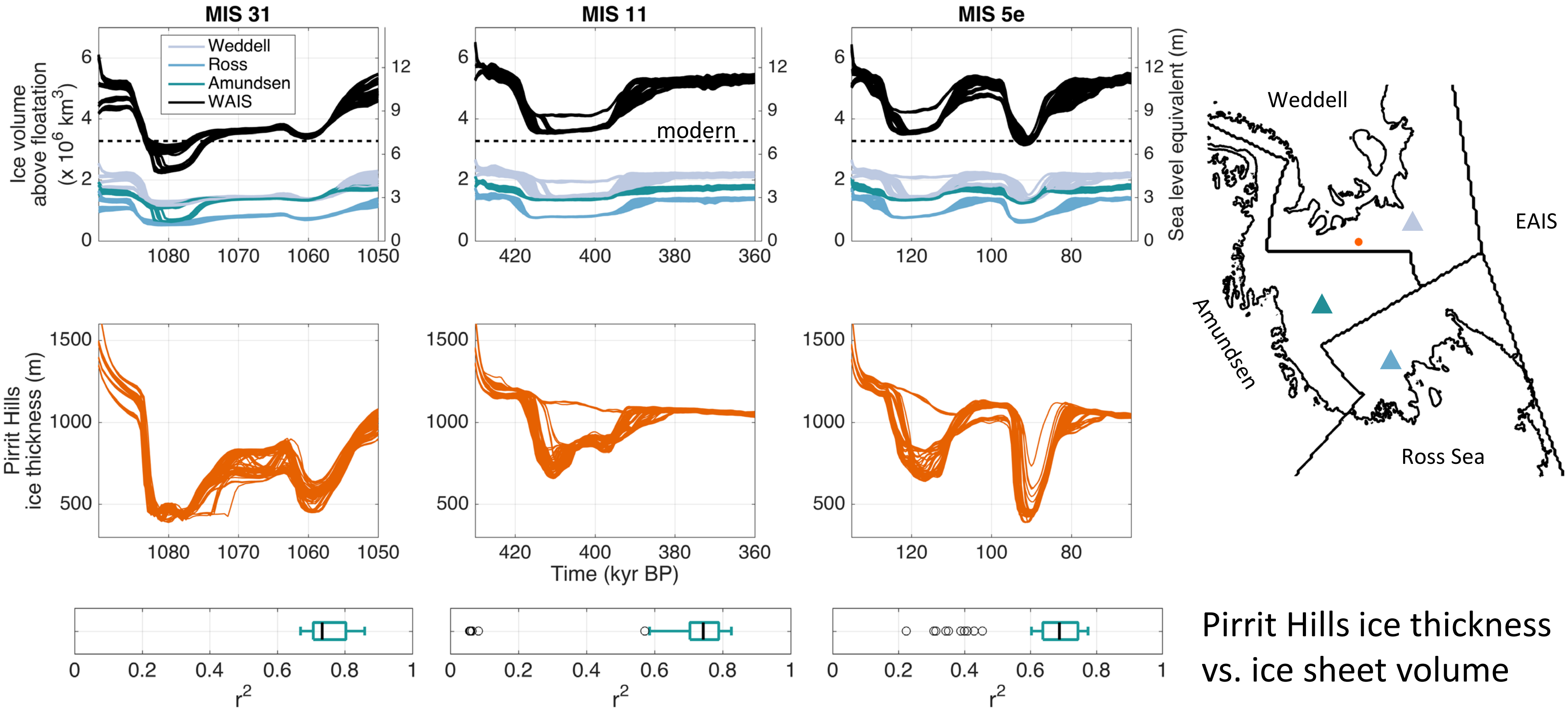
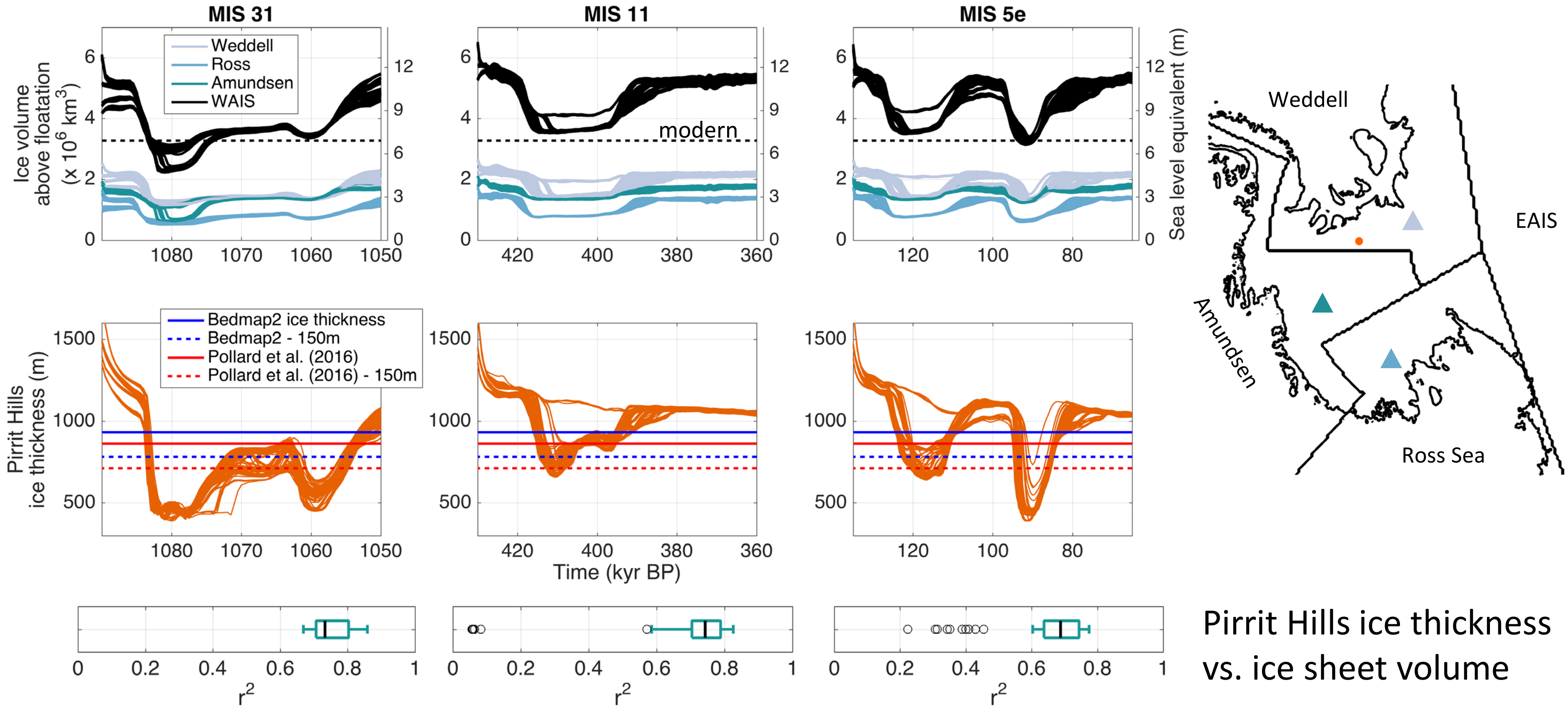


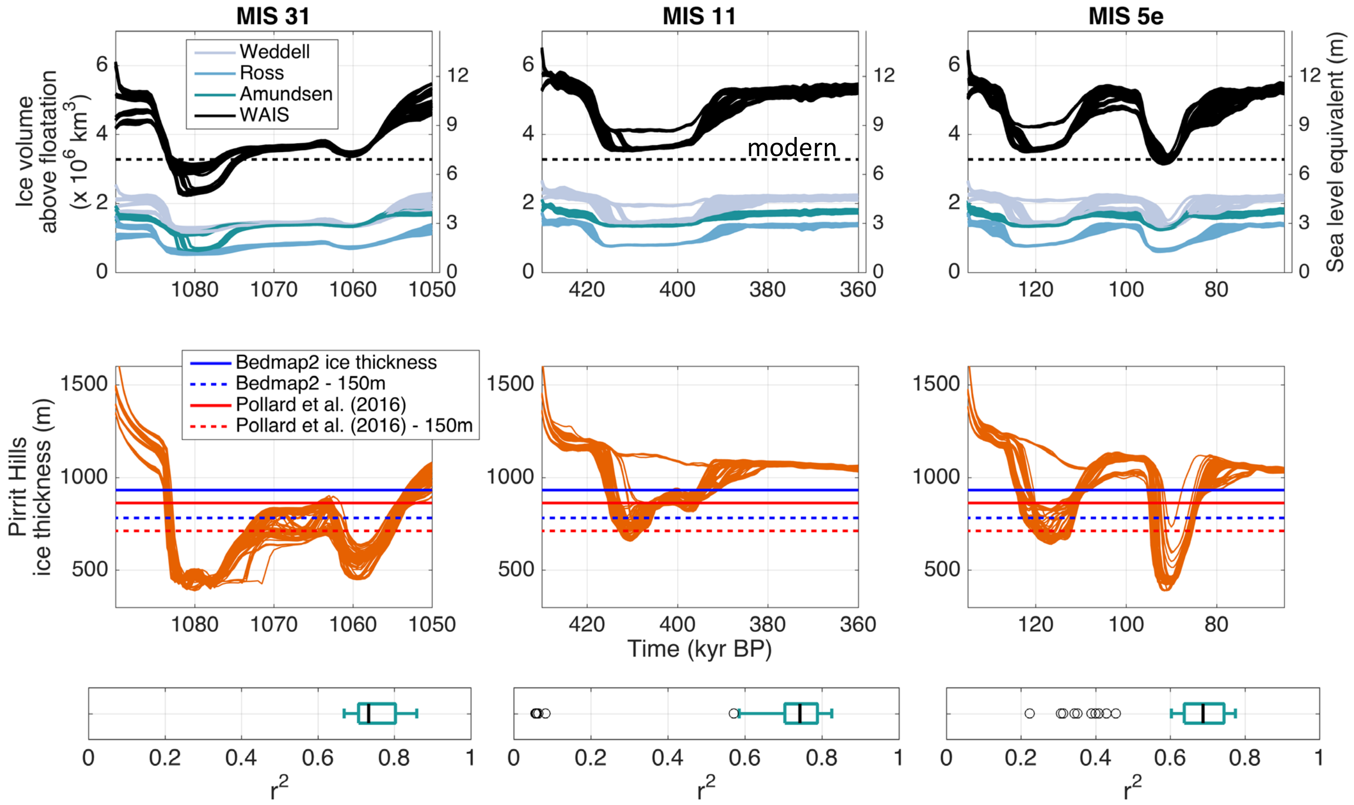
Pirrit Hills ice thickness vs. ice sheet volume

Results: Pirrit Hills ice thickness and WAIS volume



Pirrit Hills ice thickness vs. ice sheet volume

Results: Pirrit Hills ice thickness and WAIS volume



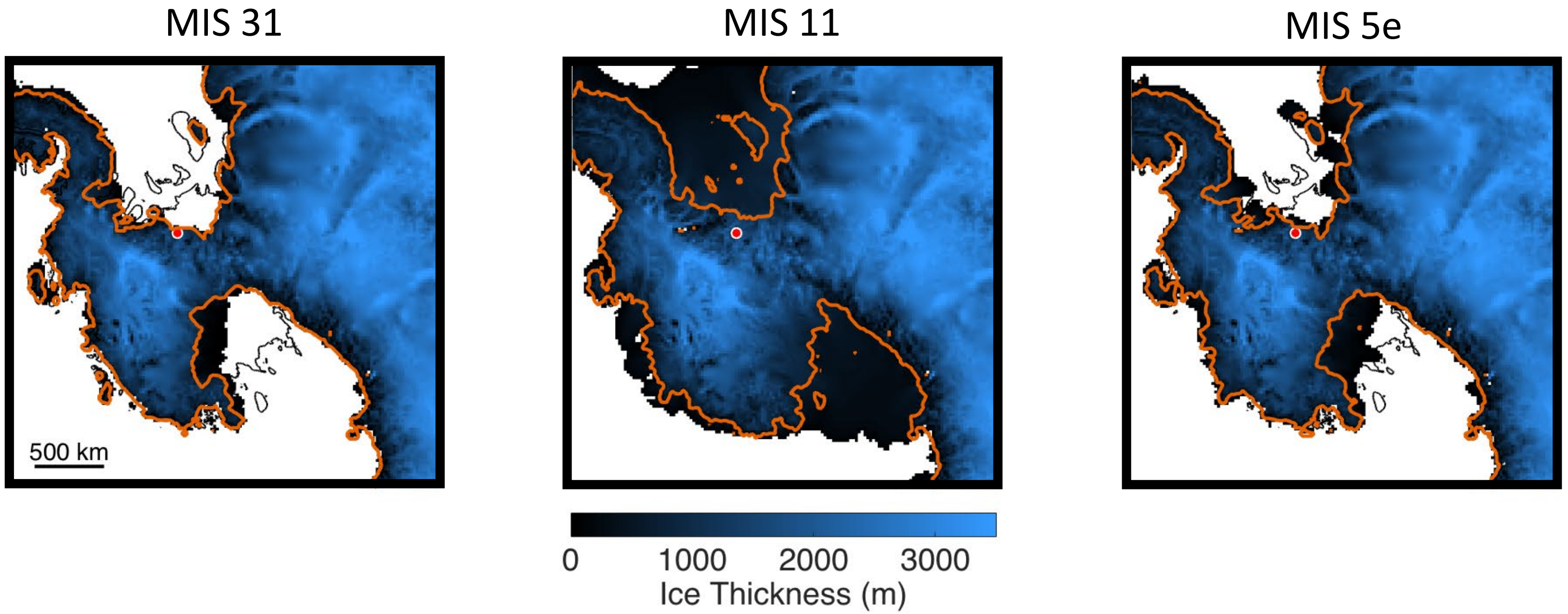
Takeaways:

1) Modeled ice thickness at the Pirrit Hills is a good predictor of ice-sheet volume.

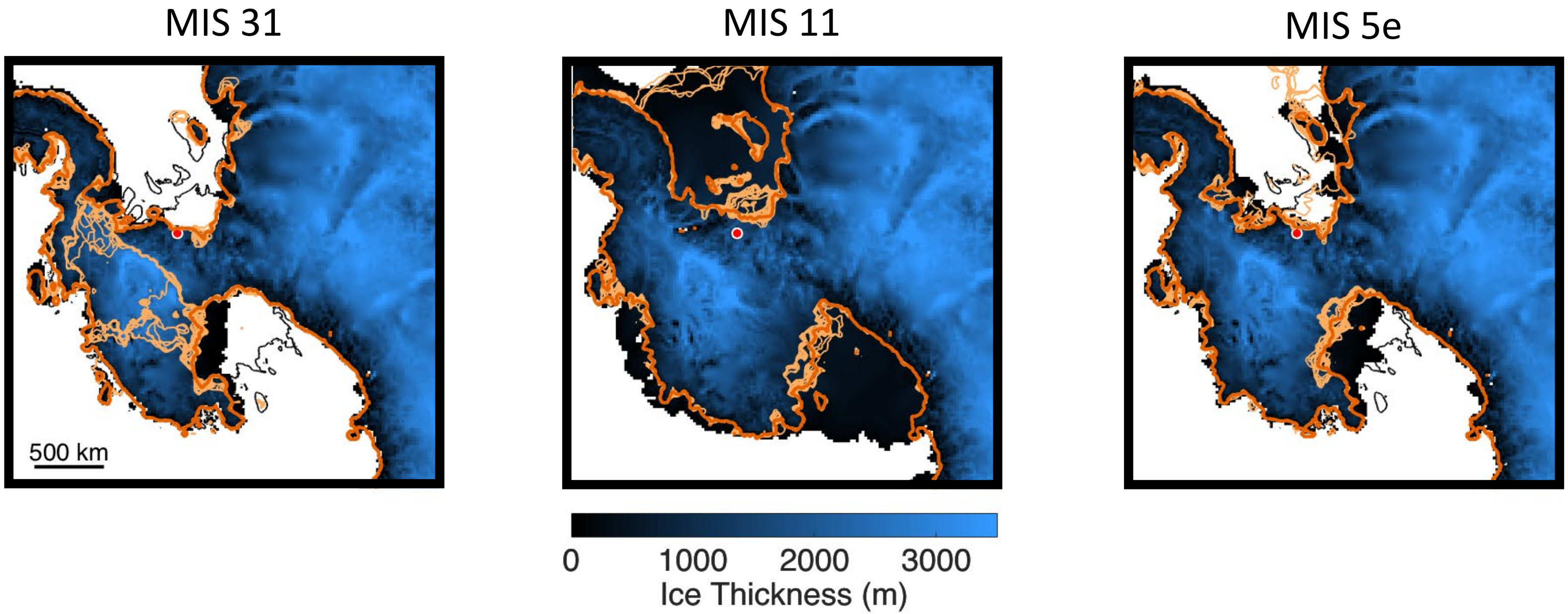
2) But model results disagree with isotope results!

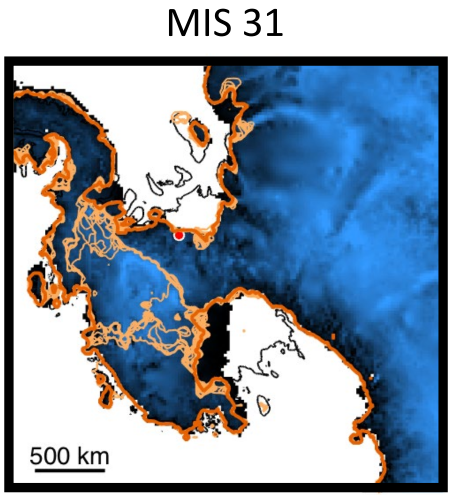
Pirrit Hills ice thickness vs. ice sheet volume

Large retreat, but not full collapse



Okay, a few collapses

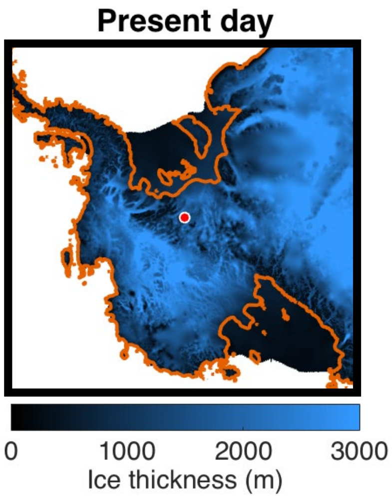




Collapses require:

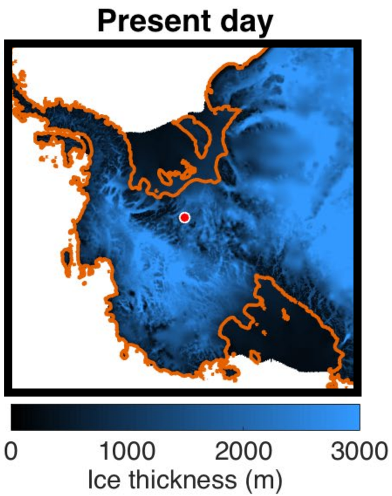
- Increased ice shelf melt
- Ice shelf hydro-fracture
- Ice cliff collapse
- 3,000 year rebound timescale
- A resistant bed over modern seafloor

Sensitivity to other patterns of collapse



- PISM model forced with modern melt rates in Amundsen Sea (Feldmann & Levermann, 2015)

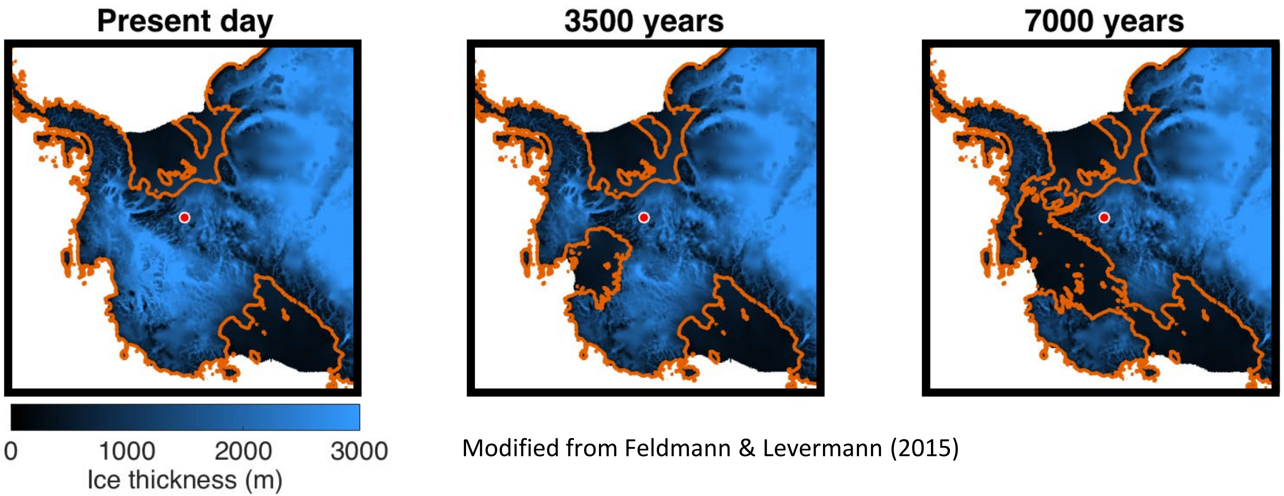
Sensitivity to other patterns of collapse



Modified from Feldmann & Levermann (2015)

- PISM model forced with modern melt rates in Amundsen Sea (Feldmann & Levermann, 2015)

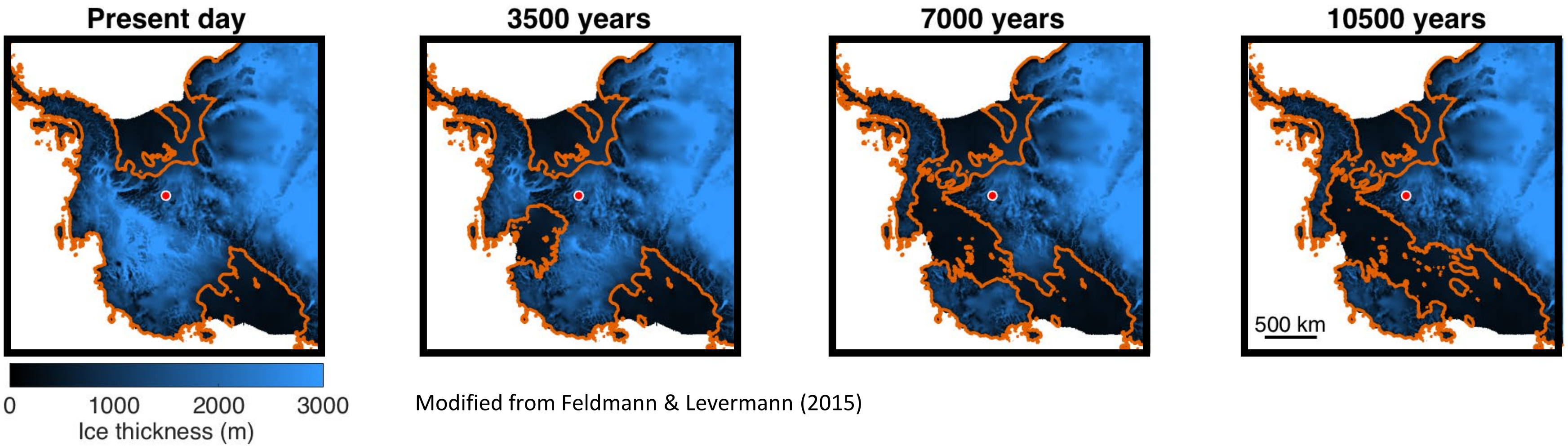
Sensitivity to other patterns of collapse



Modified from Feldmann & Levermann (2015)

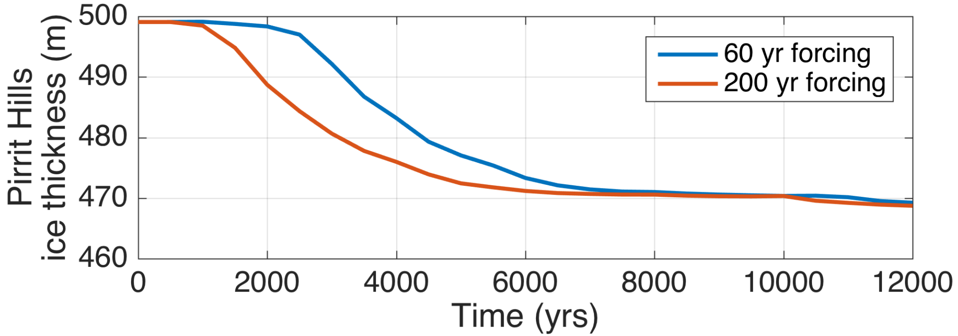
- PISM model forced with modern melt rates in Amundsen Sea
- >60 years elevated melt causes full WAIS collapse

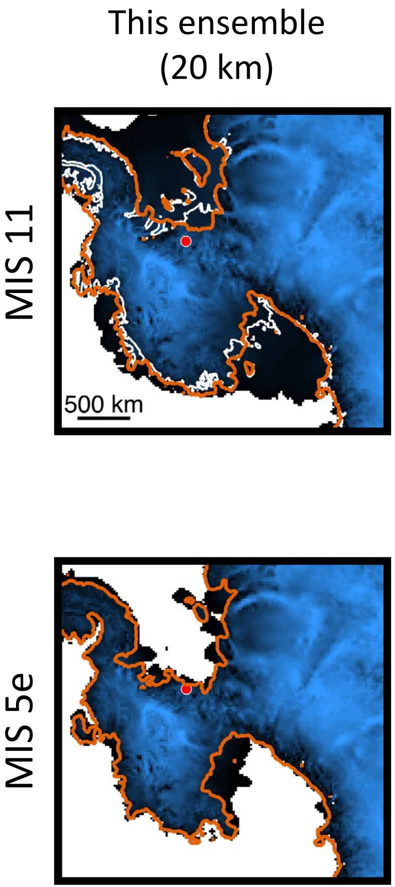
Sensitivity to other patterns of collapse

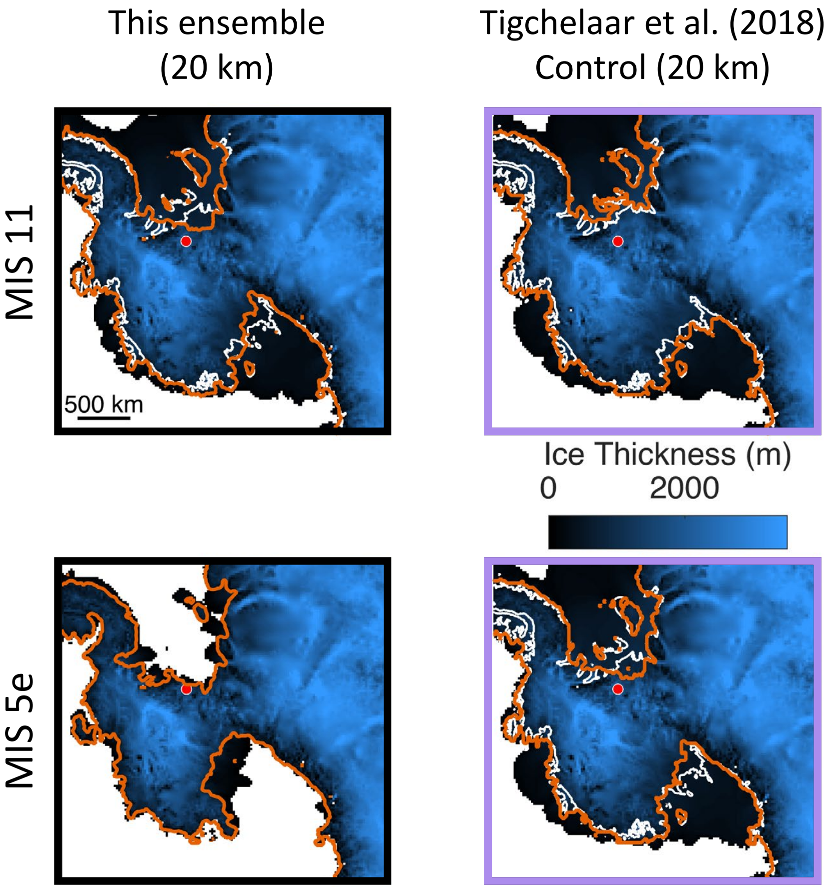


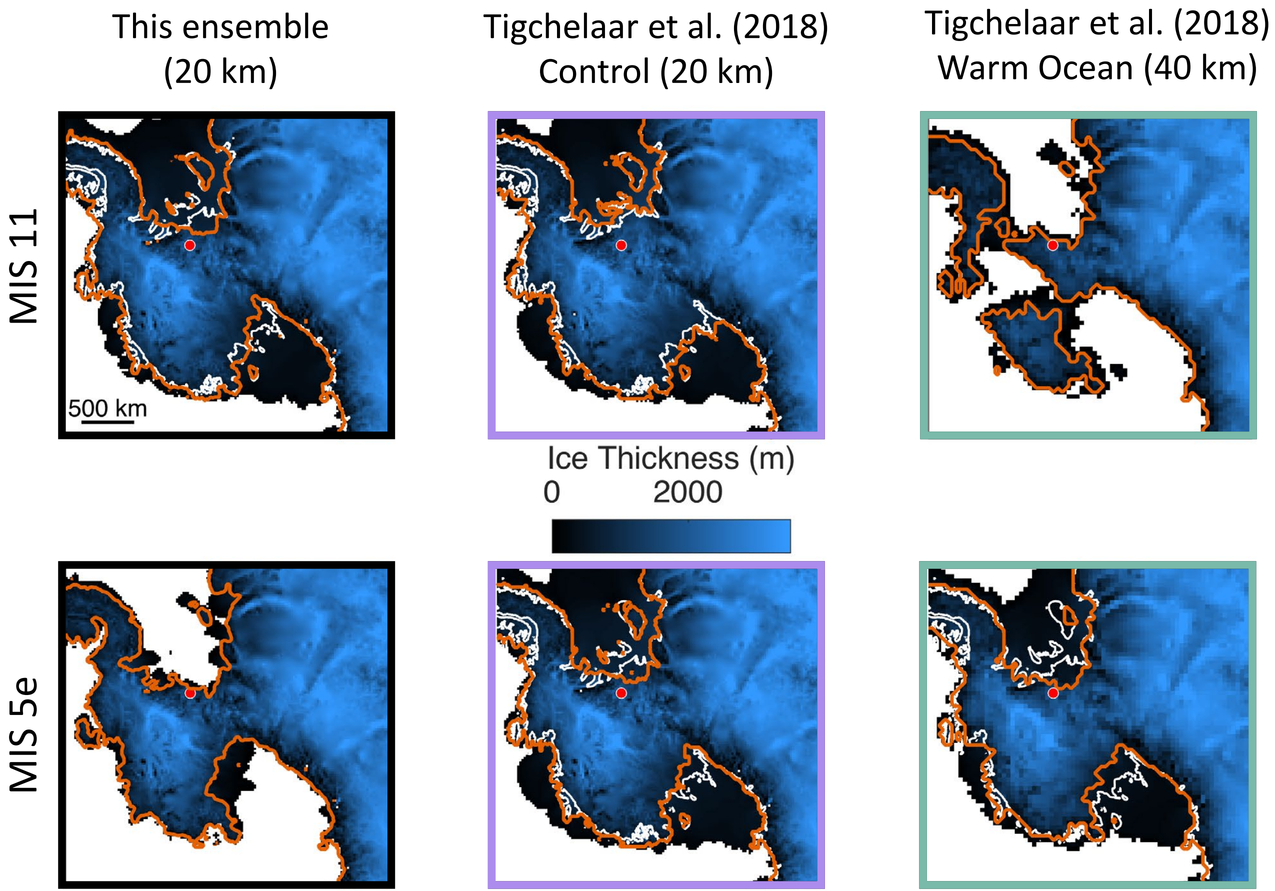
Modified from Feldmann & Levermann (2015)

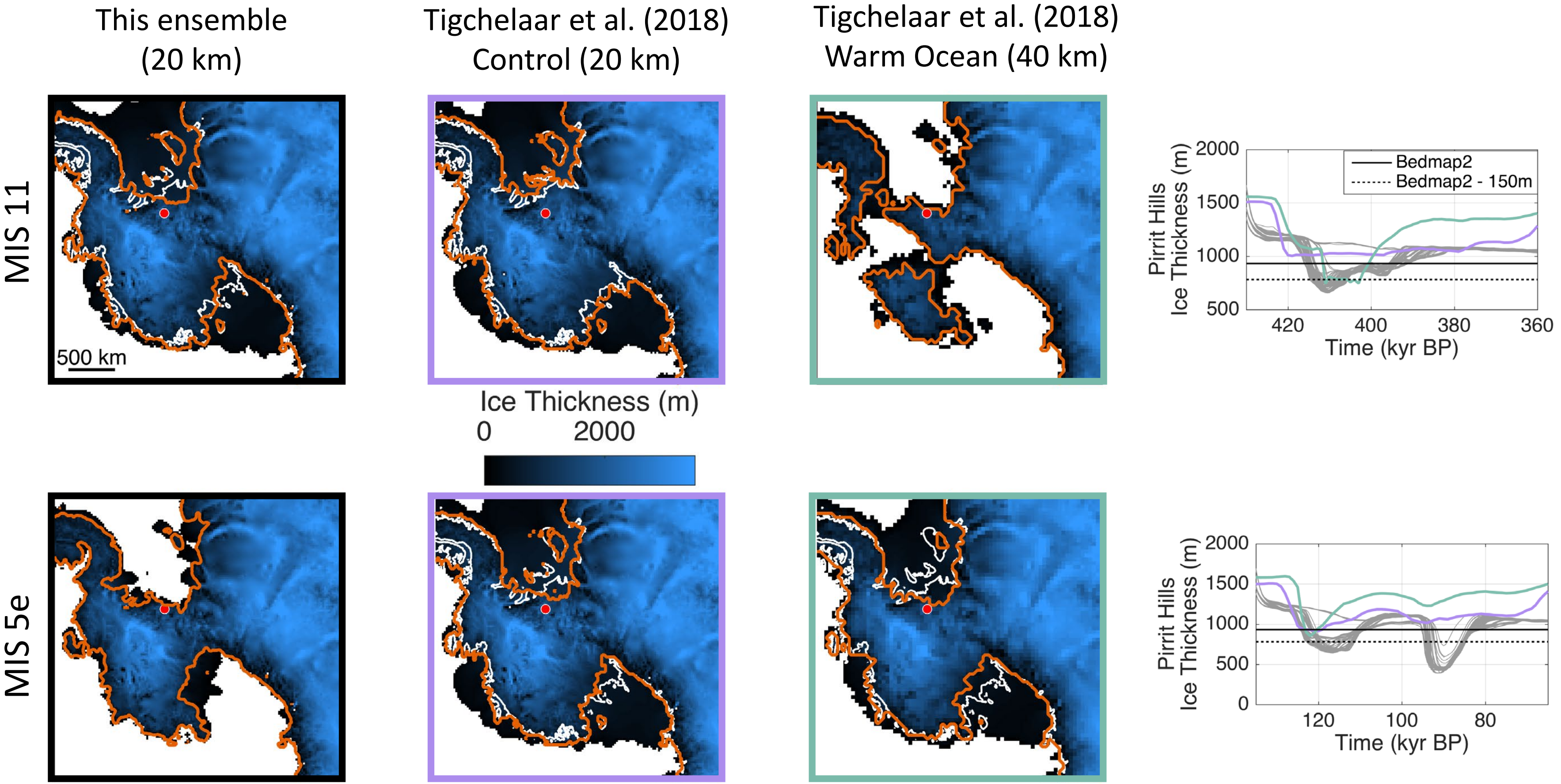
- PISM model forced with modern melt rates in Amundsen Sea
- >60 years elevated melt causes full WAIS collapse
- **No loss of ice shelves → No large change at Pirrit Hills**




This ensemble
(20 km)
MIS 11
500 km
MIS 5e


This ensemble
(20 km)
Tigchelaar et al. (2018)
Control (20 km)
MIS 11
MIS 5e
500 km
Ice Thickness (m)
0
2000


This ensemble
(20 km)
Tigchelaar et al. (2018)
Control (20 km)
Tigchelaar et al. (2018)
Warm Ocean (40 km)
MIS 11
MIS 5e
500 km
Ice Thickness (m)
0
2000

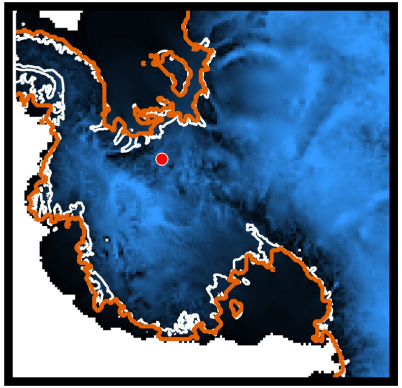


This ensemble
(20 km)
Tigchelaar et al. (2018)
Control (20 km)
Tigchelaar et al. (2018)
Warm Ocean (40 km)
MIS 11
MIS 5e
500 km
Ice Thickness (m)
0
2000
Bedmap2
Bedmap2 - 150m
Pirrit Hills
Ice Thickness (m)
2000
1500
1000
500
420
400
380
360
Time (kyr BP)
Pirrit Hills
Ice Thickness (m)
2000
1500
1000
500
0
120
100
80
Time (kyr BP)

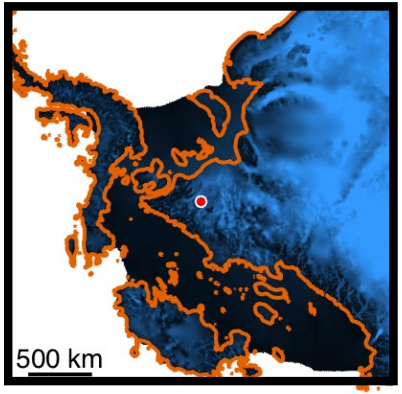
Conclusions

- Ice around the Pirrit Hills has not been 150 m thinner than today in the last few million years
- Ice thickness at the Pirrit Hills is a good predictor of WAIS volume.
  - Large drawdowns at Pirrit Hills require ice shelf loss
- Model ensemble results suggest that if the WAIS *and its ice shelves* collapsed in the last few million years, we should see a signal in Pirrit Hills bedrock.

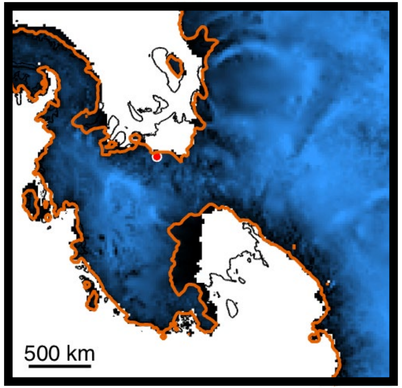
Conclusions



or



, but not




Eskimo
A 15
A09