Interactions between ice sheets from Greenland to Antarctica

ice sheets as interactive components

Christian Rodehacke[1,2], Lars Ackermann[1], Paul Gierz[1], Shuting Yang[2], Gerrit Lohmann[1]

1) Alfred Wegener Institute for Polar and Marine Reserach (AWI)
2) Danish Meteorological Institute (DMI)

Polar Science Week, 2024-09-05. Copenhagen, Denmark

THIS PROJECT HAS RECEIVED FUNDING FROM THE EUROPEAN UNION'S HORIZON 2020 RESEARCH AND INNOVATION PROGRAMME UNDER GRANT AGREEMENT 869304.
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Coupling: AWI-ESM with 2 x PISM

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- Northern hemisphere
- Greenland domain
- Paleo Ice sheet: Northern hemisphere domain

Climate Model

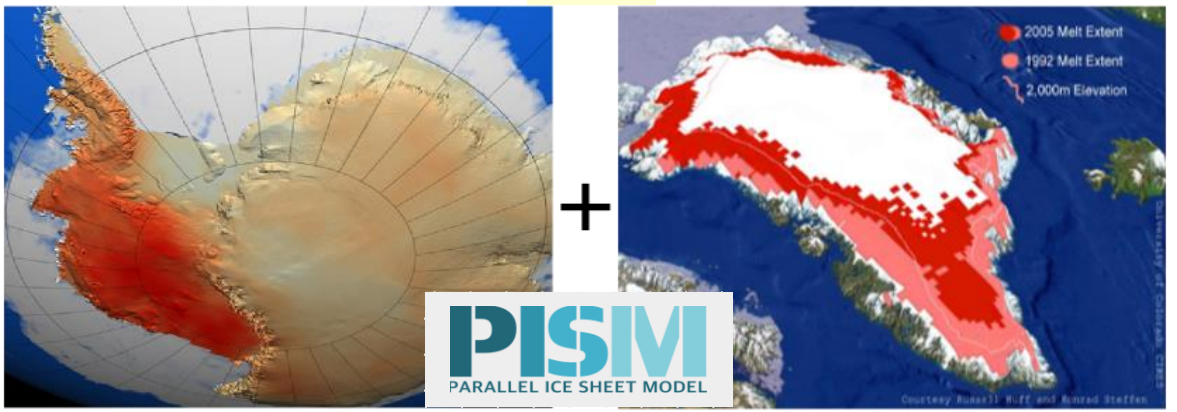
Atmosphere and Ocean Forcing

A

B

Antarctica

Greenland



Ice sheet model

Meltwater is routed by the hydrological scheme and enters the ocean at the surface.

Runoff
Topography
etc

PISM
PARALLEL ICE SHEET MODEL

HELMHOLTZ ASSOCIATION

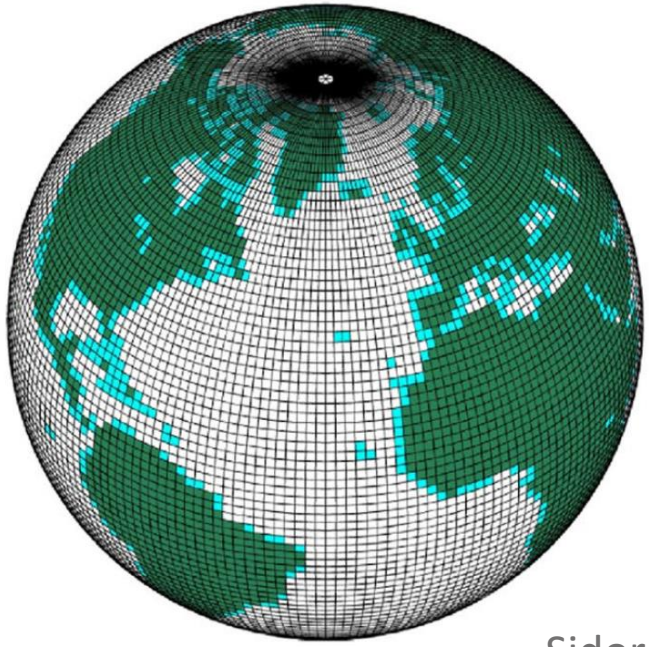
AWI-ESM2.x: ECHAM6 & FESOM2

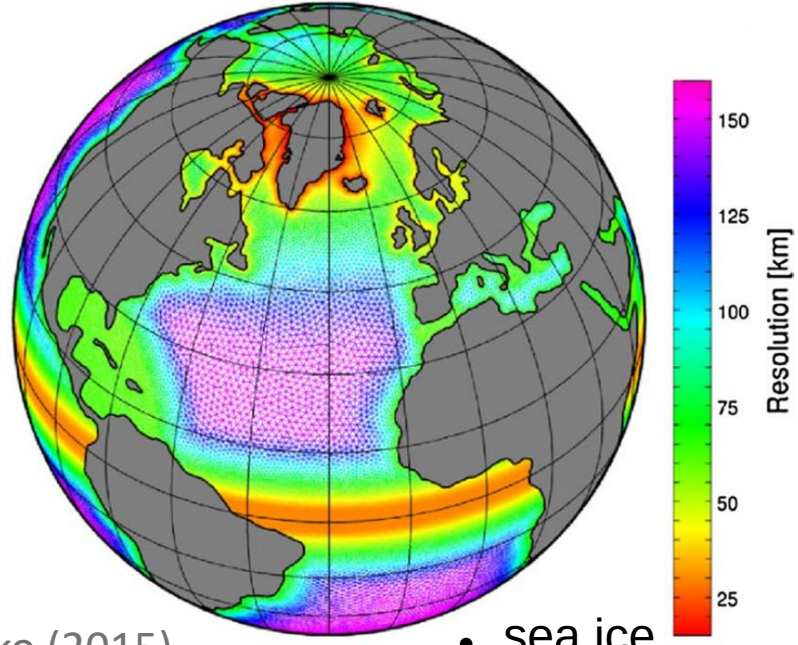
Climate Model

A

ECHAM6: T63L47
~ 1.85°

FESOM2: L47
~ 20–120 km





Including
- JSBACH
- Hydrological discharge

Sidorenko (2015)

- sea ice

PISM: Parallel Ice Sheet Model

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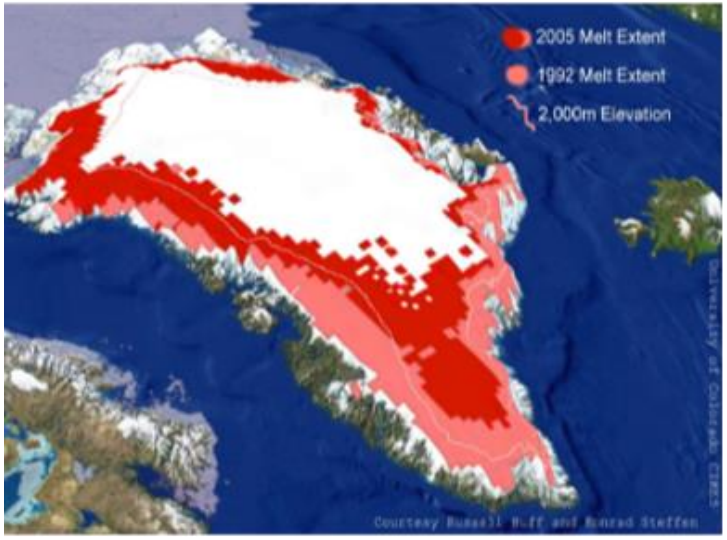
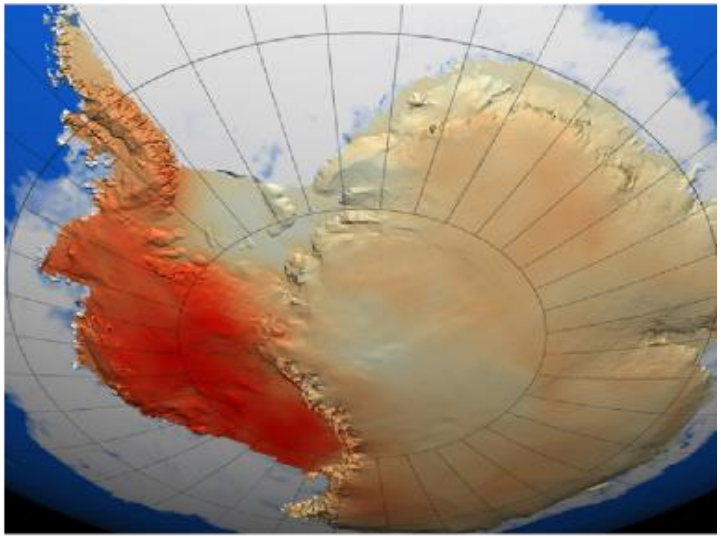


B

PISM
PARALLEL ICE SHEET MODEL

<u>Approximations</u>

- SIA
- SSA



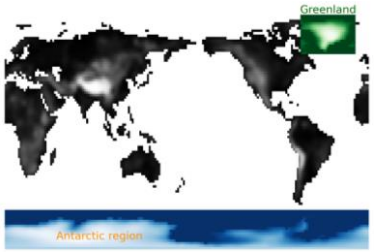
- 5 km resolution
- SMB: dEBM (Krebs-Kanzow, 2021)
- Ocean melt: temp/salt via 3Eqn.
- Calving: Eigen, Thickness (200), mask

- 8 km resolution
- SMB: PPD
- Ocean melt: temp/salt via ice shelf pump (PICO)
- Calving: Eigen, Thickness (75), mask

Freely evolving ice shelf edges (*troubling*)

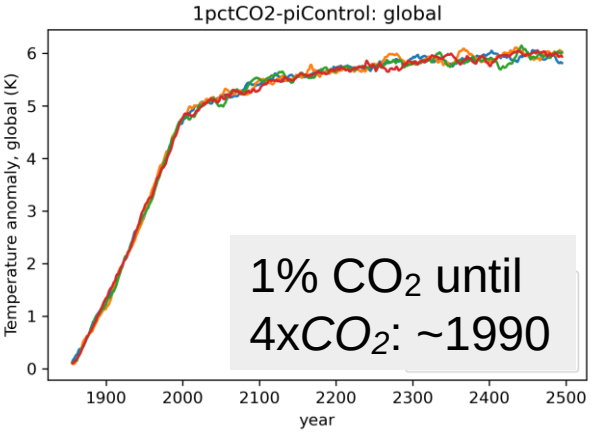
1pct4CO2 scenario

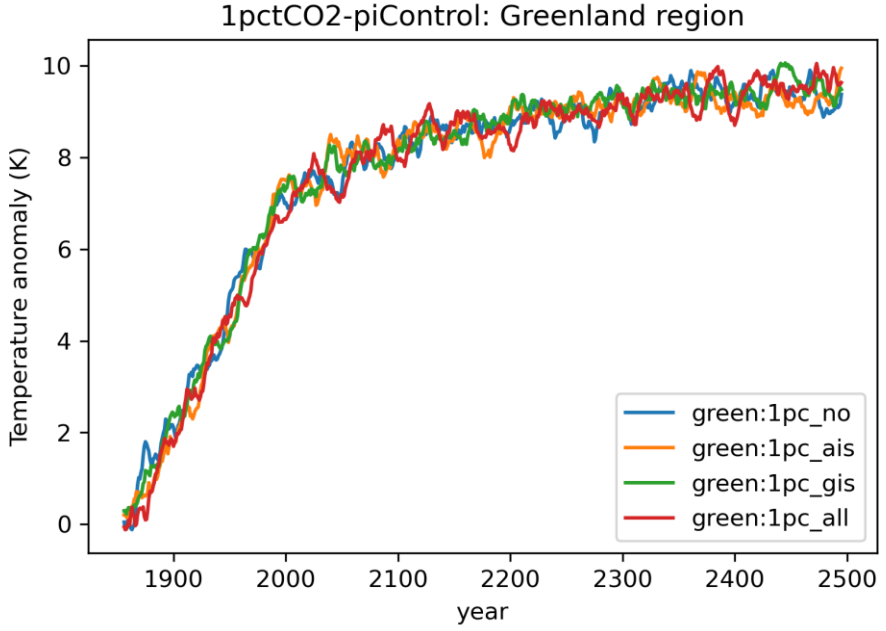
2m air temperature

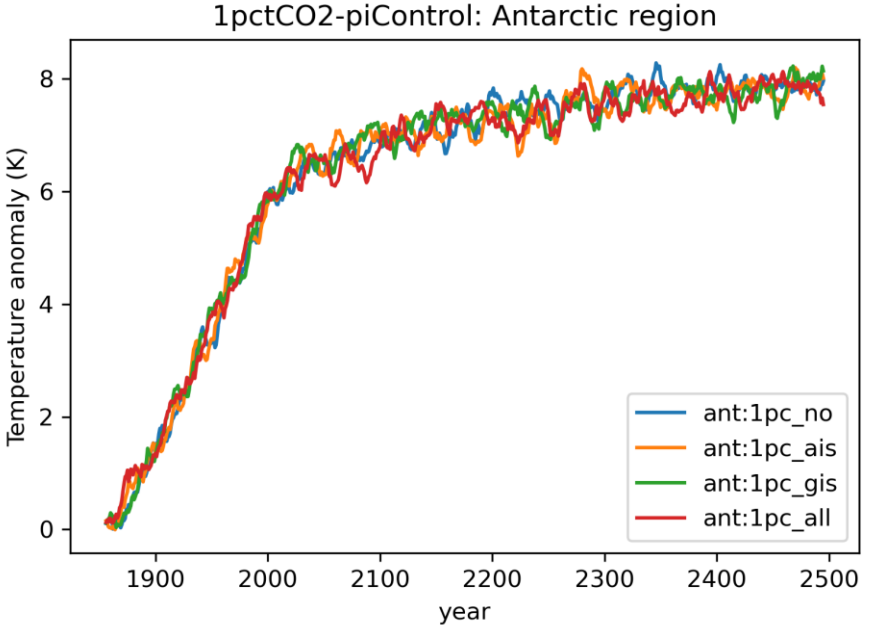


Simulations

- No interacting ice sheets
- Antarctica interacts
- Greenland interacts
- Both (AIS+GIS) interact





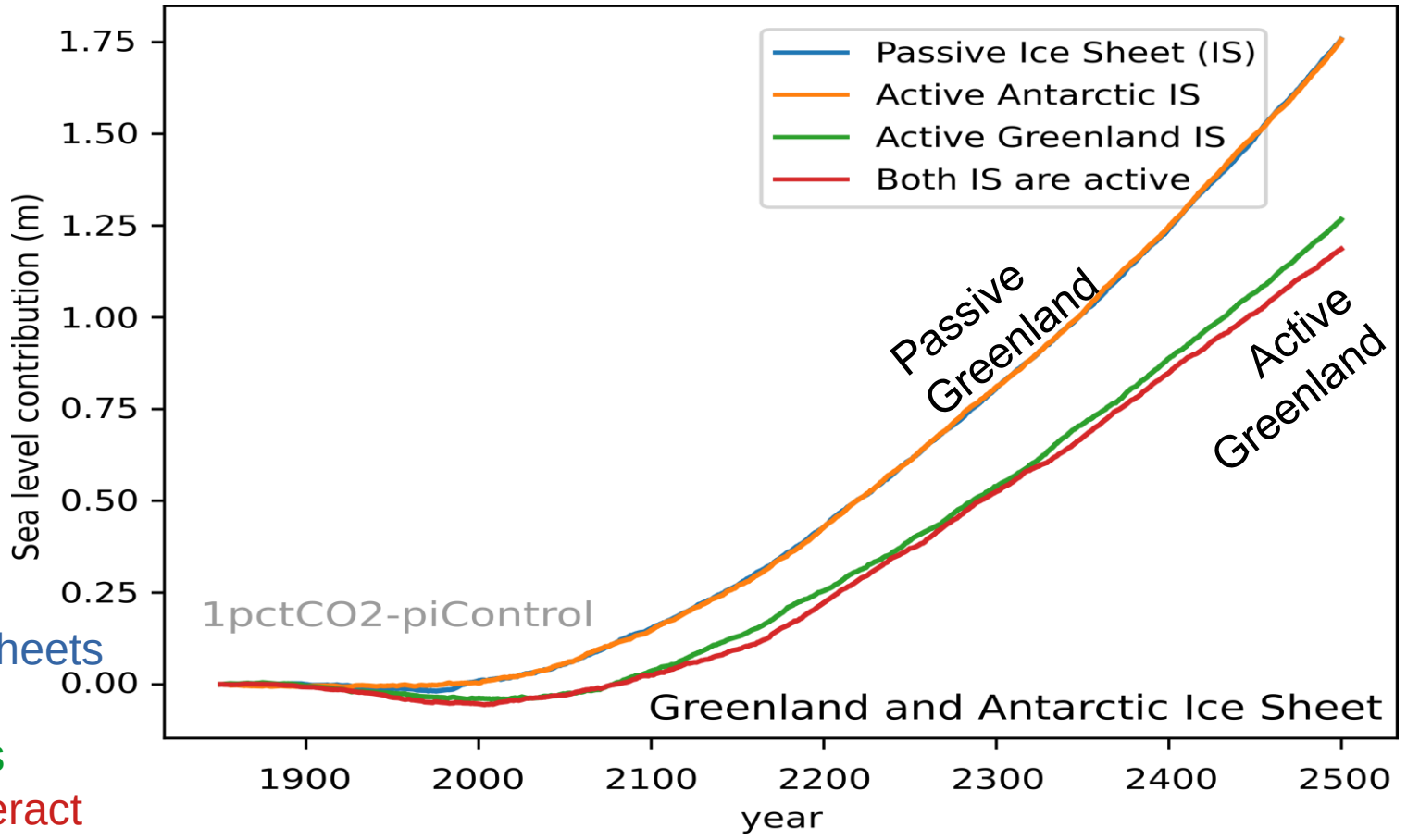


Global Sea Level Contribution I

Combined contribution under 1% raising atmospheric CO_2 concentration until 4 * CO_2 – reached 1990

Subtracted trend of control run.

- No interacting ice sheets
- Antarctica interacts
- Greenland interacts
- Both (AIS+GIS) interact

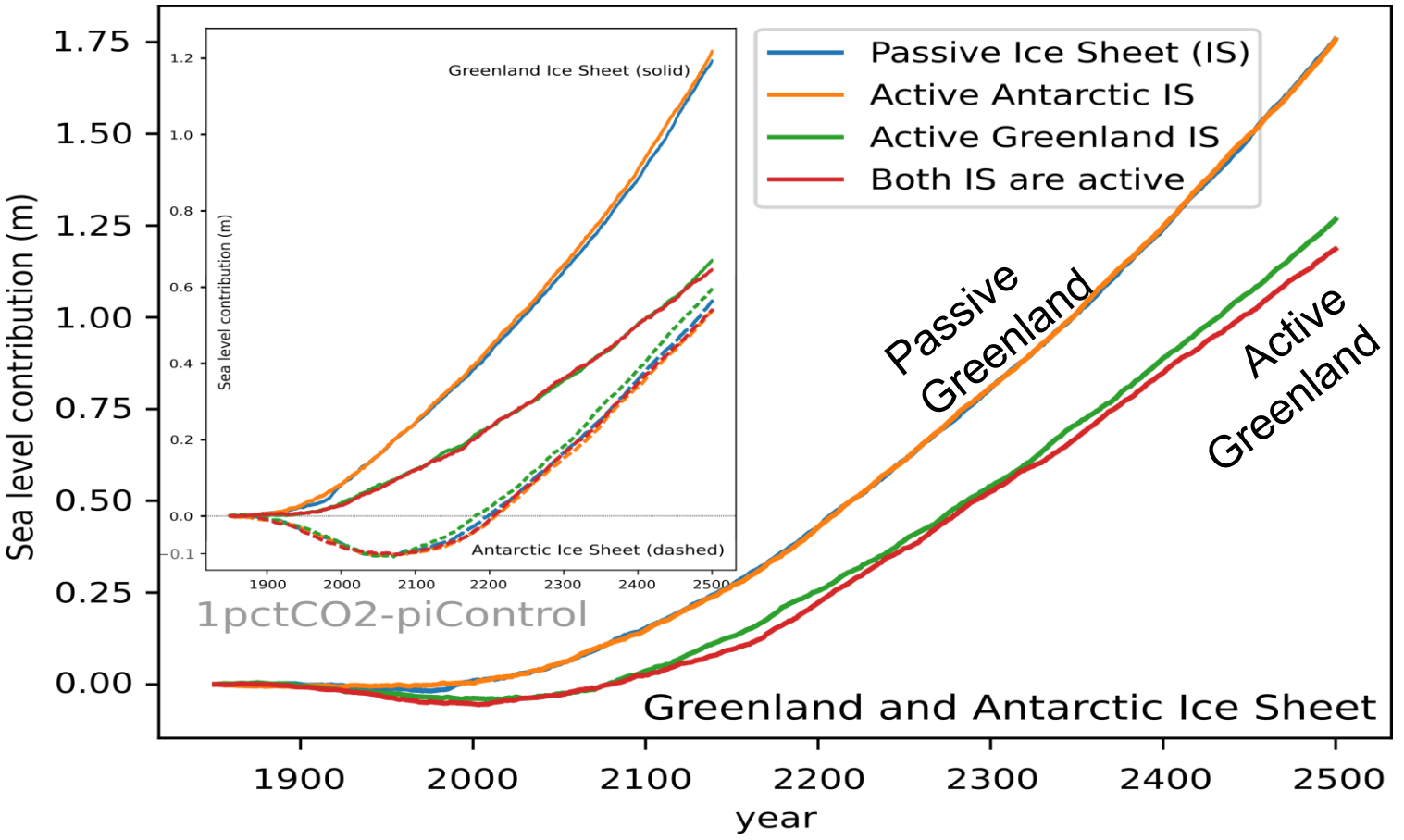


Global Sea Level Contribution II

Greenland losses ice from the start by enhanced surface melting.

Antarctica gains first mass before mass loss takes over.
- Redistribution

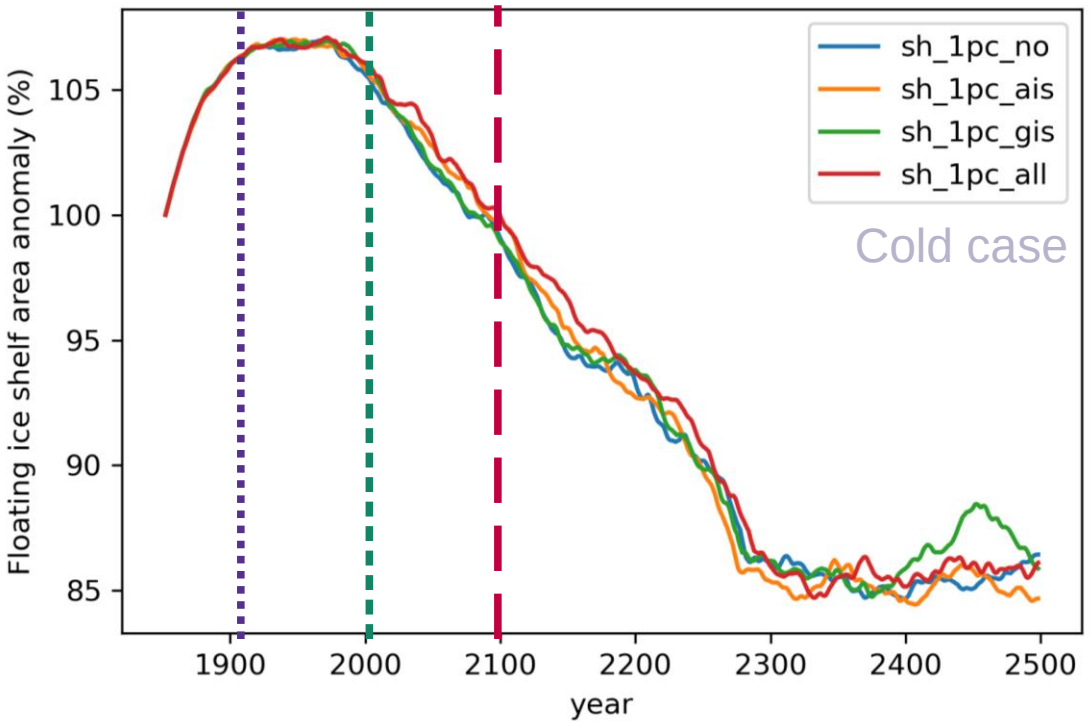
Passive Greenland outpaces other combination



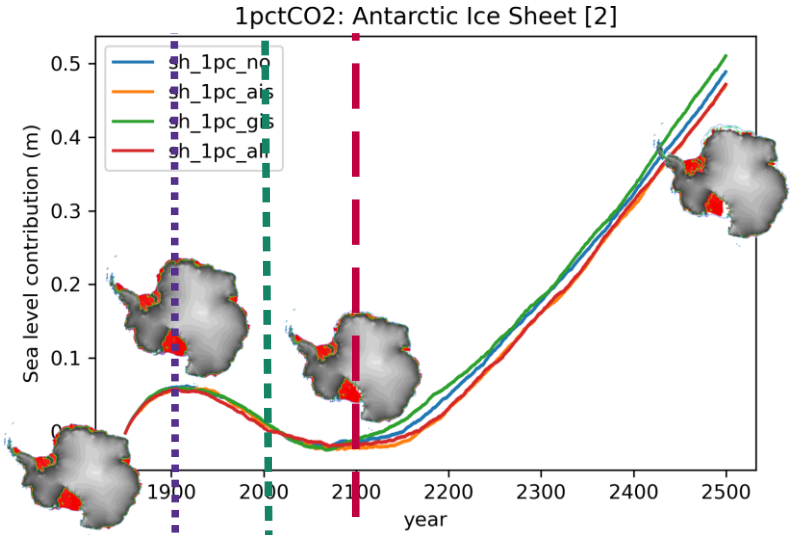
Ice mass vs sea level

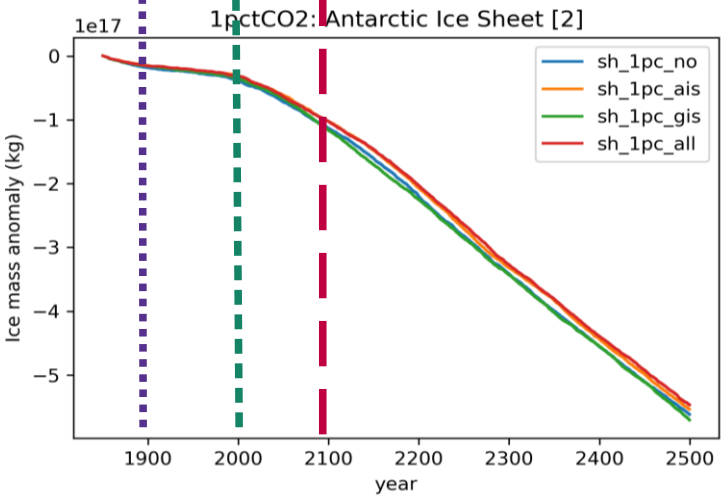
Antarctic Ice Sheet

w/o subtration of control trend

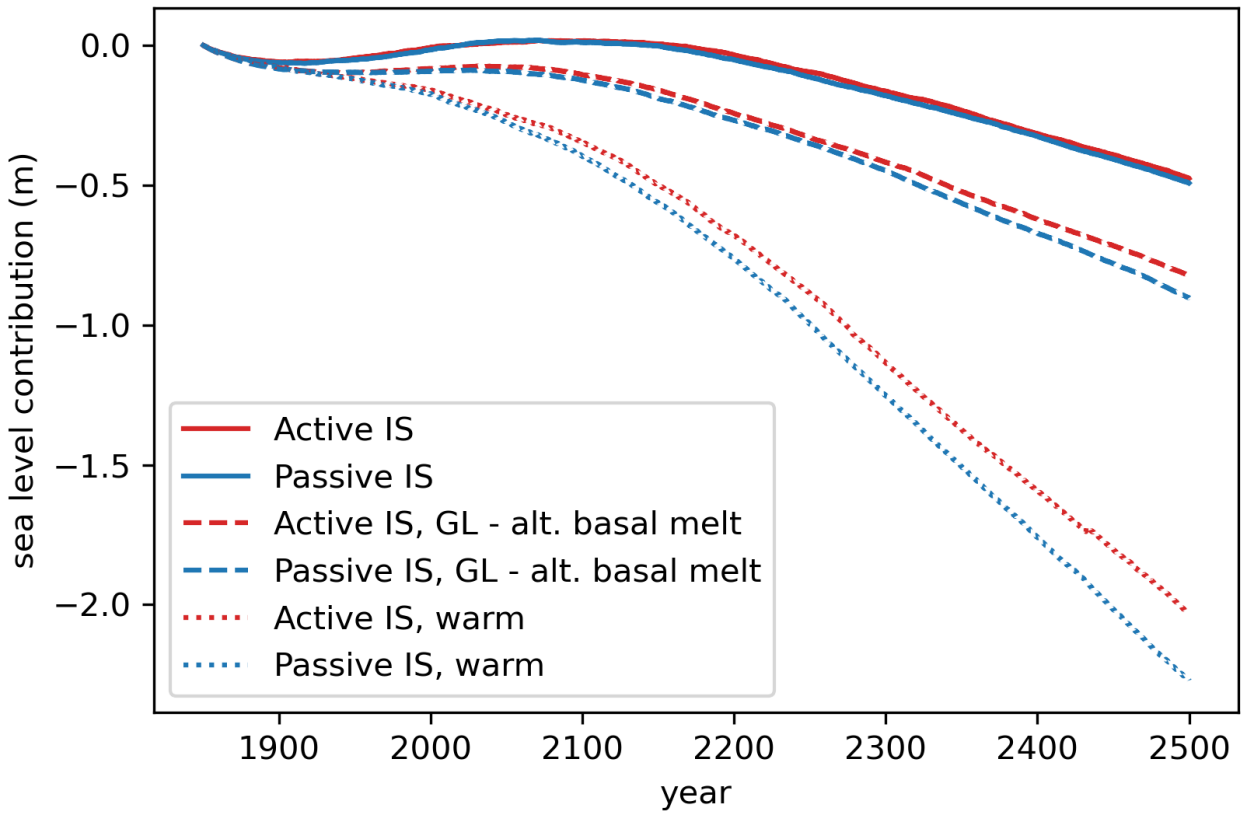


Rearrangement of mass between grounded and floating ice



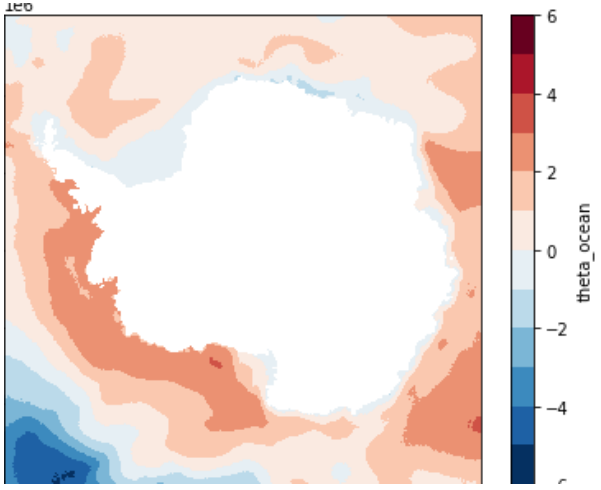


Antarctica's sea level: sensitivities



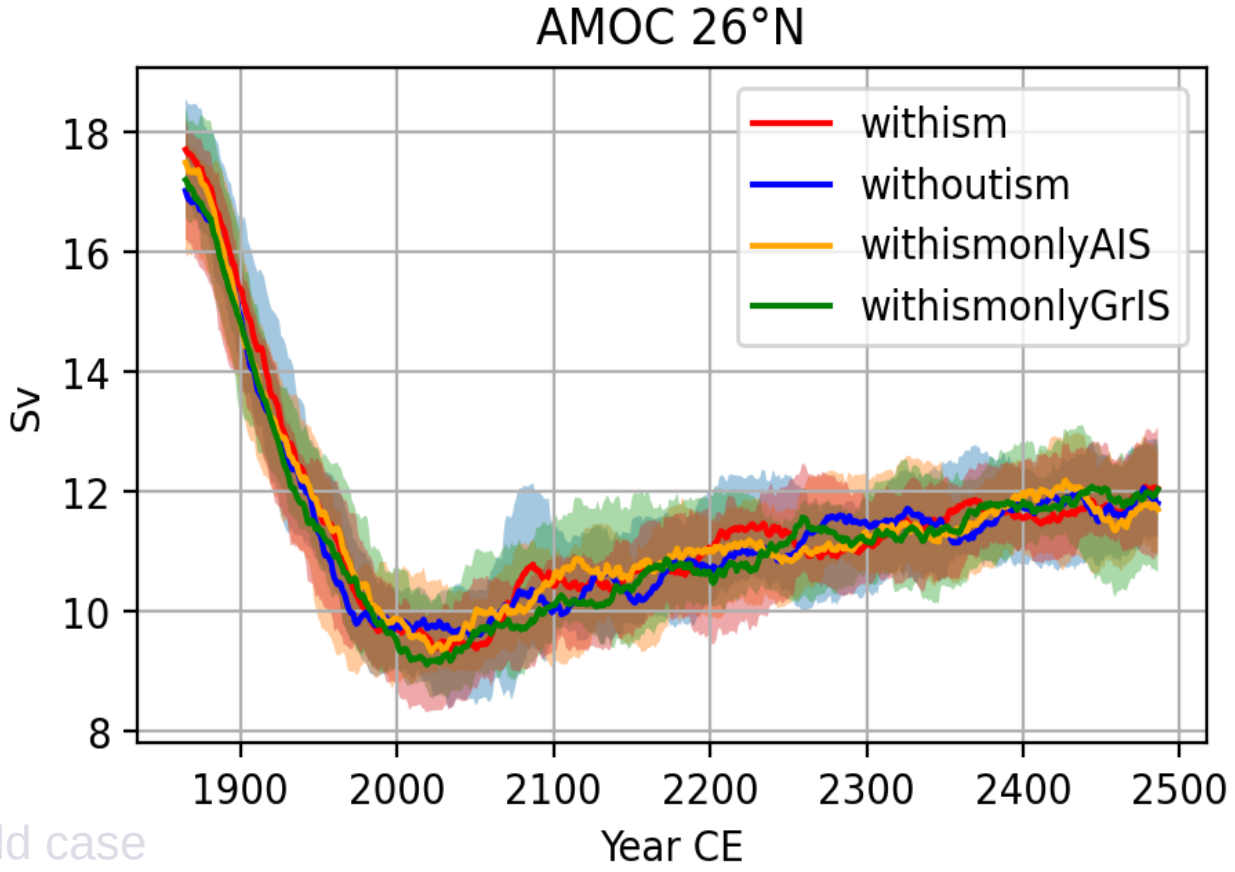
Grounding line - basal melt

- Floating fraction
- Floating/grounding fraction



Warm Anomaly ocean temperature

AMOC as driver of Greenland divergence?



Cold case

Ackermann (2024, per comm.)

Warming upper ocean
→increased stratification
→less deep convection
→reduced AMOC

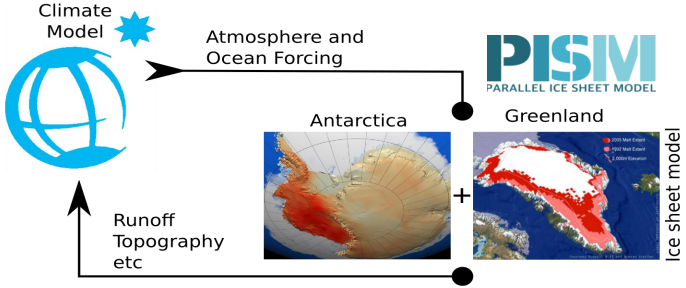
Release additional freshwater reenforces it

Active ice sheets may tend to delay the downward trend but within the variability

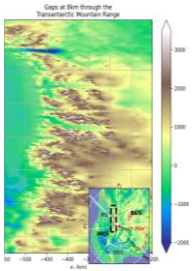
AMOC is not a driver, nor a victim

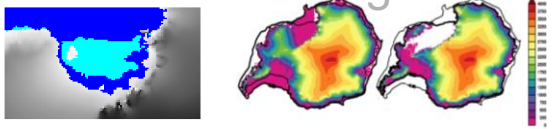
AWI-ESM & Greenland+Antarctica

- AWI-ESM + 2 ice sheets
- freshwater enters the ocean surface
- anomaly coupling in Antarctica

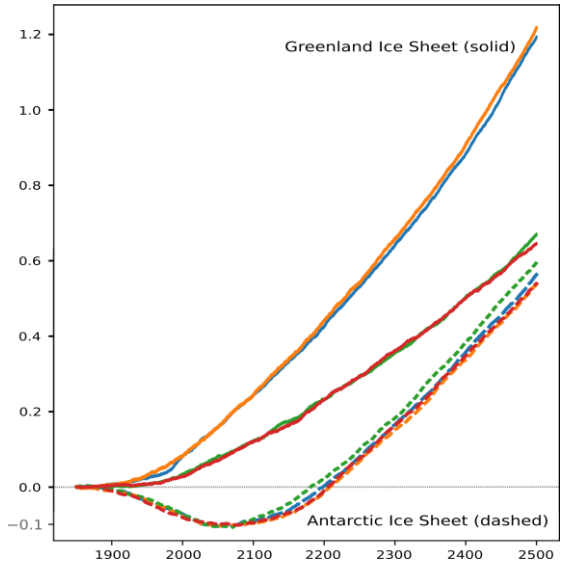


- Trouble with Antarctica
- Required resolution
  - Ice flow through the TAMR
- Iceberg calving
  - Fix back-hole calving
  - Enforced calving mask …



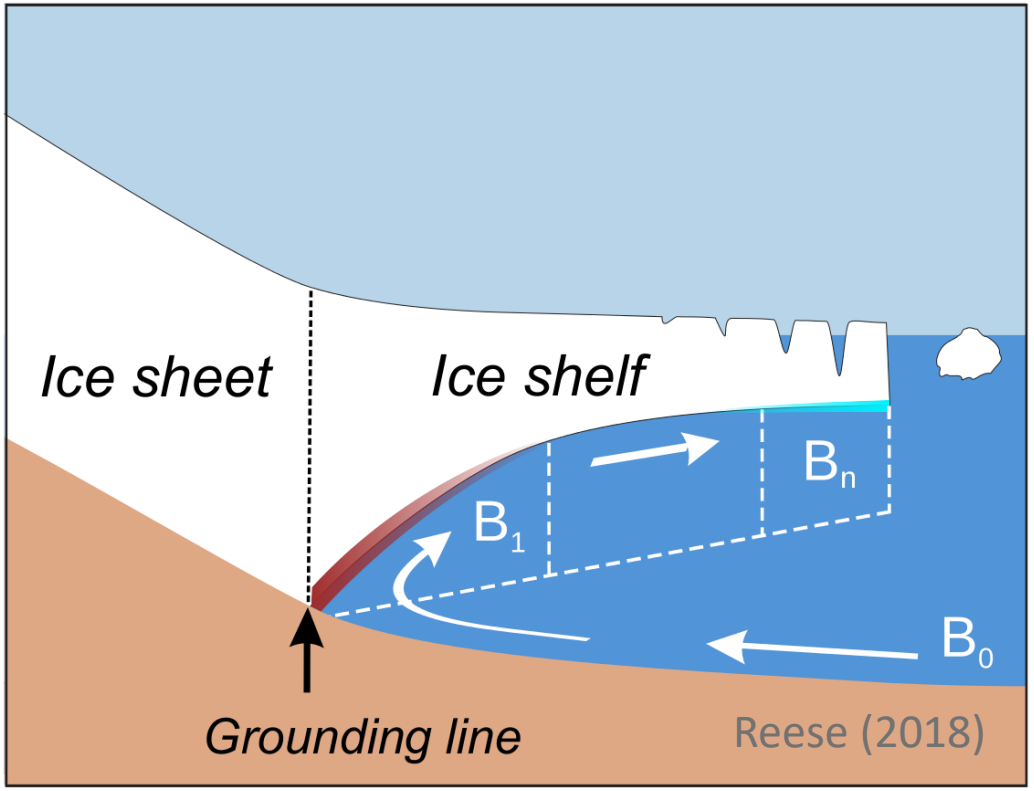


- Ice sheets influence the climate
- Interacting Greenland controls sea level
  - Overestimation by standalone models?
- Antarctica may outpace Greenland
  - Too stable Antarctica?

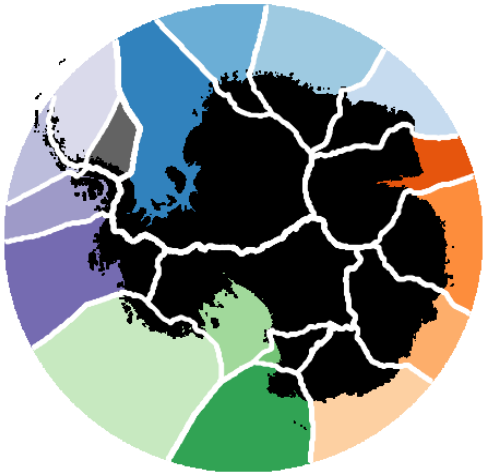


HELMHOLTZ ASSOCIATION

PICO Model: Basal ice shelf melting



Basins



Conditions

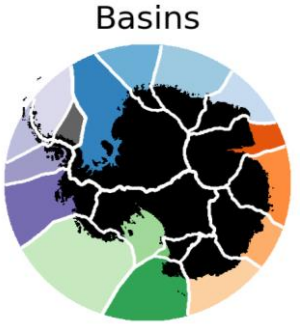
Melting (1 row) > 0

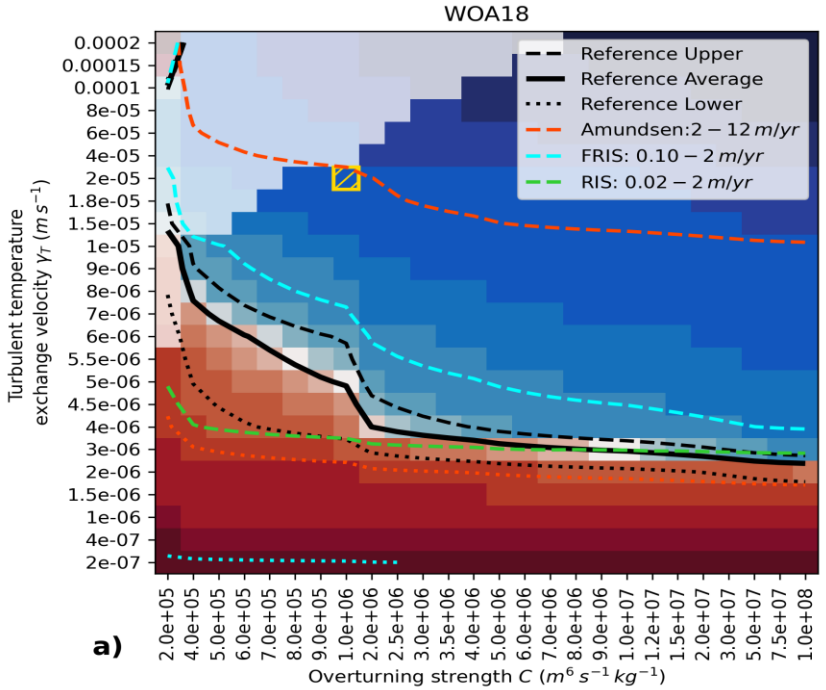
Melting (2 row) < Melting (1 row)

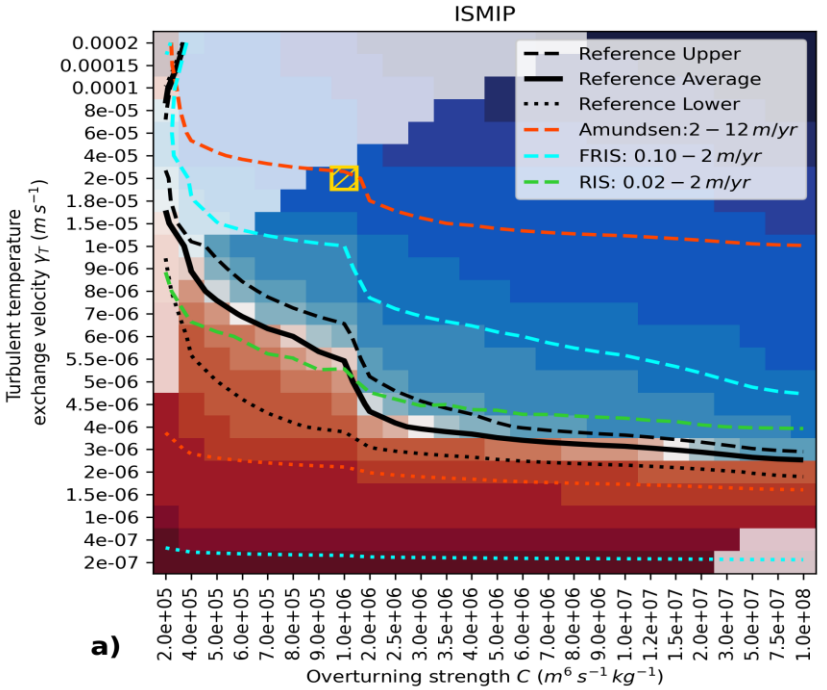
Parameters control “Ice shelf pump”

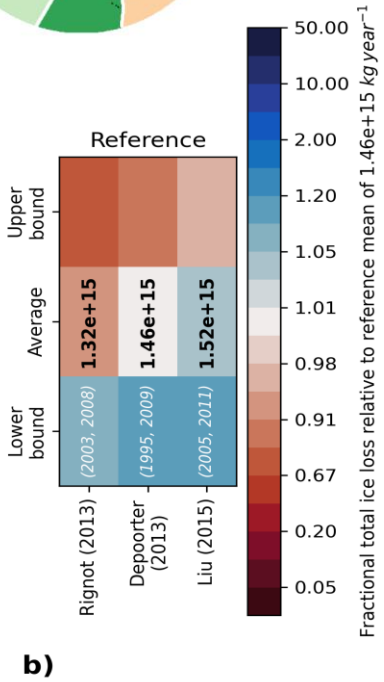
- Thermal exchange velocity
- Overturning strength

PICO Parameter space
WOA18 & ISMIP-data set









Topo: BEDMAP2

Faded areas (upper left)

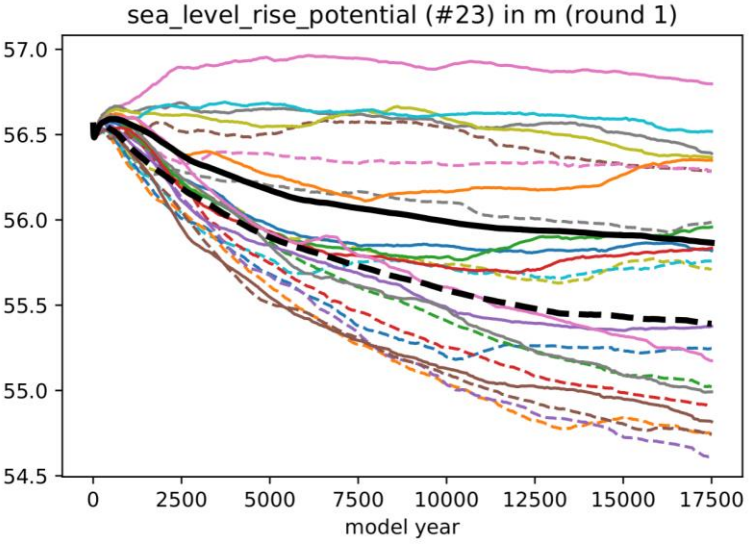
Additional constrain of PICO are violated

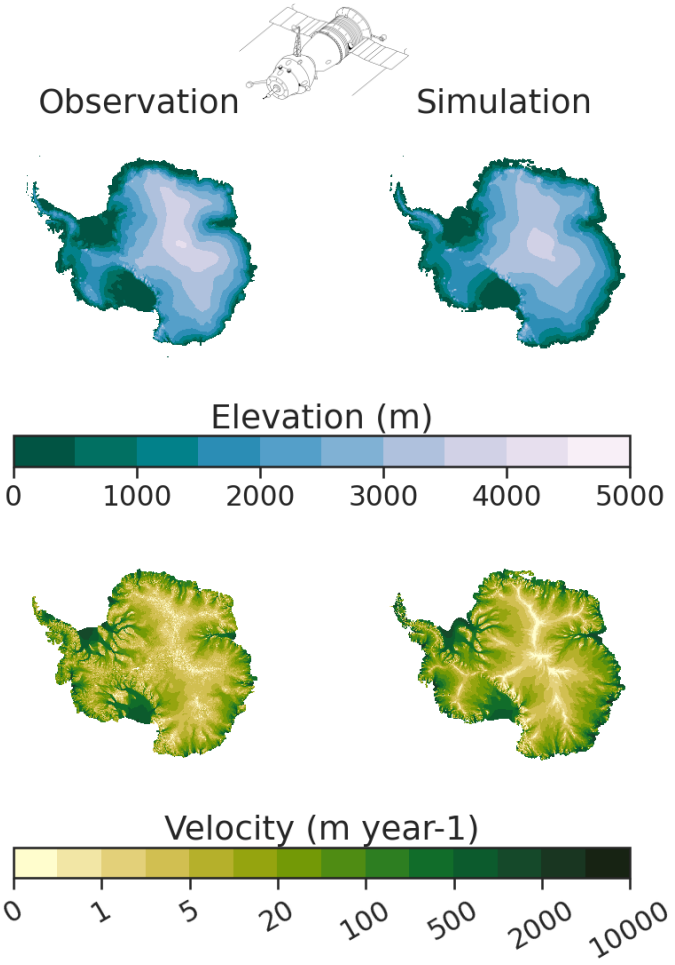
Spin-up Antarctica: Climatological forcing

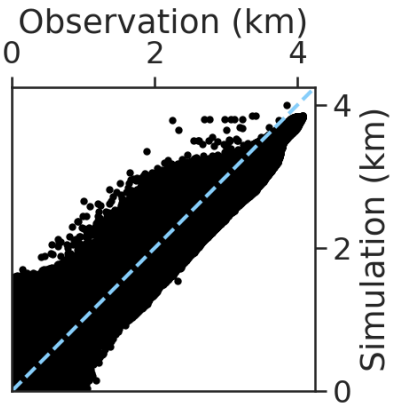
- 350,000 year thermal spin-up
- Retuned PICO parameters
- Reasonable patterns for climatology-driven simulations, e.g., ISMIP or WOA18

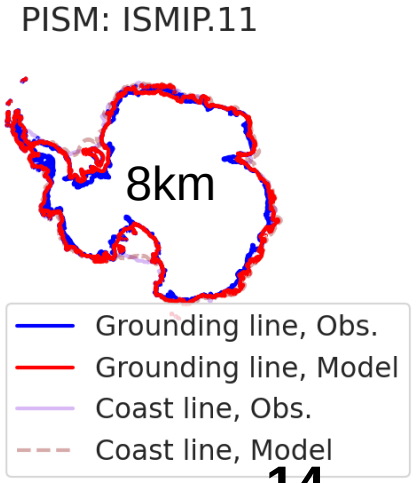
Model year 17,500

Calving thickness 75 m

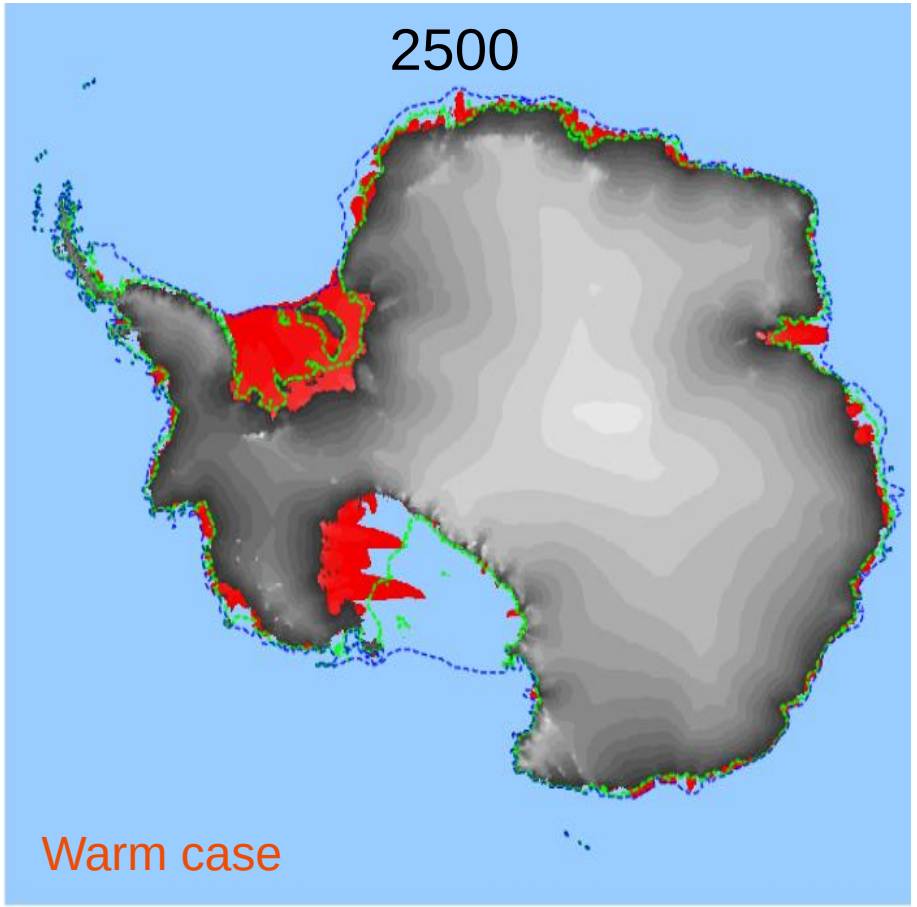


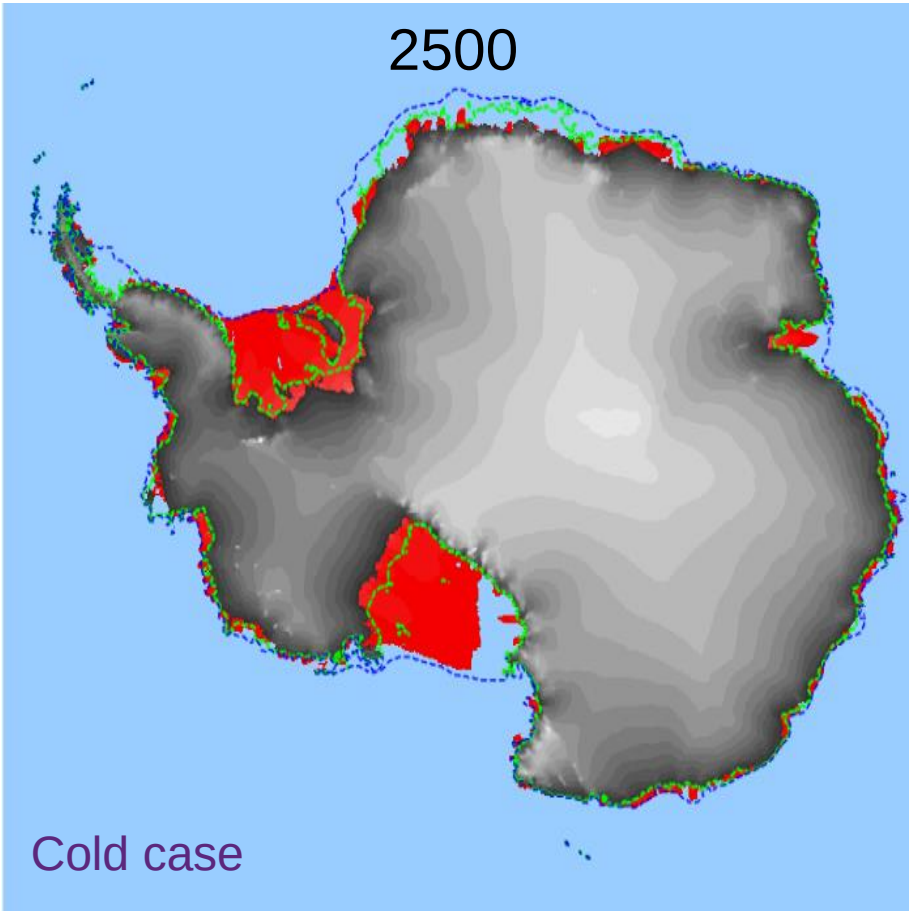




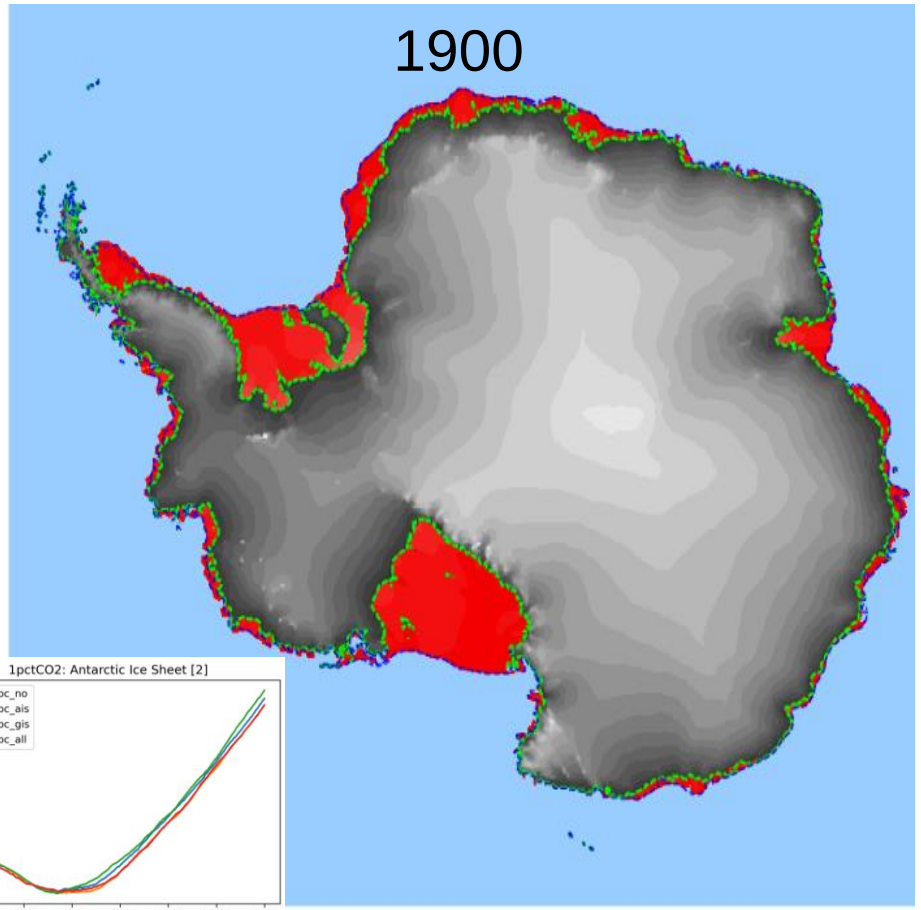


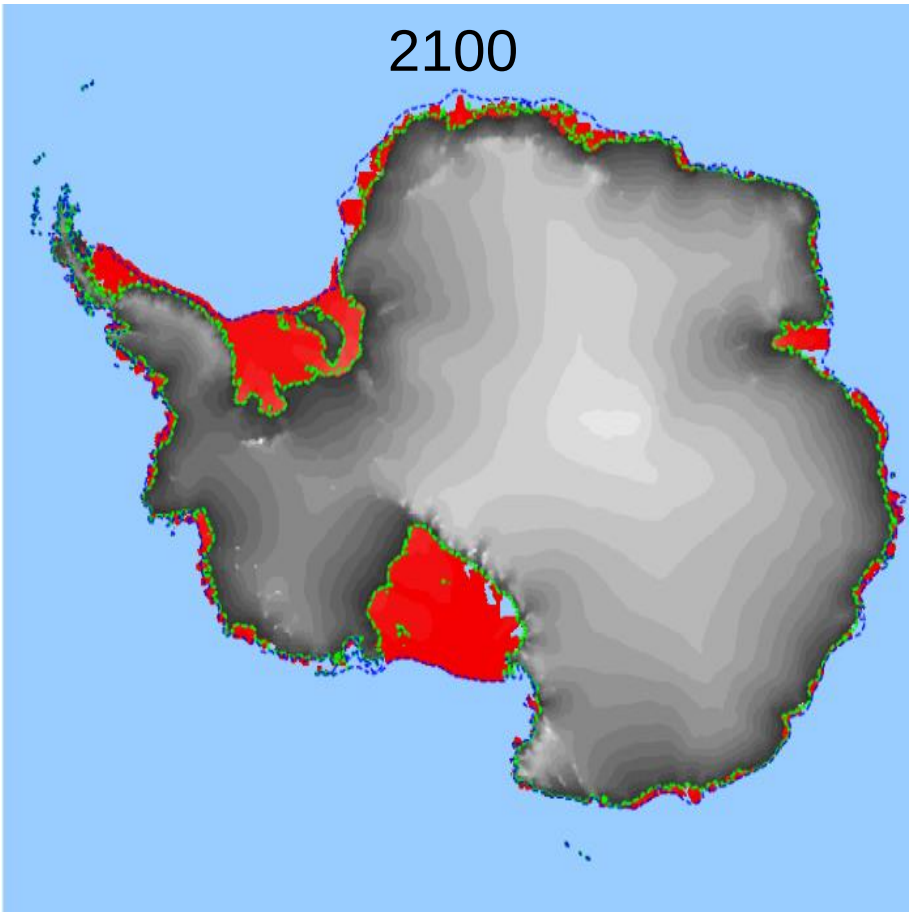
Ice shelf status and decay, year 2500

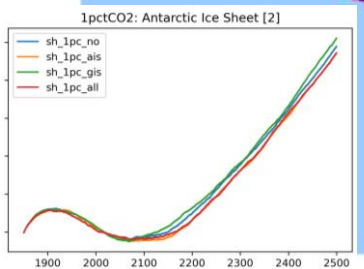




Ice mass redistribution (cold)

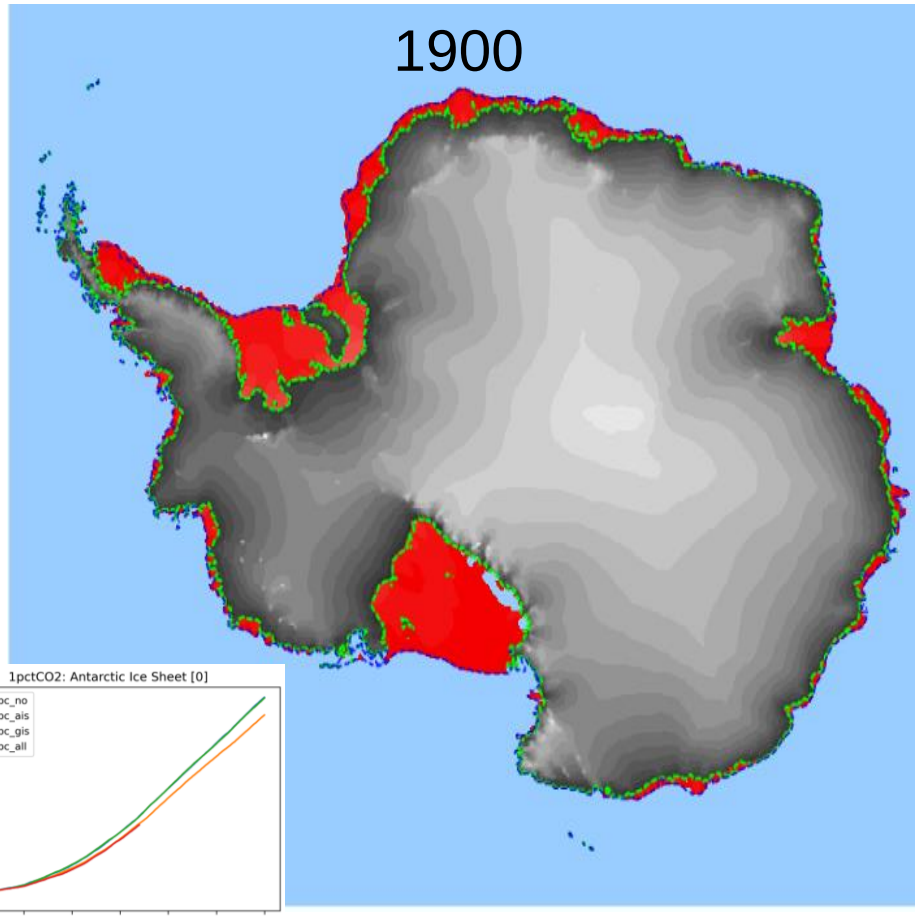


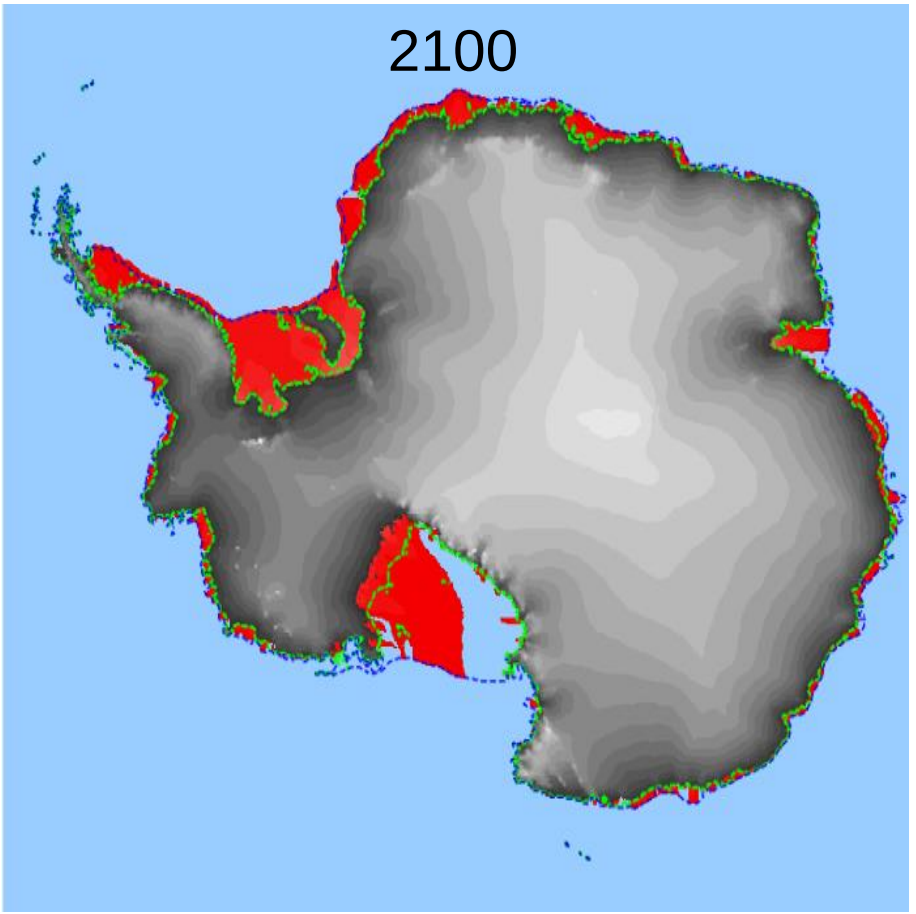


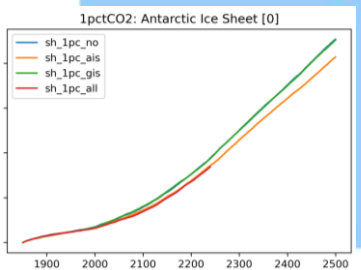


Cold case

Ice mass redistribution (warm)



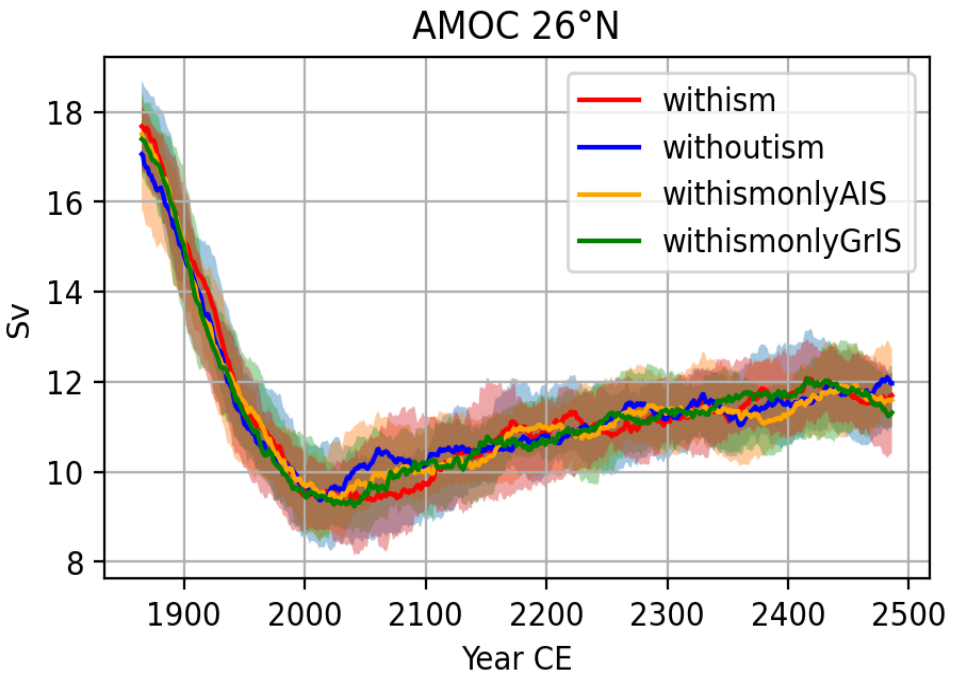




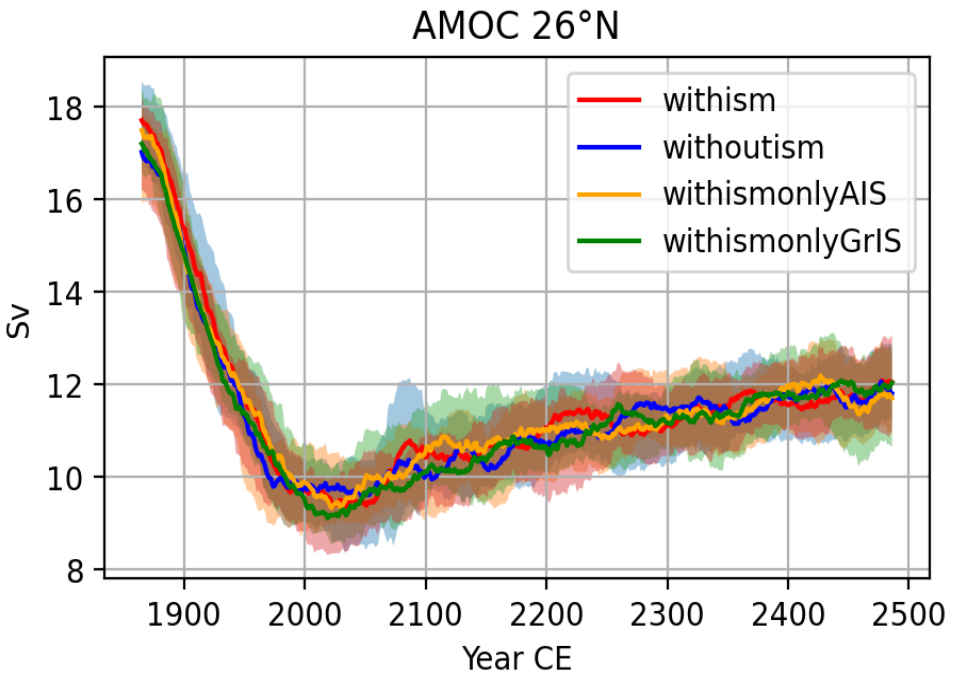
Warm case

AMOC as driver of Greenland divergence?

Warm case



Cold case



Rather not …

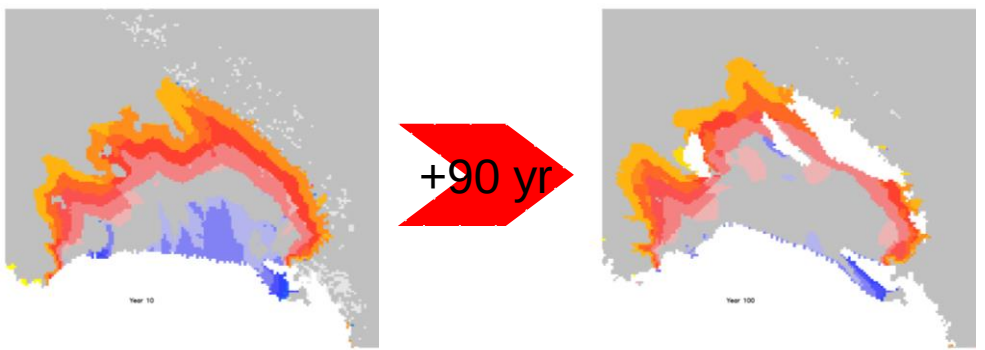
Ackermann (2024, per comm.)

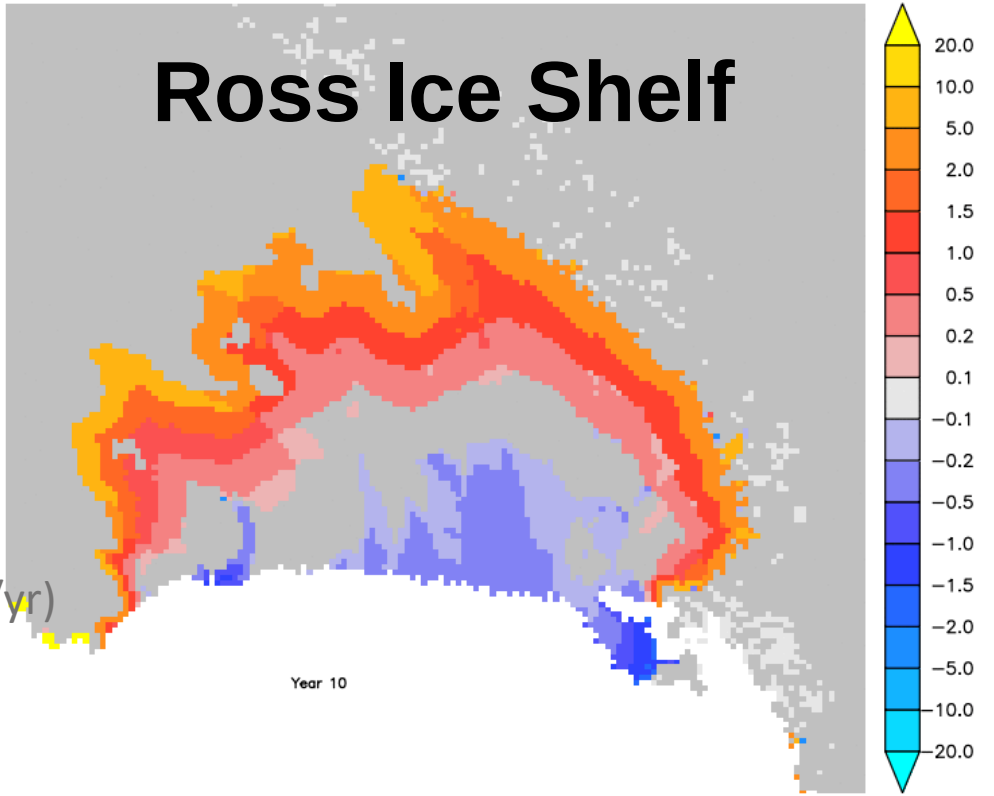
Give it a try with EC-Earth forcing!

Antarctica Simulation

- **P**arallel **I**ce **S**heet **M**odel
- Ocean via **PICO**
- 8 km
- EC-Earth piControl

Light gray: ice-free ground
Gray: _____grounded ice
Color:_____Ross Ice Shelf:
Basal Melting Rate (m/yr)





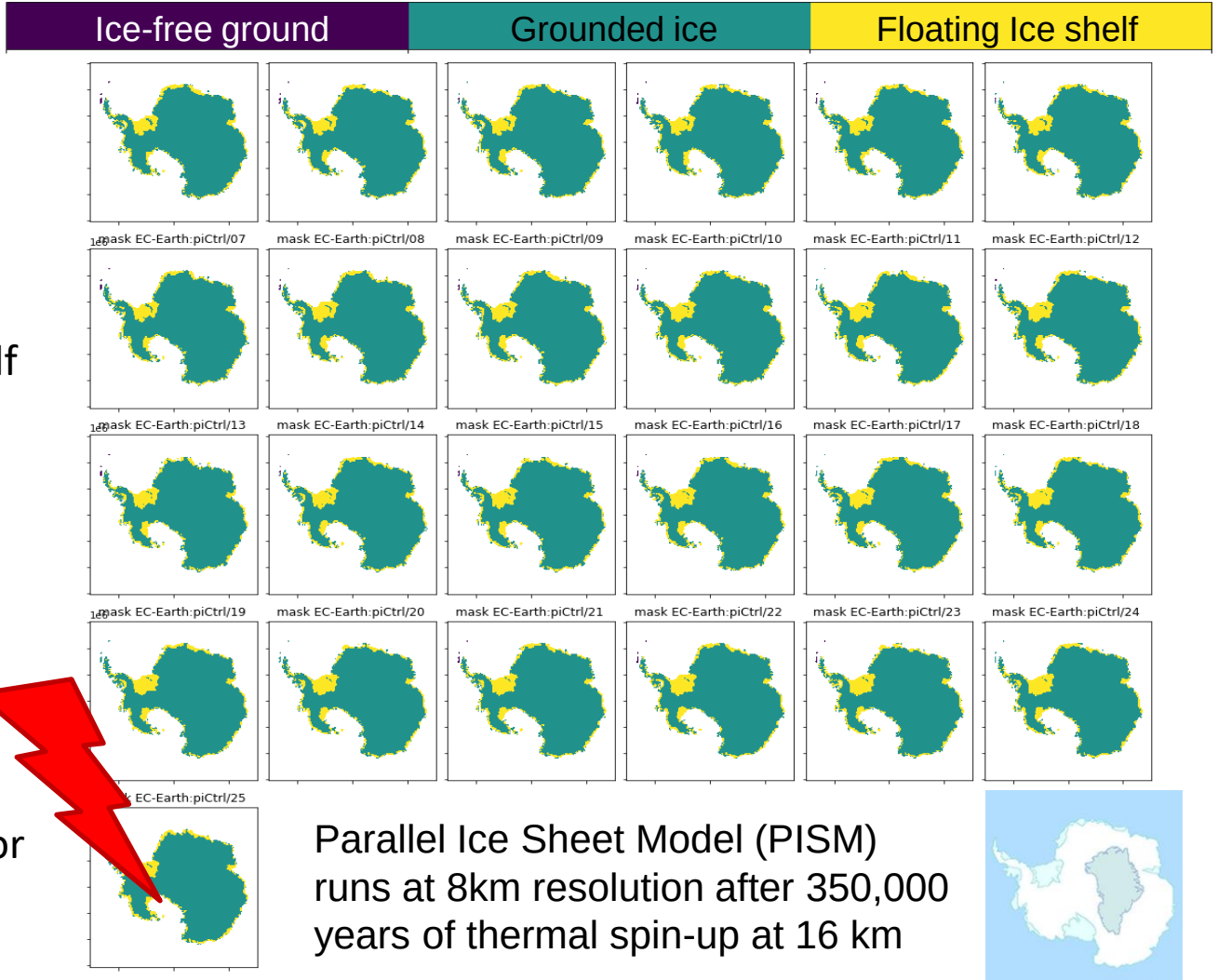
Diagnostic EC-Earth

25 Ensemble members
Variation of the **two** parameters describing ocean-driven basal ice shelf melting in PICO

Ocean forcing
EC-Earth piControl

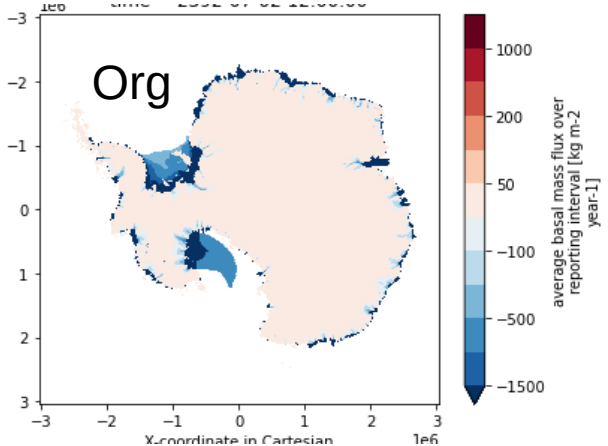
Model year 3000

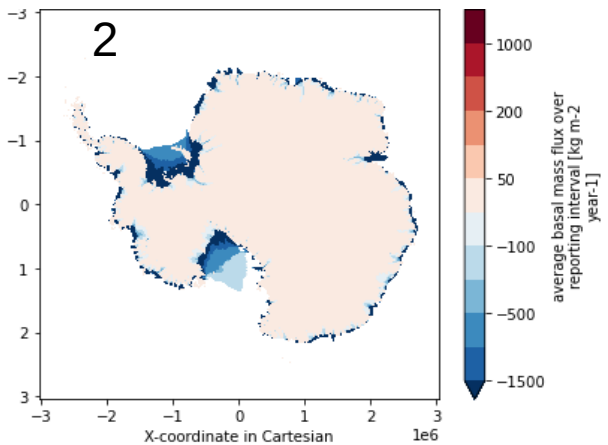
West Antarctica collapses
Ongoing downward trend. No hope for healing in longer simulations

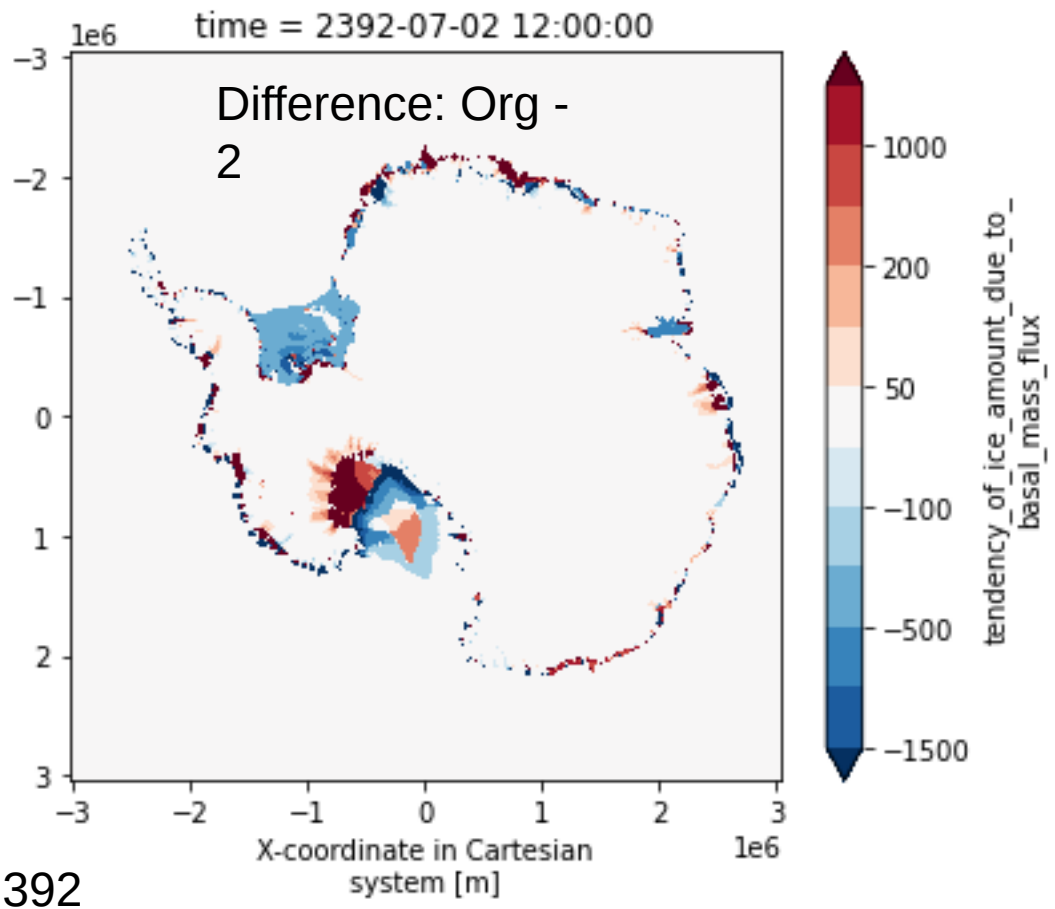


Parallel Ice Sheet Model (PISM) runs at 8km resolution after 350,000 years of thermal spin-up at 16 km

1pct4CO2: Basal melting patterns





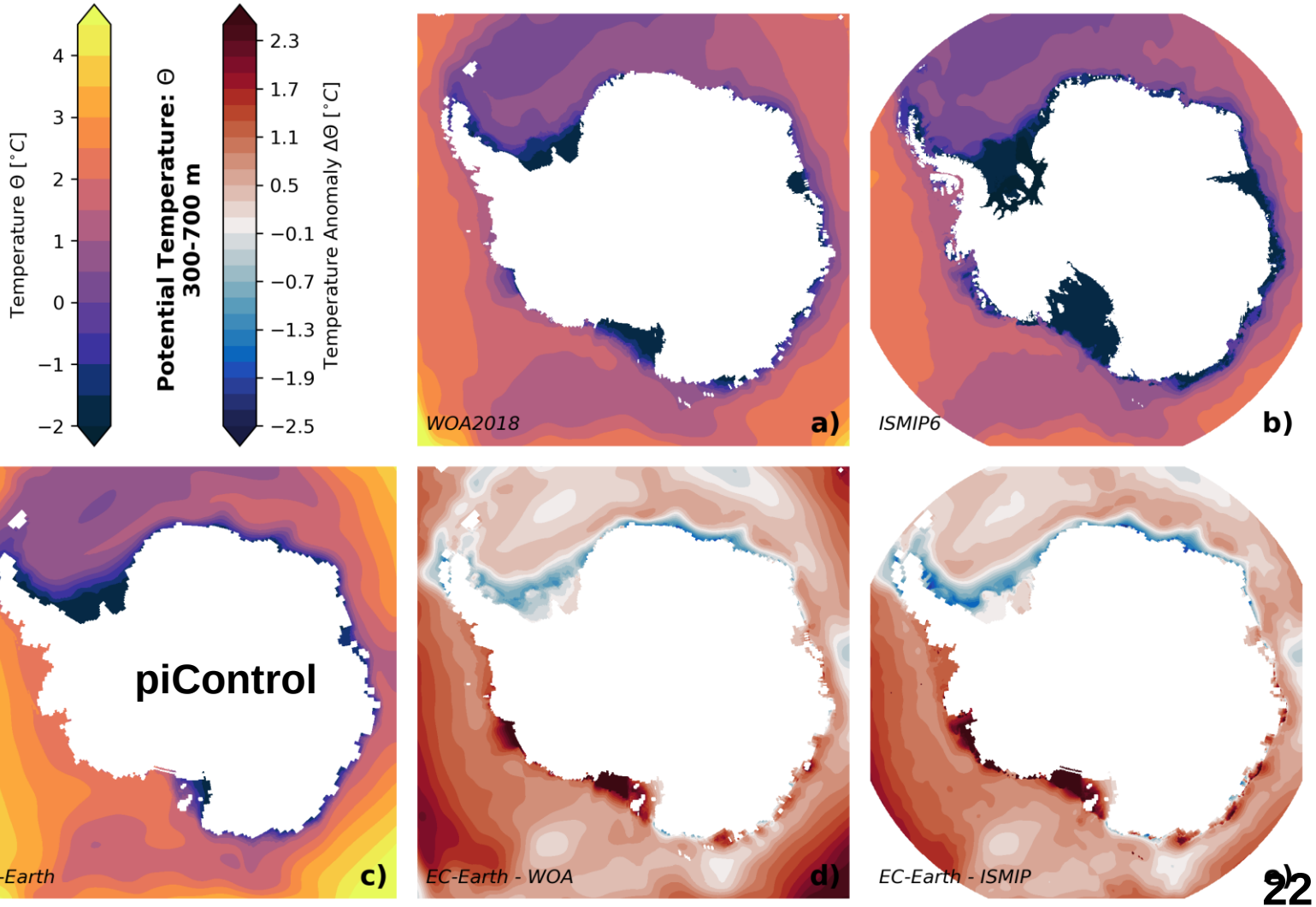


Year: 2392

Ocean Θ

Model bias example

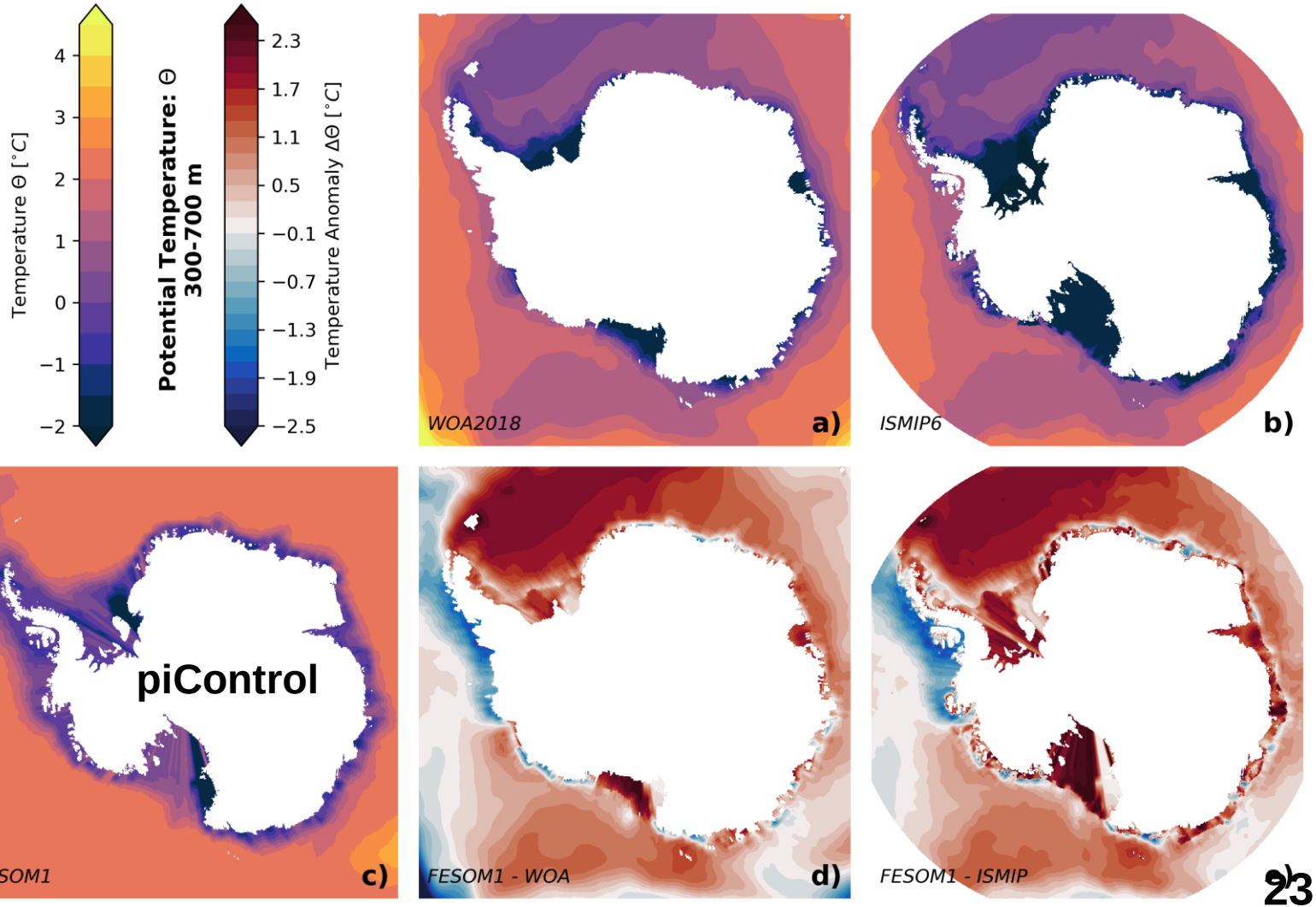
EC-Earth v3



Ocean Θ

Model bias example

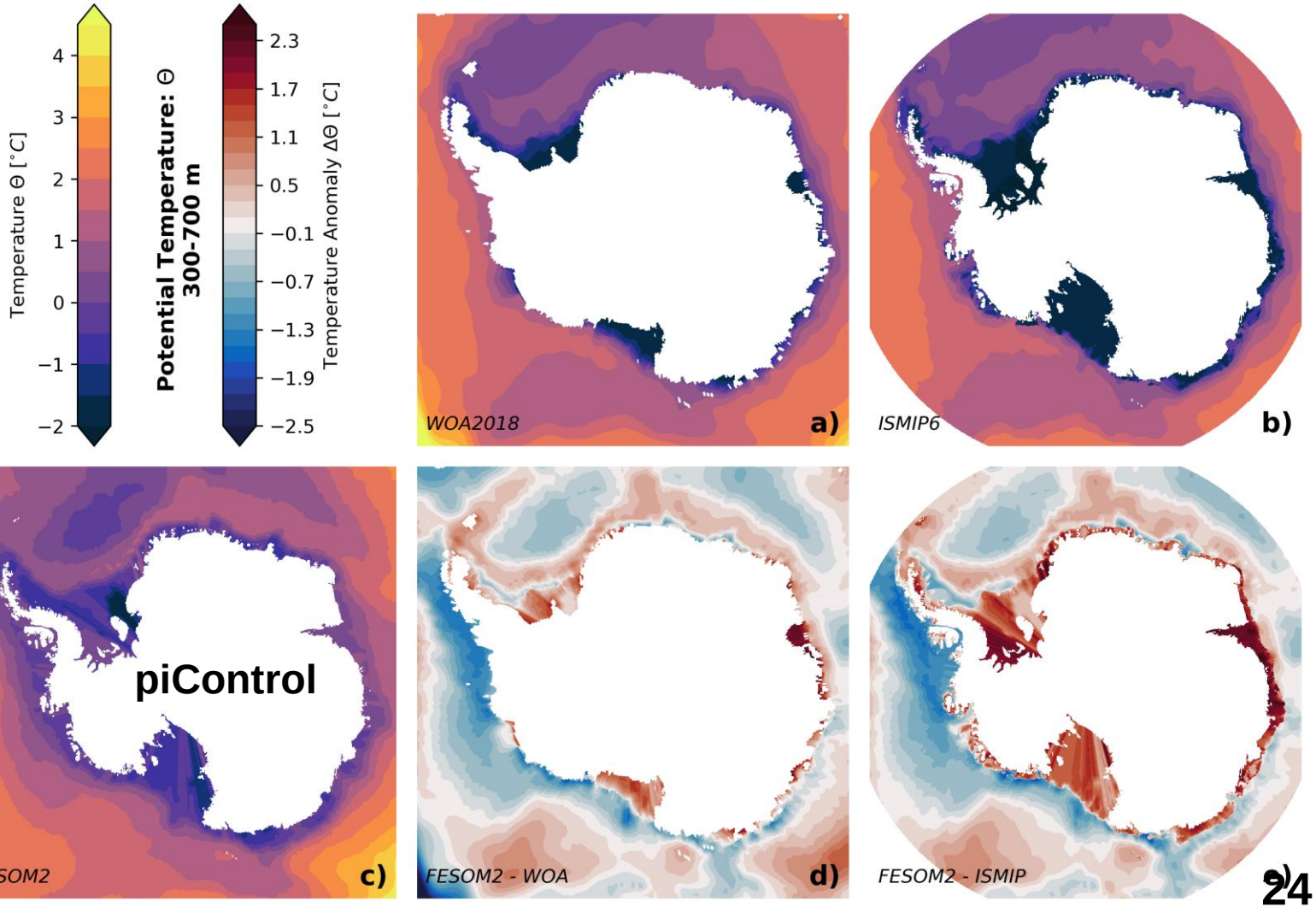
FESOM1



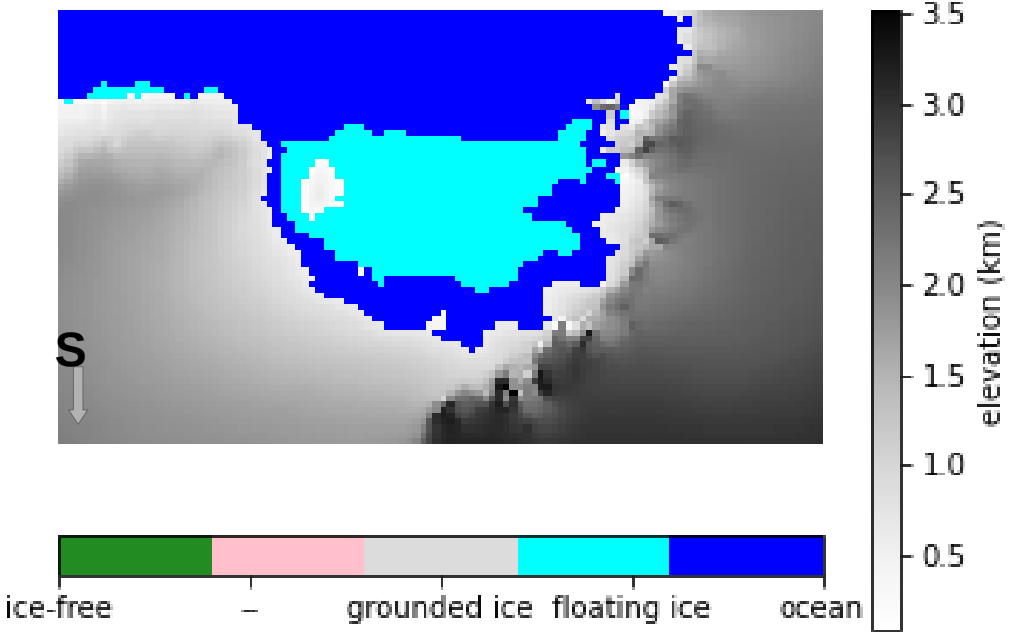
Ocean Θ

Model bias example

FESOM2



Run a coupled simulation … (bahh)



- AWI-ESM+PISM-Antarctica/GrIS
- PISM Resolution: 16 km (fast)
- Anomaly (flux correction) coupling
  - Atmosphere
  - Ocean
- Black-hole calving, again
- The island holds the ice shelf

Protect
CRYOSPHERE & SEA LEVEL

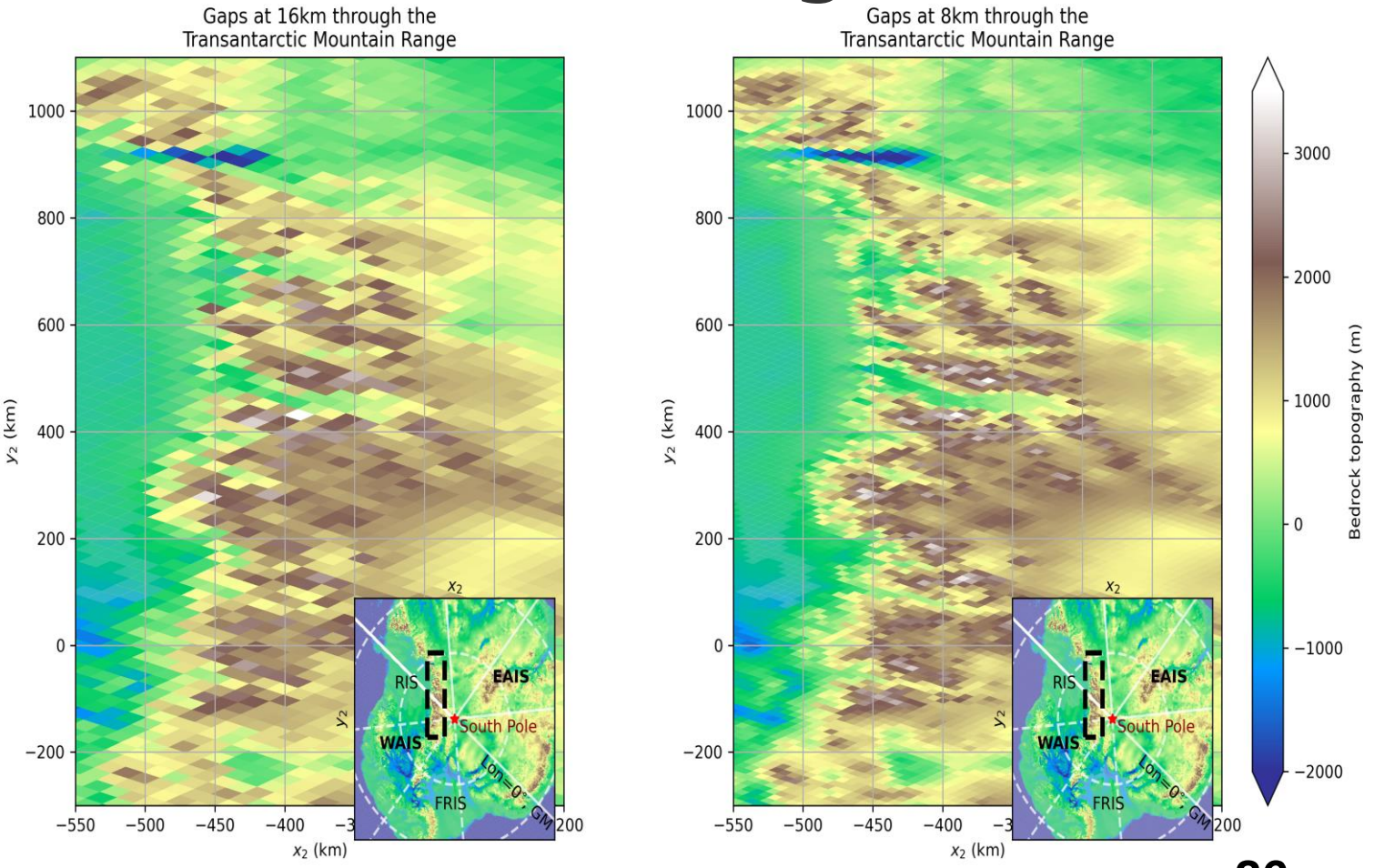
Transantarctic Mountain Range

16 km common for PISM Antarctica

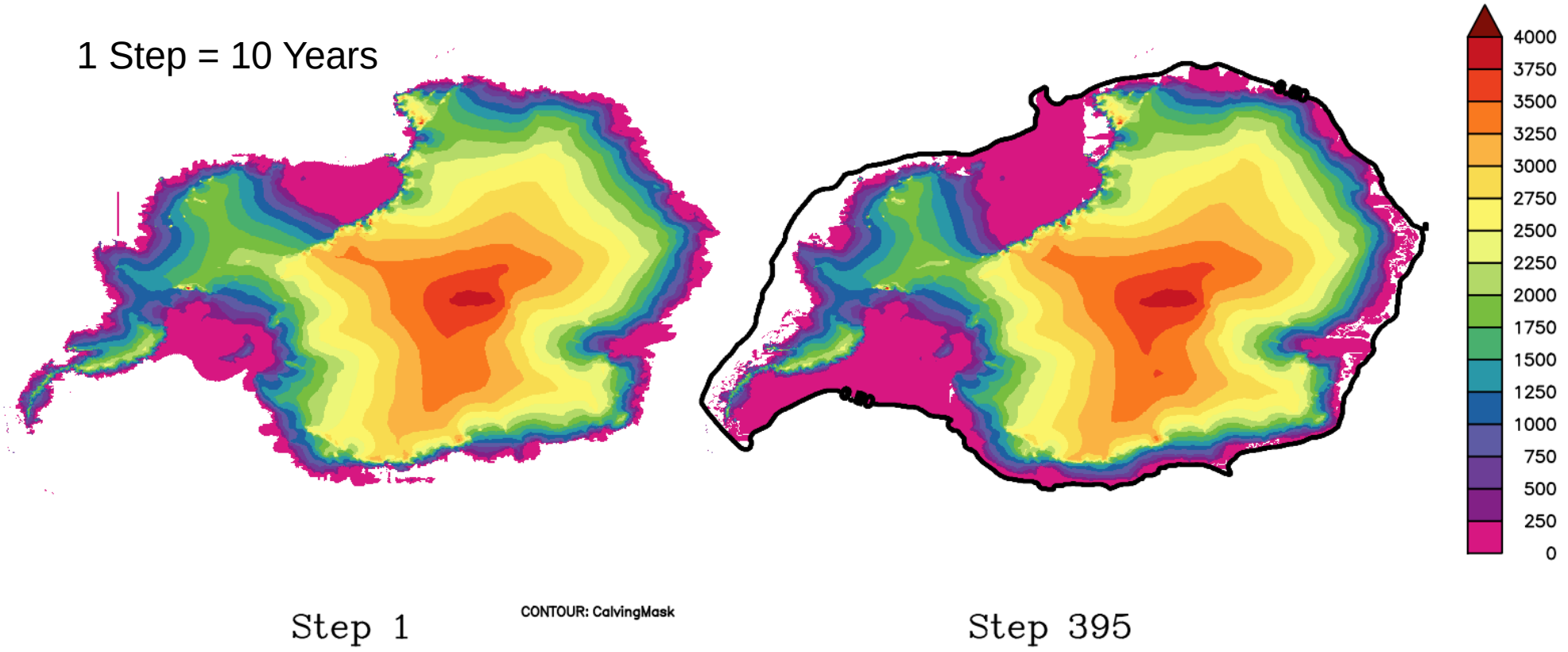
16 km vs 8 km

- Badly resolved troughts
- Curtate ice streams
- Suppress recovery after initial coupling

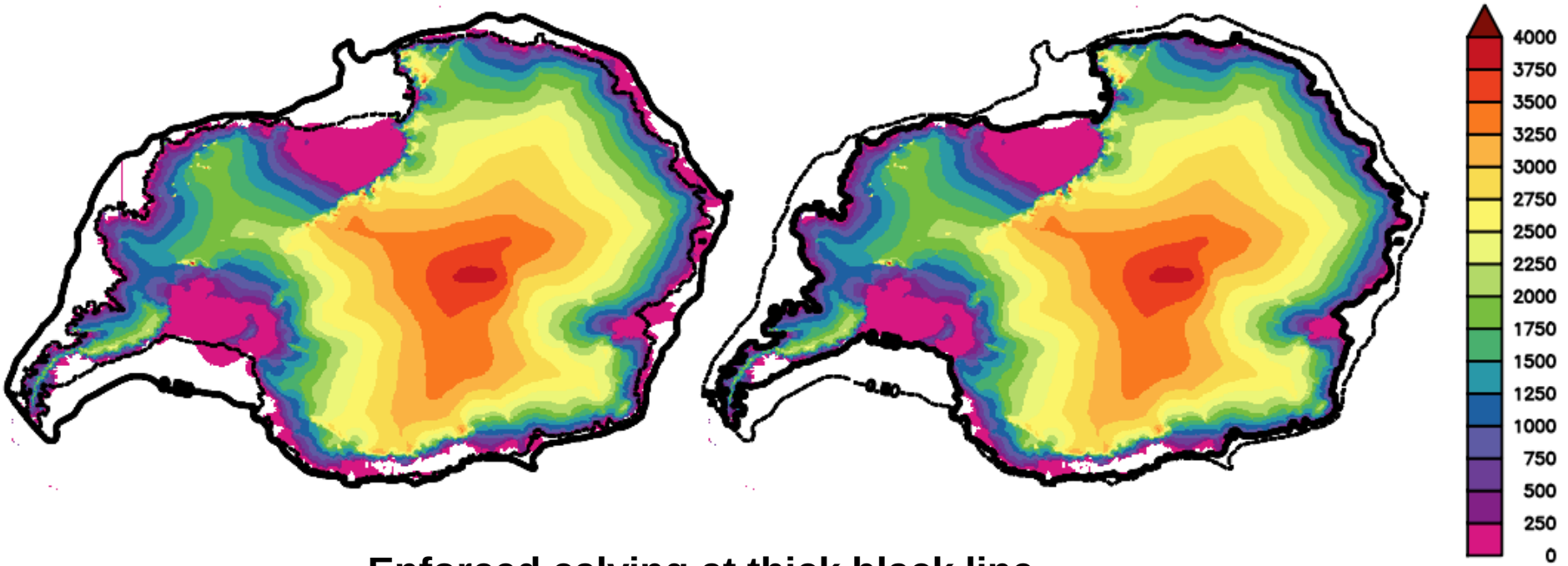
Protect
CRYOSPHERE & SEA LEVEL



Coupled (piCtrl): anomaly coupling, suppressed black-hole calving, 8 km



Coupled: different enforced calving *Guess what happens*



Enforced calving at thick black line

West Antarctica is gone …

1 Step = 10 Years