Ice in the climate system: past, present, future

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Ice in the climate system

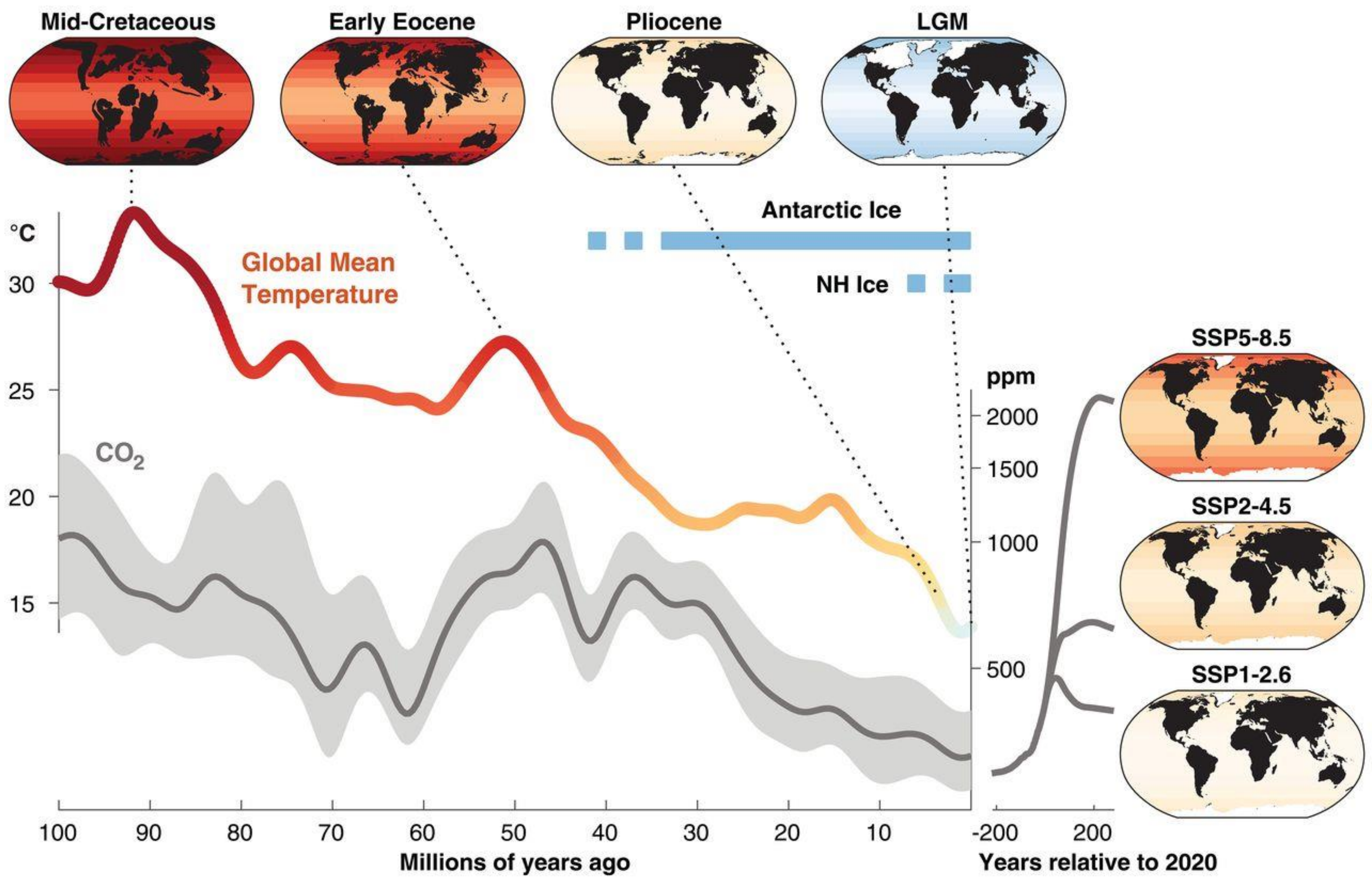
Space

- Ice as an archive of climate change
- Ice reacts to / drives climate change

Time

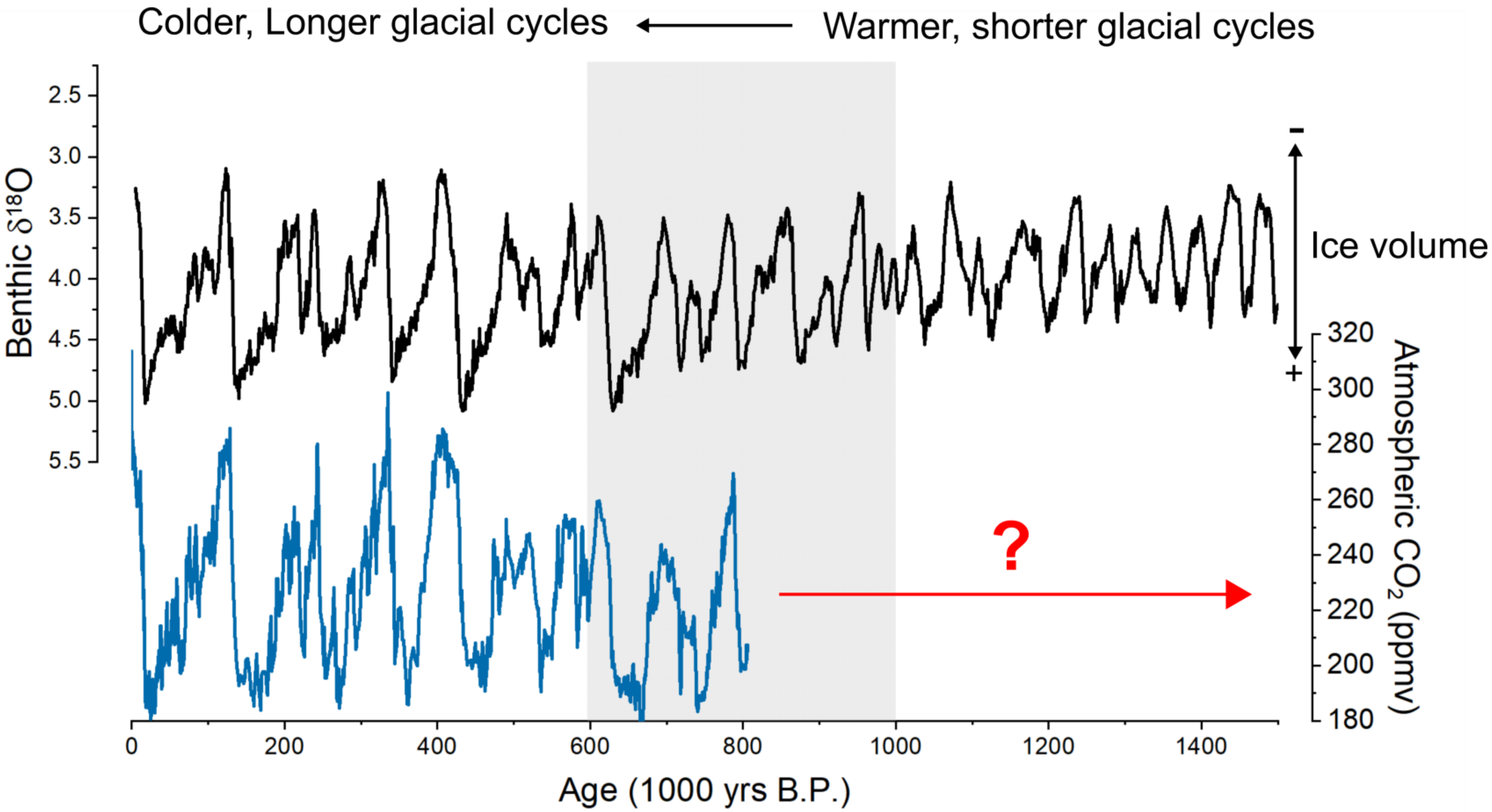
- Ice in the past
- Present changes in ice
- Future projections of ice and sea level

Focus on land ice (glaciers, ice sheets)

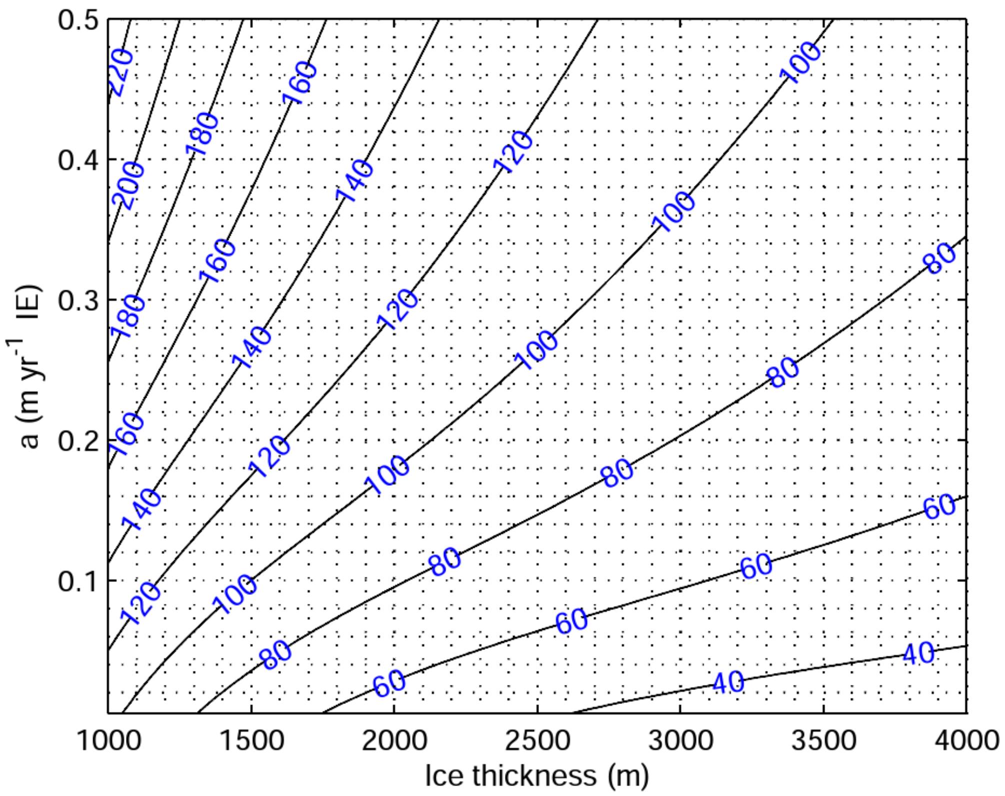


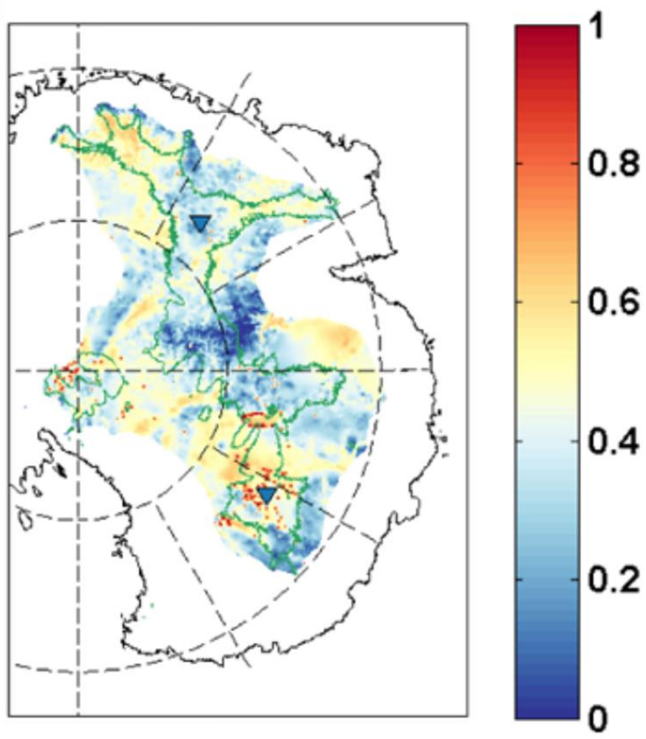
Mid-Cretaceous
Early Eocene
Pliocene
LGM
Antarctic Ice
NH Ice
°C
30
25
20
15
Global Mean Temperature
CO2
ppm
2000
1500
1000
500
SSP5-8.5
SSP2-4.5
SSP1-2.6
100
90
80
70
60
50
40
30
20
10
Millions of years ago
-200
200
Years relative to 2020

Ice as an archive of temperature and CO_2



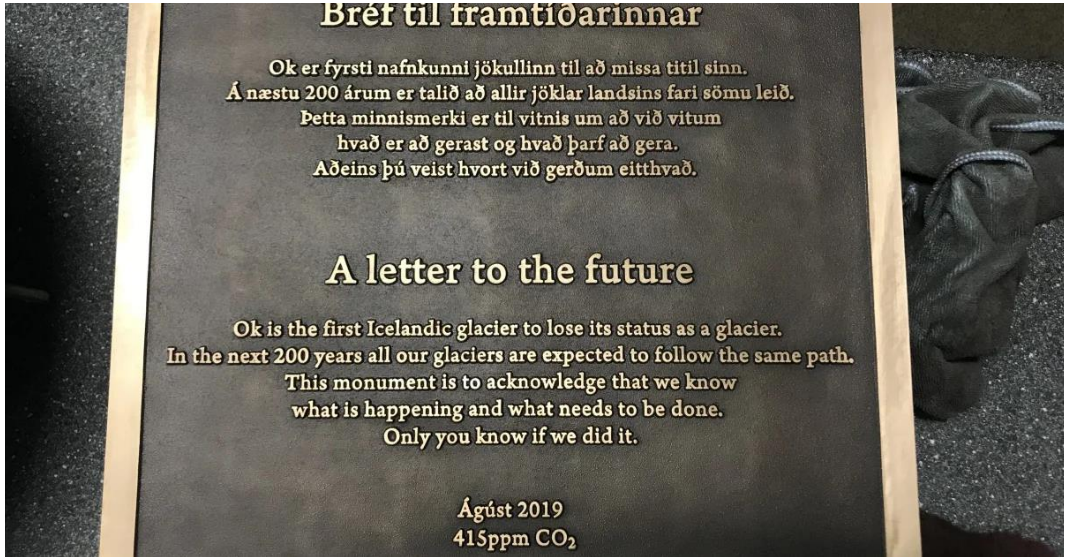
To find “Oldest Ice” is a story of ice dynamics

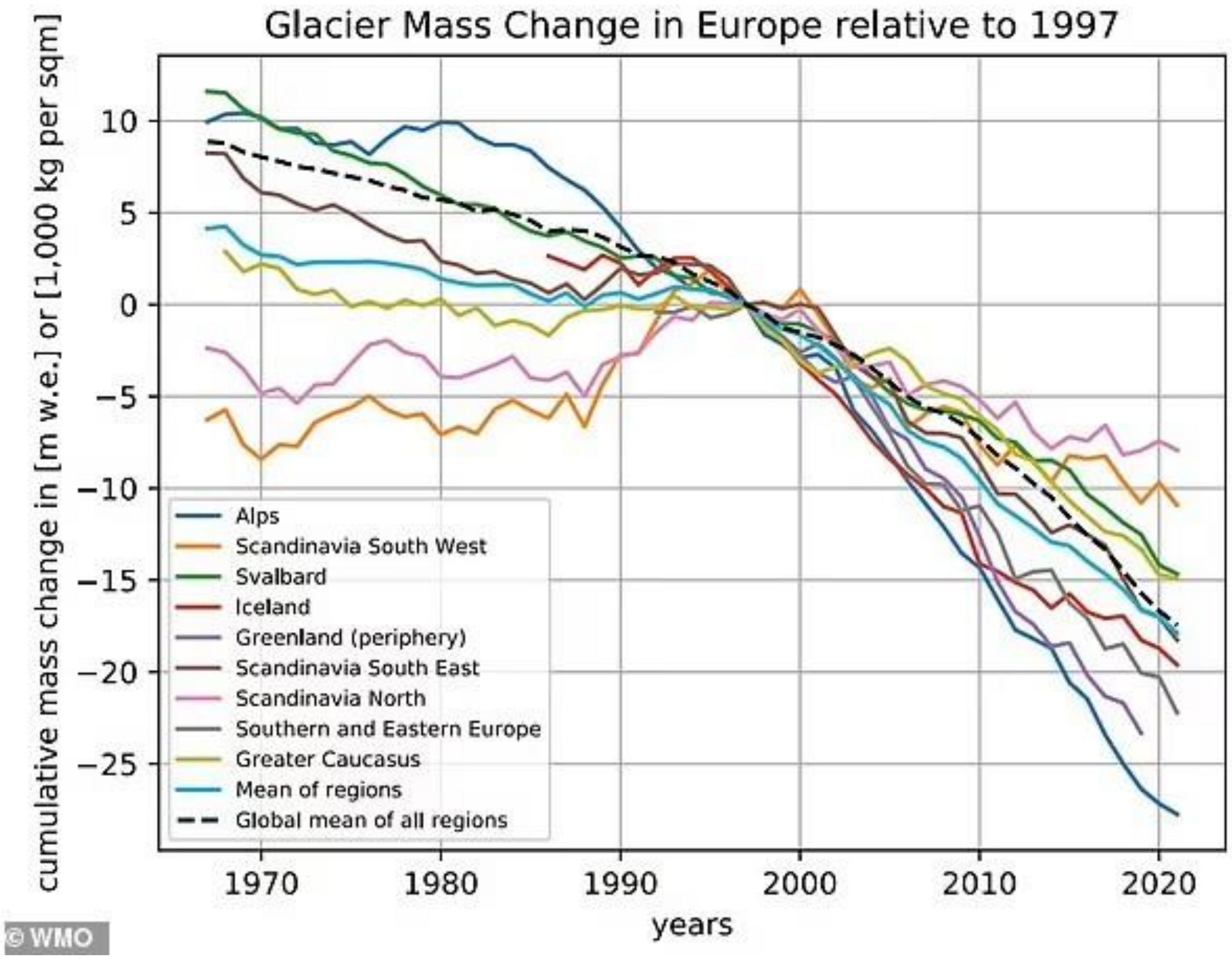




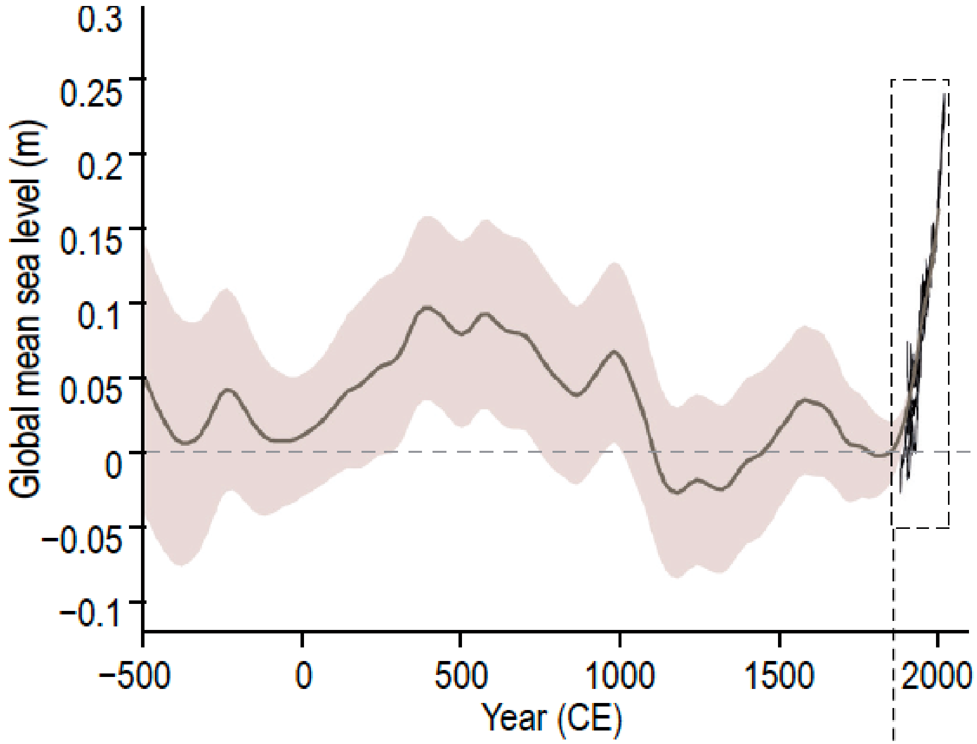
Left: Geothermal heat flow (mW/m²) needed to have ice melted at the base as a function of ice thickness and surface accumulation rate; **Right**: Probability of finding ice at melting point (Van Liefferinge and Pattyn, 2013).

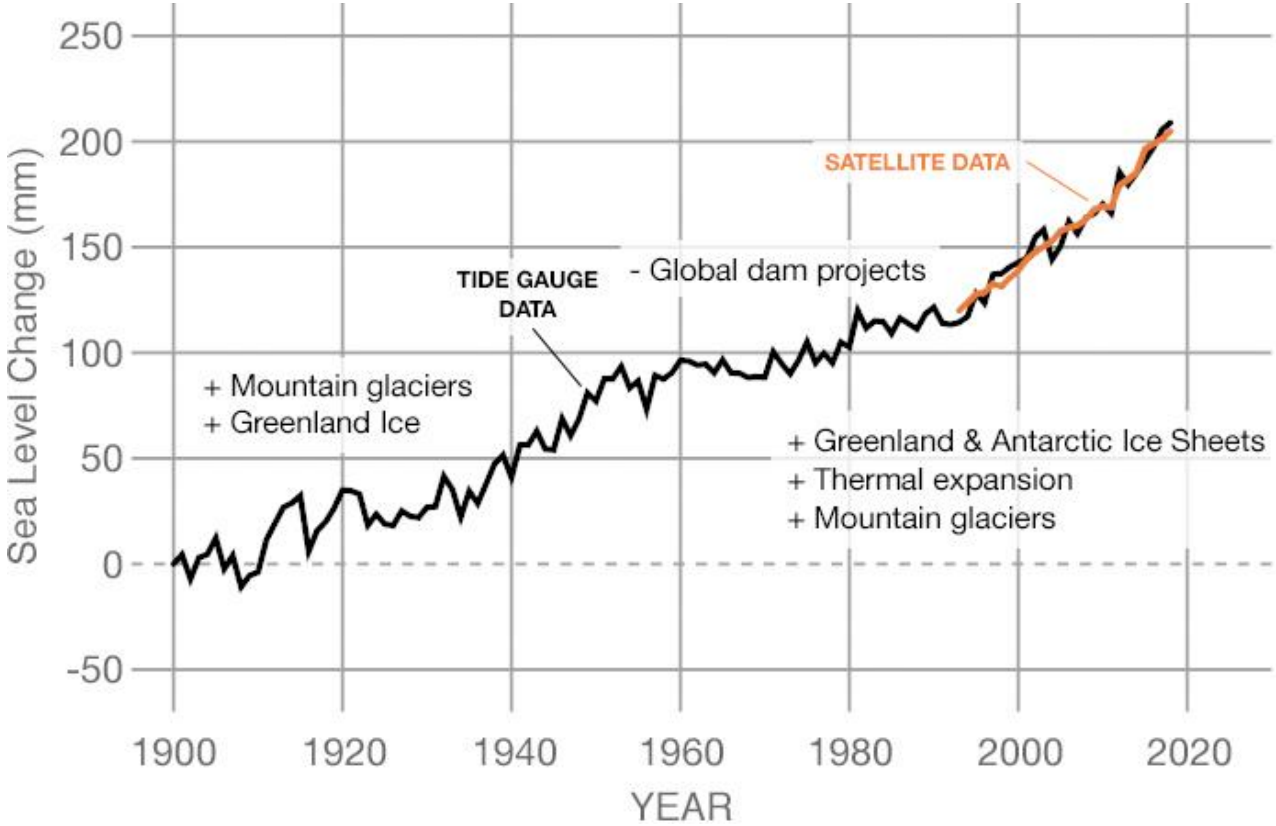
Unprecedented in 2000 years



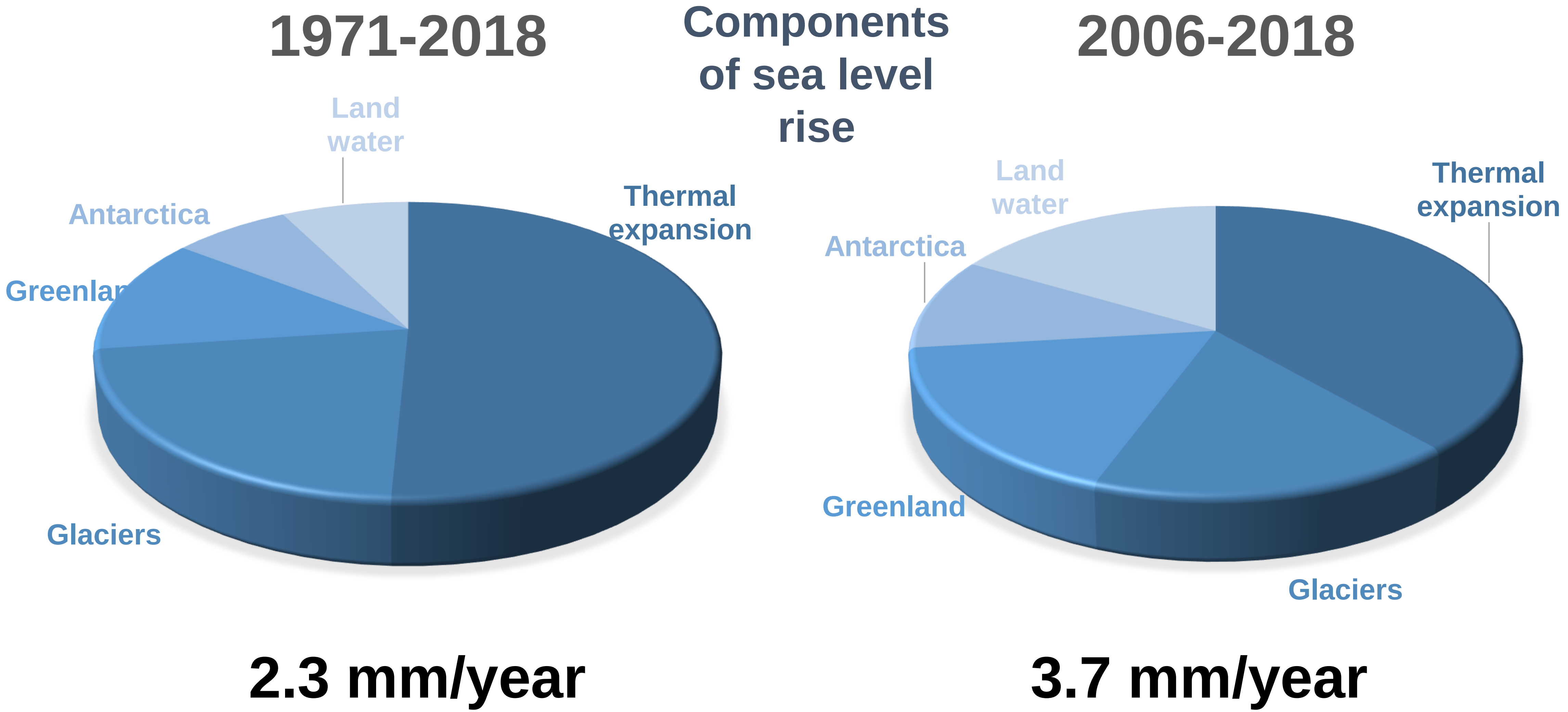


Unprecedented in 3000 years

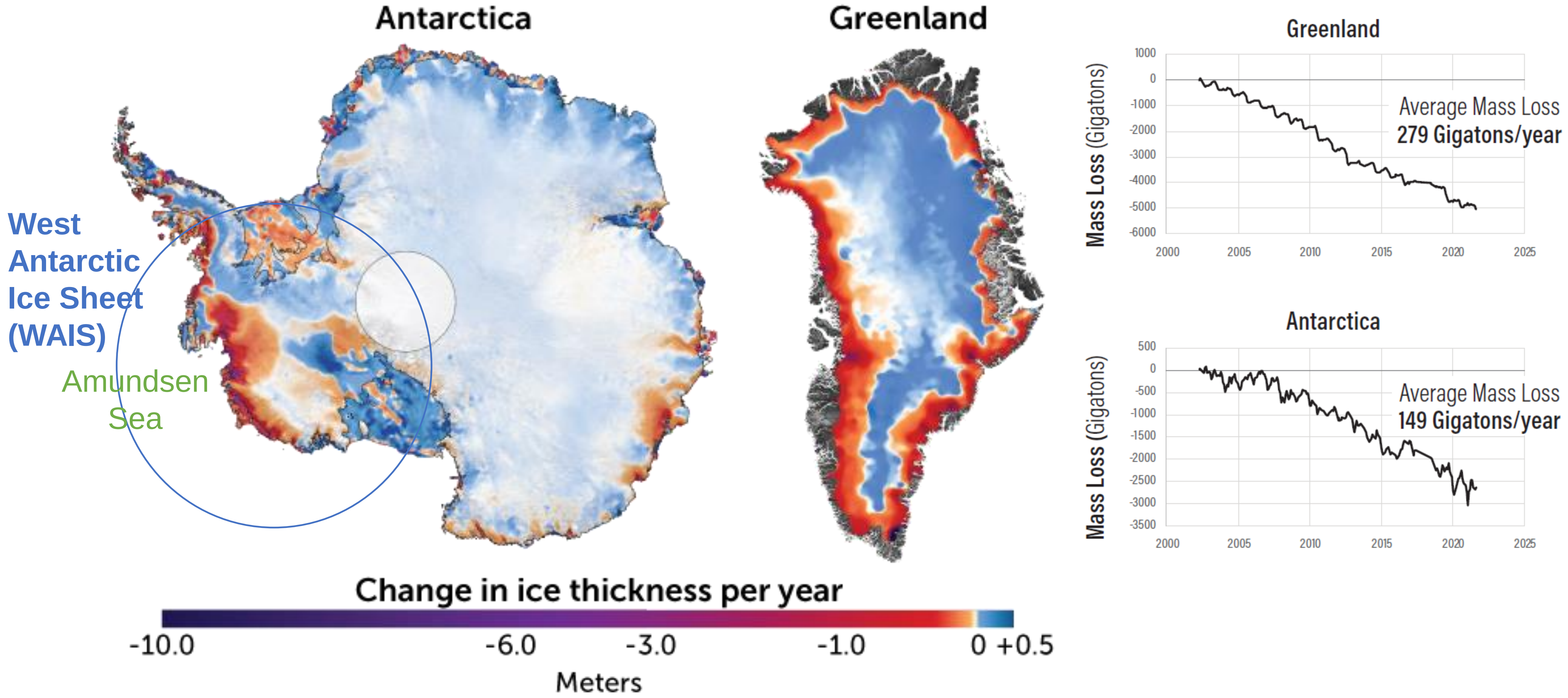




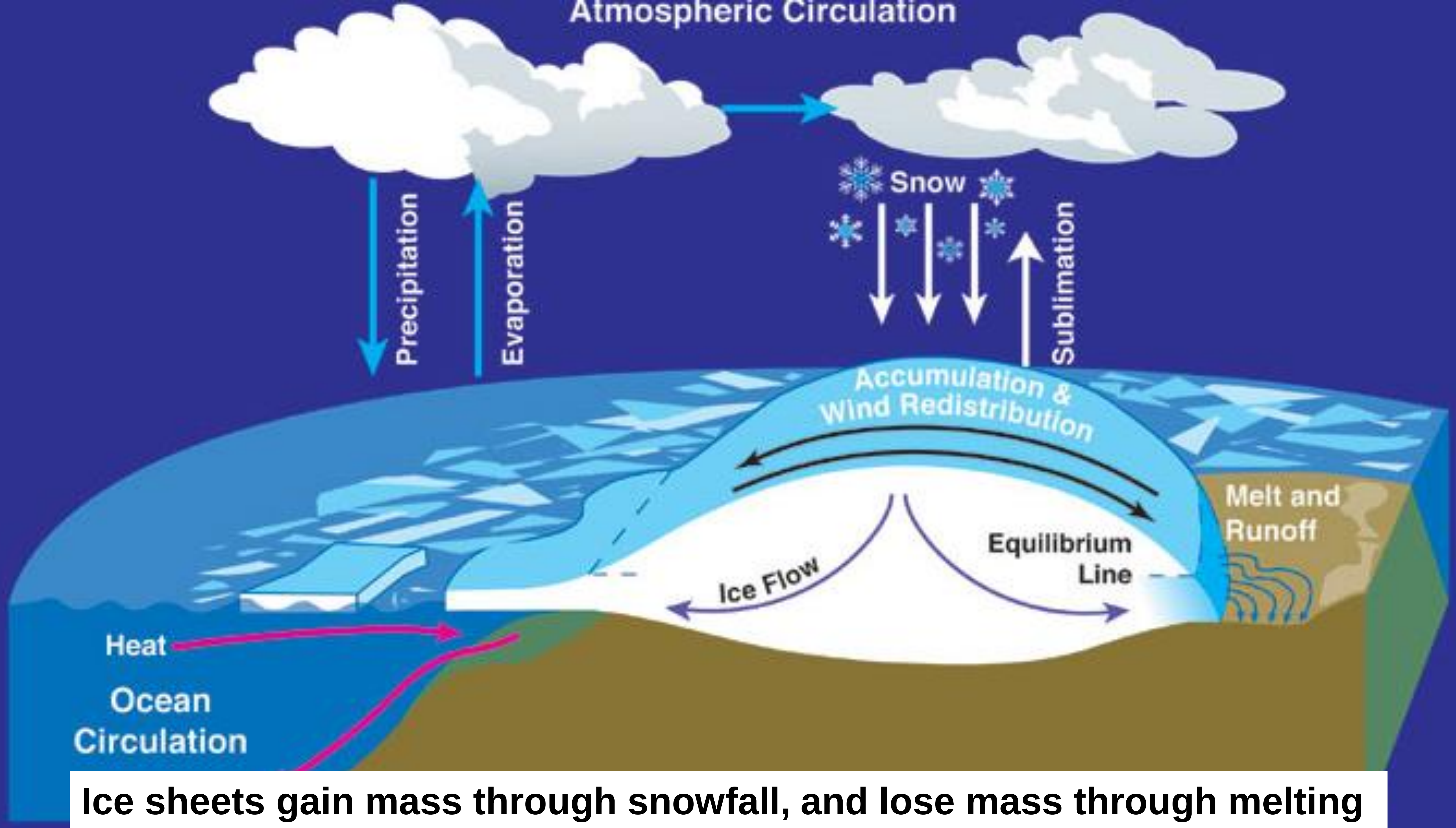
Melting ice now accounts for half the sea level rise



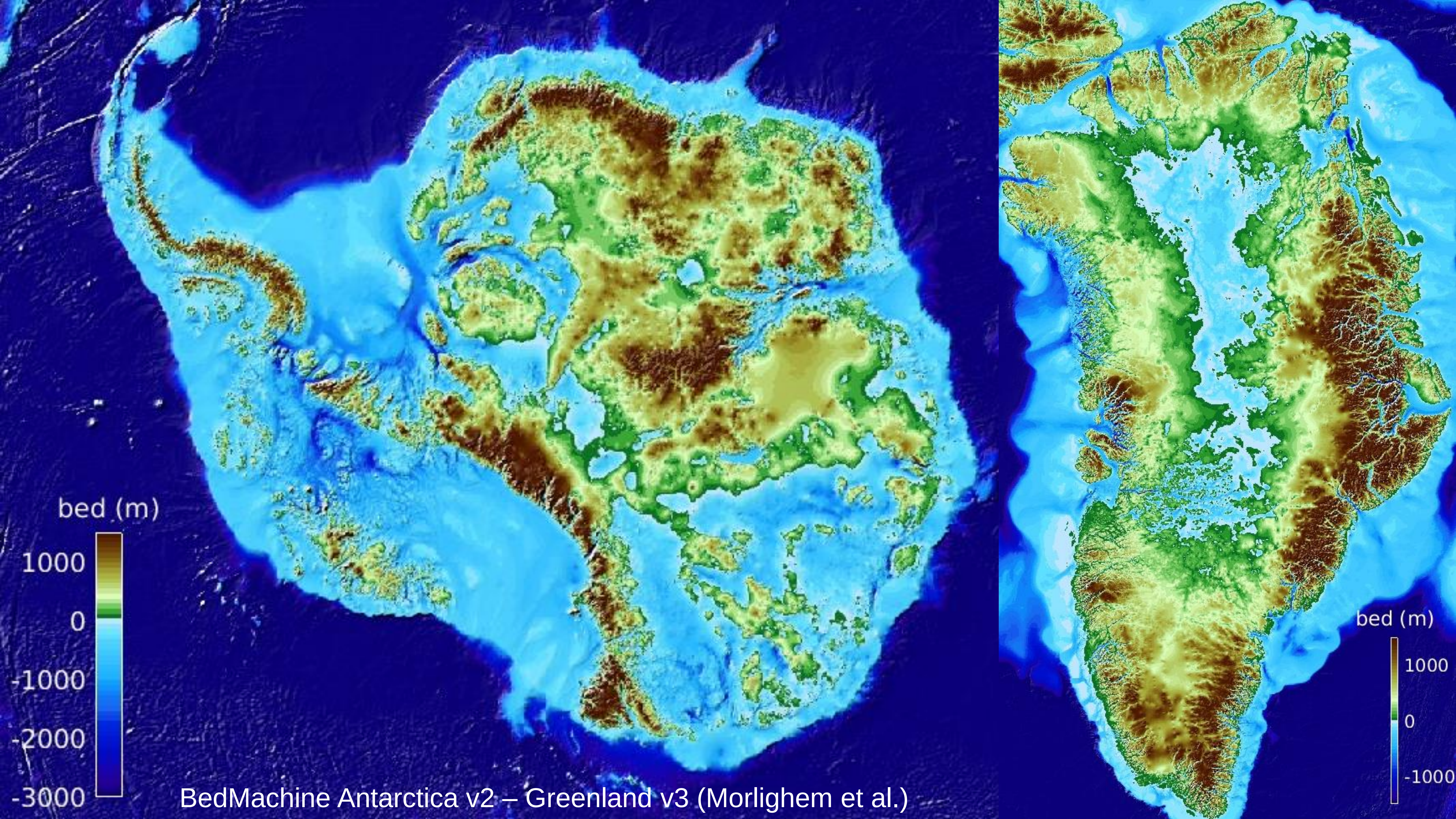
IPCC AR6 (2021)



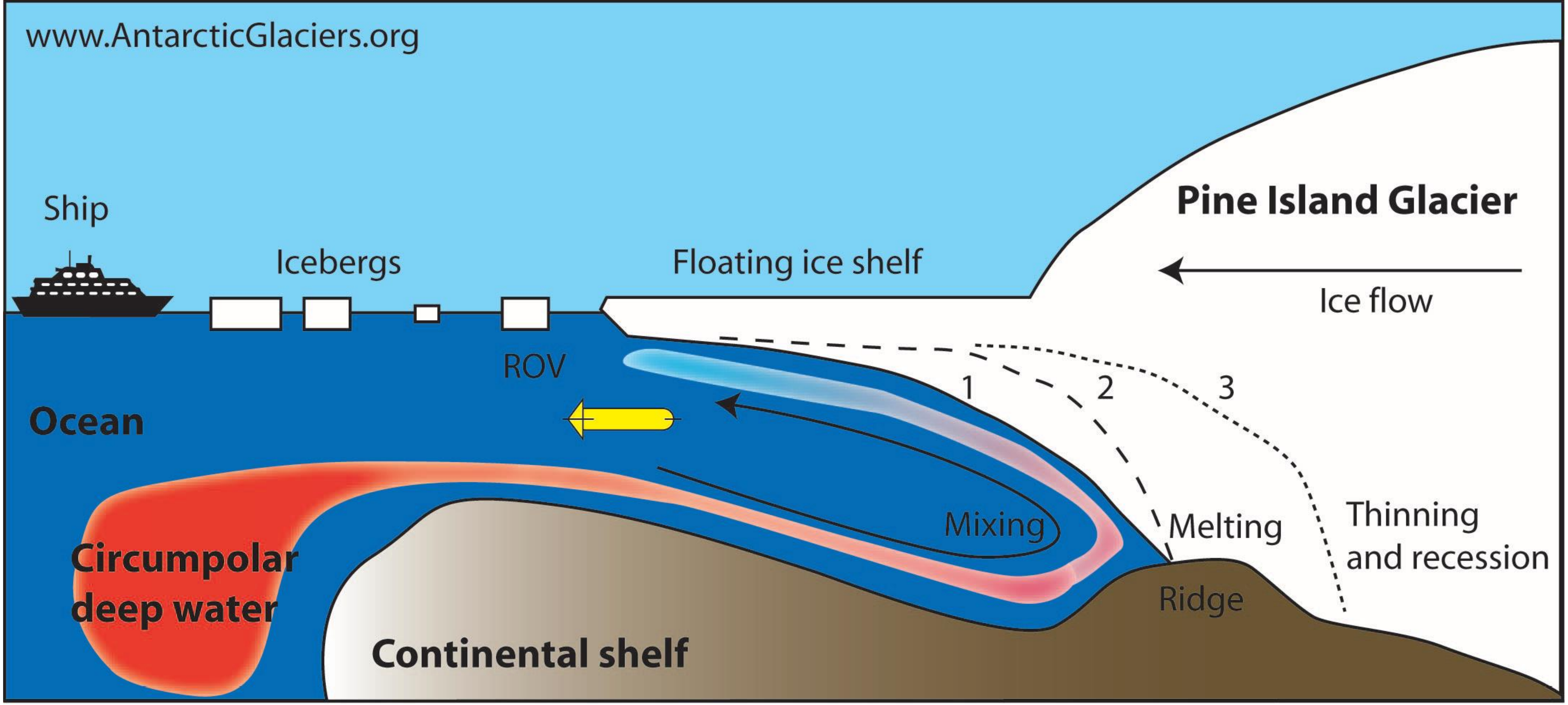
Smith et al. (2020) – www.iccinet.org/statecryo21



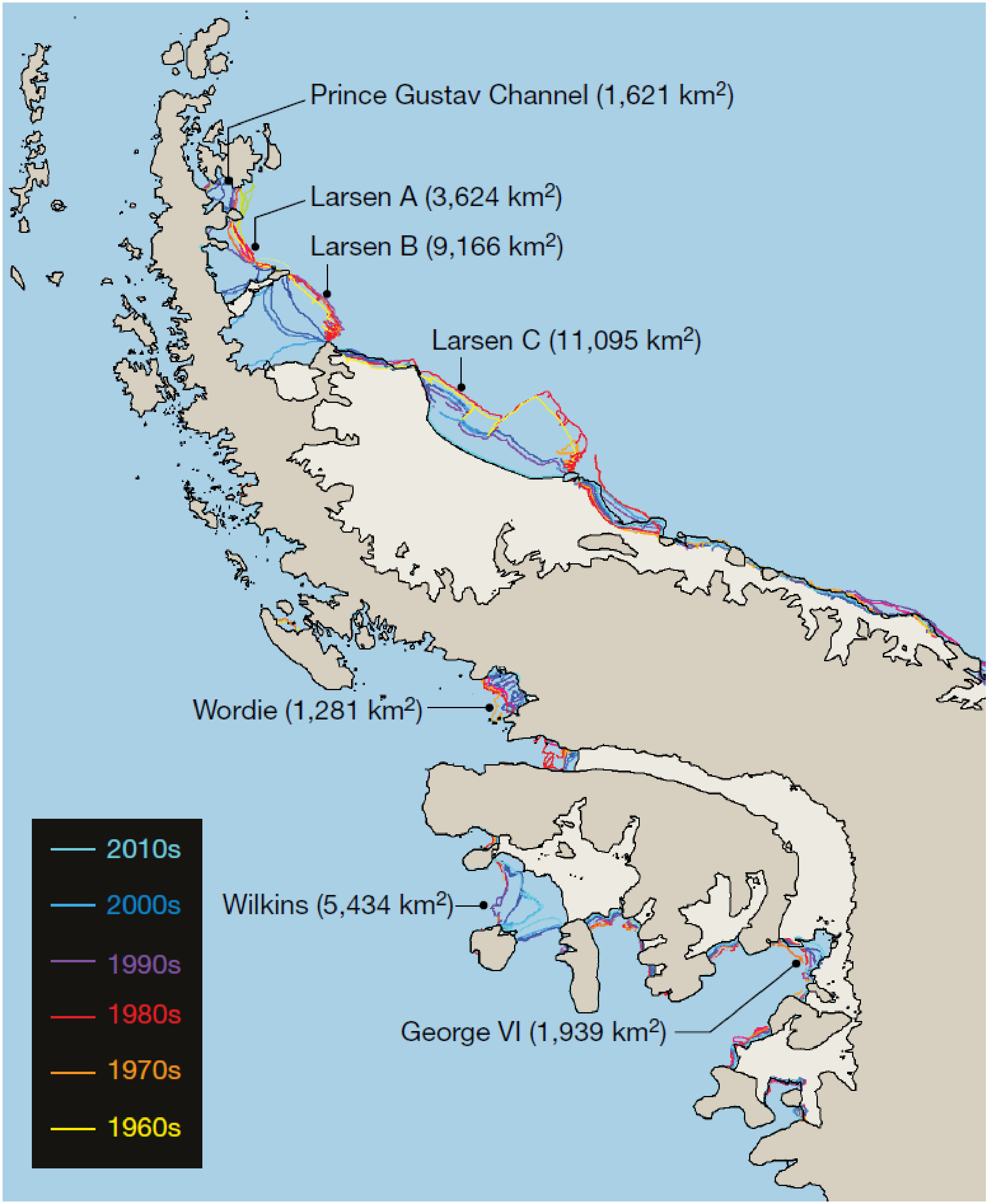
Ice sheets gain mass through snowfall, and lose mass through melting



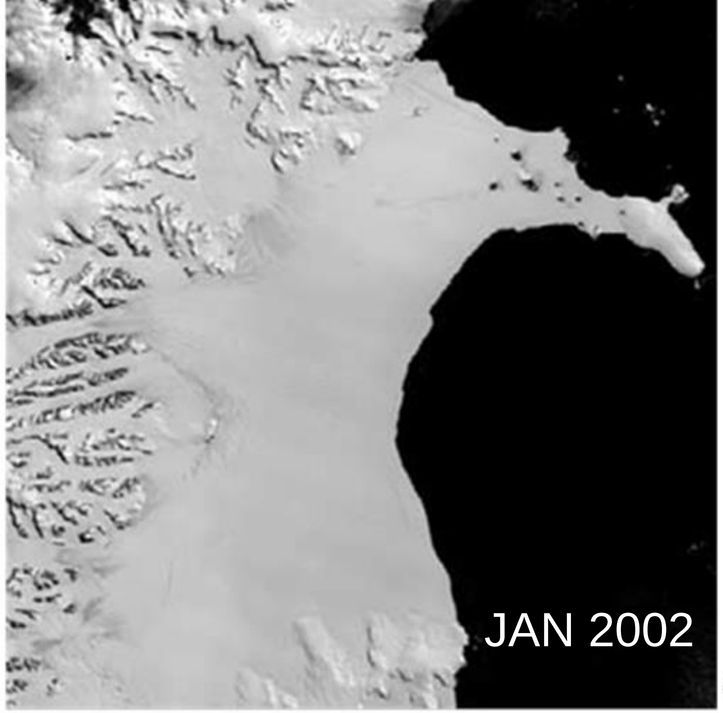
BedMachine Antarctica v2 – Greenland v3 (Morlighem et al.)



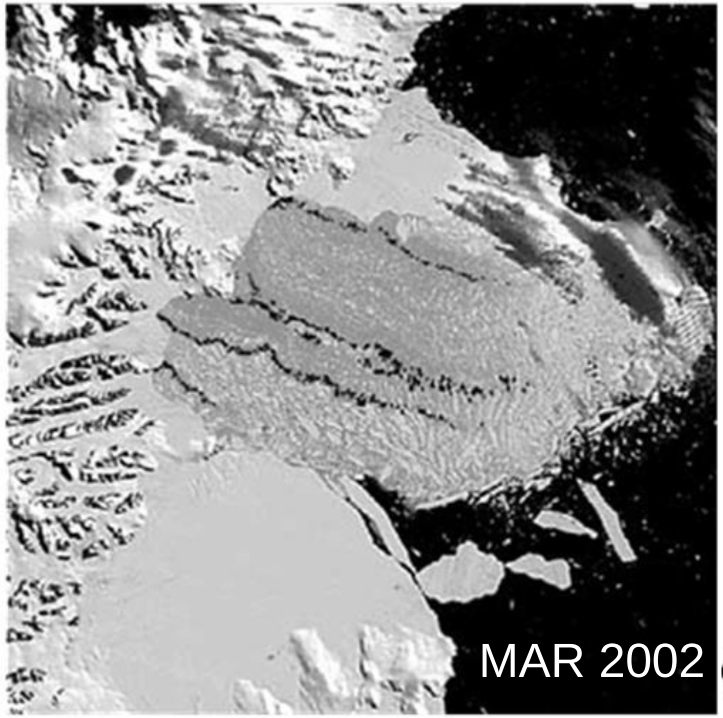
1. Early 1970s. Pine Island Glacier is grounded at a bedrock ridge.
2. Warm, inflowing Circumpolar Deep Water melts the base of the glacier. The glacier steepens and accelerates.
3. Present day, observed by a remotely operated vehicle (ROV). Glacier is thinning and receding.



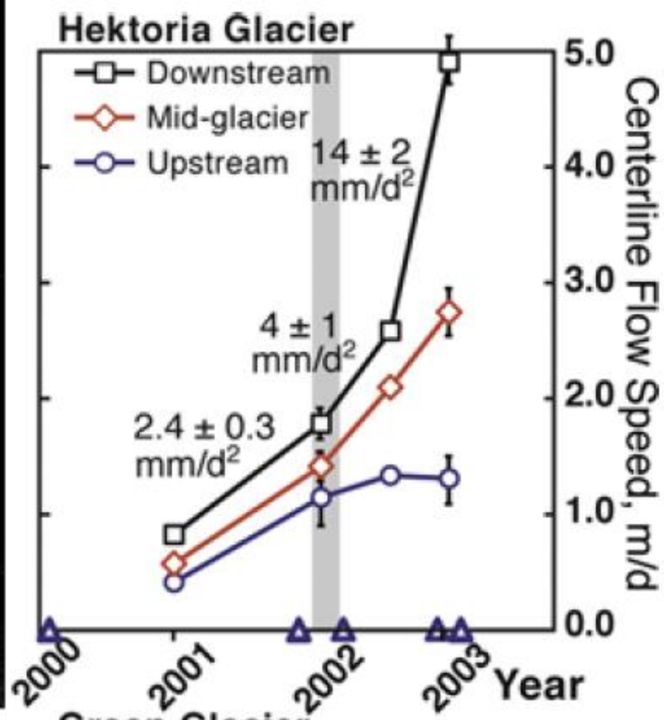
Prince Gustav Channel (1,621 km²)
Larsen A (3,624 km²)
Larsen B (9,166 km²)
Larsen C (11,095 km²)
Wordie (1,281 km²)
Wilkins (5,434 km²)
George VI (1,939 km²)
2010s
2000s
1990s
1980s
1970s
1960s



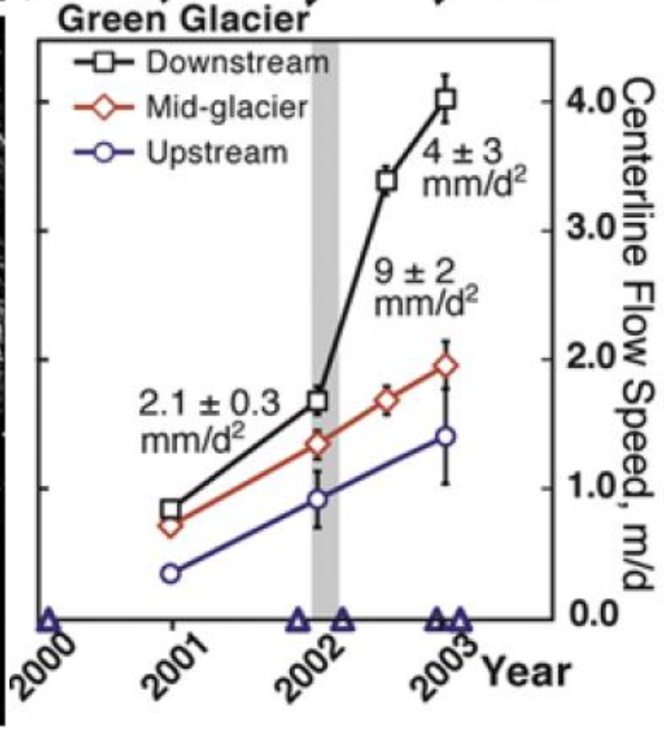
JAN 2002



MAR 2002

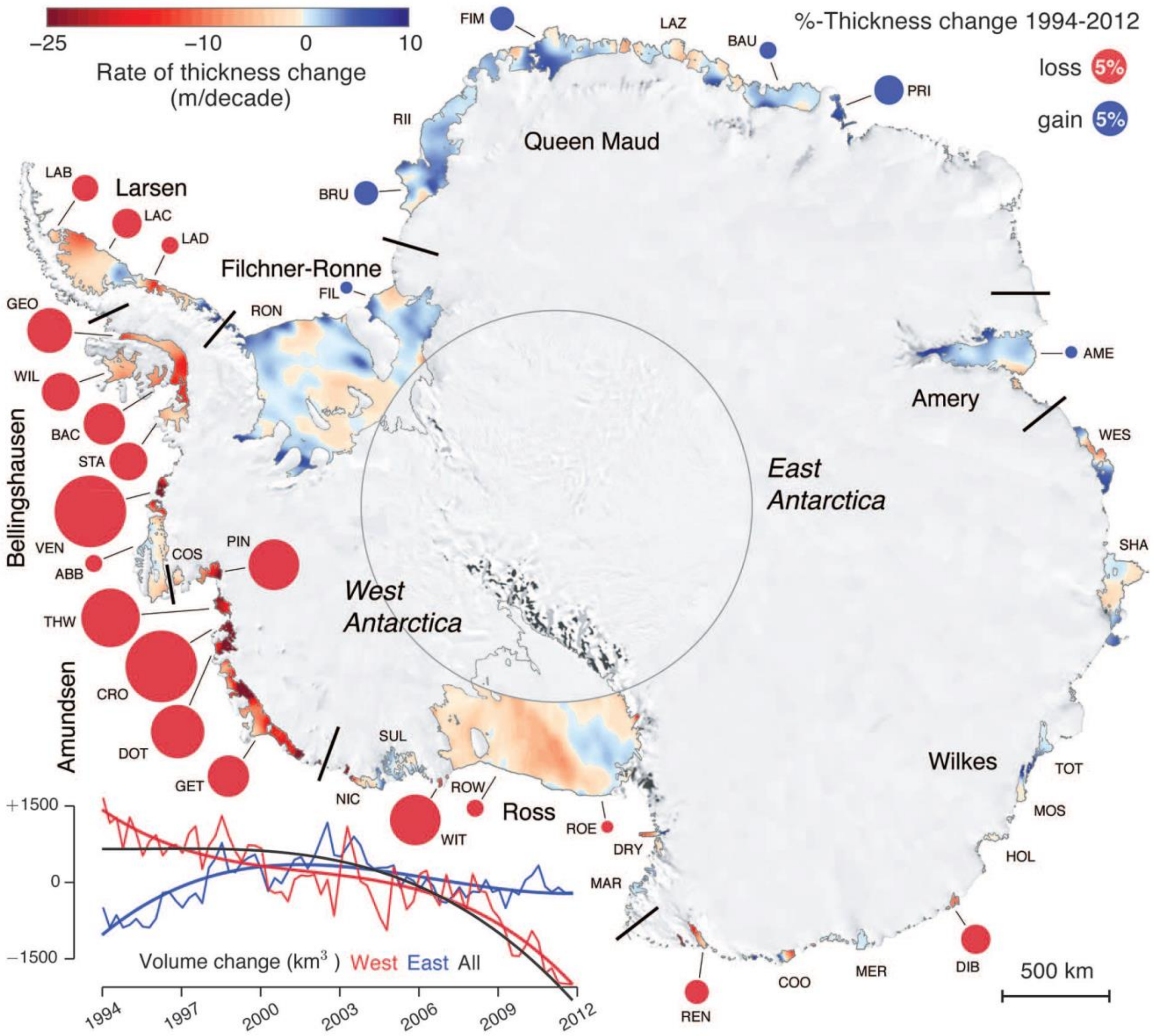


Hektoria Glacier
Downstream
Mid-glacier
Upstream
14 ± 2 mm/d²
4 ± 1 mm/d²
2.4 ± 0.3 mm/d²
5.0
4.0
3.0
2.0
1.0
0.0
Centerline Flow Speed, m/d
2000
2001
2002
2003
Year



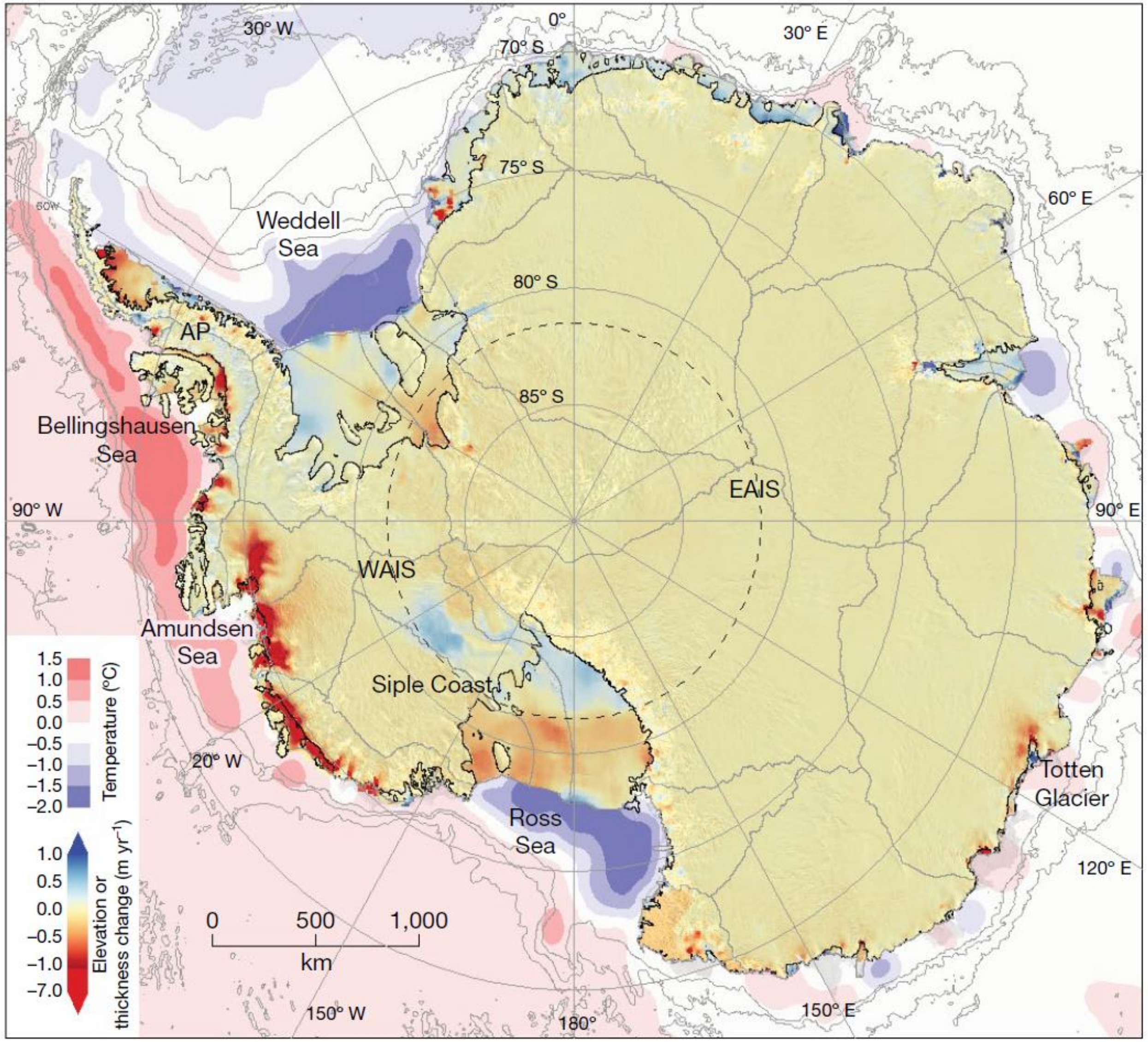
Green Glacier
Downstream
Mid-glacier
Upstream
4 ± 3 mm/d²
9 ± 2 mm/d²
2.1 ± 0.3 mm/d²
4.0
3.0
2.0
1.0
0.0
Centerline Flow Speed, m/d
2000
2001
2002
2003
Year

Thinning of ice shelves



Paolo et al. (2015)

Thinning of the ice sheet



Shepherd et al. (2018)

Atmosphere-ocean-ice interaction: uncertainties from drivers to response

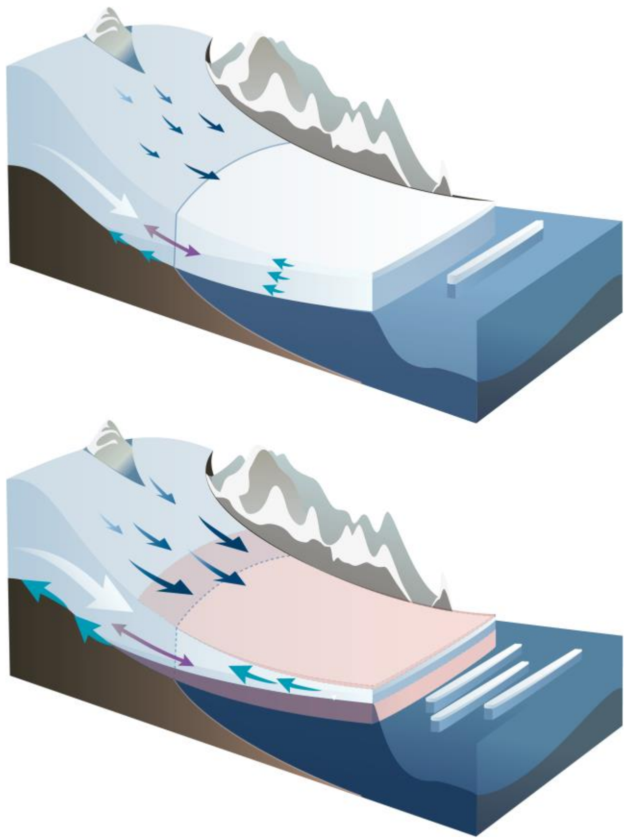
Noise

Drivers of melt → Ice shelf thinning → Ice sheet mass loss

- Atmosphere forcing
- Ocean forcing
- Ocean circulation in sub-shelf cavities

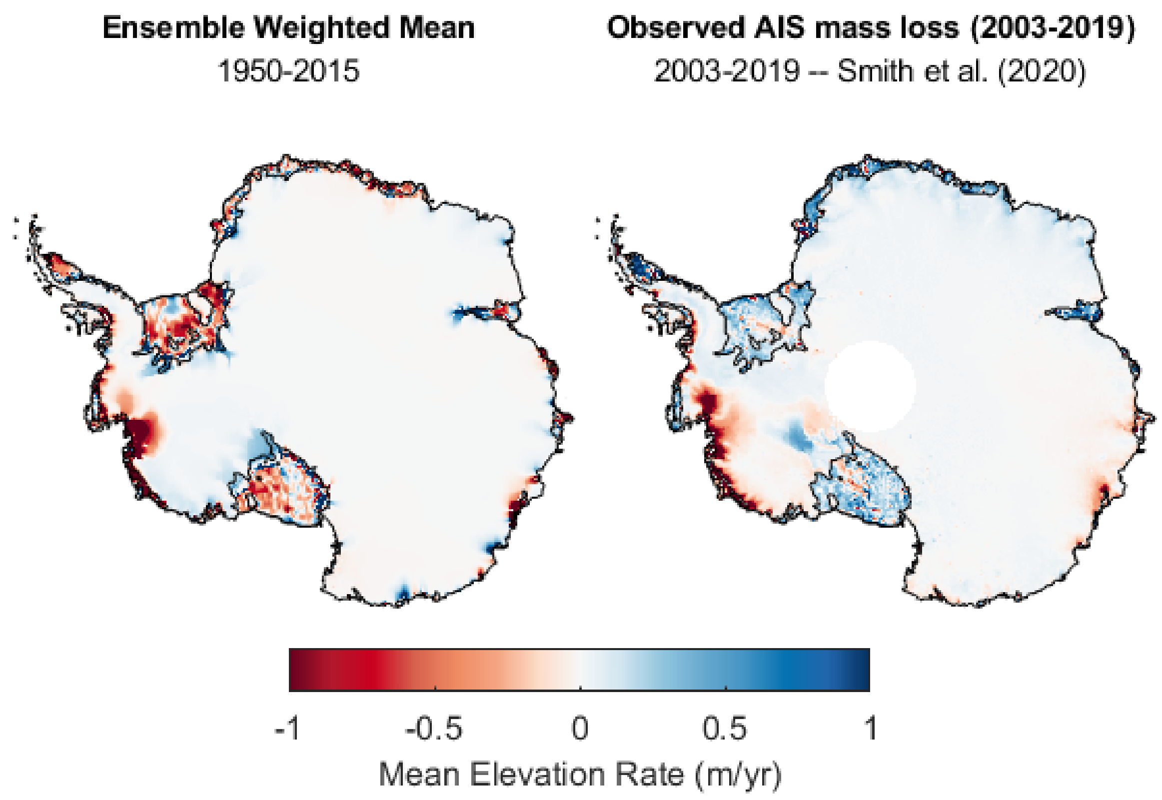
- Sub-shelf melt
- Surface melt
- Upstream ice flux
- Calving, damage

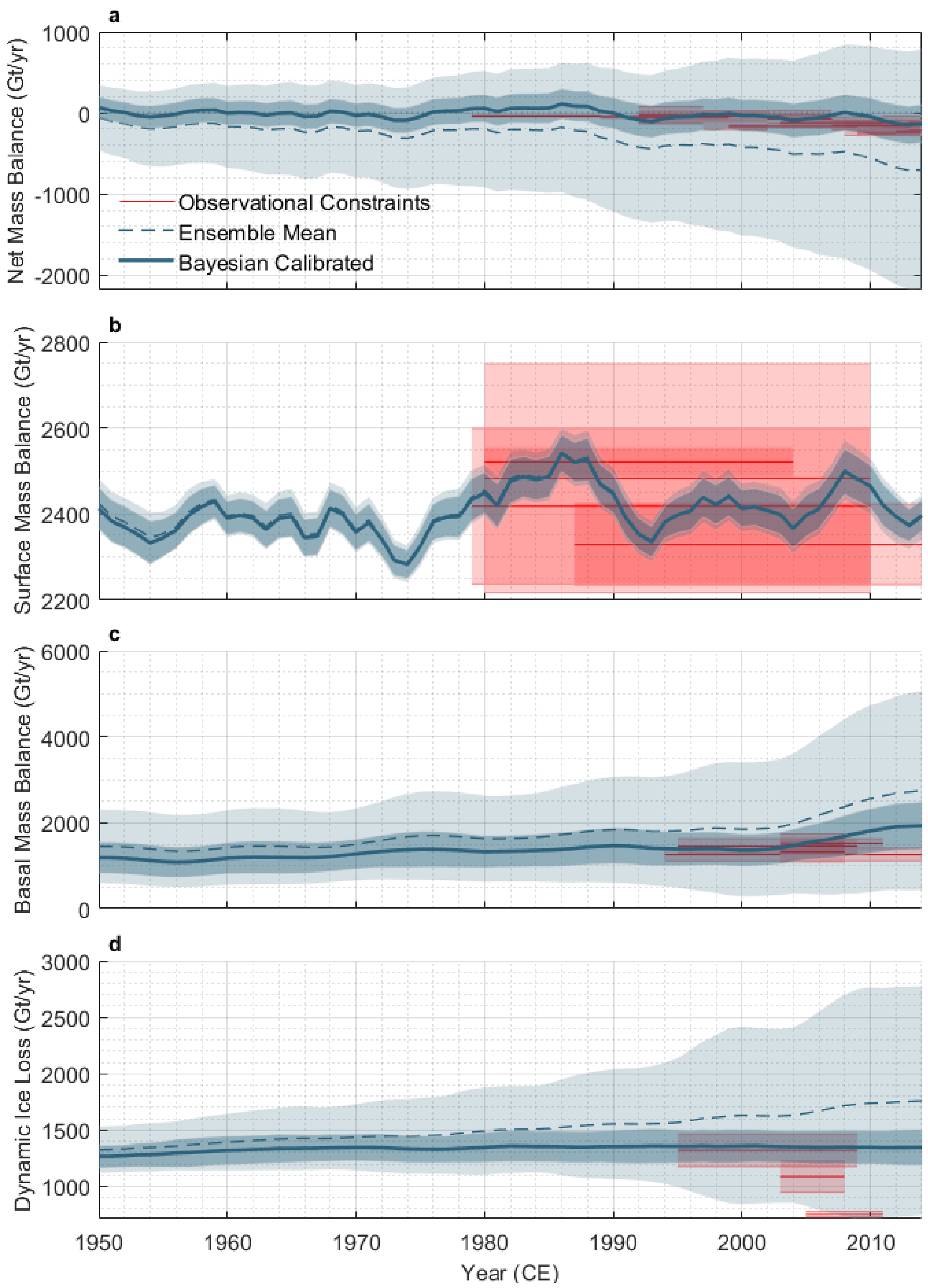
- Grounding line retreat
- Ice shelf buttressing
- Ice flow acceleration
- Basal sliding
- Surface mass balance



Gudmundsson et al (2019)

Model simulations of the observational period





Coulon (2022)

PARAMOUR

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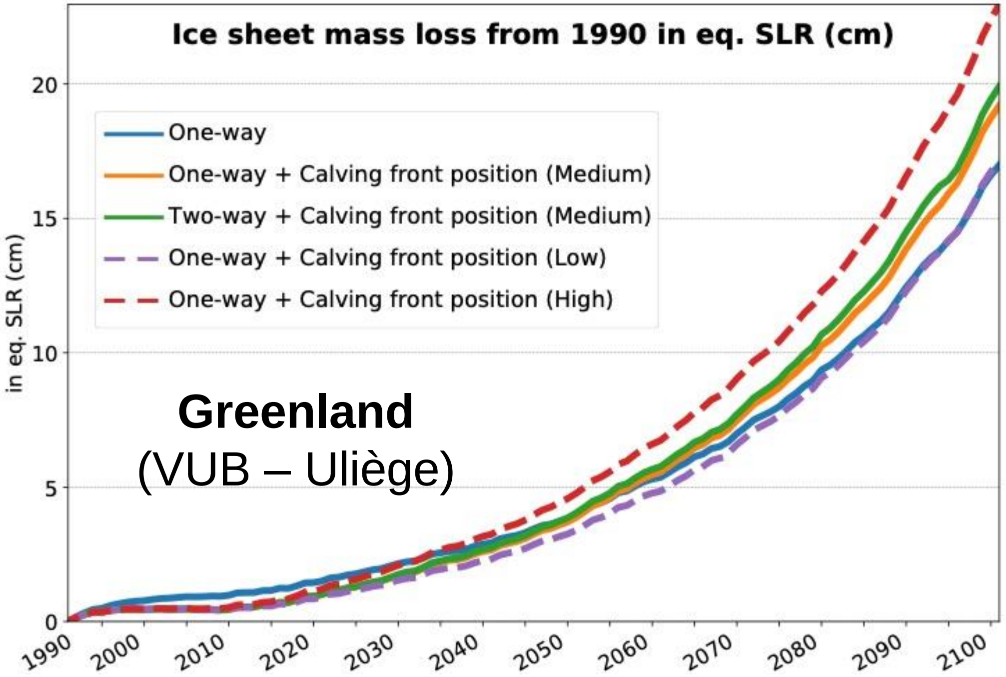
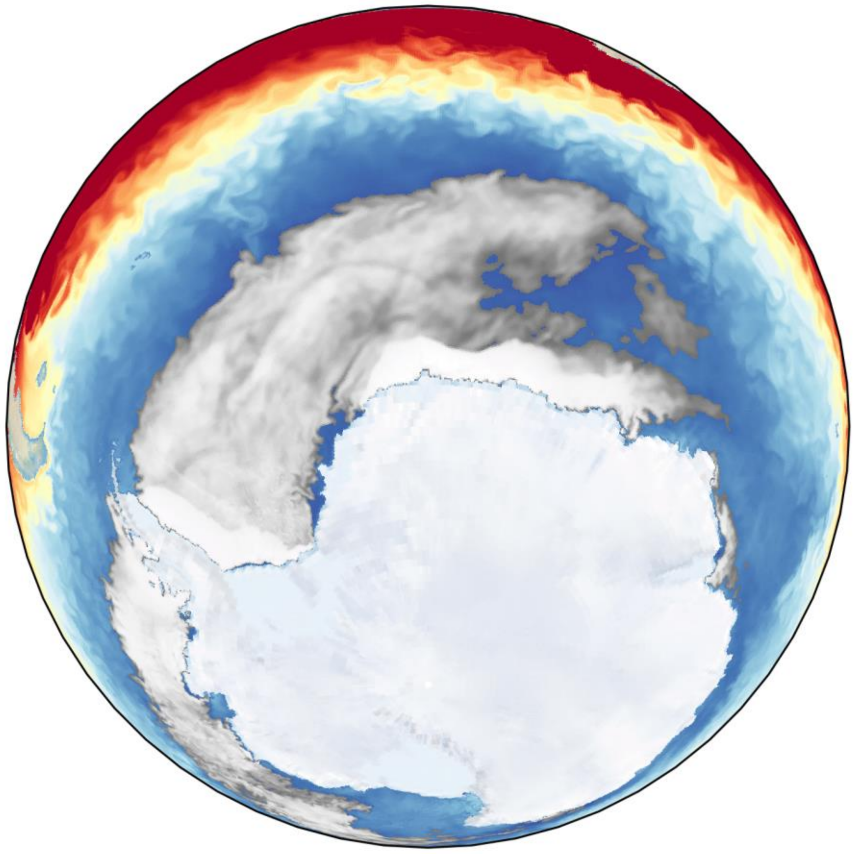
Coupled model simulations over the observational period

What sets the predictability of the **coupled ice sheet-sea ice-ocean-atmosphere** system?



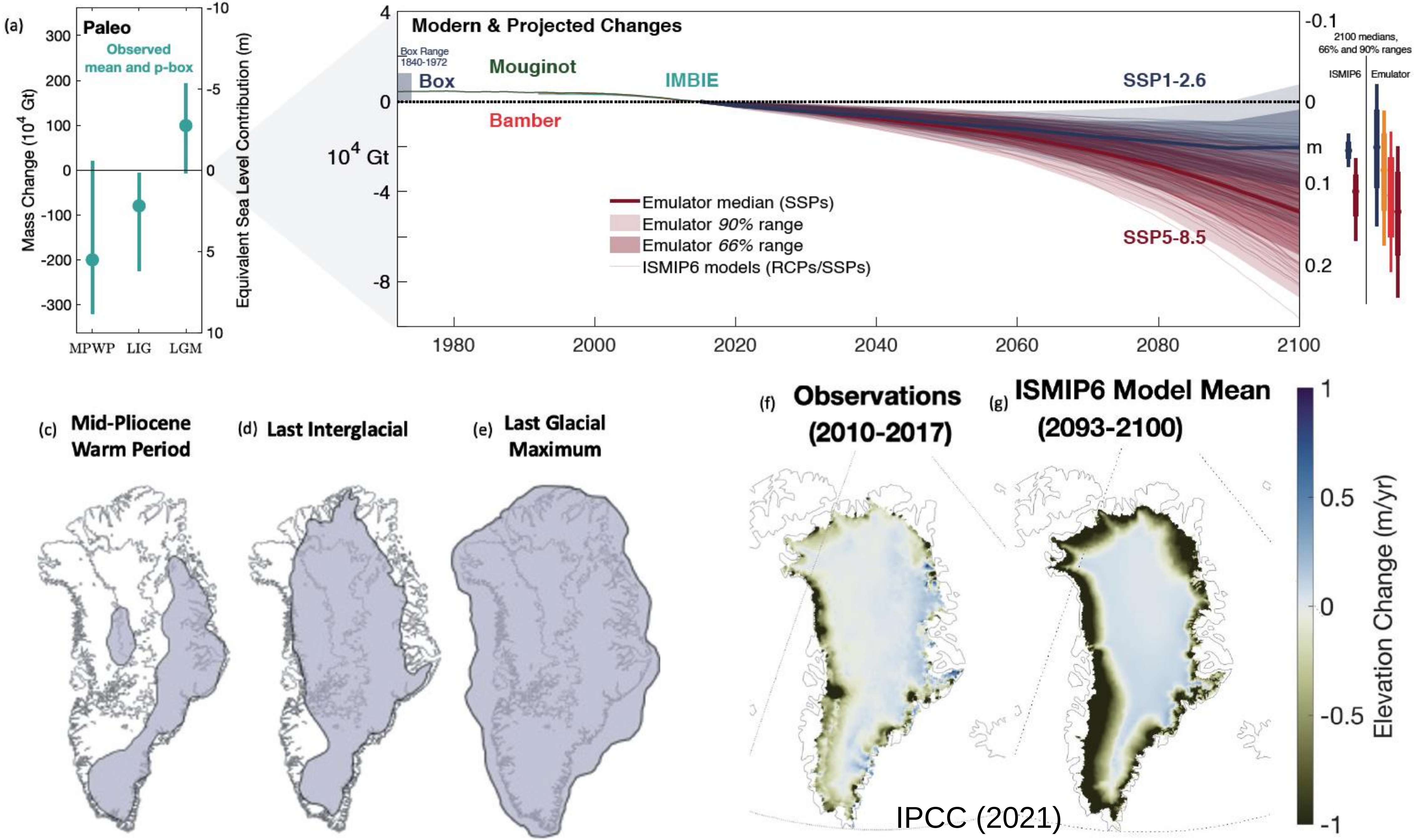
Greenland
(VUB – Uliège)

1/4° reconstruction of the ocean and sea ice states
www.climate.be/paramour



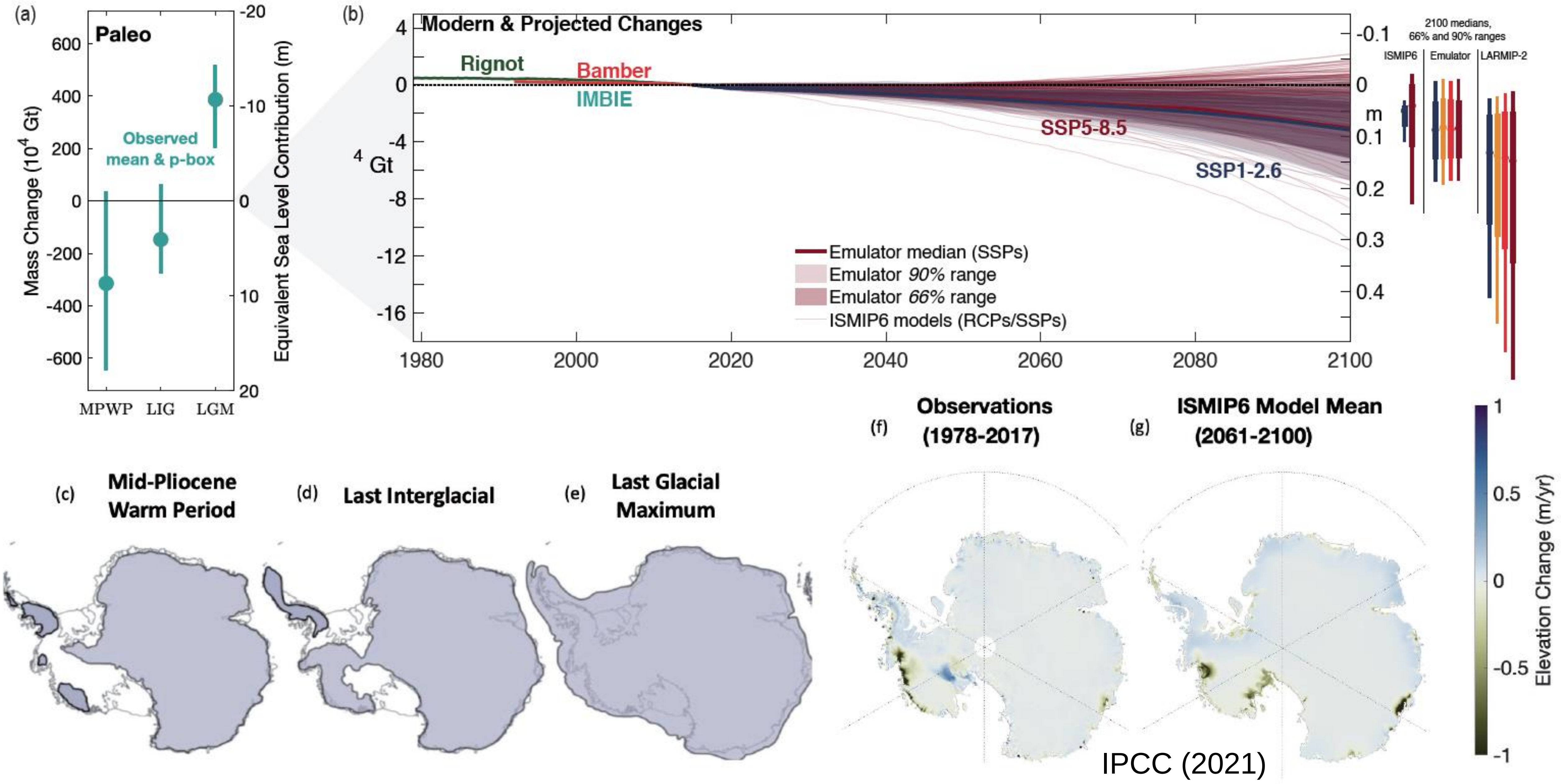
Antarctica
UCLouvain – KULeuven - ULB

Greenland ice sheet cumulative mass change and equivalent sea level contribution



IPCC (2021)

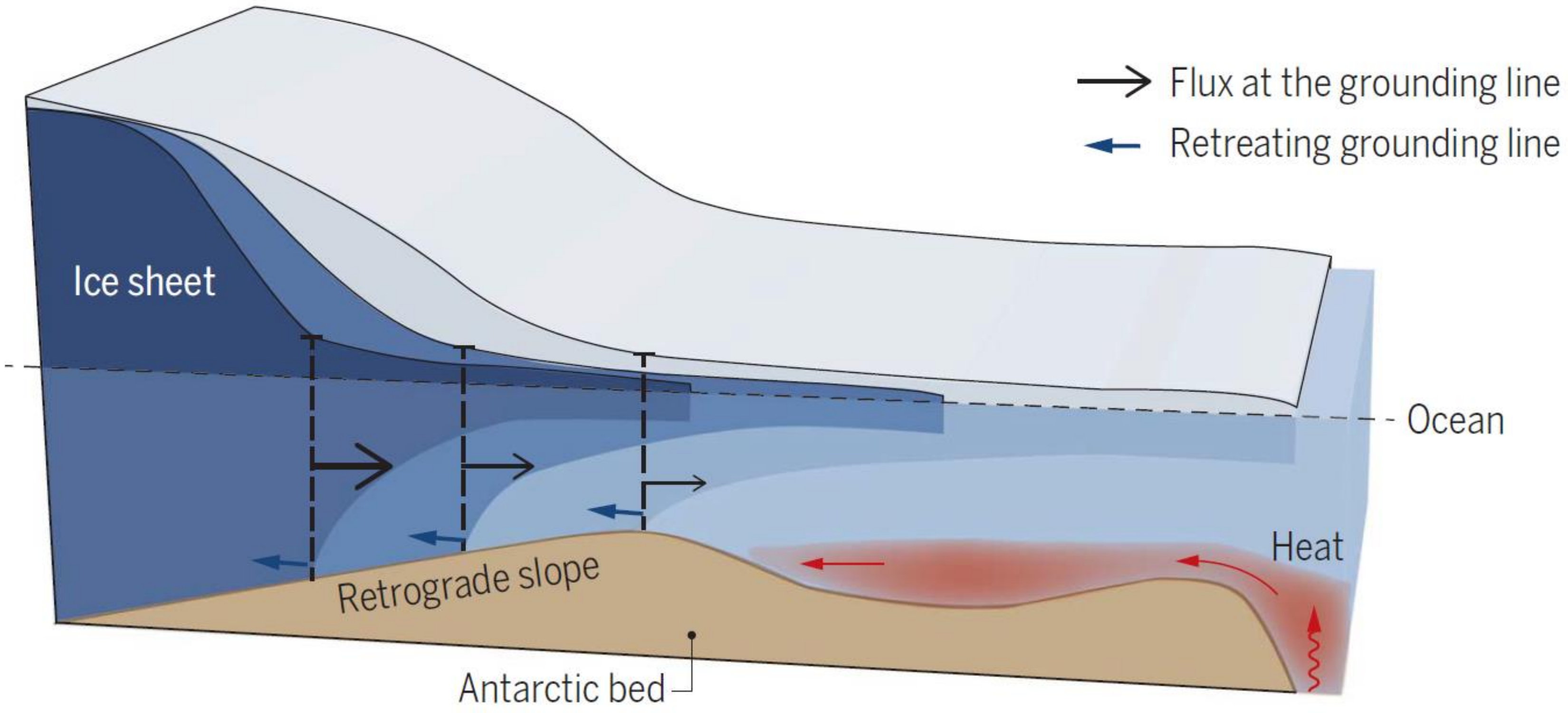
Antarctic ice sheet cumulative mass change & equivalent sea level contribution

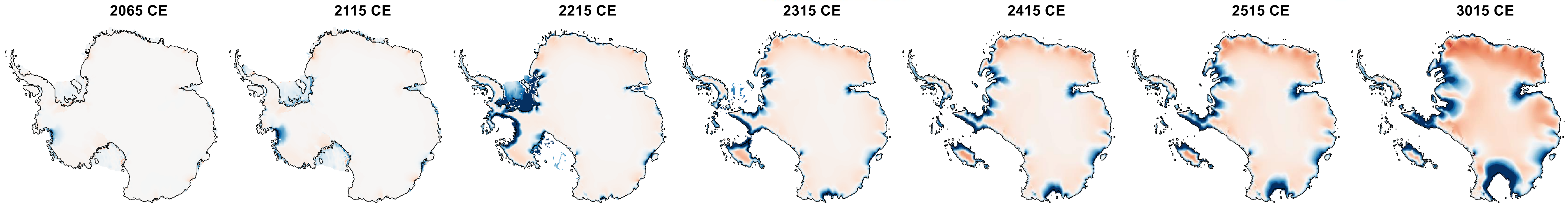


IPCC (2021)

Antarctica: melting ice shelves may lead to ice sheet instability

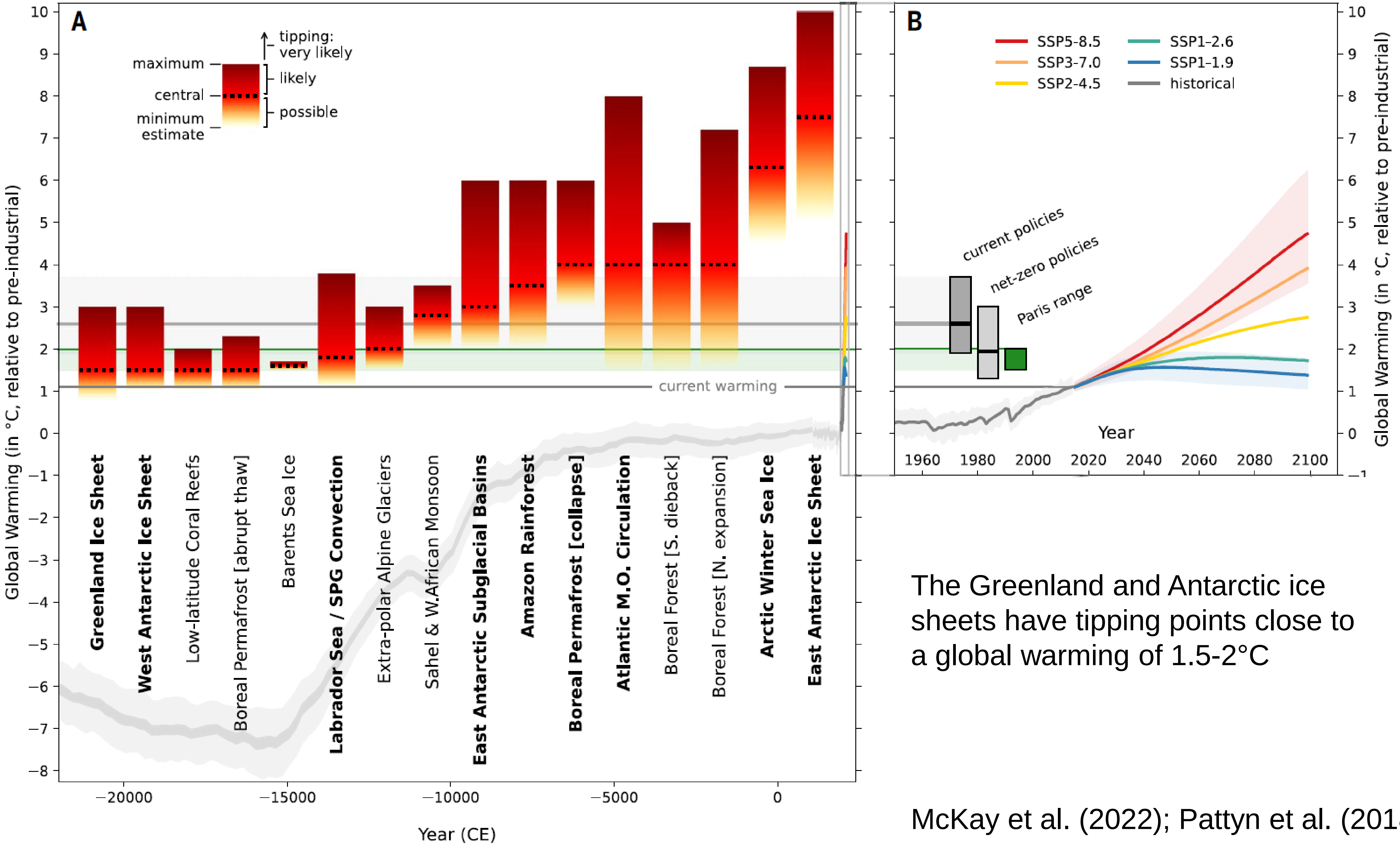
WHEN and WHERE?





Pattyn and Morlighem (2020), Coulon (2022)


Irreversible
for hundreds
or thousands
of years
Ocean warming
Ice sheets
Sea level rise
NASA



The Greenland and Antarctic ice sheets have tipping points close to a global warming of 1.5-2°C

McKay et al. (2022); Pattyn et al. (2018)

Conclusions

- Ice is a crucial component of the climate system: it reacts to changes in climate with far-reaching impacts, but it also records past changes of the climate with utmost detail.

- Sea level will continue to rise for centuries to come, irrespective of actions taken to reduce global warming. However, fast and catastrophic sea level rise can be avoided with strong climate mitigation.

- For warming levels above 2°C, ice loss from the Greenland and Antarctic ice sheets may become irreversible (tipping points).