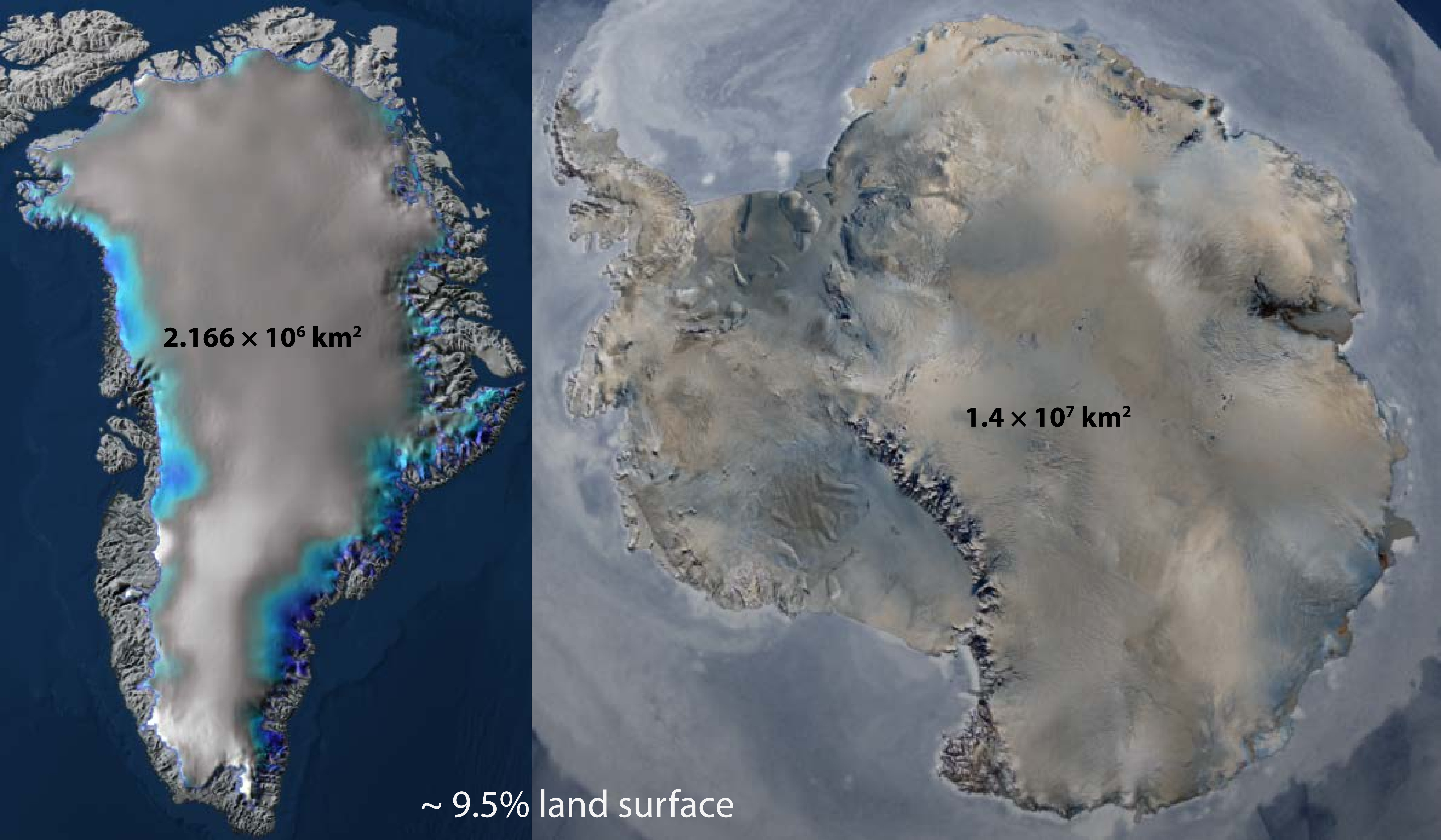
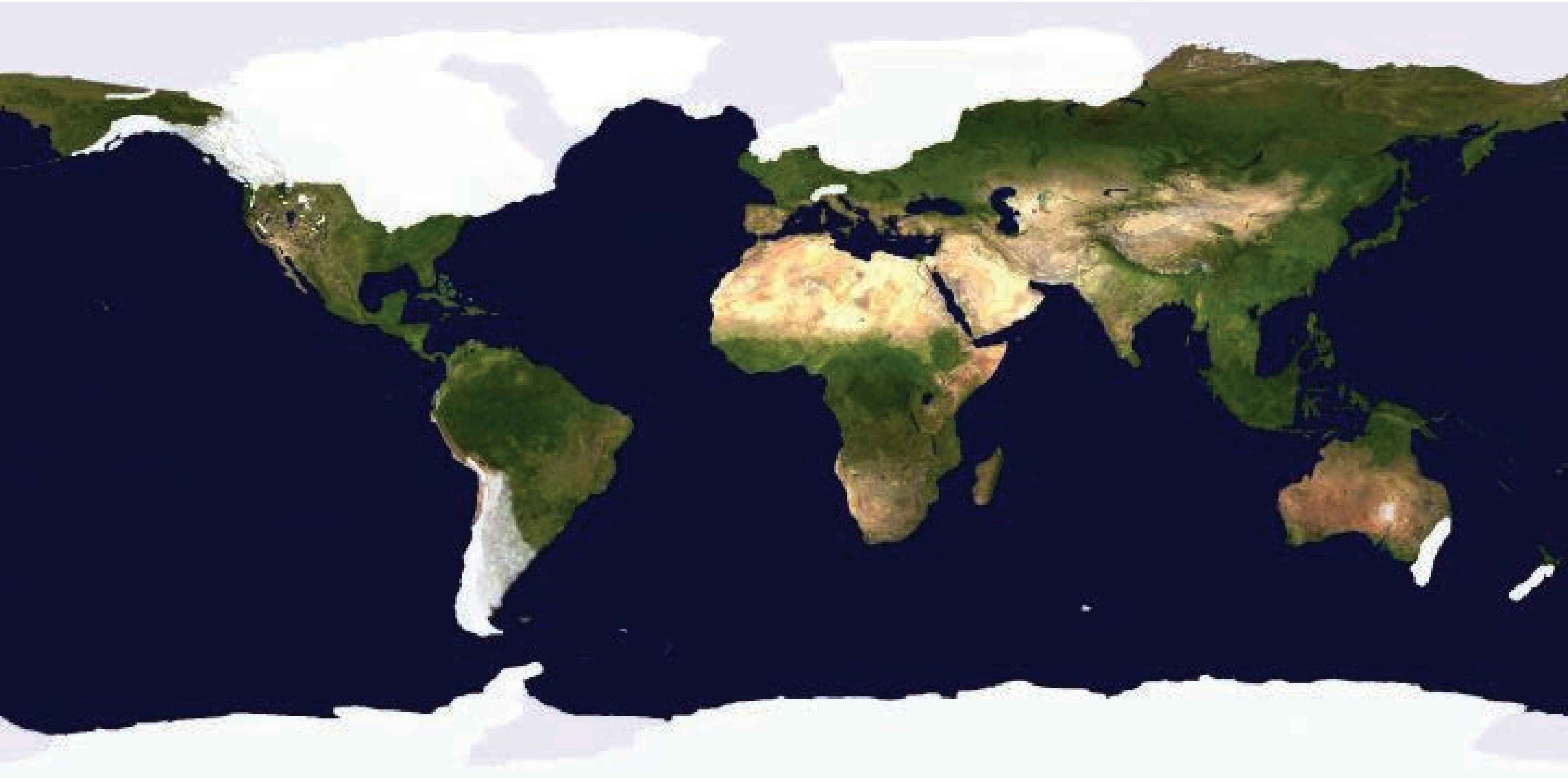
Interactions and feedbacks between ice sheets and the rest of the Earth system

Olga Sergienko
GFDL/Princeton University



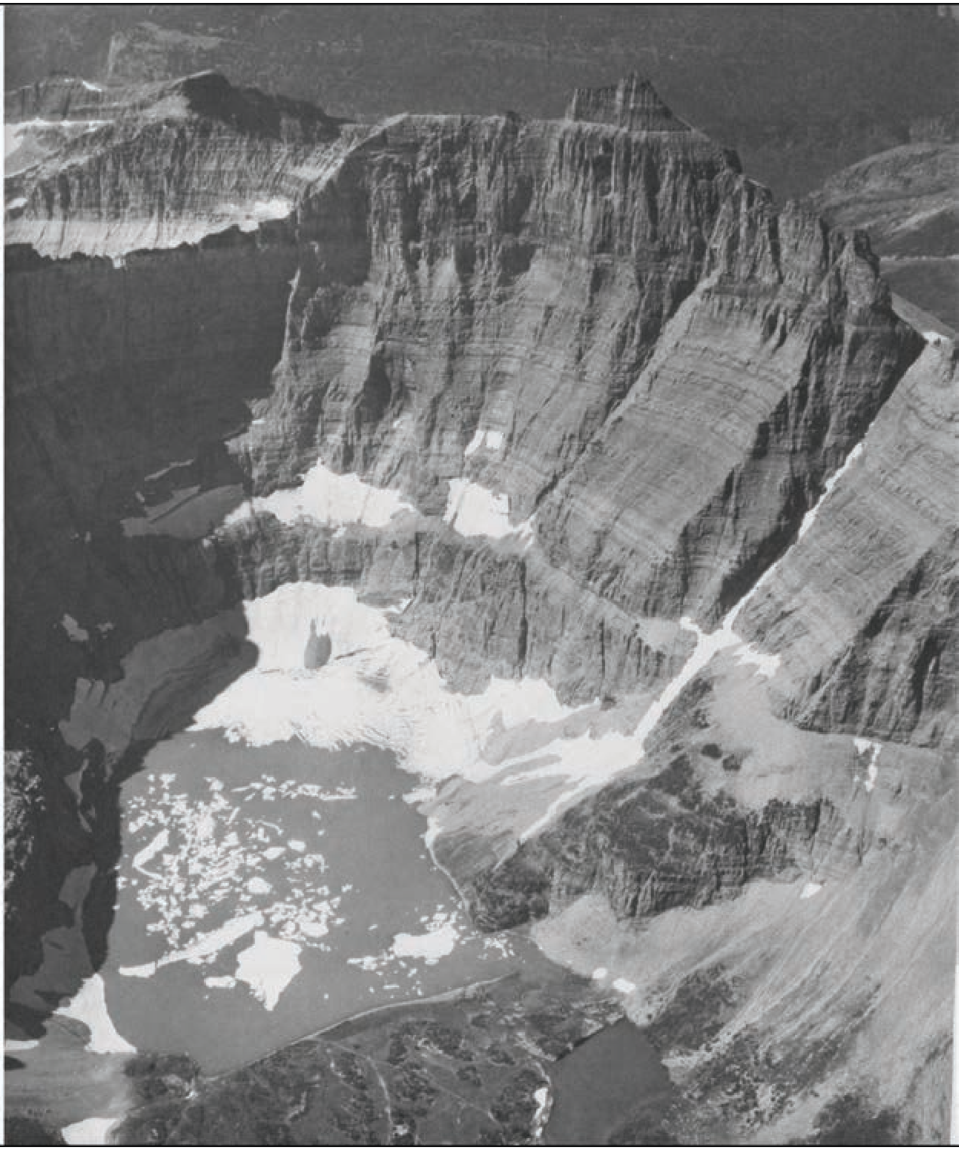
2.166 × 10⁶ km²
1.4 × 10⁷ km²
~ 9.5% land surface

Last Glacial Maximum ~ 26,000 yrs ago



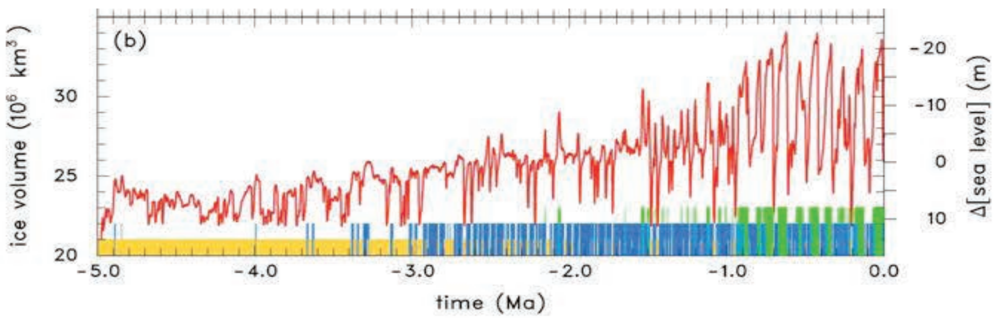
~ 25% land surface

Glacial landforms

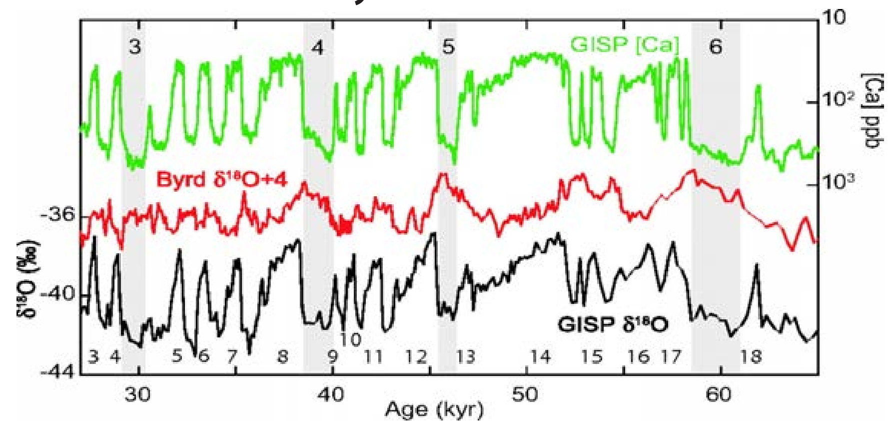


Time scales

100s kyr glaciation-deglaciation

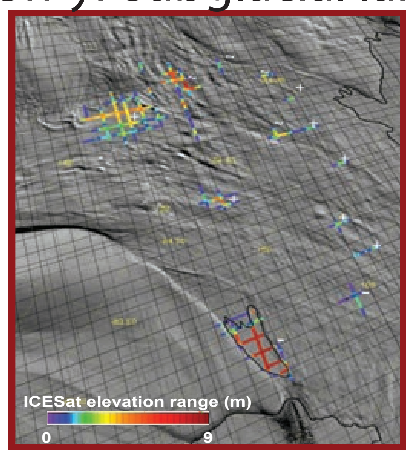


7-12 kyr Heinrich events

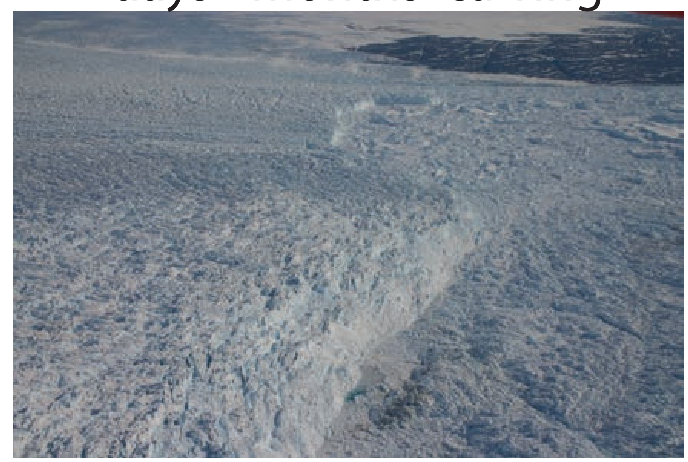


50 -100 yr calving

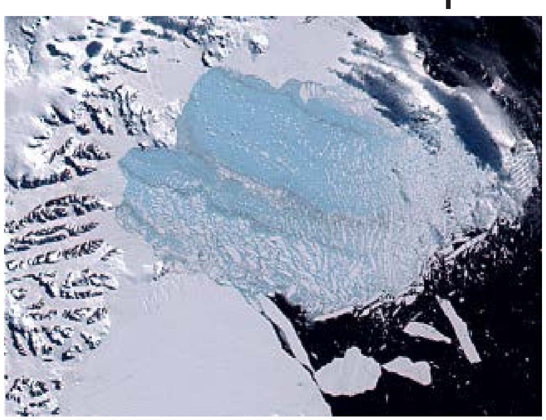
few yr subglacial lakes



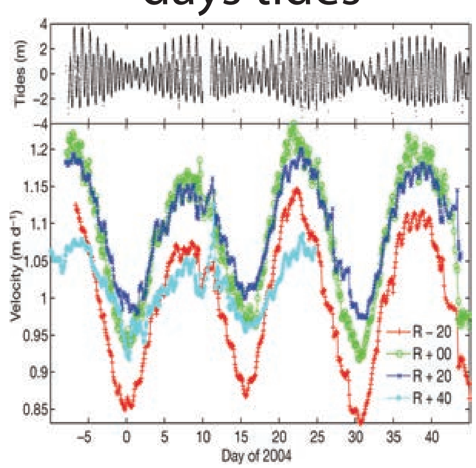
days - months calving



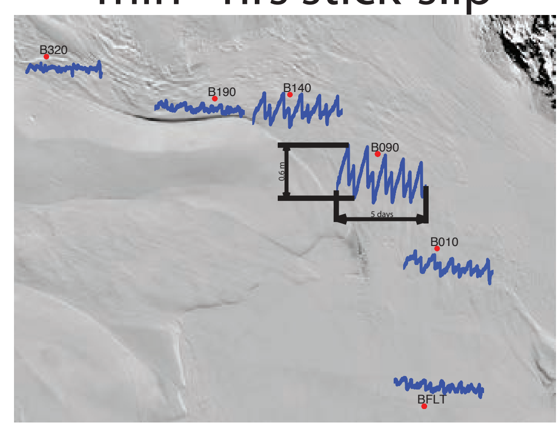
weeks ice-shelf collapse



days tides

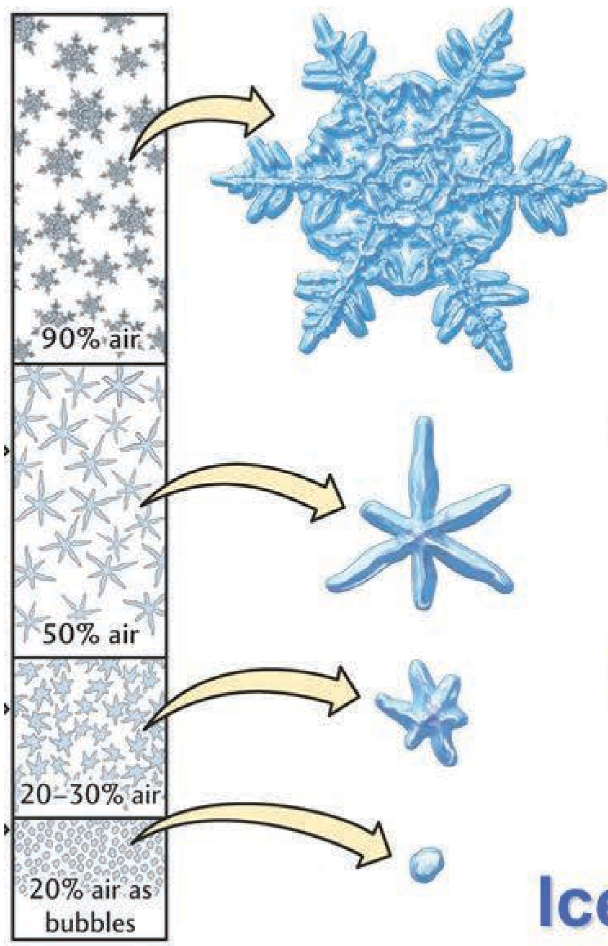


min - hrs stick-slip



Glacial ice ≠ frozen water

Transformation of Snow to Glacial Ice



(Like metamorphism)

Snow 90% porosity

(Like Sand)

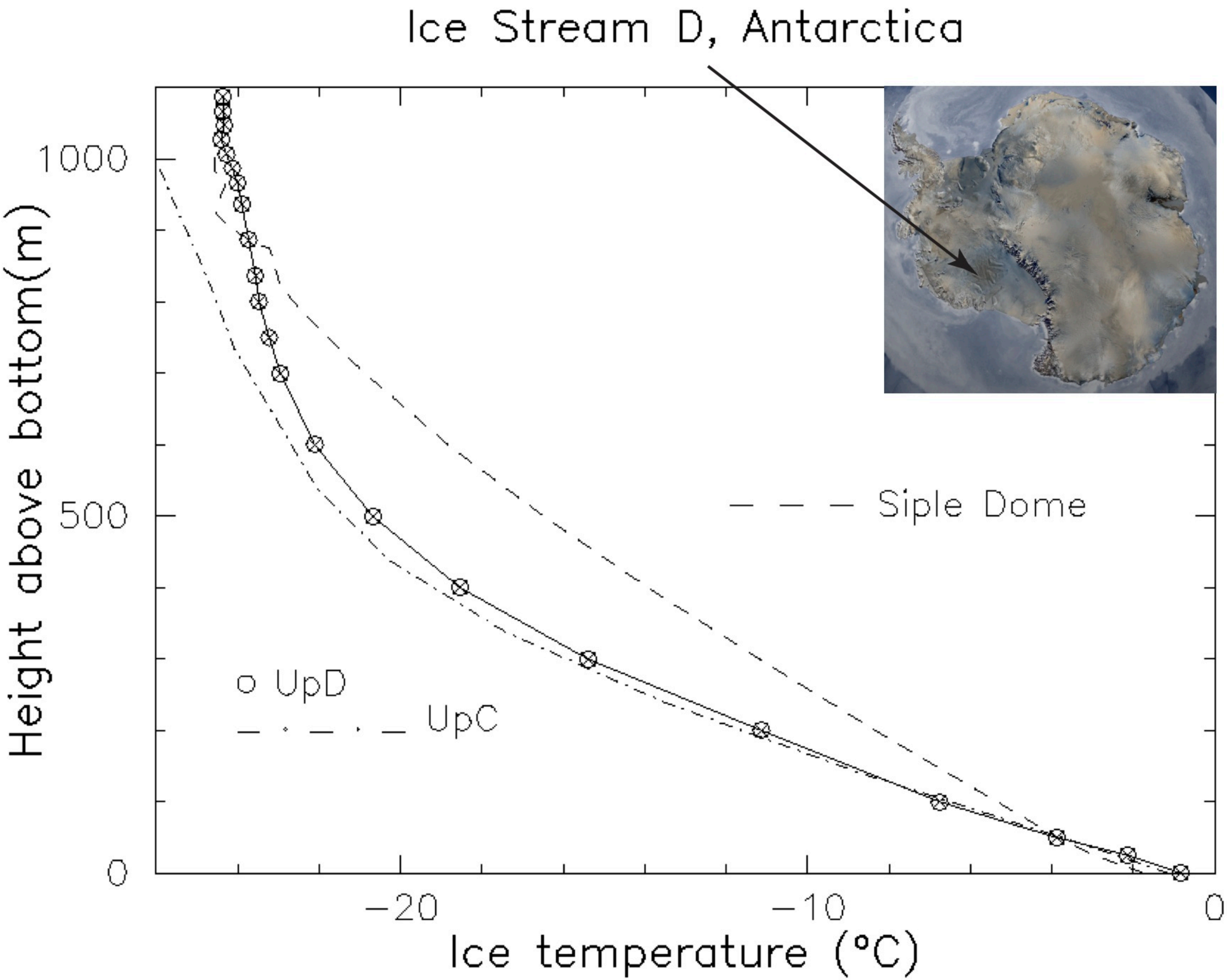
Granular Ice (50% porosity

(Like Sandstone)

Firn (20%)

Glacial Ice (0% except bubbles)

(Like quartzite)

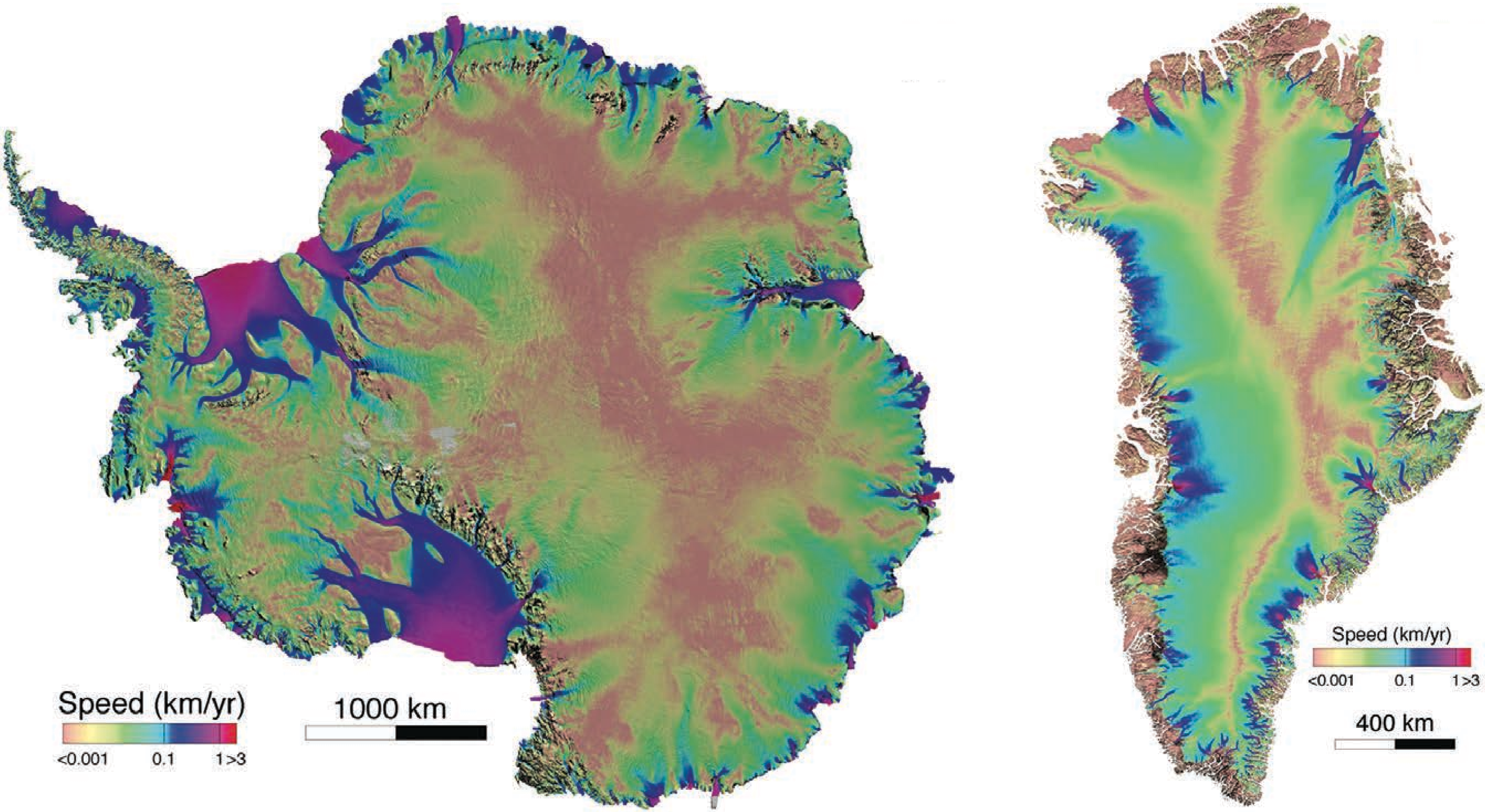


Ice Stream D, Antarctica
Height above bottom(m)
1000
500
0
−20
−10
0
Ice temperature (°C)
Siple Dome
o UpD
UpC

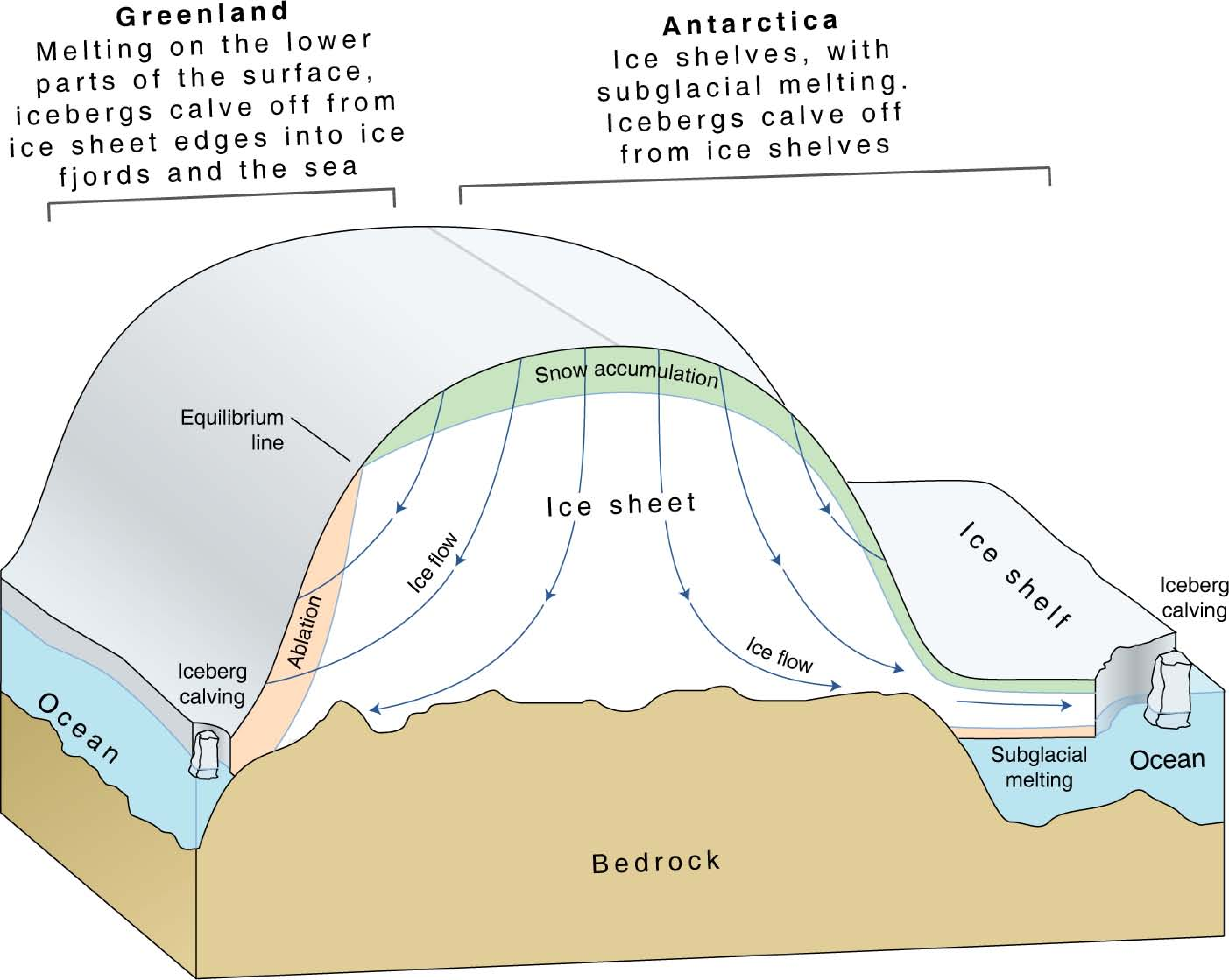
Ice is treated as a non-Newtonian fluid

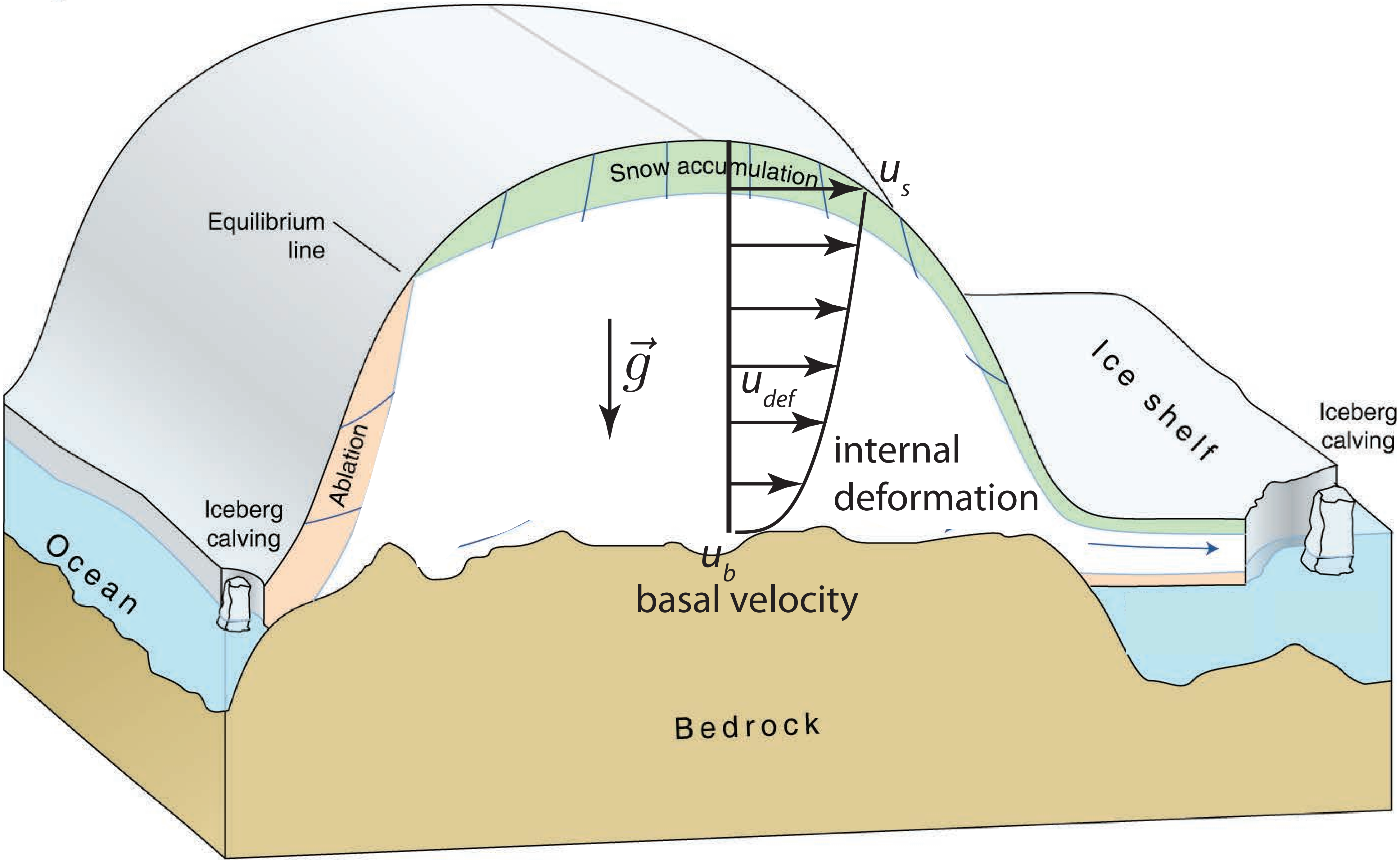
viscosity changed with applied stress

Surface ice speed



Mouginot et al. (2017)


Greenland
Melting on the lower parts of the surface, icebergs calve off from ice sheet edges into ice fjords and the sea
Antarctica
Ice shelves, with subglacial melting. Icebergs calve off from ice shelves
Snow accumulation
Equilibrium line
Ice sheet
Ice flow
Ice flow
Ablation
Iceberg calving
Ice shelf
Iceberg calving
Ocean
Ocean
Subglacial melting
Bedrock



Snow accumulation
u_s
Equilibrium line
$\vec{g}$
u_{def}
internal deformation
Ablation
Iceberg calving
Ocean
u_b
basal velocity
Ice shelf
Iceberg calving
Bedrock

AGU100 ADVANCING EARTH AND SPACE SCIENCE

Reviews of Geophysics

REVIEW ARTICLE

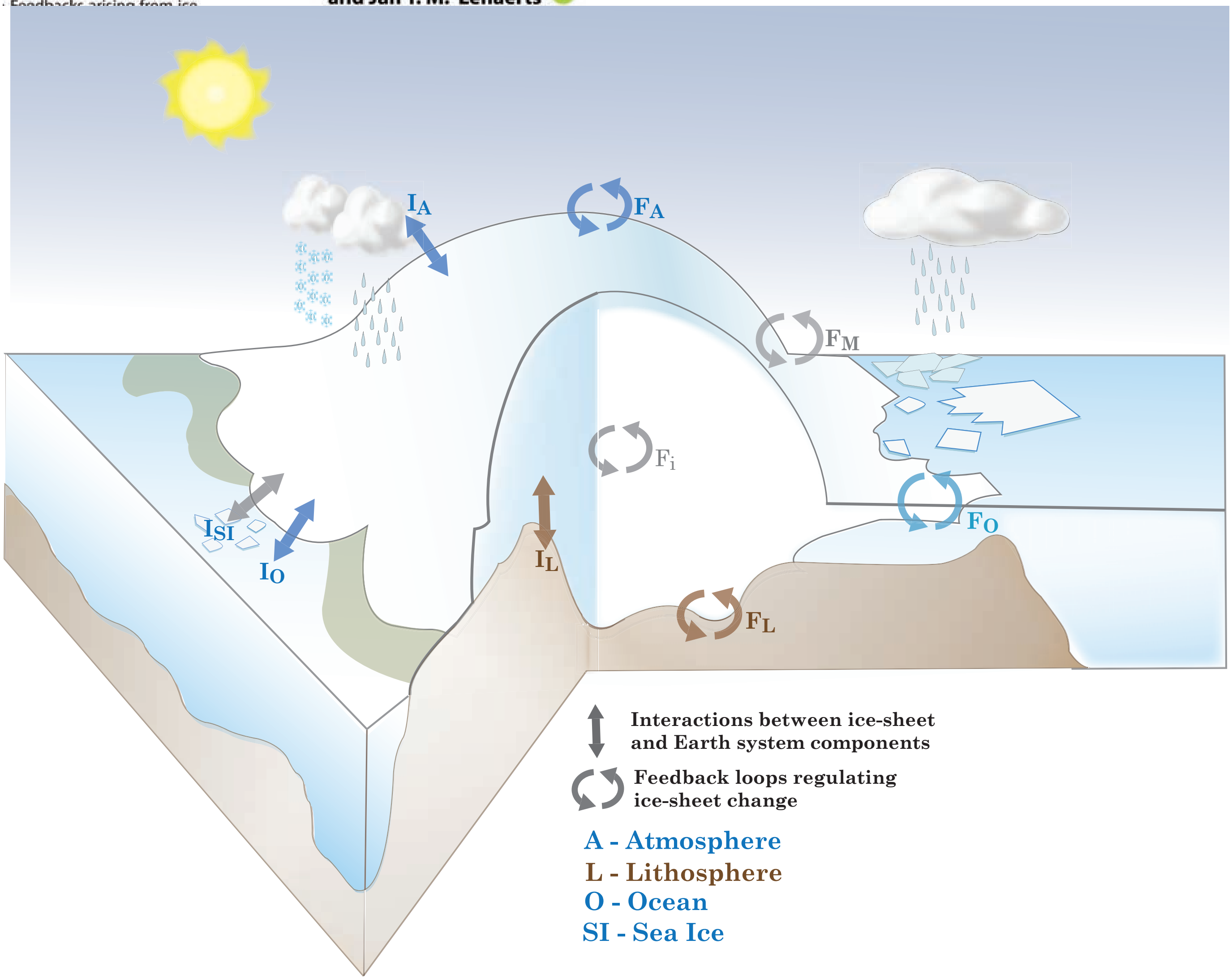
10.1029/2018RG000600

An Overview of Interactions and Feedbacks Between Ice Sheets and the Earth System

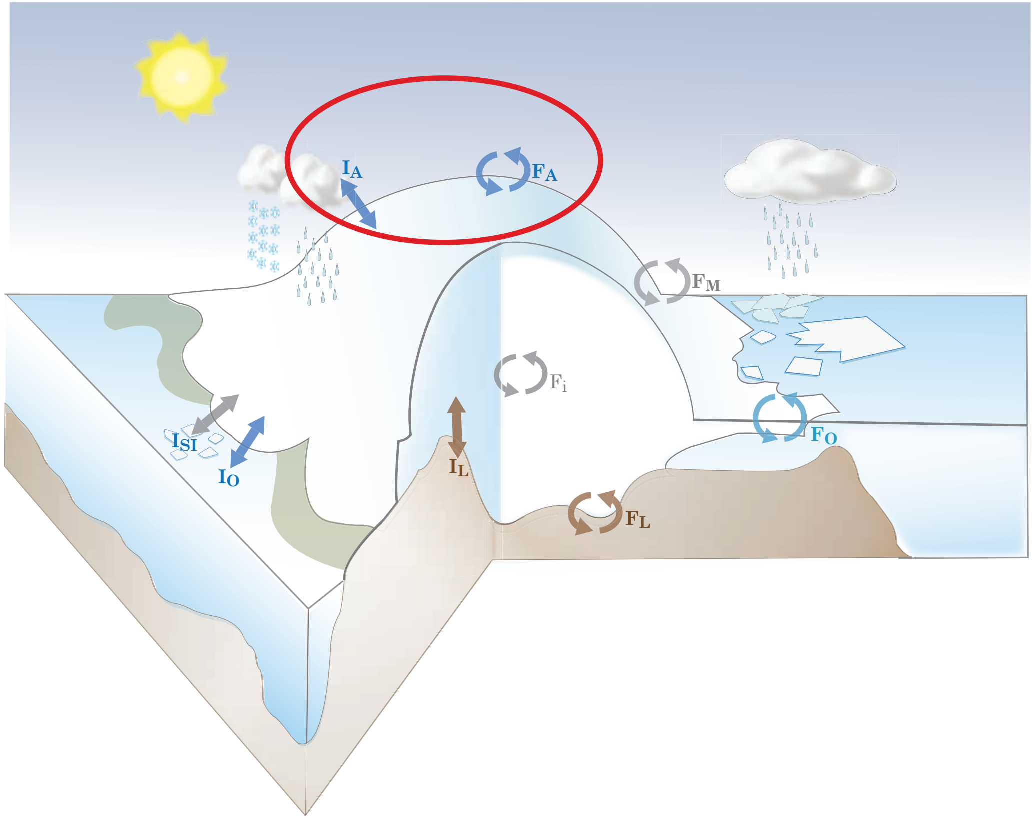
Jeremy Fyke[1,2], Olga Sergienko[3], Marcus Löfverström[4], Stephen Price[1], and Jan T. M. Lenaerts[5]

Key Points:

- Ice sheets are tightly coupled components of the Earth system



Ice sheet - atmosphere



Feedbacks

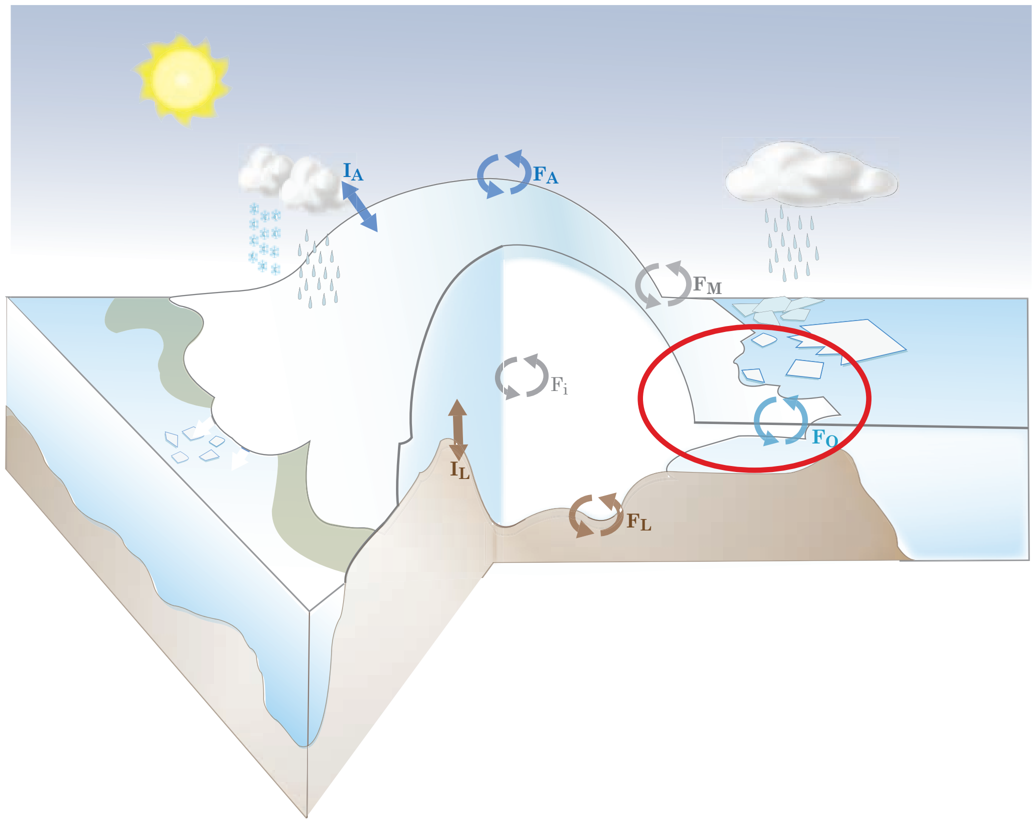
$T_{surf}(z)$ —> ablation vs accumulation

Albedo

Increase/decrease in precipitation —> increase/decrease in ice discharge

Orographic

Ice sheet - ocean



Feedbacks

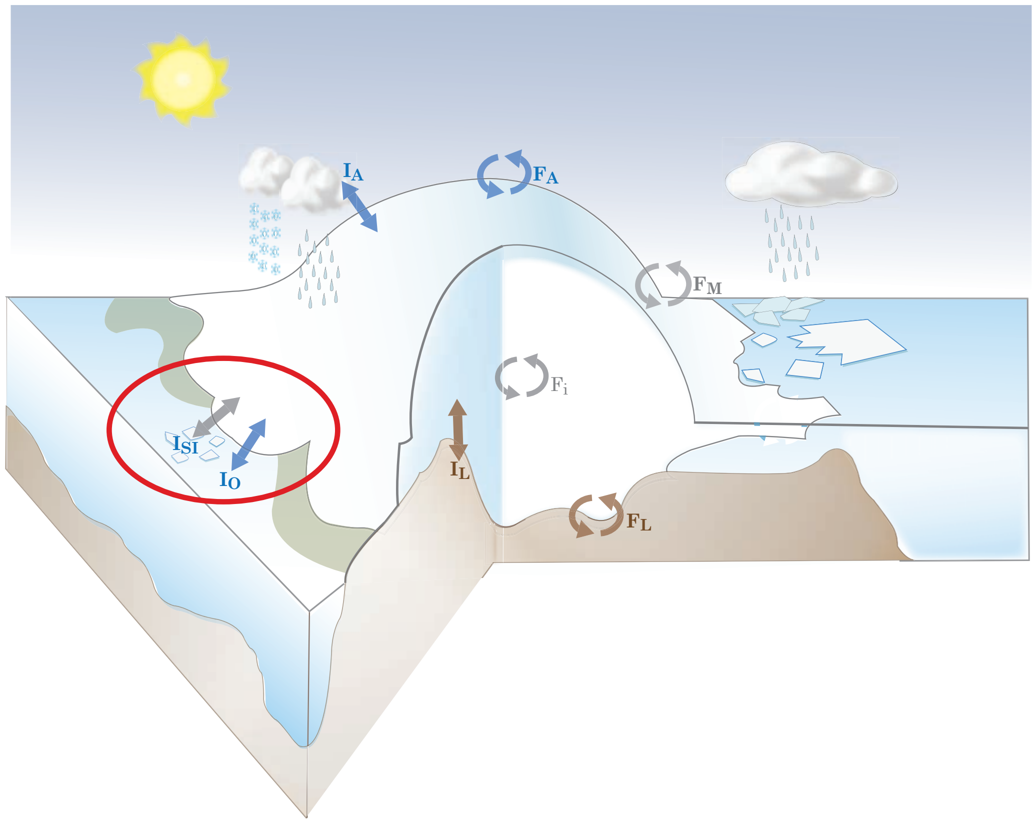
Freshwater

Melt water —> stable stratification —> warmer subsurface ocean —> melting

Geometric

Sub-ice-shelf cavity shape —> cavity circulation —> melting/freezing —> cavity shape

Ice sheet - sea ice



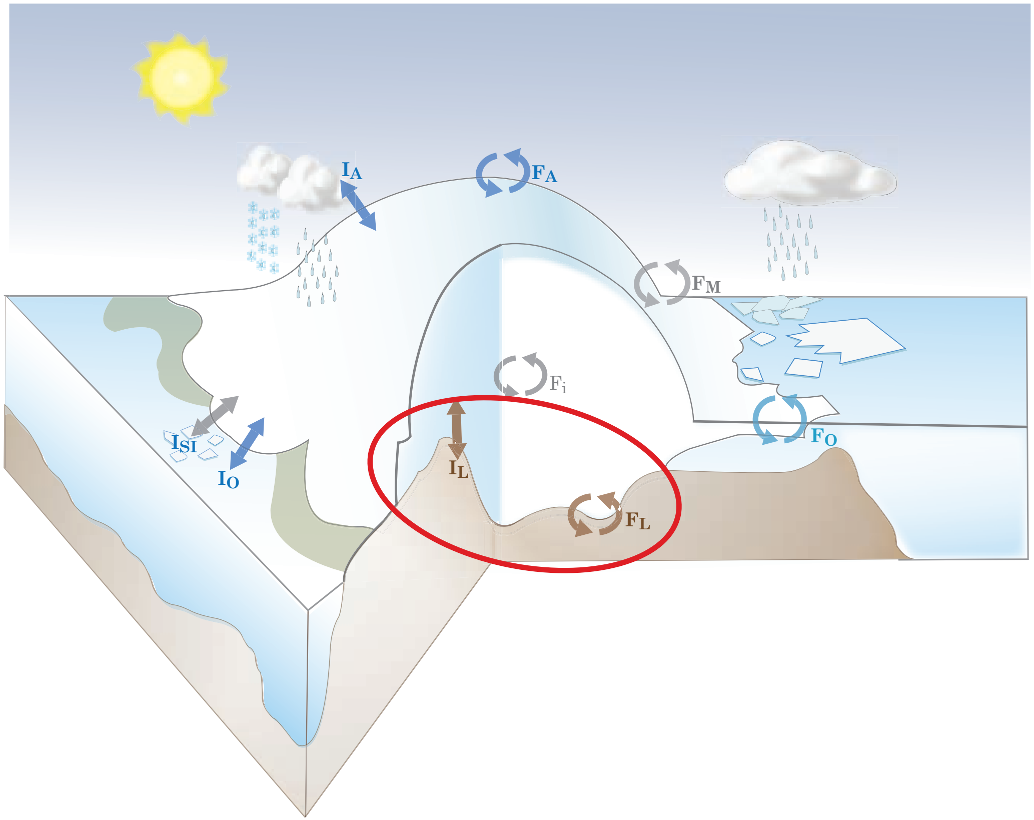
Feedbacks

Freshwater

Melt water —> stable stratification —> colder surface ocean —> sea ice

“Backstress”

Ice sheet - lithosphere



Feedbacks

Weathering and erosion

Isostasy

Gravitational field

ARTICLE

https://doi.org/10.1038/s41586-018-0712-z

Change in future climate due to Antarctic meltwater

Ben Bronselaer[1,2,3]*, Michael Winton[2], Stephen M. Griffies[2,3], William J. Hurlin[2], Keith B. Rodgers[3], Olga V. Sergienko[2,3], Ronald J. Stouffer[1,2] & Joellen L. Russell[1]

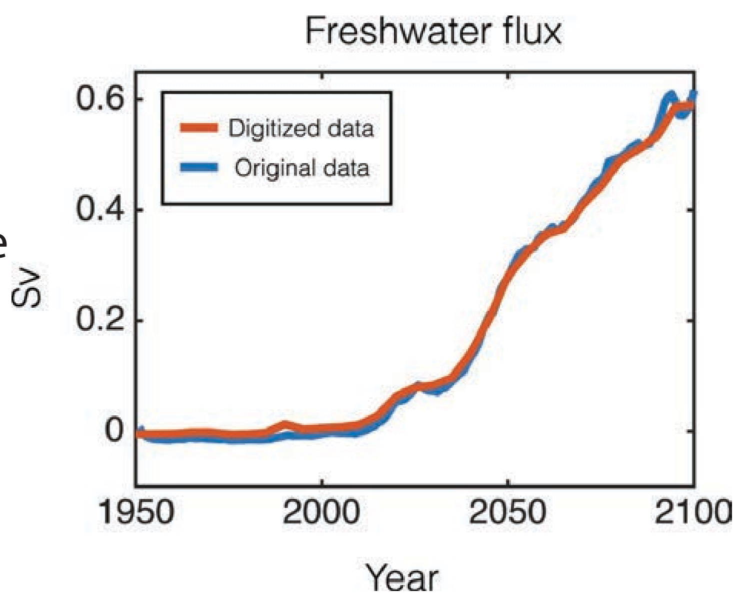
RCP 8.5 scenario, 30 ensemble members

CM2M 1°×1° (Southern boundary at the ice-shelf front)

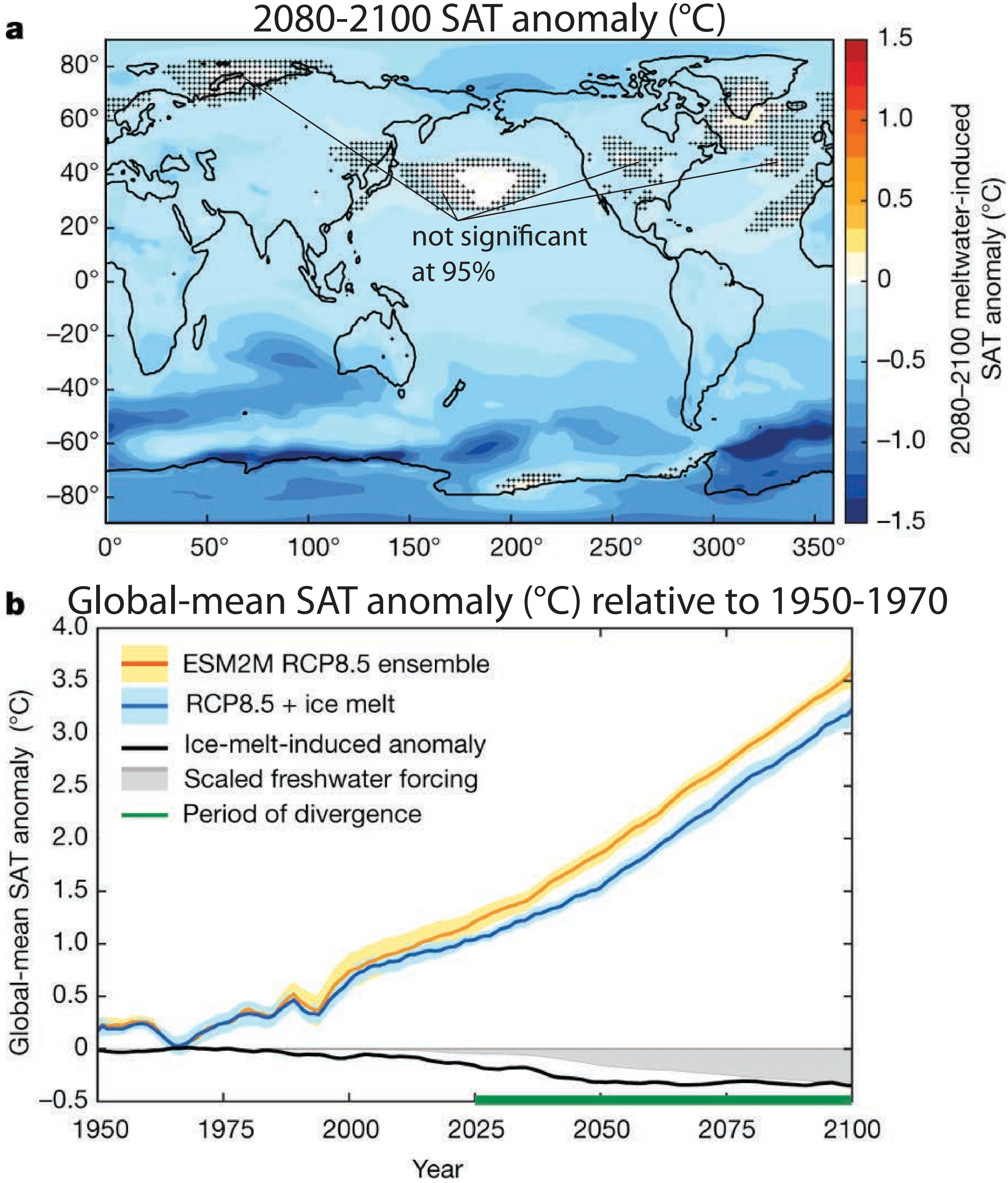
10 "meltwater" members forced with freshwater flux computed by DeConto & Pollard (2016) applied to1950 - 2100

Freshwater flux applied uniformly around Antarctic coast

Metrics:
surface air temperature,
precipitation,
sea-ice area (SH),
subsurface ocean temperature

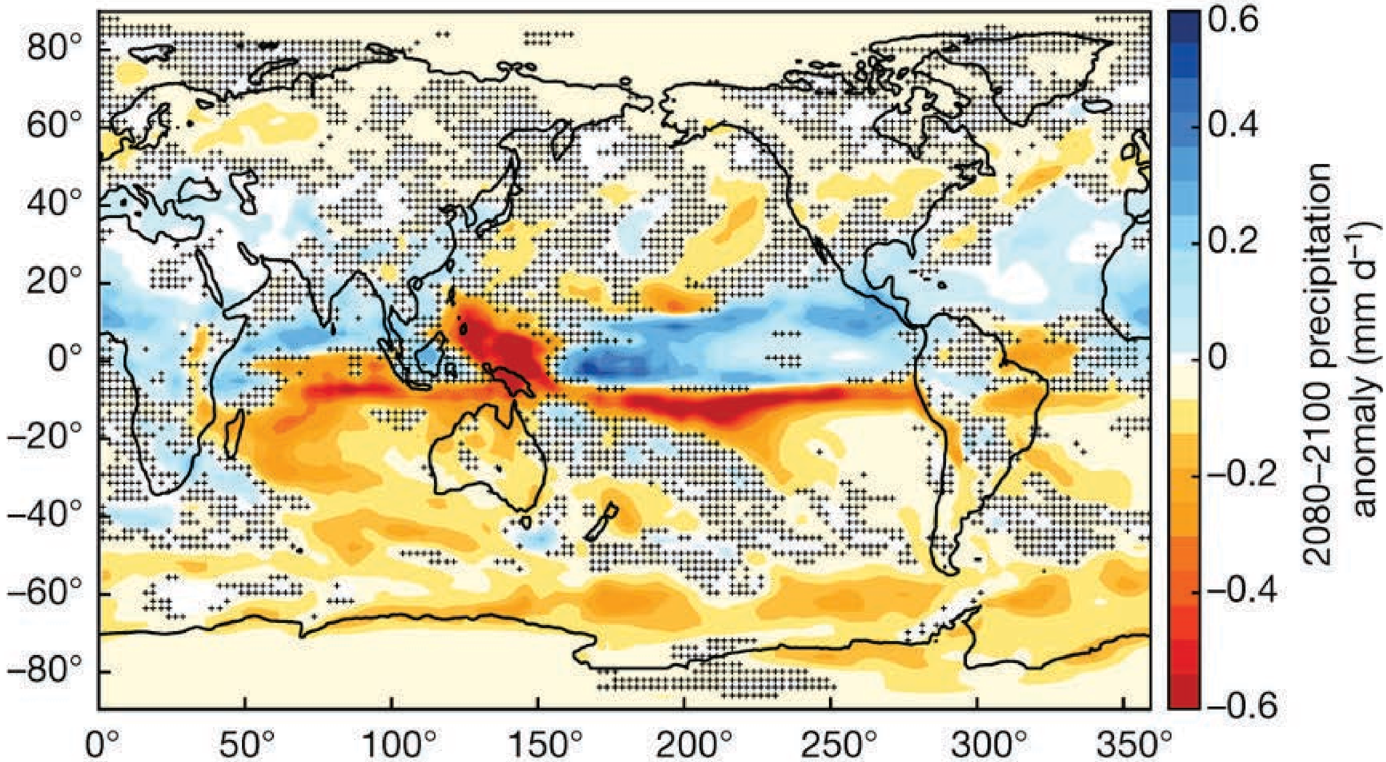


Surface Air Temperature

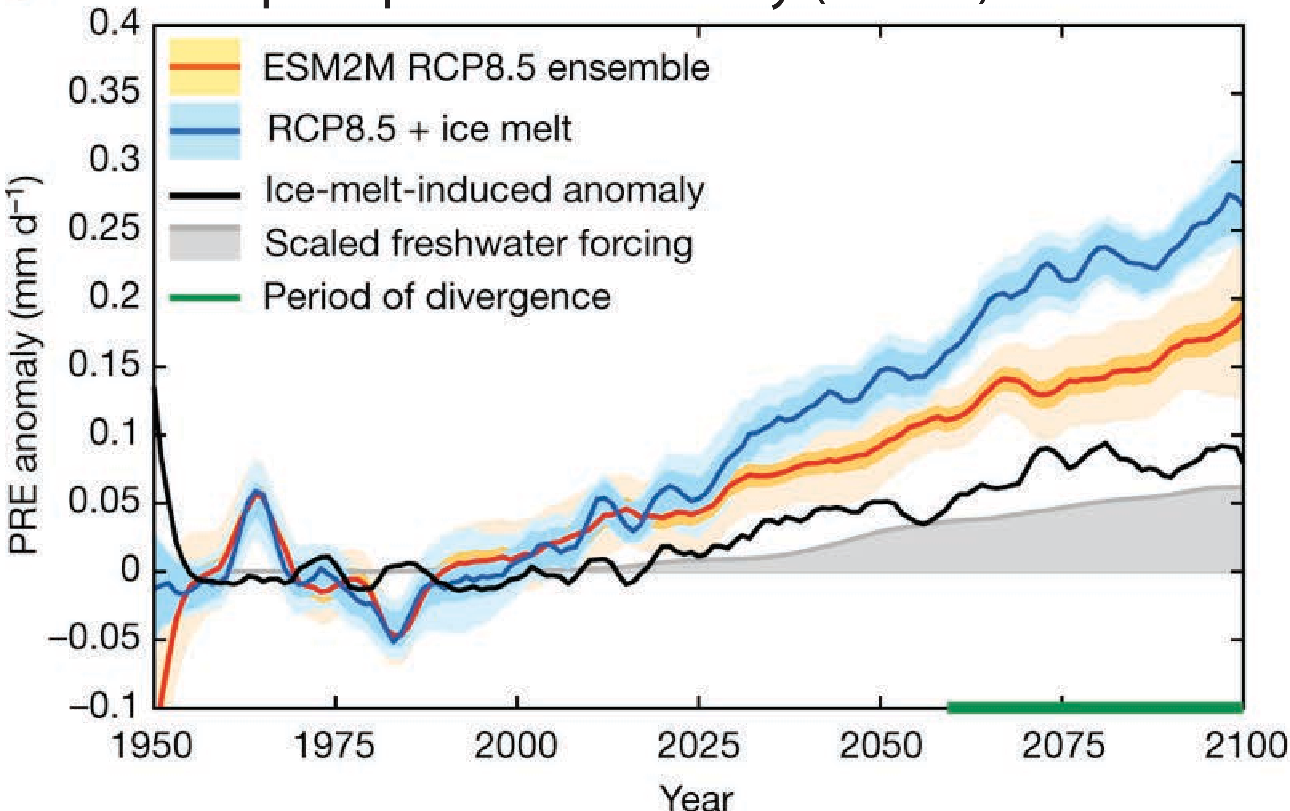


Precipitation

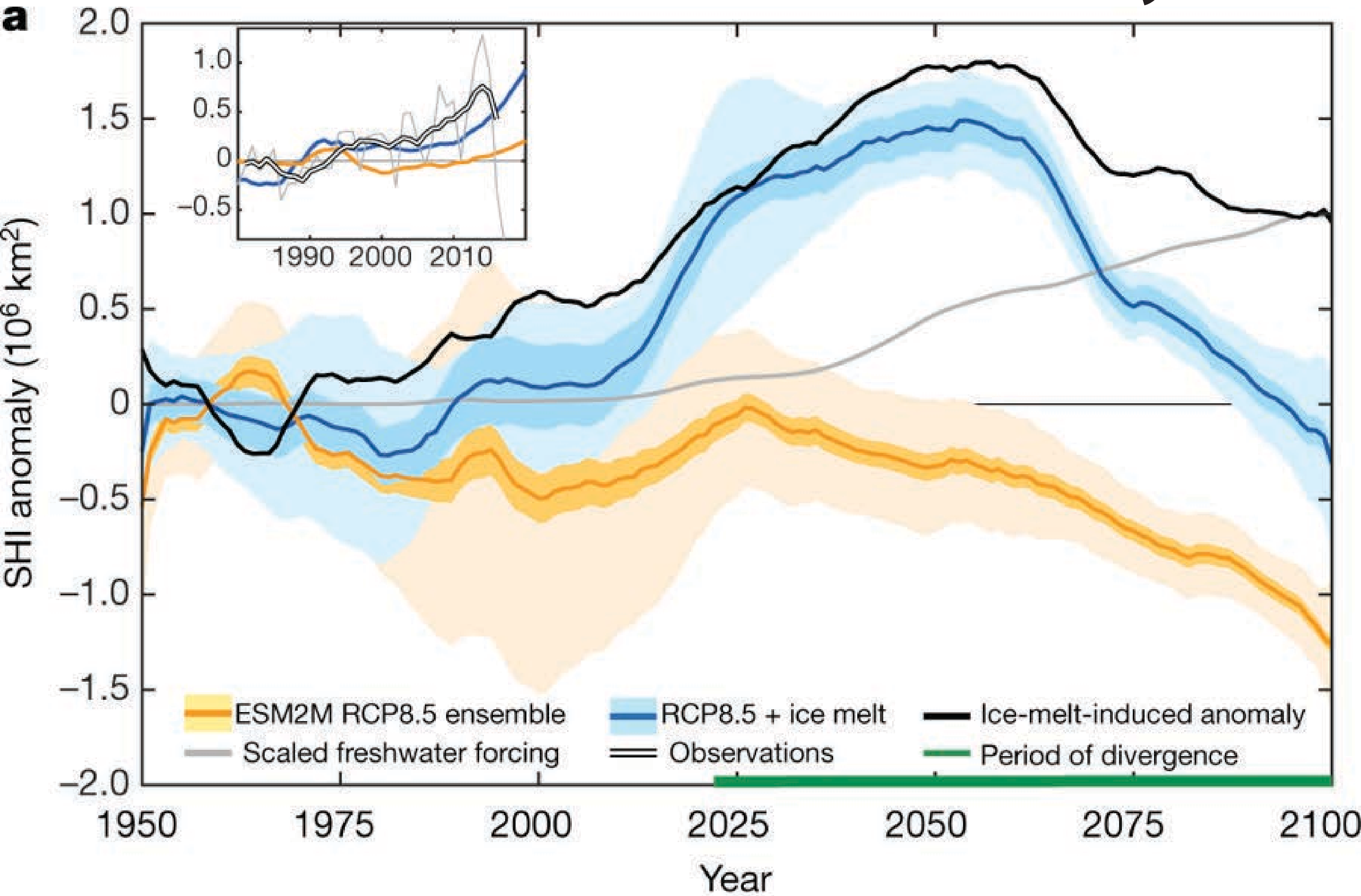
2080-2100 precipitation anomaly (mm/d)



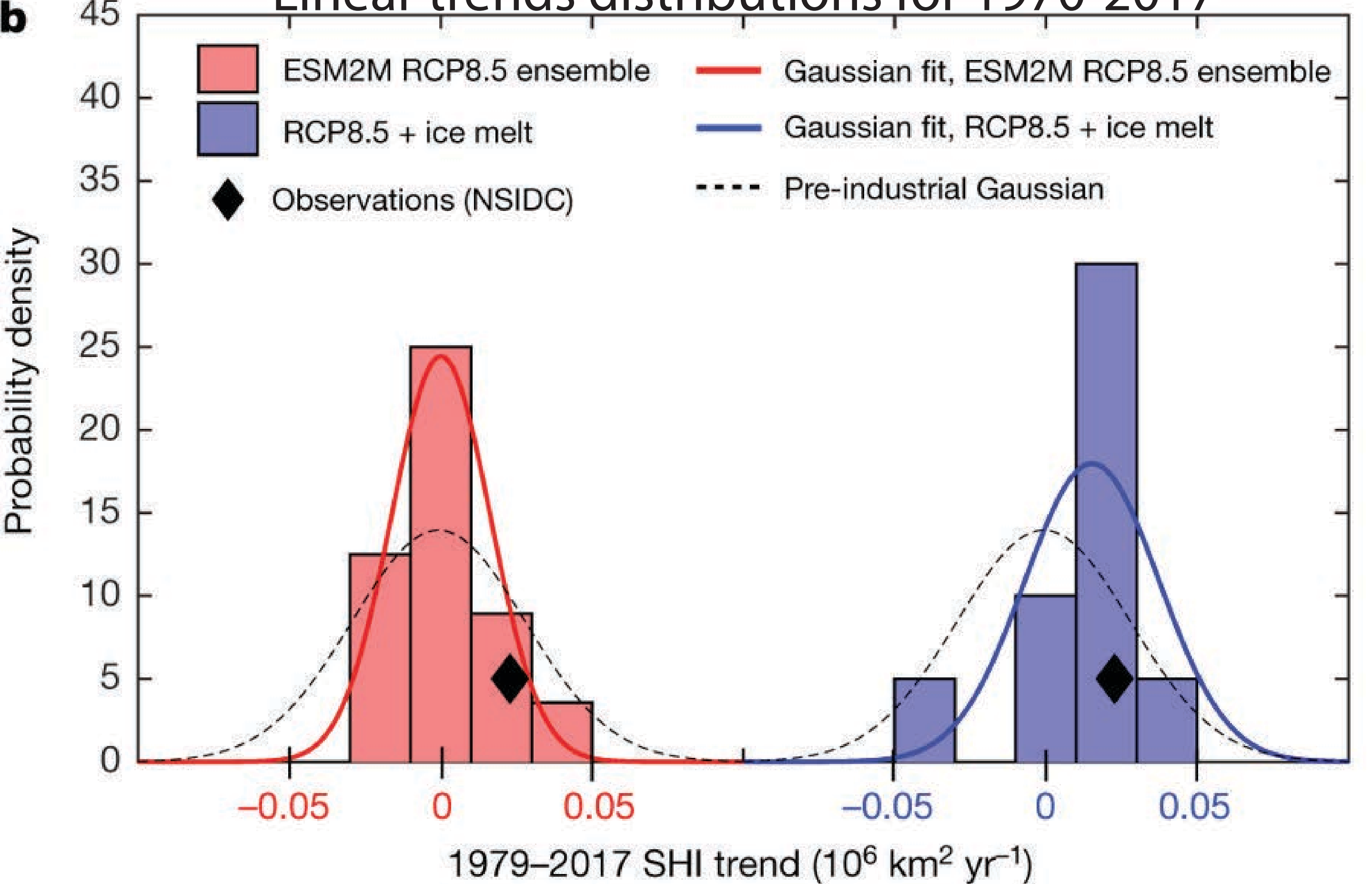
Global-mean precipitation anomaly (mm/d) relative to 1950-1970



SH sea ice area anomaly

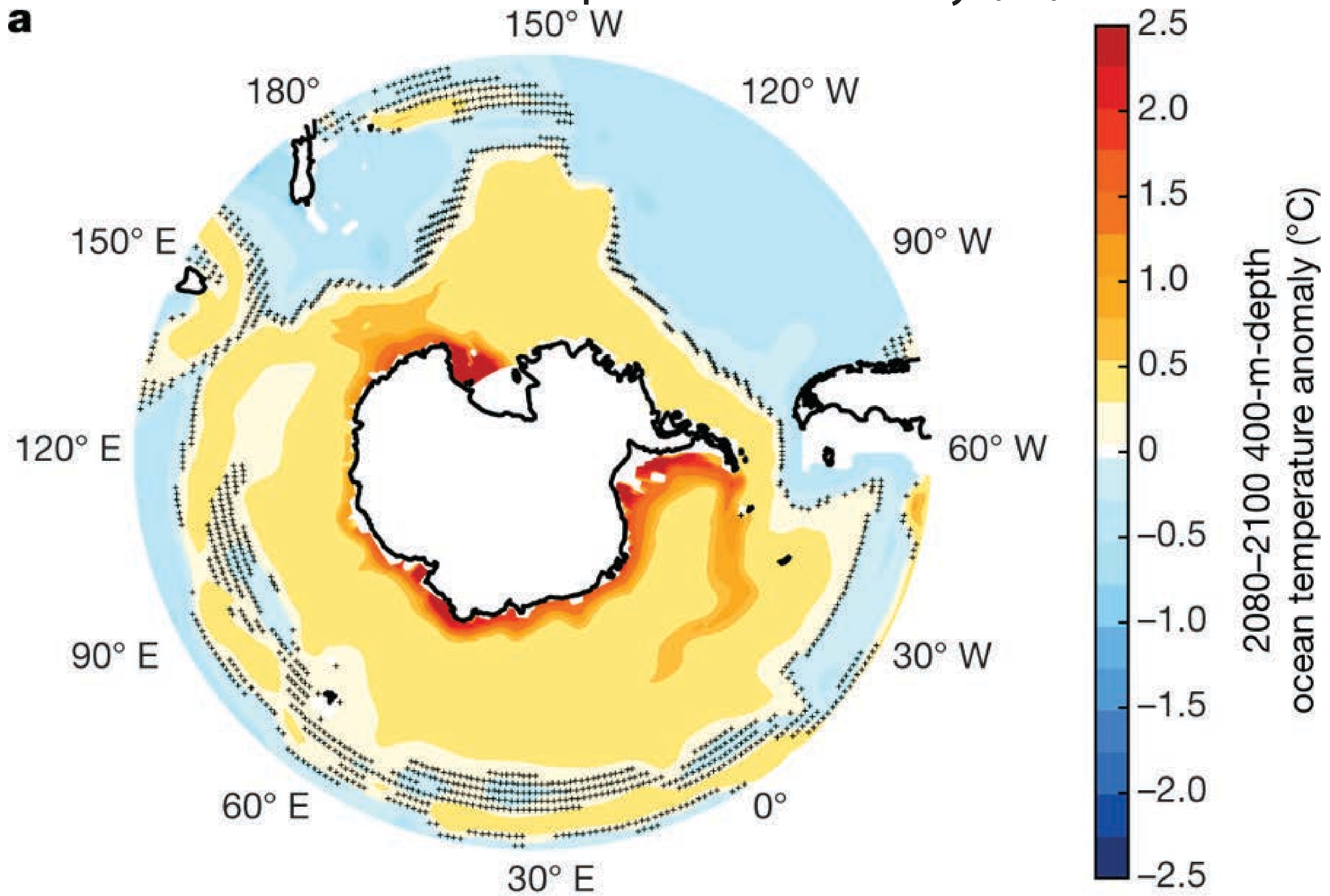


Linear trends distributions for 1970-2017

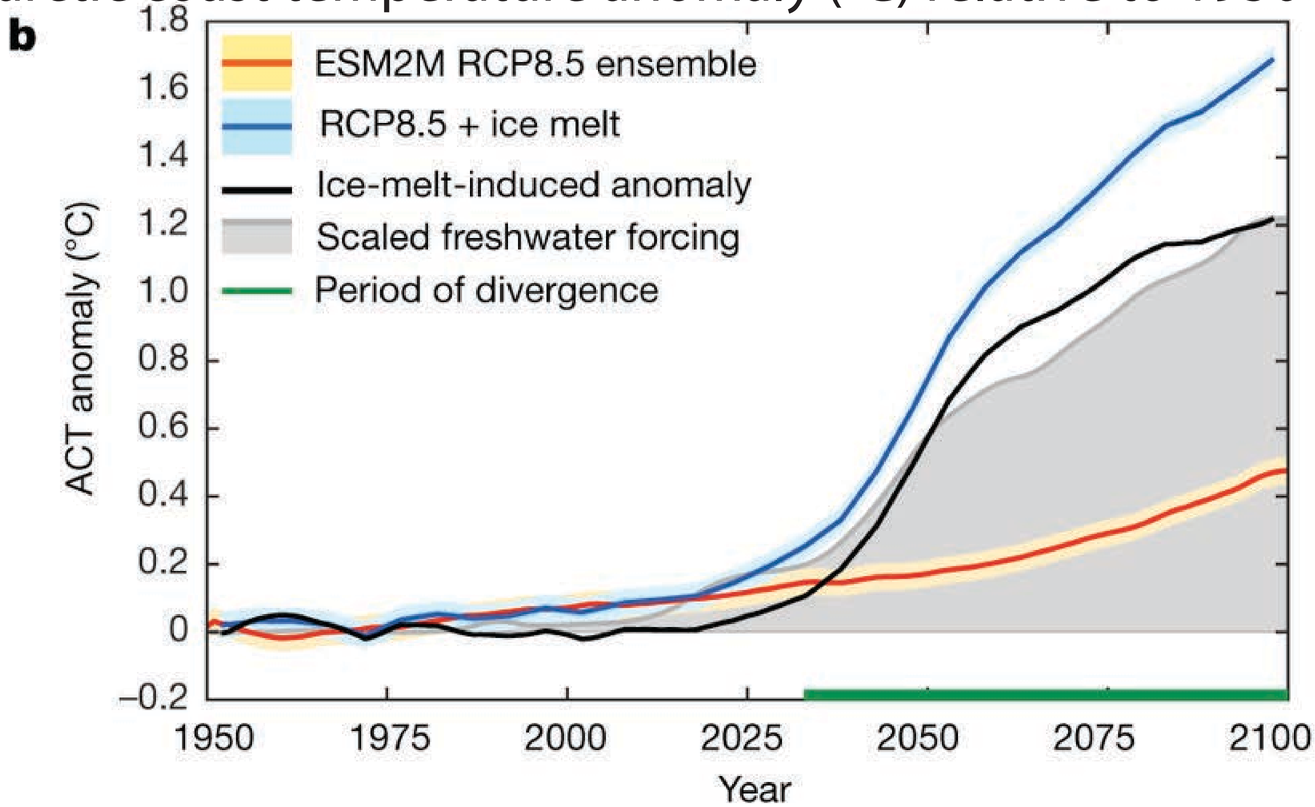


Subsurface (400 m) ocean temperature

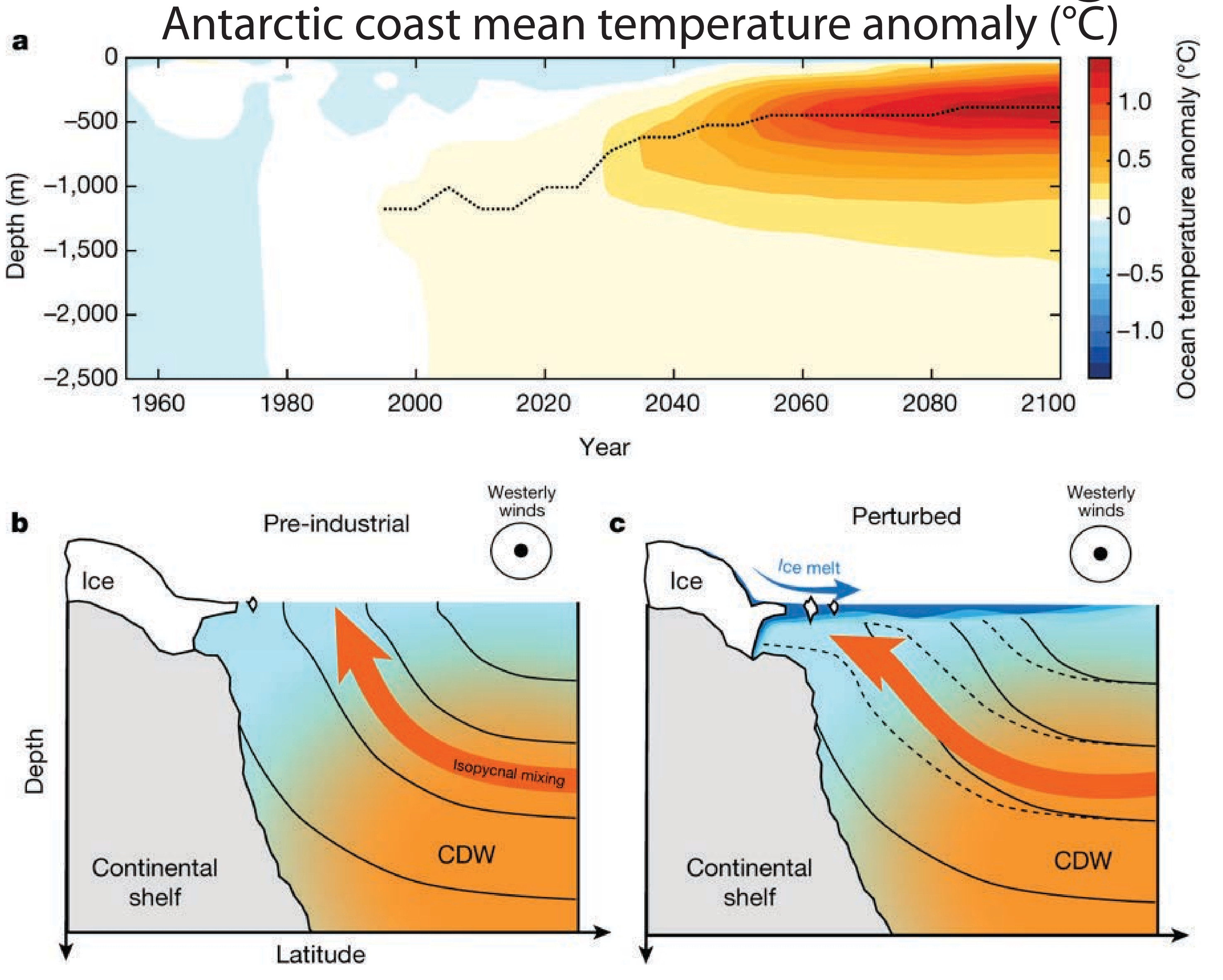
2080-2100 temperature anomaly (°C)



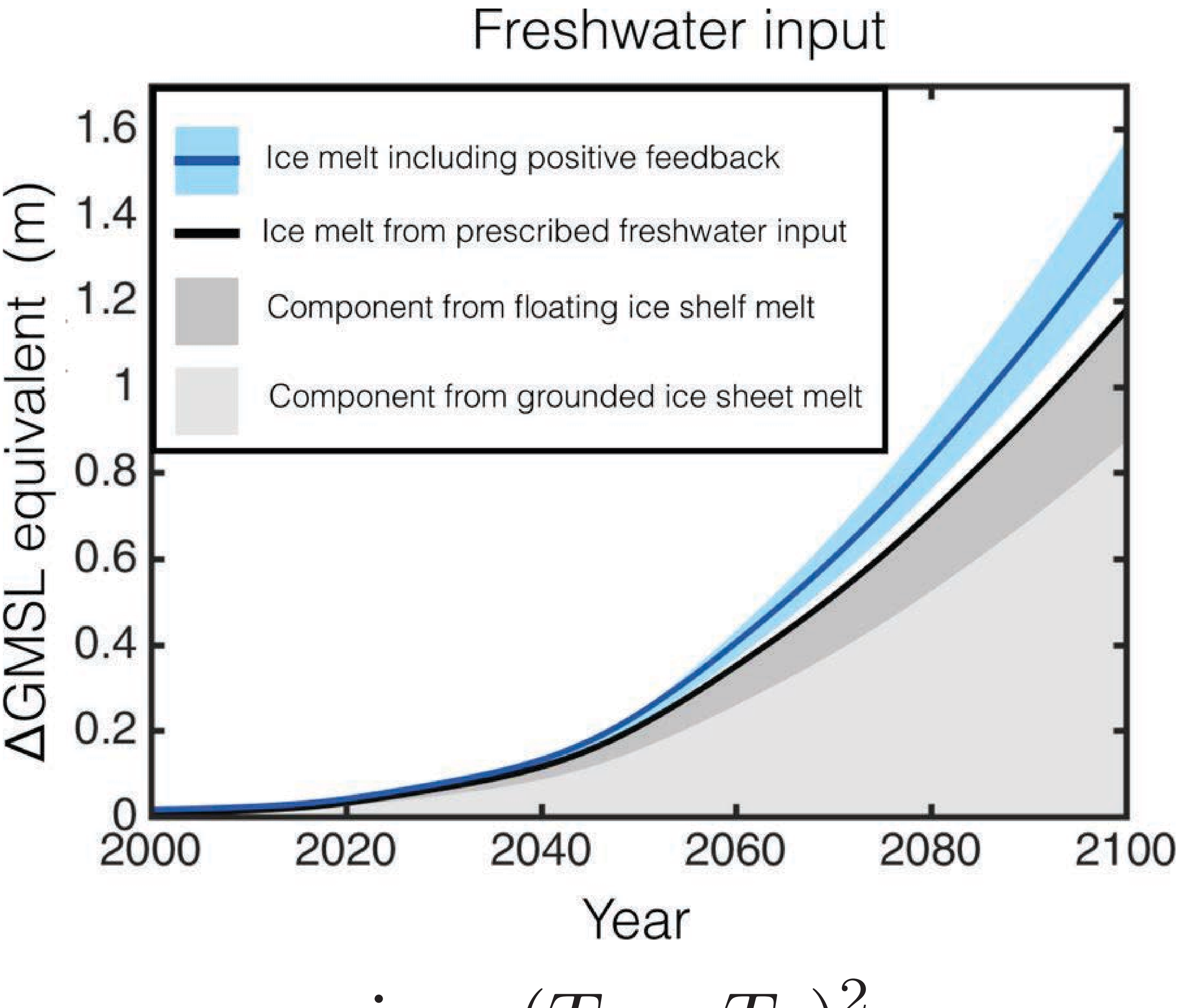
Antarctic coast temperature anomaly (°C) relative to 1950-1970 mean



Subsurface ocean warming



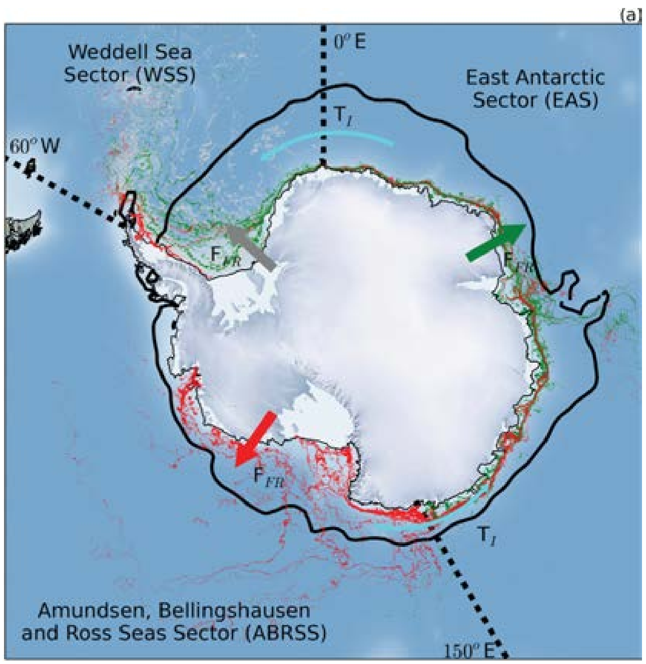
Ice-shelf melting feedback

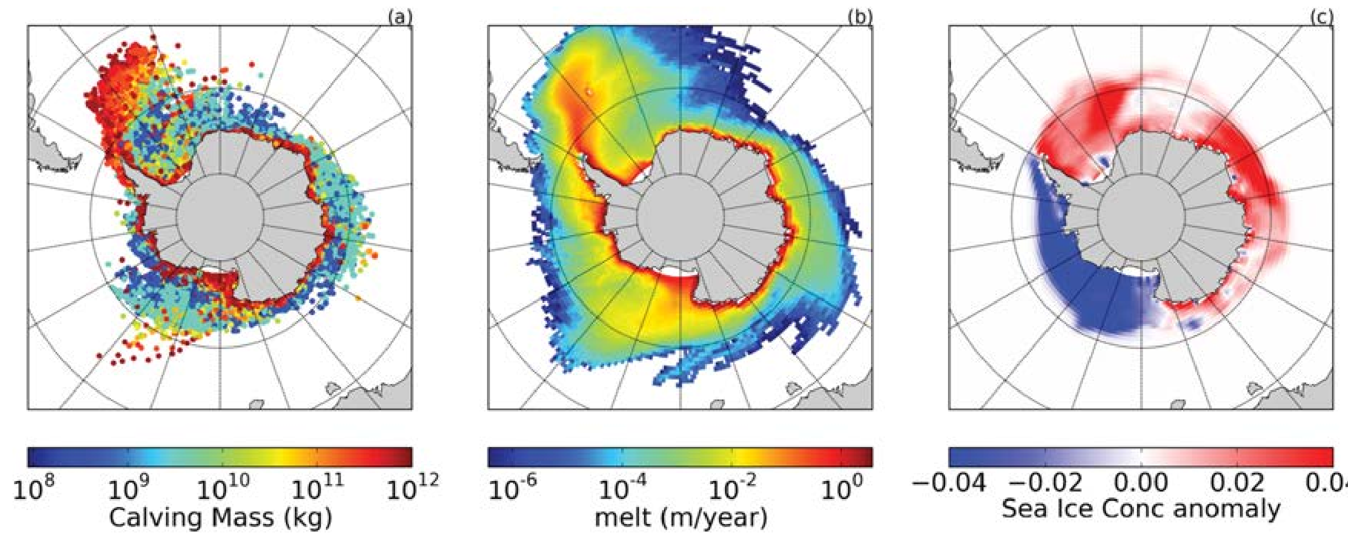


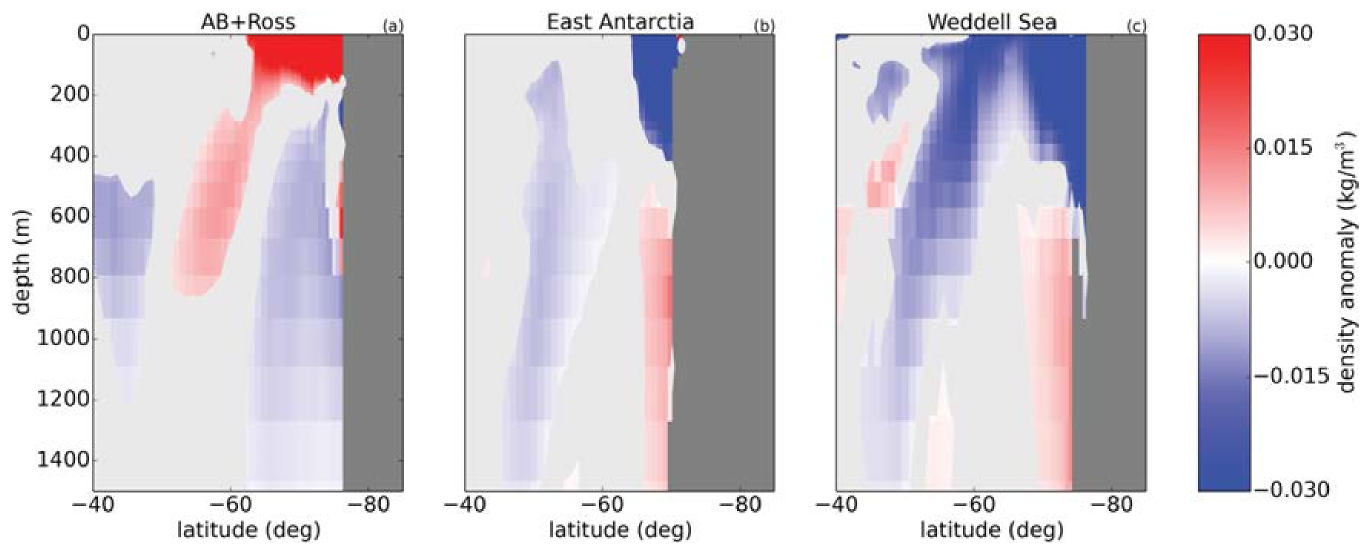
$$\dot{m} \sim (T_o - T_f)^2$$

"Lagrangian" icebergs in a climate model

CM2G climate model, MOM6 ocean component, 1° resolution

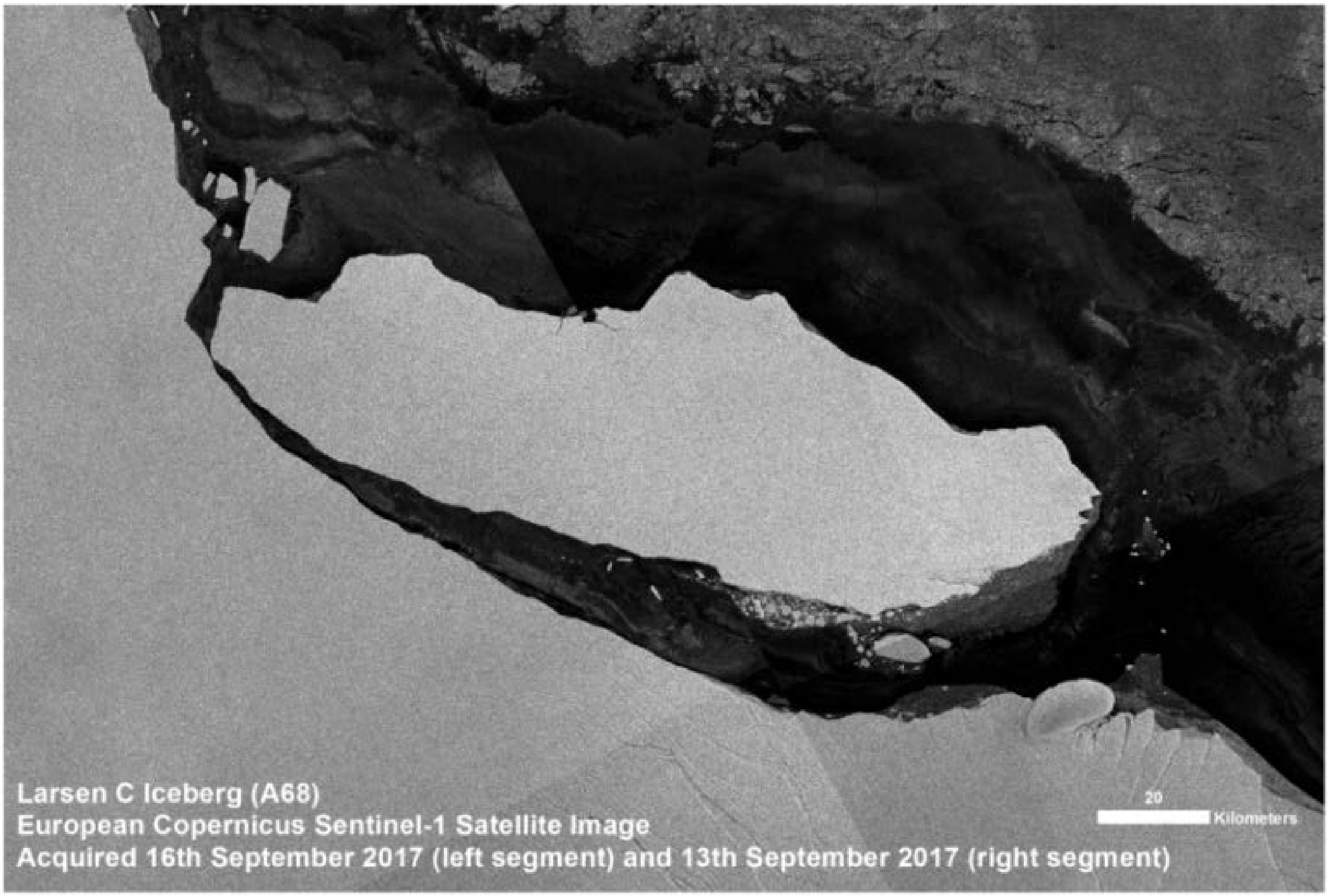






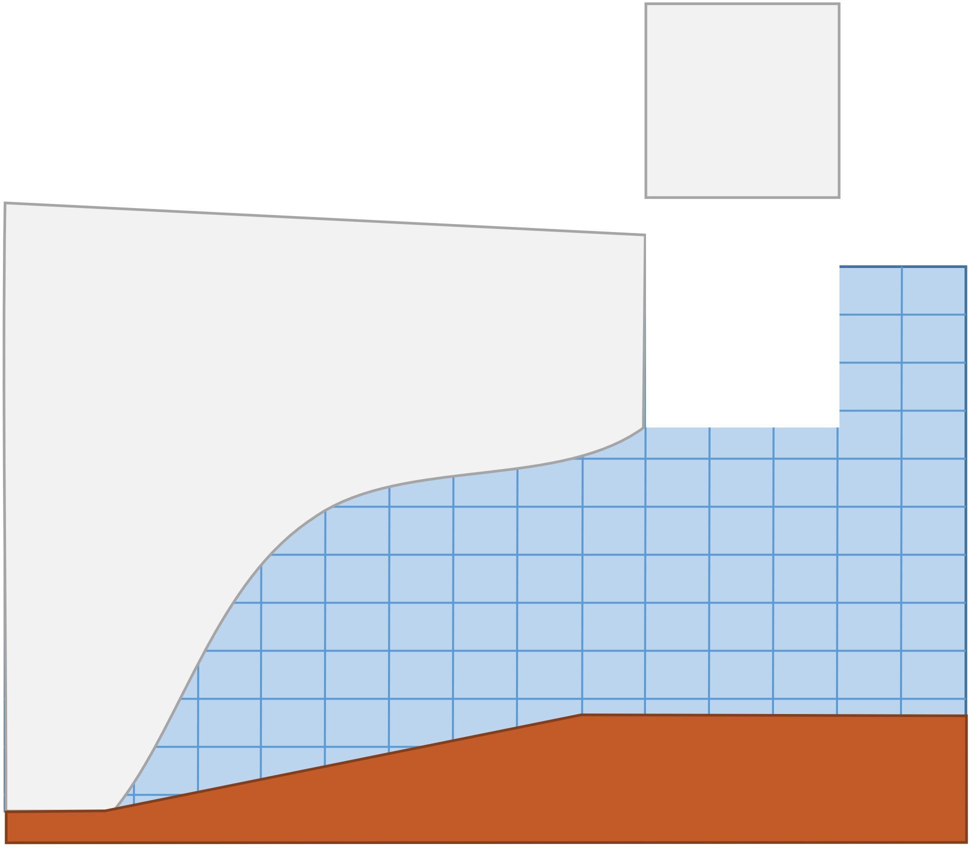
Stern at al. (2016)

Tabular icebergs

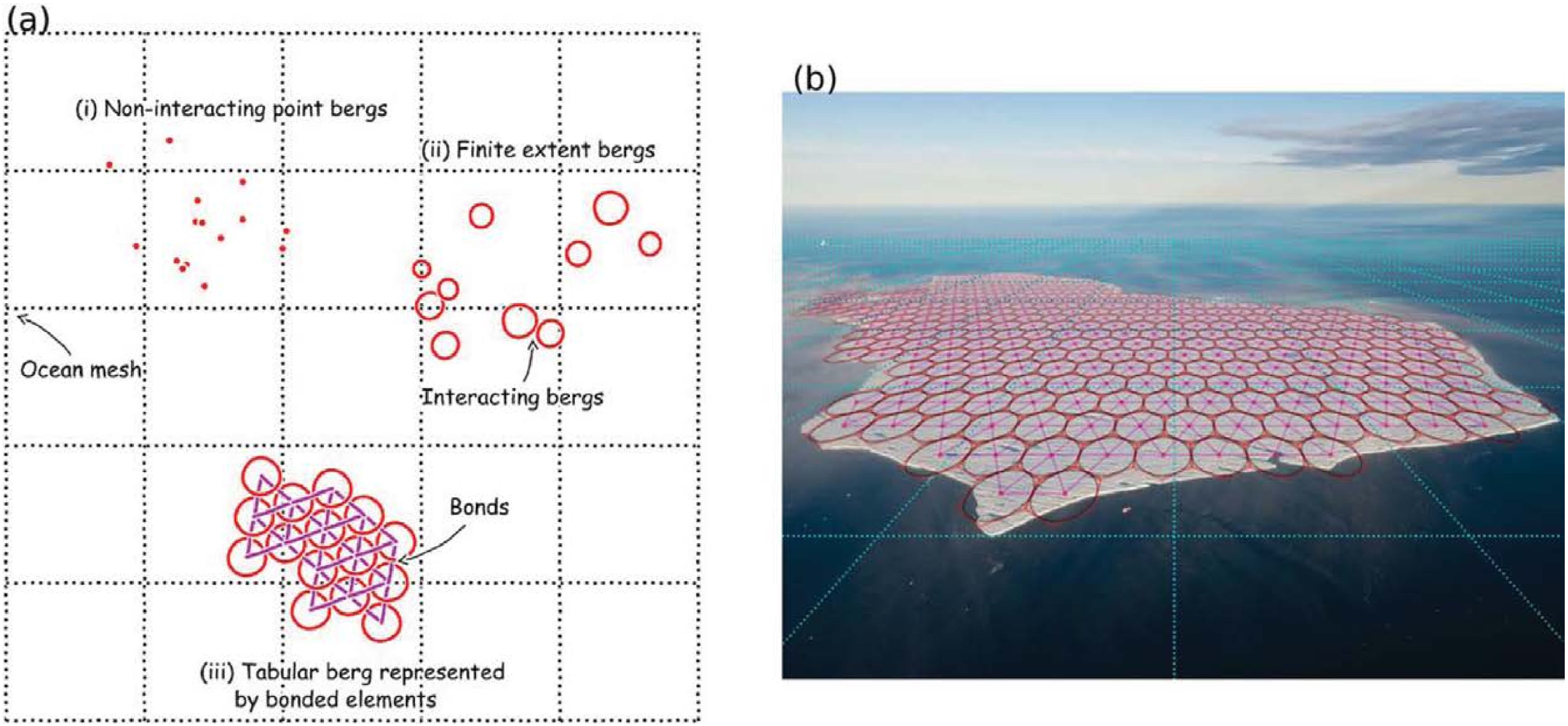


20-50 km × 100-300 km
1 Pt
50 - 70 years

“Levitating” icebergs

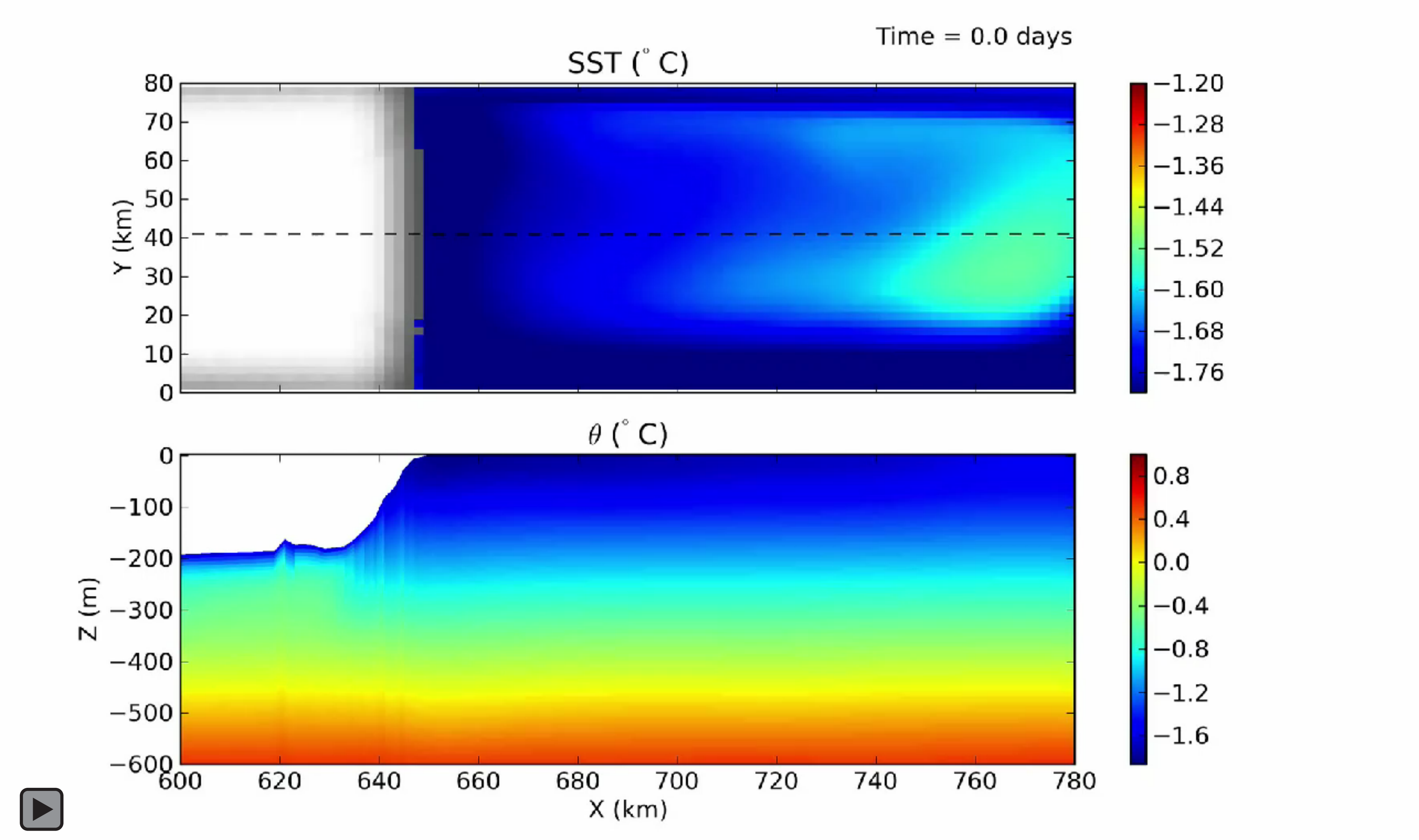


Immersed tabular icebergs



Stern at al. (2017)

Immersed tabular icebergs



Ocean temperature (°C)

Stern at al. (2017)

Tapio's questions

How should we design a climate model to obtain better predictions of polar climates on timescales of decades?

In such a way that interactions and feedbacks are represented

How can we integrate observations better with models?

We need useful observations first

What additional observations would help improving models?

Please see a laundry list

Laundry list

(Near) Surface conditions - precipitation, temperature, fluxes, firn properties

3D ice velocity, temperature, viscosity, stress

Bed topography and bathymetry

Basal conditions - geothermal flux, subglacial hydraulic system...

Englacial water flow and storage

Sub-ice-shelf cavities and glacial fjords - melting/freezing, circulation, water-mass properties

Continental shelves - circulation, water-mass properties

Open ocean/continental shelves exchange