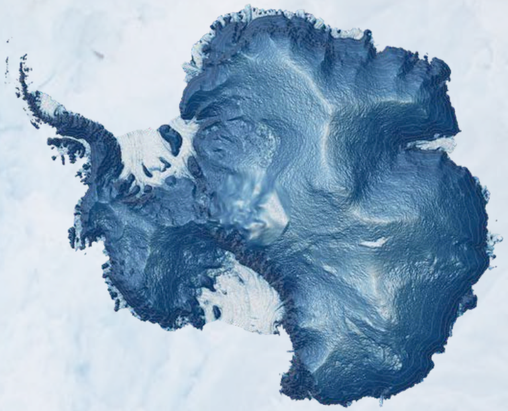
WIND-DRIVEN SNOW IMPACT ON SURFACE MELTWATER PONDING THRESHOLDS



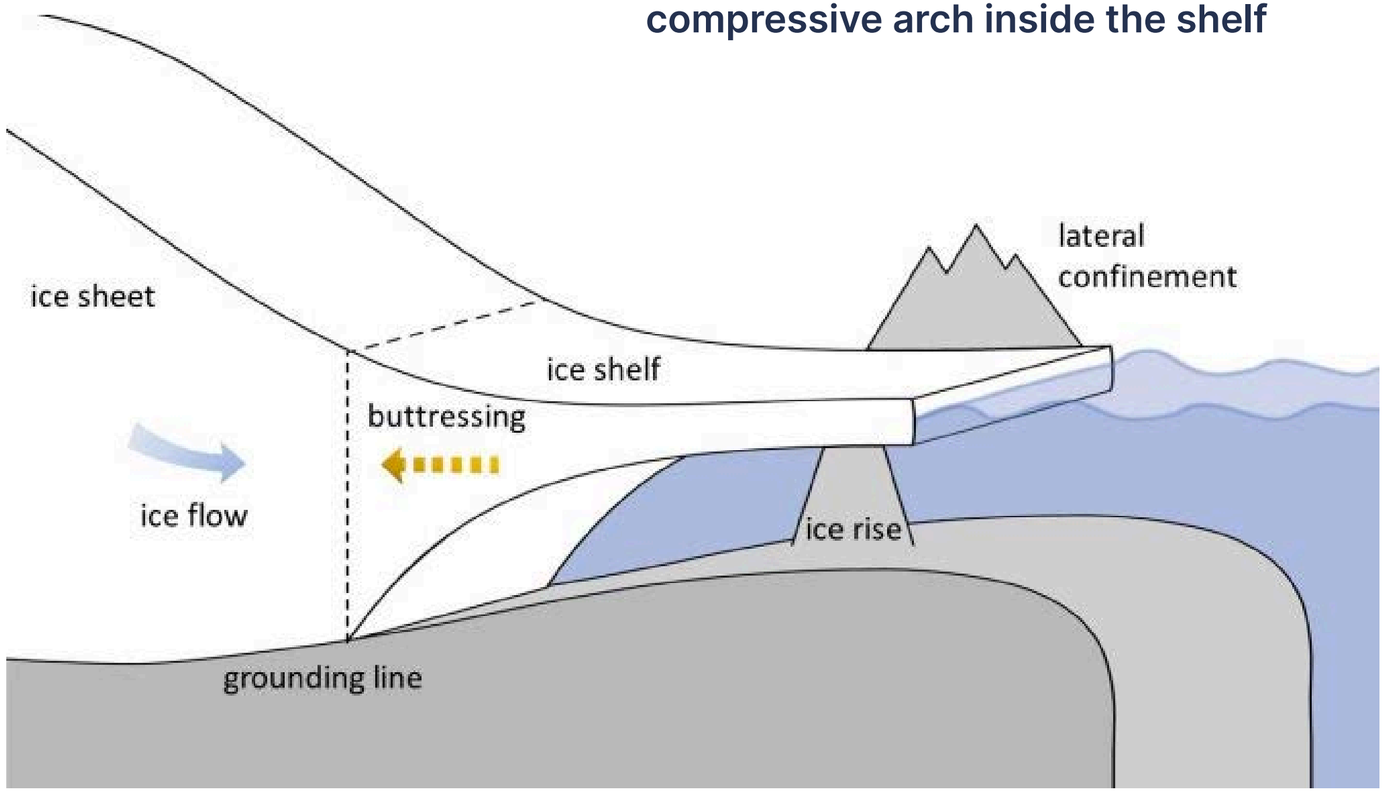
Presented by: Daria Kan
Supervised by:
Charles Amory, Vincent Favier and Florence Naaim-Bouvet

wind-driven snow, MAR, melt-over-accumulation, surface ablation, Antarctica, hydrofracturing implementation

Buttressing

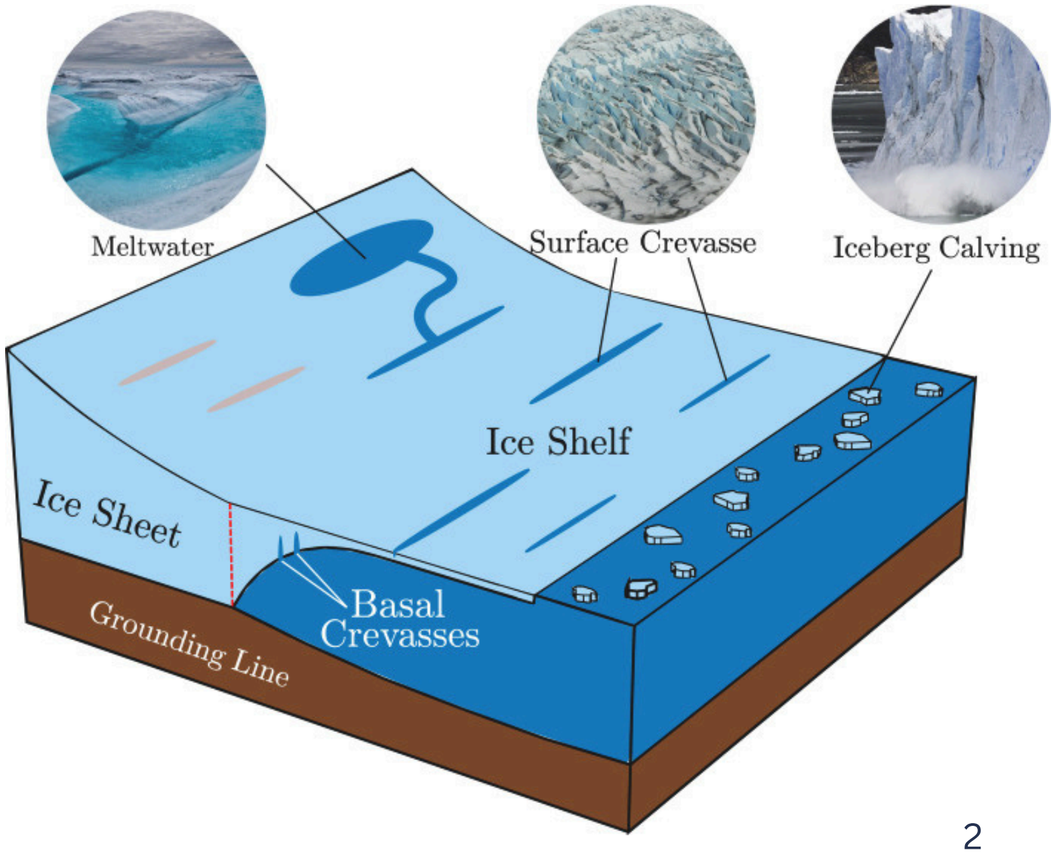
Lateral Drag (Shear Stress on Side Walls)
friction

Backstress Transmitted Upstream
compressive arch inside the shelf



Source: Ronja Reese & Maria Zeitz

Hydrofracturing



Source: ScienceDirect

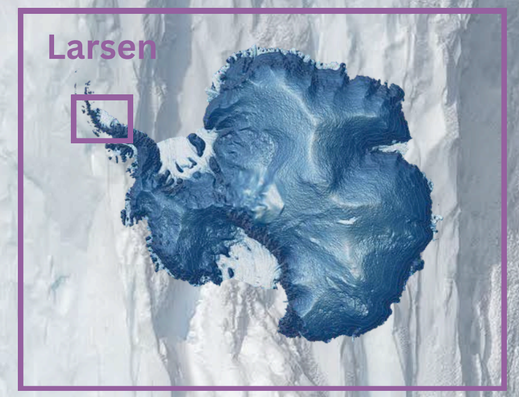
Why surface ablation matters?

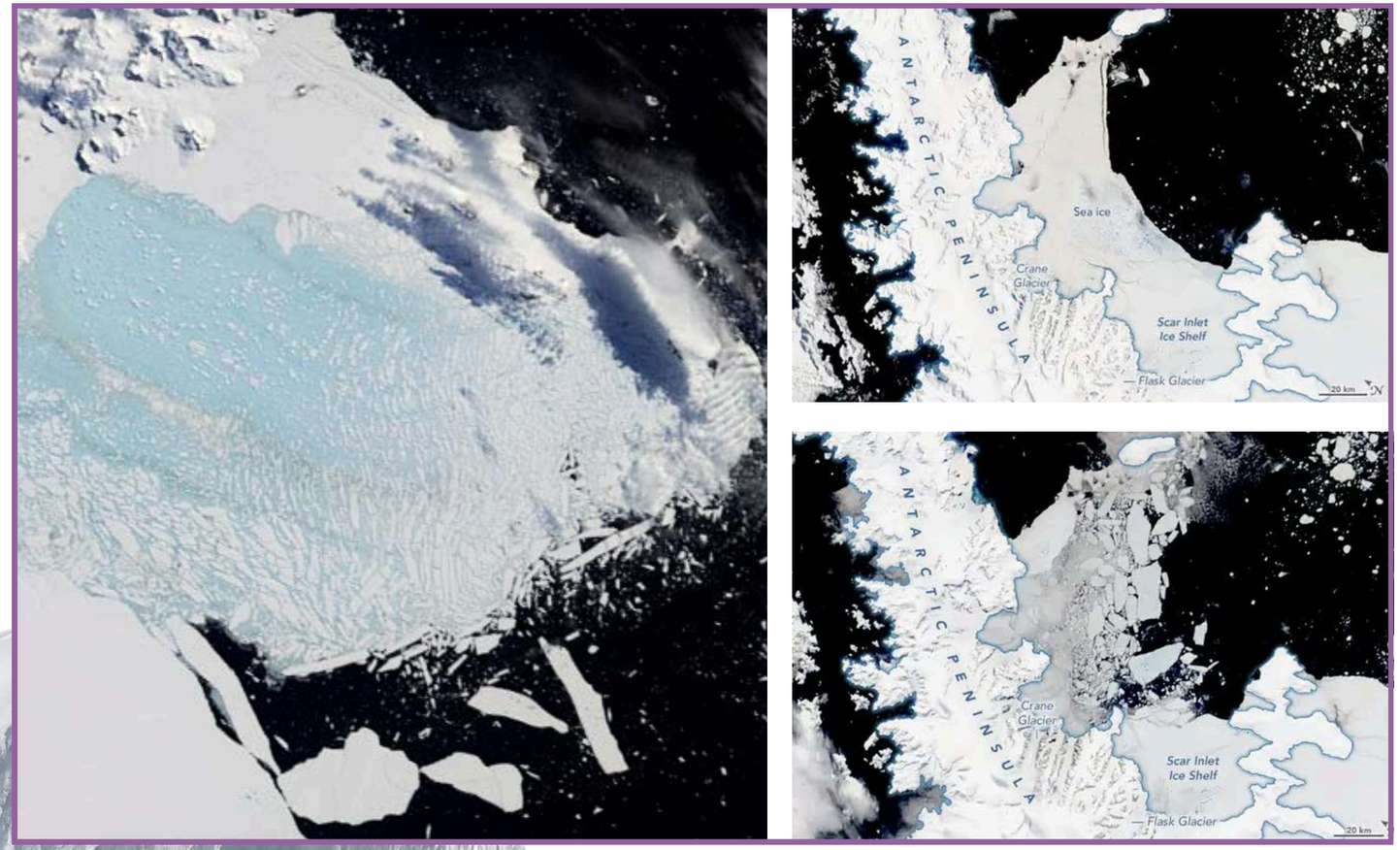
surface meltwater ponding

hydrofracturing of crevasses

ice shelf collapse

loss of buttressing





Fragments of **Larsen B Ice Shelf**
Source: Wikipedia

$$SMB = SF + RF - RU - SU - ER$$

accumulation: SF, RF

ablation: RU, SU, ER

Why surface ablation matters?

surface meltwater ponding

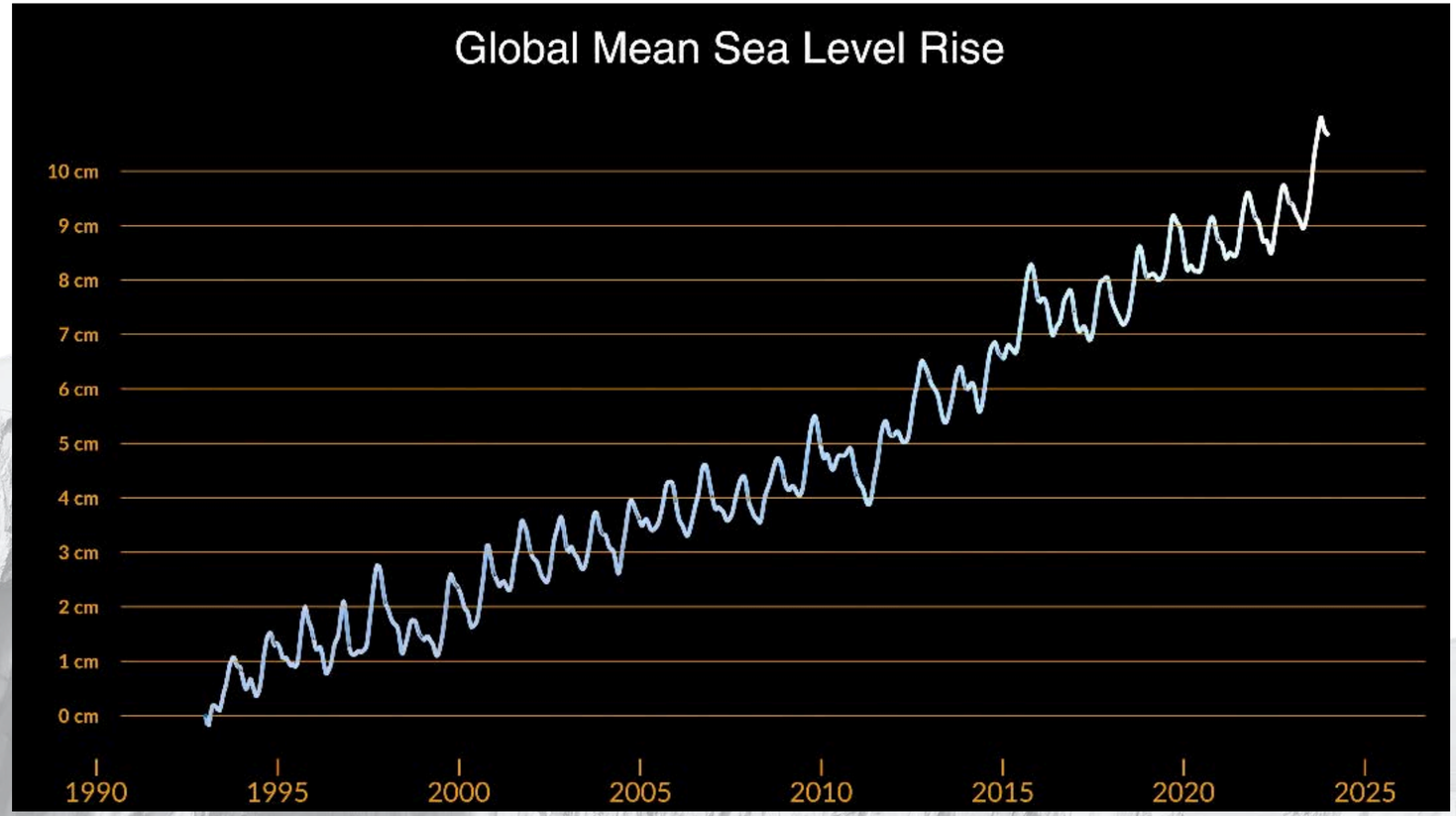
hydrofracturing of crevasses

ice shelf collapse

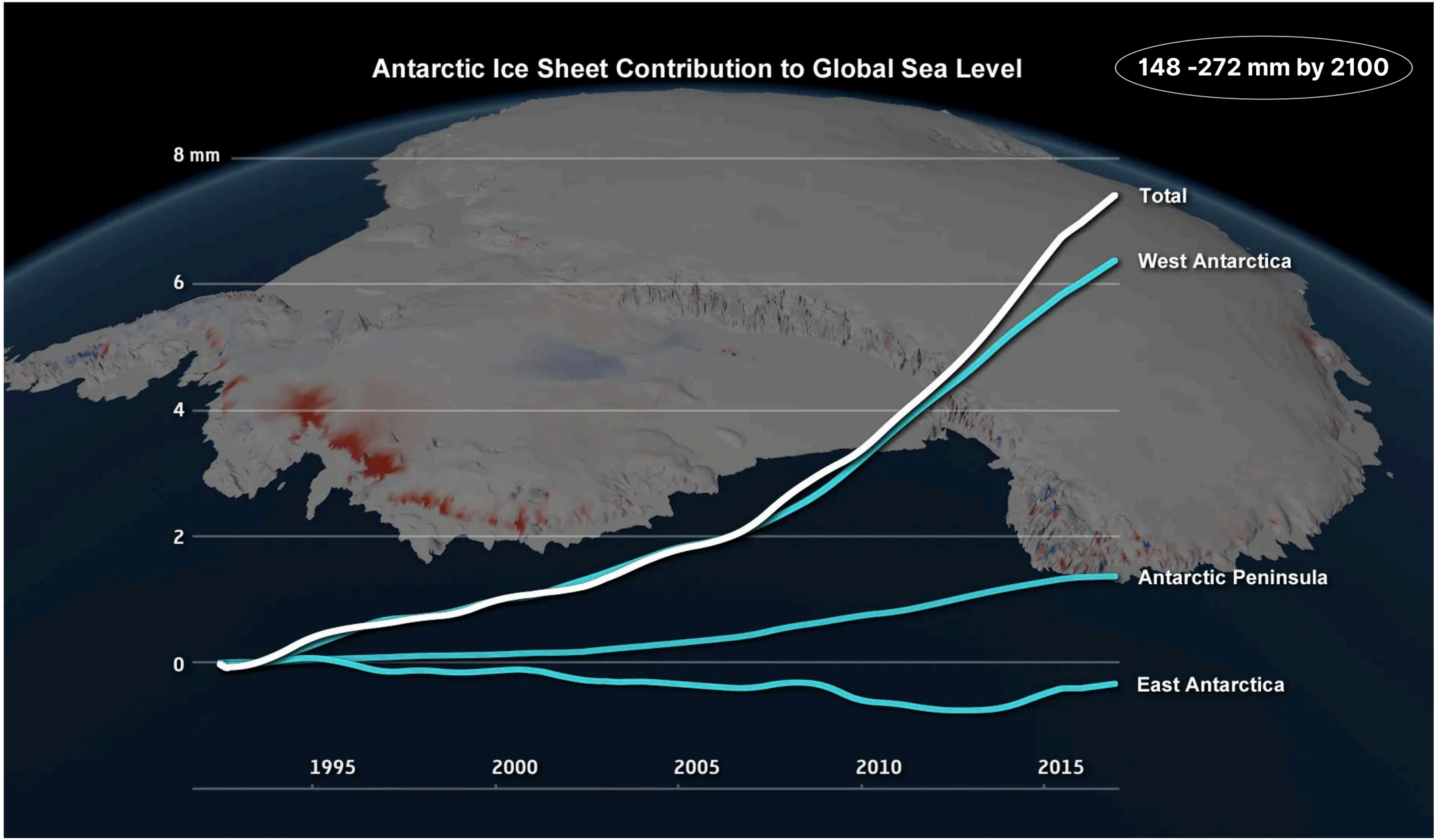
loss of buttressing

grounded ice acceleration

credits: NASA

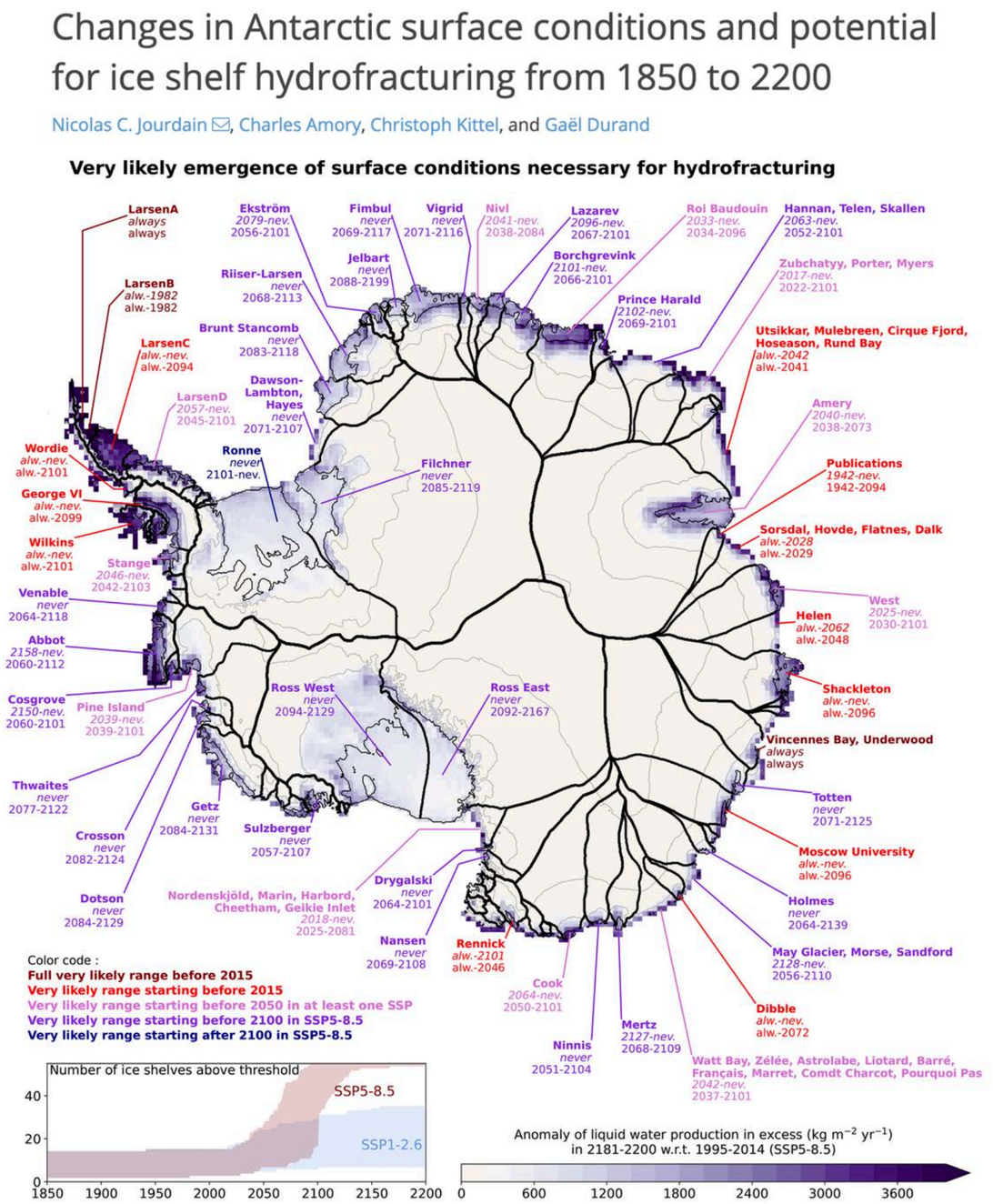


sea level rise



Changes in the Antarctic ice sheet's contribution to global sea level, 1992 to 2017

Is EAIS '*safe*' ?



EAIS second vulnerable area after Peninsula

risk assessed for the ice shelves

but what happens on the grounded ice that feeds these ice shelves ?

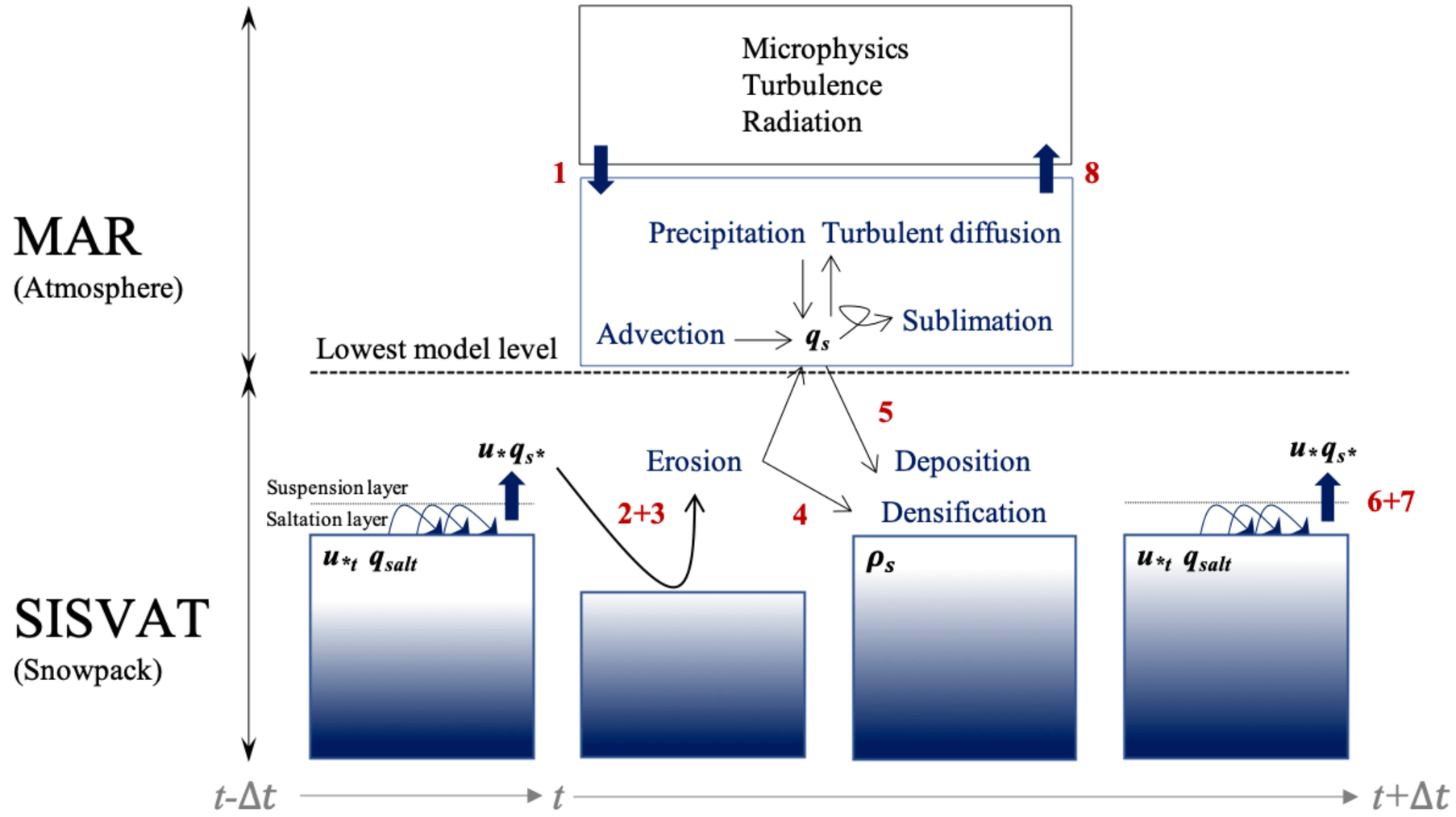

wind-driven snow
~100 m


Wind-driven snow




penguin 1 m
credits: C.Amory

Regional climate model MAR



Schematic source: Amory et al., 2021

Future period

2071-2100

Reference period

1981-2010

SSP5-8.5

CMIP6

CNRM-CM6-1

IPSL-CM6A-LR

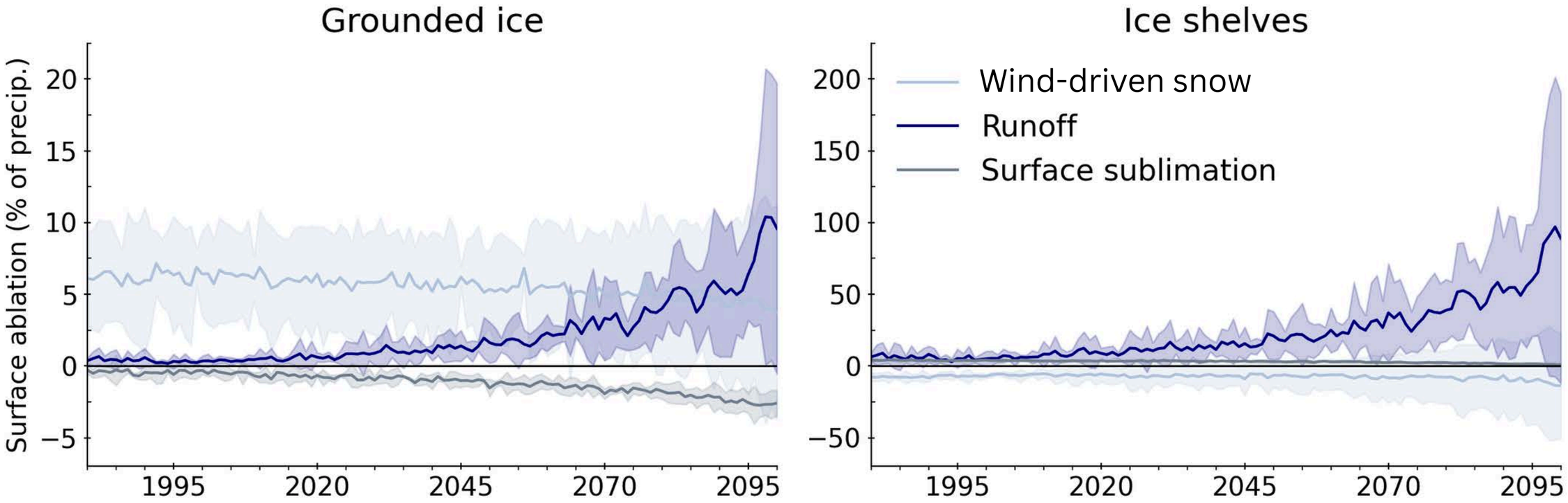
UKESM1-0-LL

MPI-ESM1-2-HR

WDS/nWDS

Surface ablation components

Wind-driven snow → **Runoff**



Wind-driven snow, meltwater runoff and surface sublimation as a percentage of precipitation, under SSP5-8.5

Methods: climatic thresholds

Warming anomaly above reference period (1981-2010)

Melt-over-accumulation

$$MOA = \frac{ME + RF}{SF - ER - SU} = 0.7$$

firn can no longer absorb meltwarter > RU/ponding

T_{MOA}

Ablation-over-accumulation

$$AOA = \frac{ER + SU + RU}{SF + RF} = 1$$

ablation = accumulation; regime becomes fully ablation-dominated

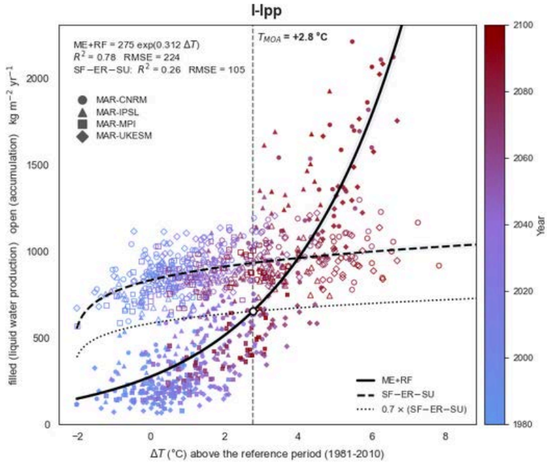
T_{AOA}

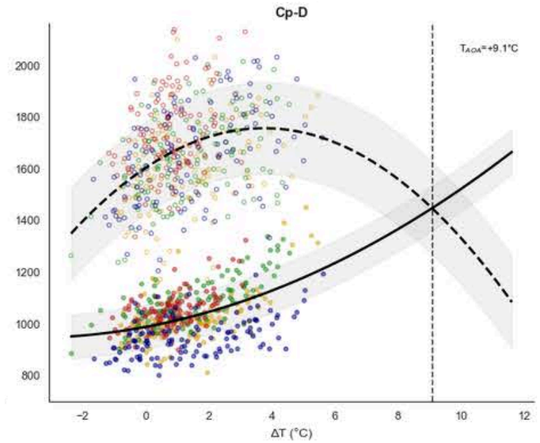
Change in mass loss

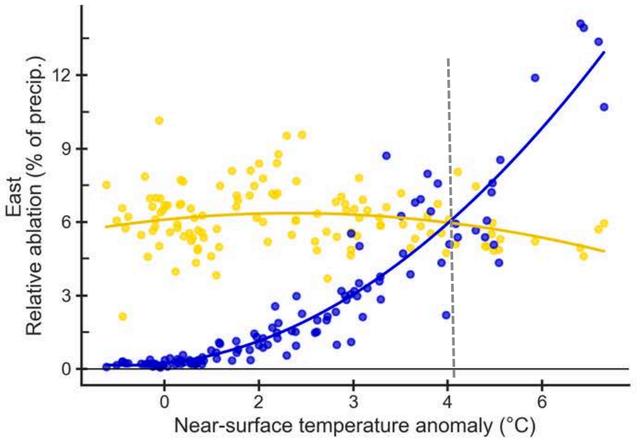
$$RU > ER$$

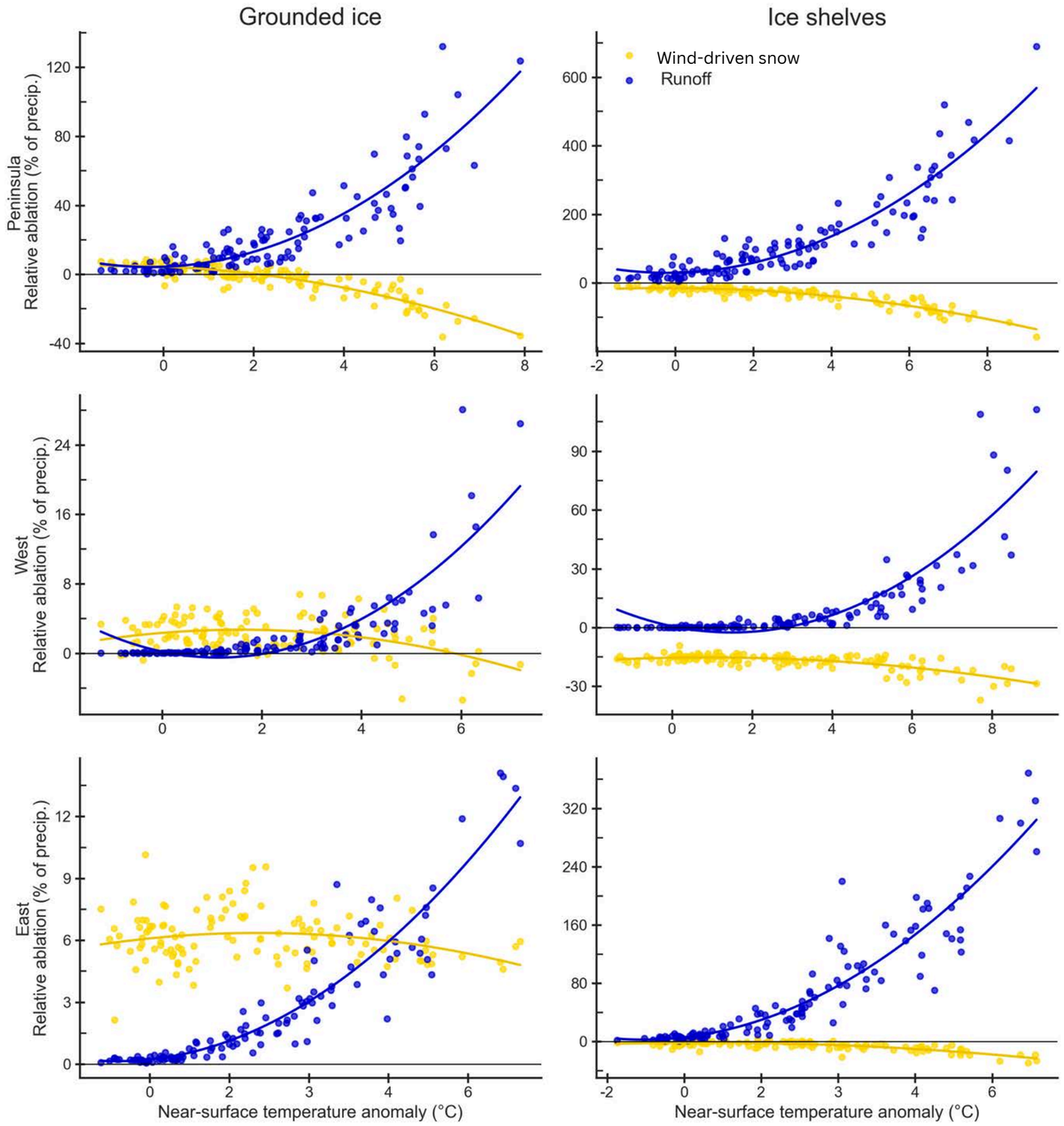
warming at which runoff overtakes snow transport

T_{CROSS}





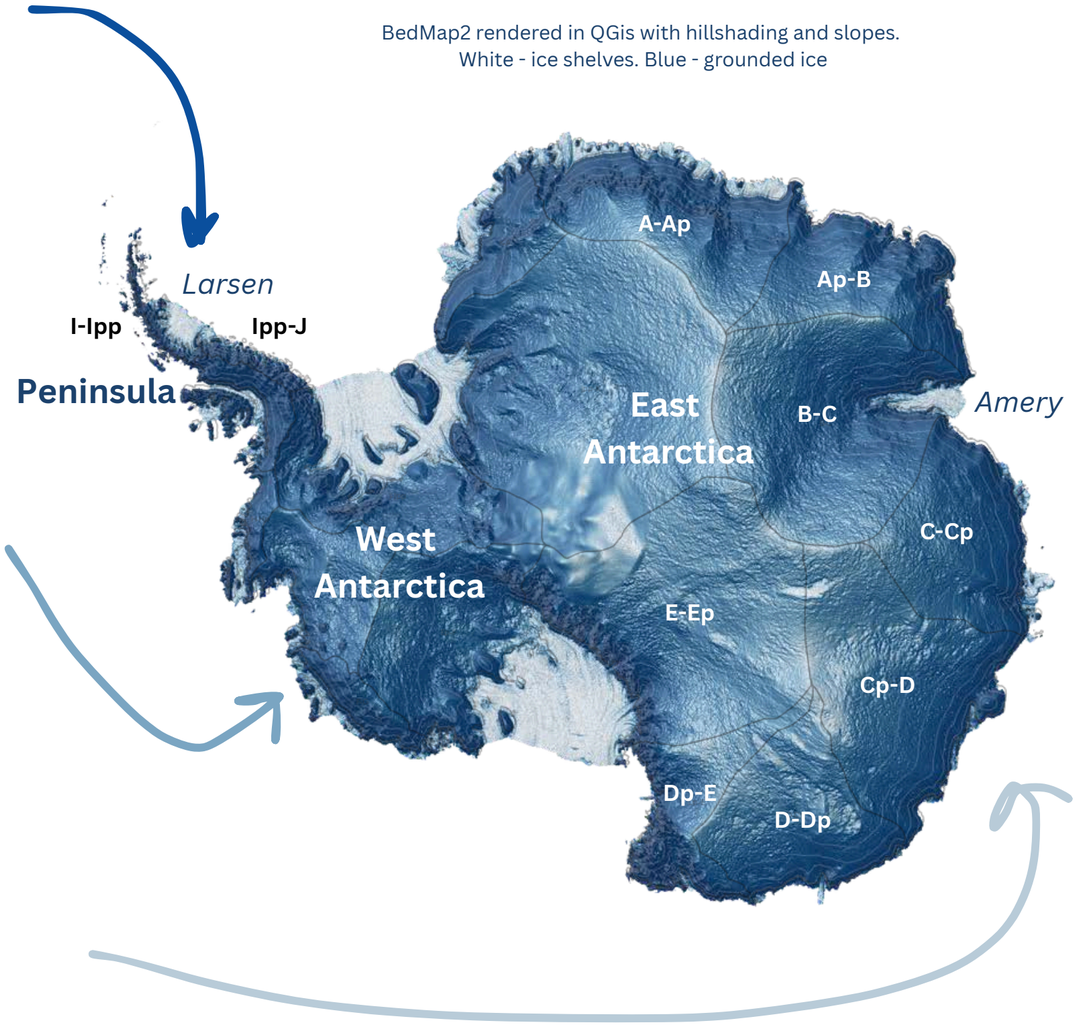


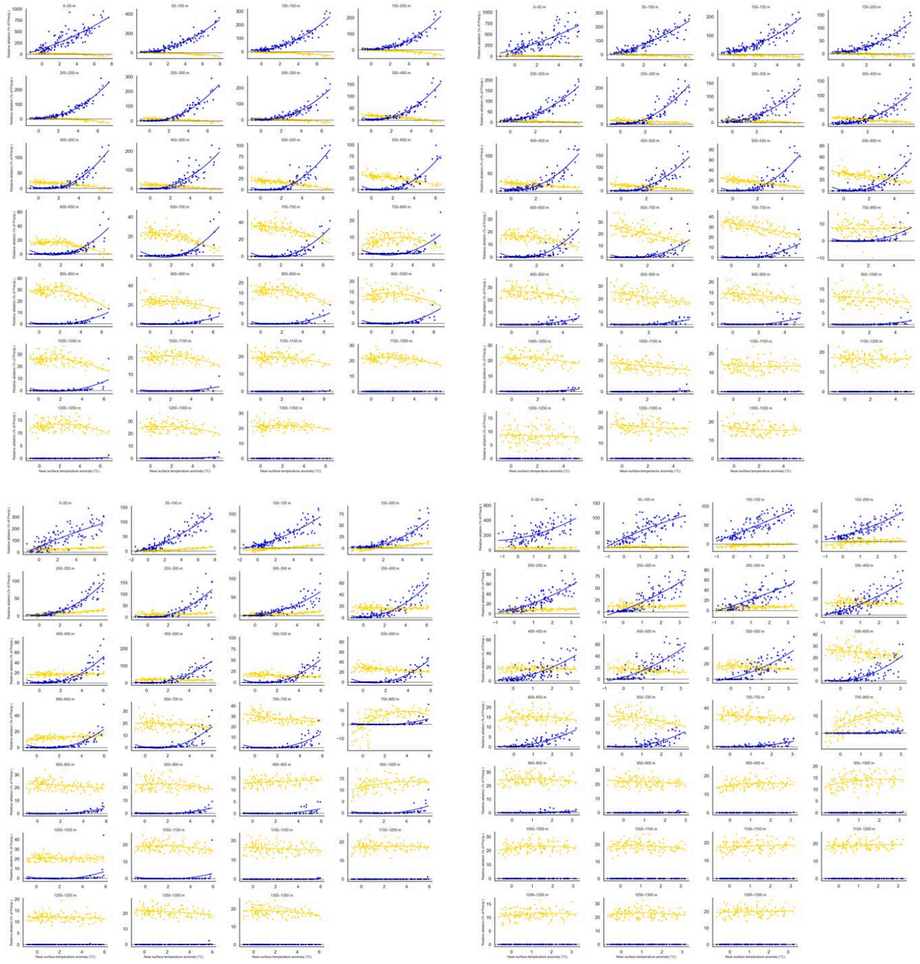


Wind-driven snow (yellow) and meltwater runoff (blue), as a percentage of precipitation, against near-surface temperature anomalies

Peninsula, EAIS, WAIS

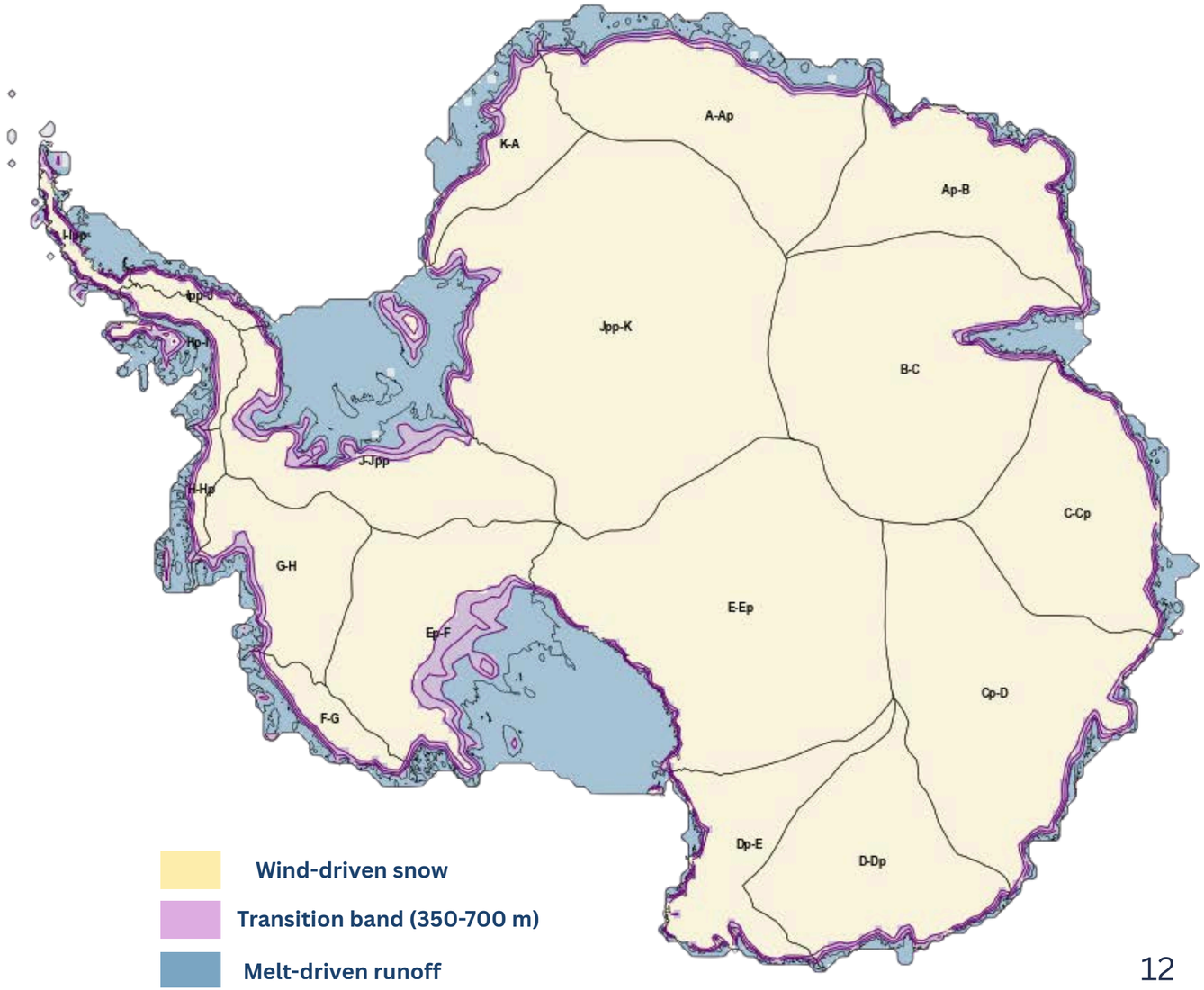
BedMap2 rendered in QGis with hillshading and slopes.
White - ice shelves. Blue - grounded ice



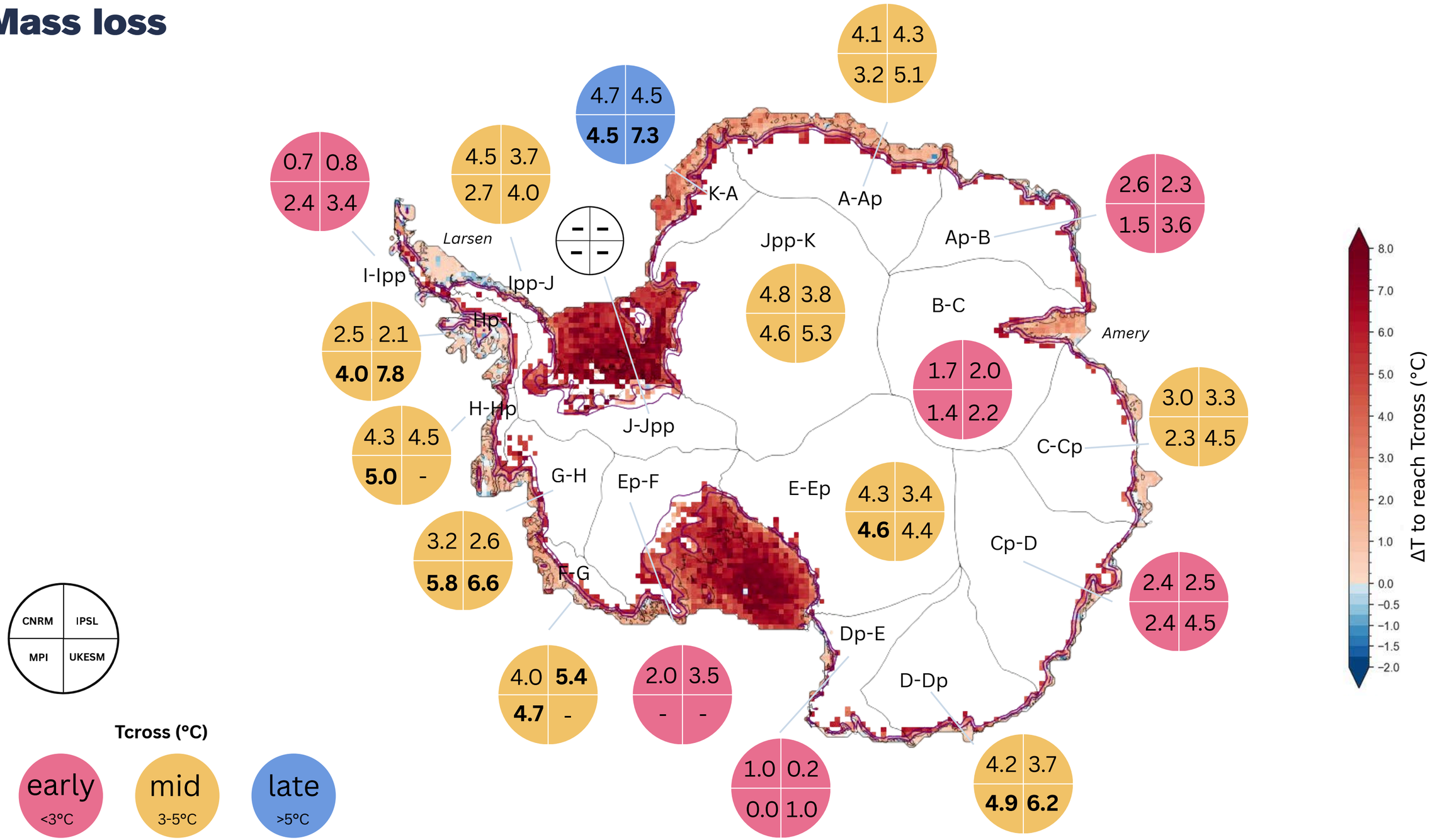


18 drainage basins grounded ice

Transition elevation band 350-700 m



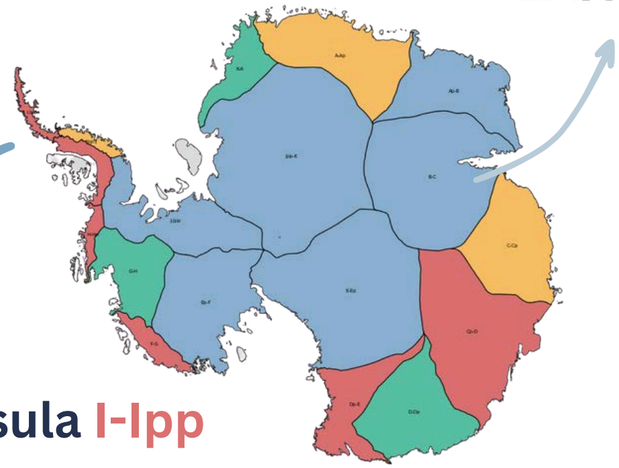
Mass loss



Warming above 1981-2010 needed to reach T_cross at which runoff overtakes wind-driven snow

two basins transition the earliest

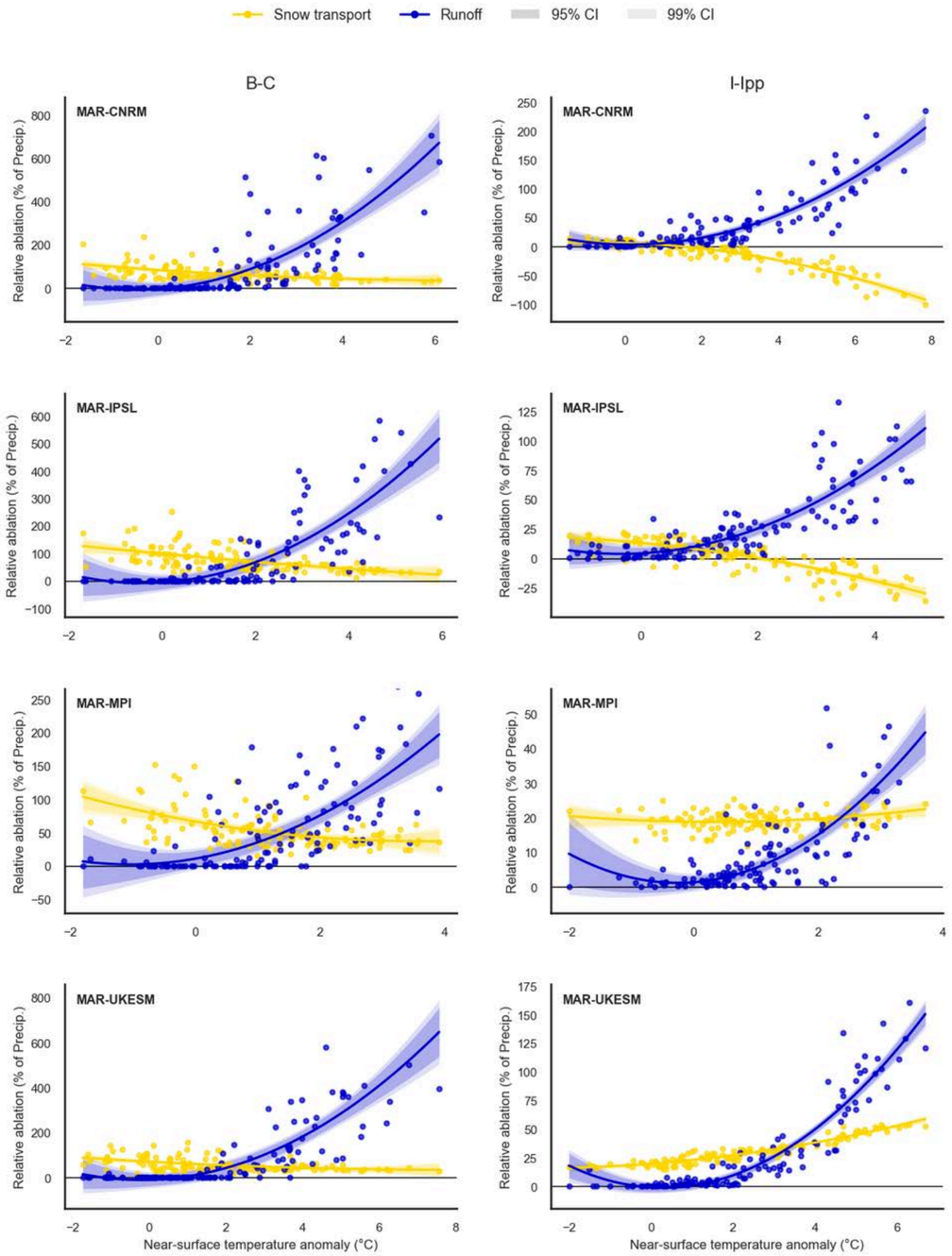
EAIS B-C



Peninsula I-Ipp

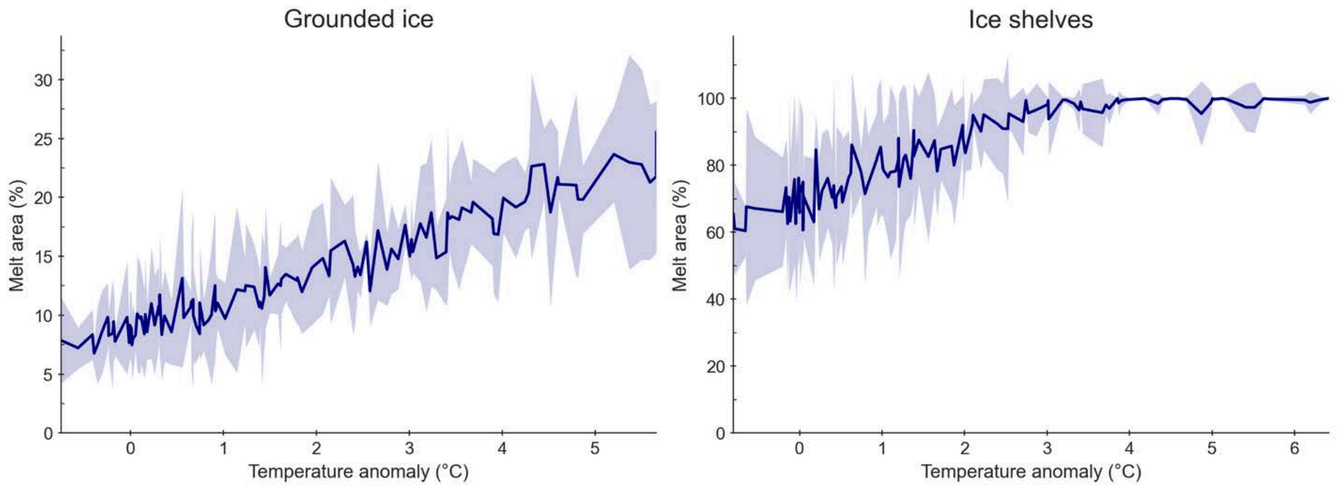
Q1 Cold+Dry Q2 Cold+Wet

Q3 Mild+Dry Q4 Mild+Wet



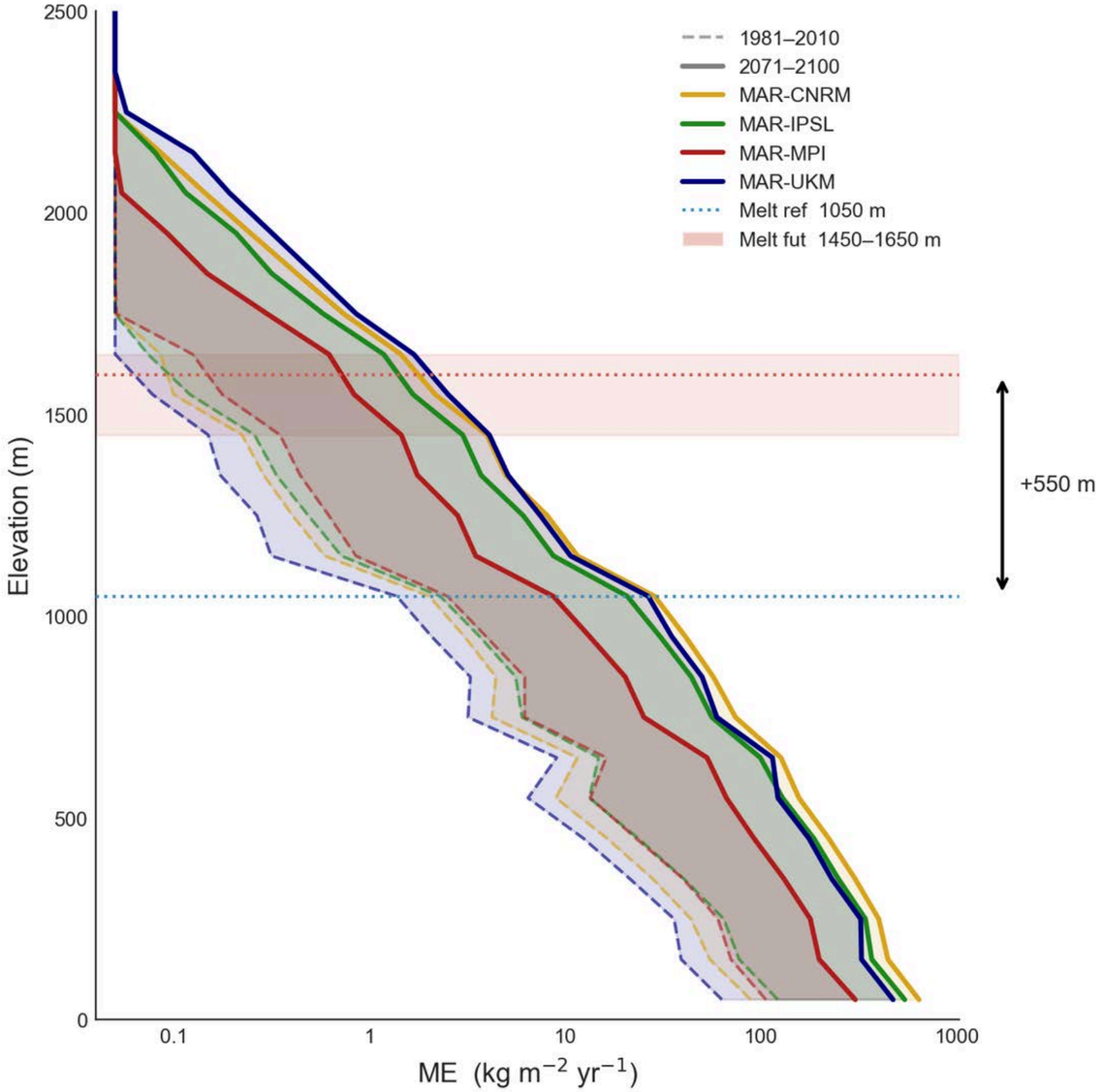
Wind-driven to a melt-driven transition. Wind-driven snow (yellow) and meltwater runoff (blue), as a percentage of precipitation, against near-surface temperature anomalies for EAIS' B–C (left) and Peninsula's I–Ipp (right)

Fraction of grounded ice and ice shelves area experiencing surface melt as a function of near-surface temperature anomaly relative to 1981-2010



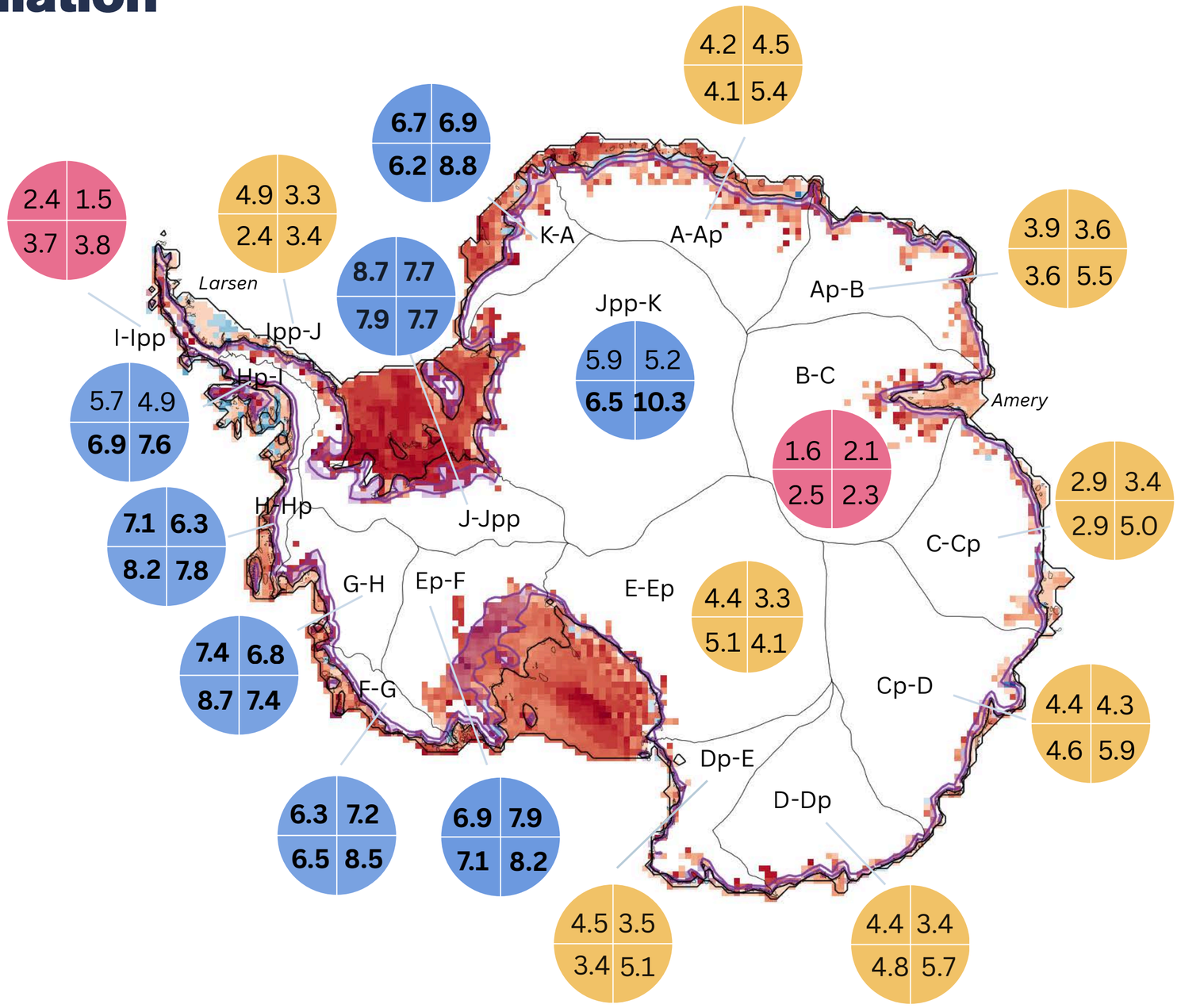
non-linear increase of melt

significant response of MOA



Melt as a function of elevation. Dashed lines show reference period (1981-2010) and solid lines show the future period (2071-2100)

Melt-over-accumulation



CNRM | IPSL
MPI | UKESM

Tmoa (°C)

early <3°C

mid 3-5°C

late >5°C

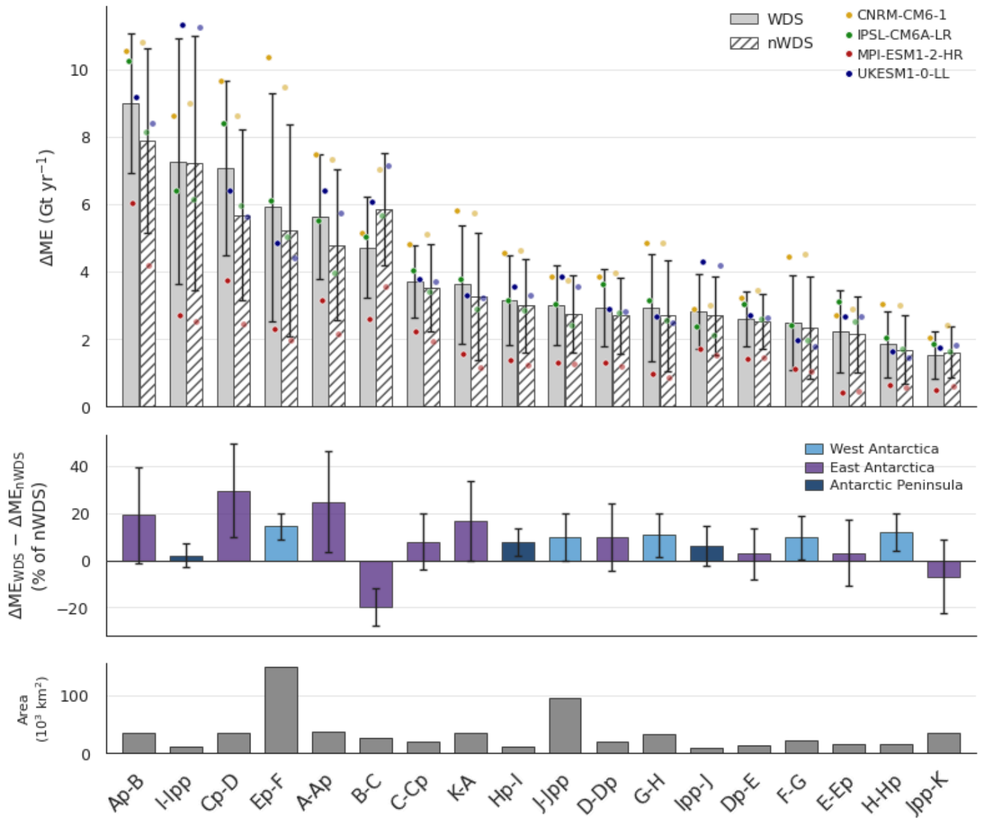
Warming above 1981-2010 needed to reach MOA=0.7 (T_moa)

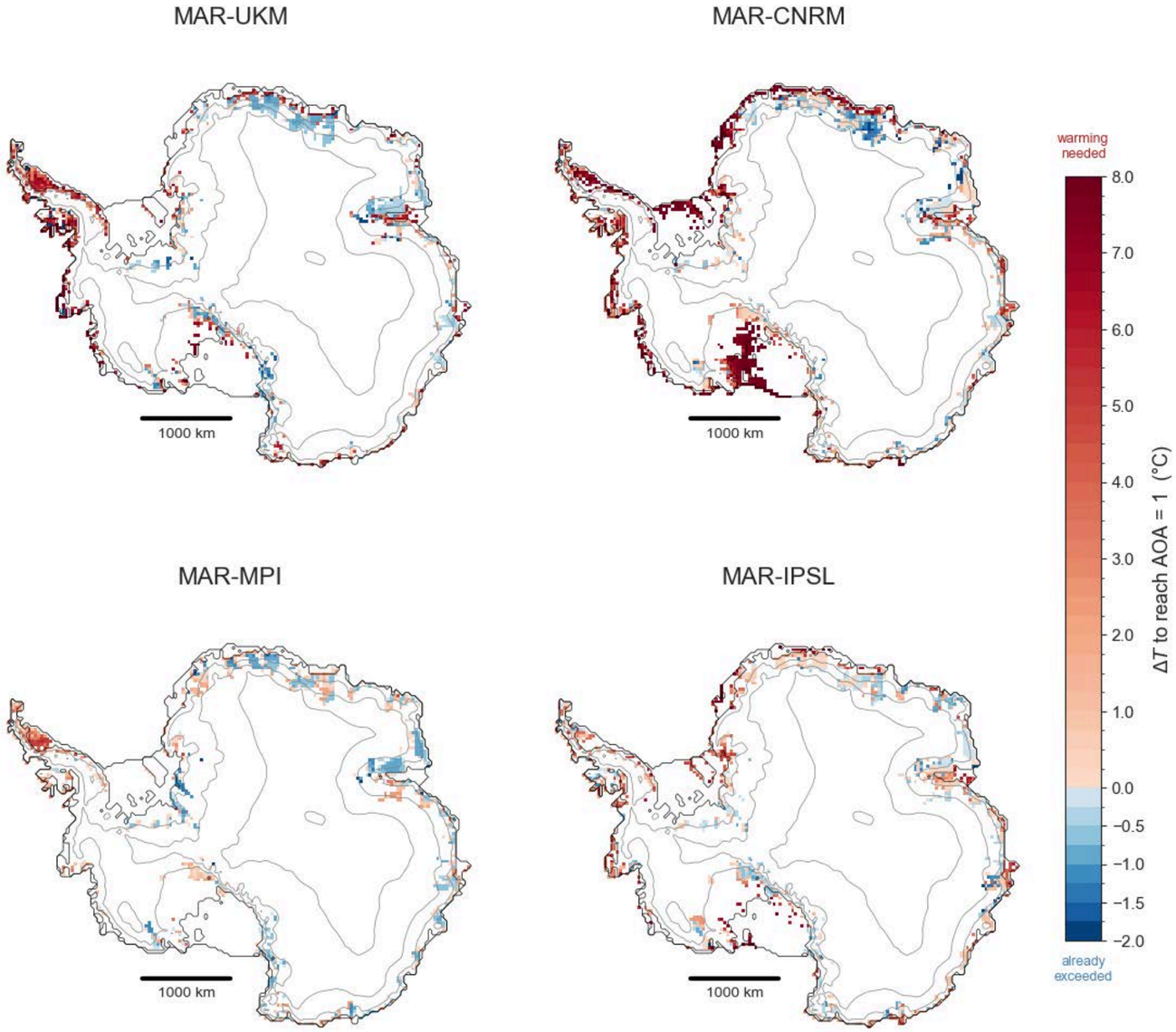
Different pathways

ER/SF = 0.89

1. **too little snow left B-C**
2. **too much melt I-Ipp**

Wind-driven snow effect on the projected melt by basin. Melt anomaly (2071-2100 minus 1981-2010) with wind-driven snow (WDS; filled) and without wind-driven snow (nWDS; hatched)





Spatial distribution of the surface temperature anomaly above reference period (1981-2010) at which AOA=1

Feedbacks

negative
limits transport

erosion exposes darker snow, blue ice > more melt



melt and refreezing bond grains > less transport

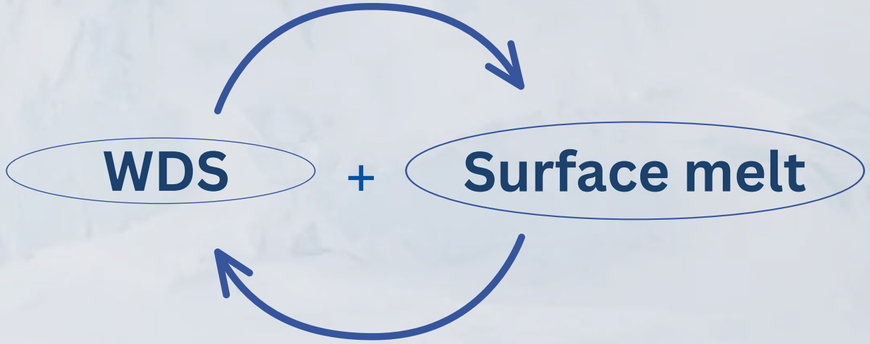
wind hardening

sintering under warming

positive
sustains transport by limiting melt

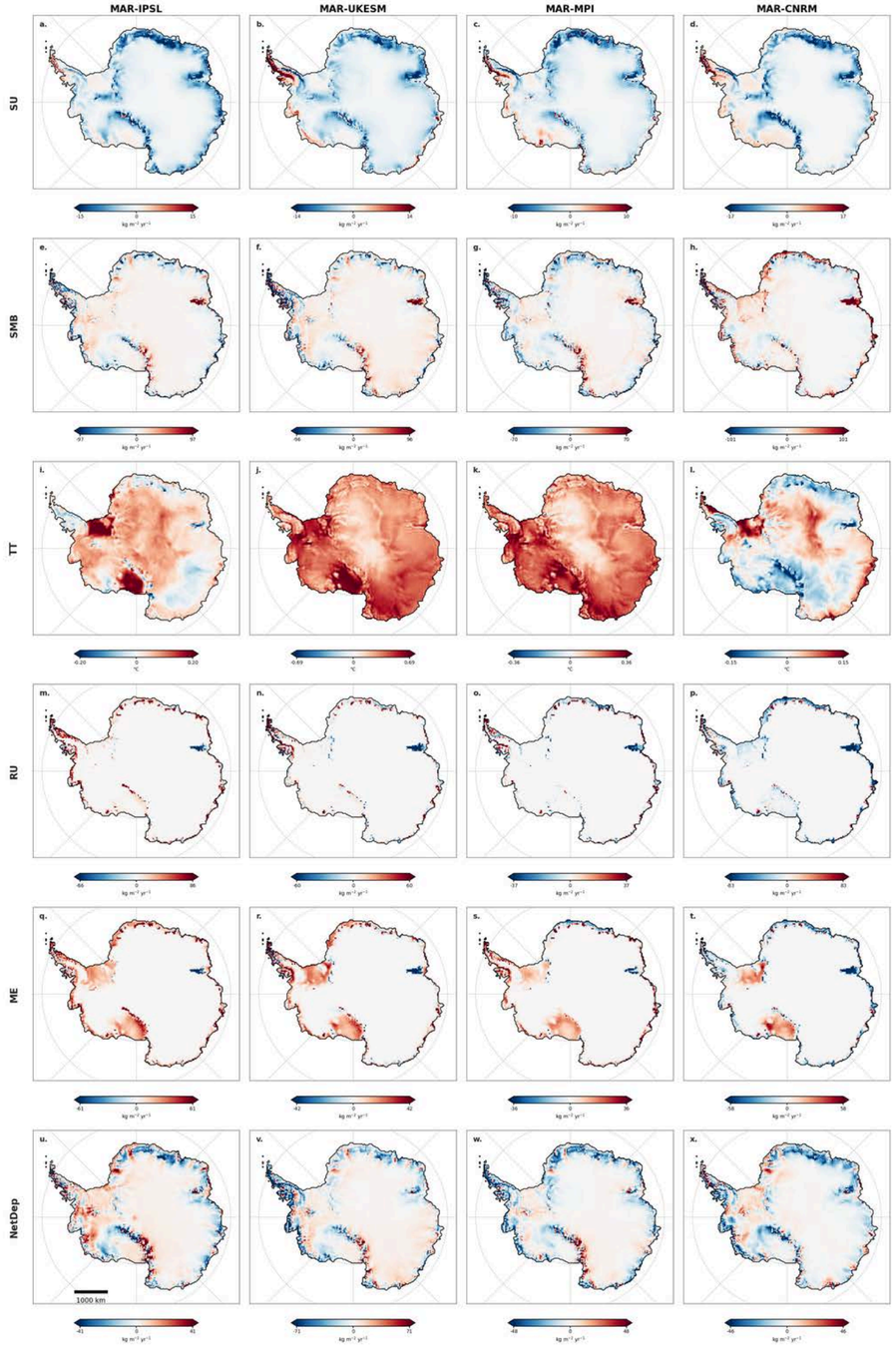
deposition: bright snow over darker layers

sublimation: cooler near-surface > less melt

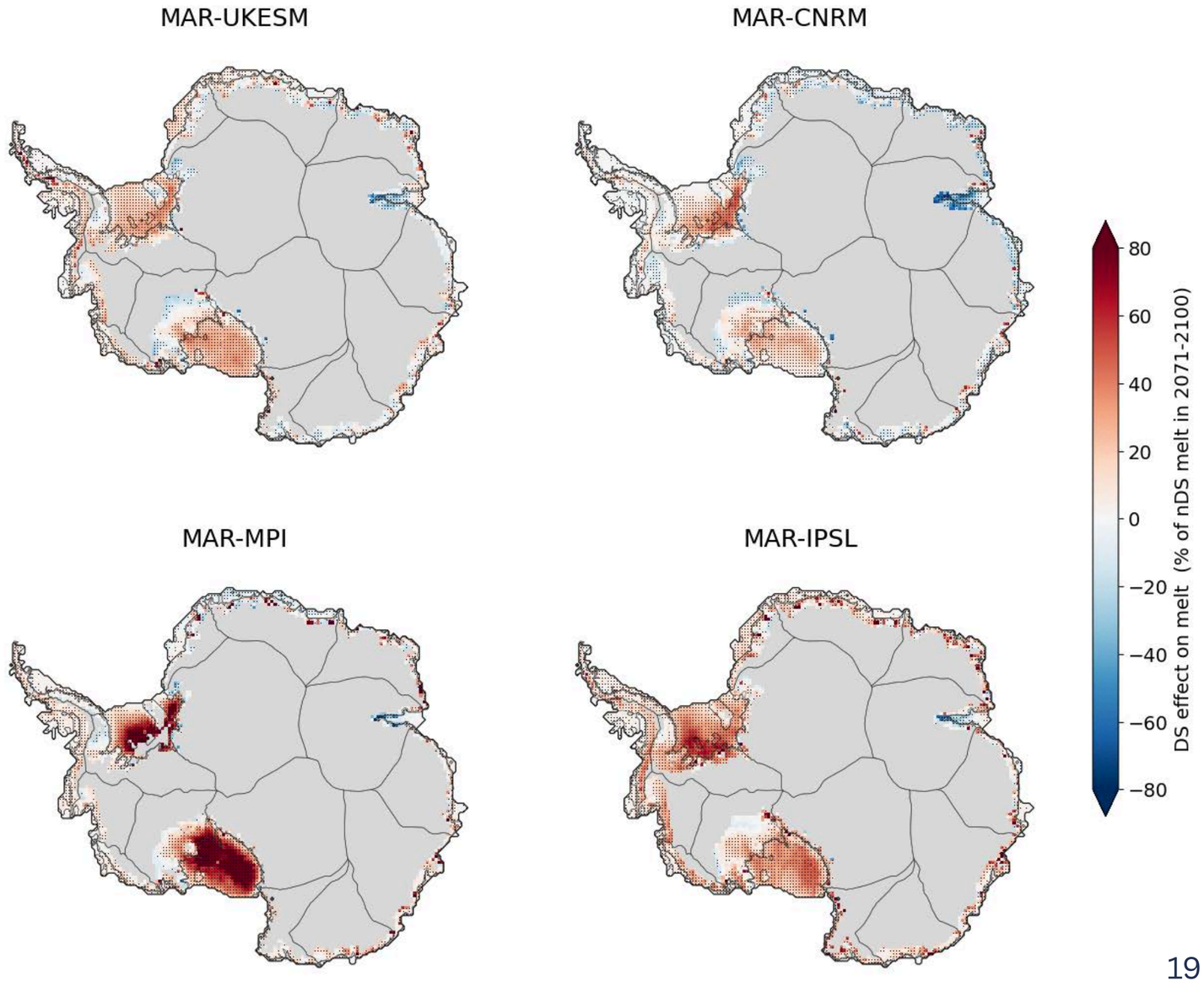


partly offset: moister air > more cloud > more net surface radiation

Wind-driven snow impact on SMB and Melt

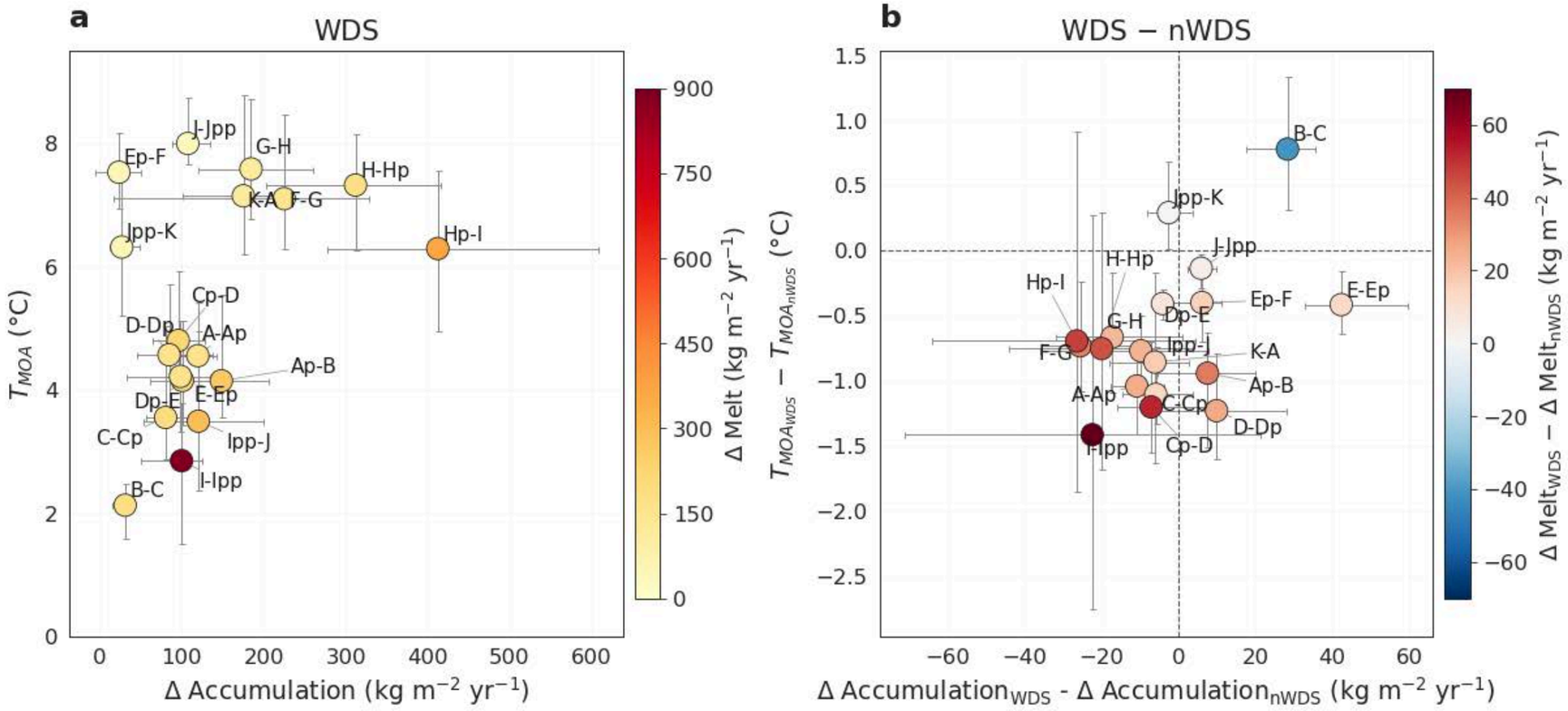


DS((2071-2100)-(1981-2010))-nDS(2071-2100)-(1981-2010))



Wind-driven snow effect on the projected surface melt change. Shown as a percentage of the melt simulated without wind-driven snow (nWDS) over the future period (2071-2100). Black dots mark grid cells where the change in difference is significant at 5%

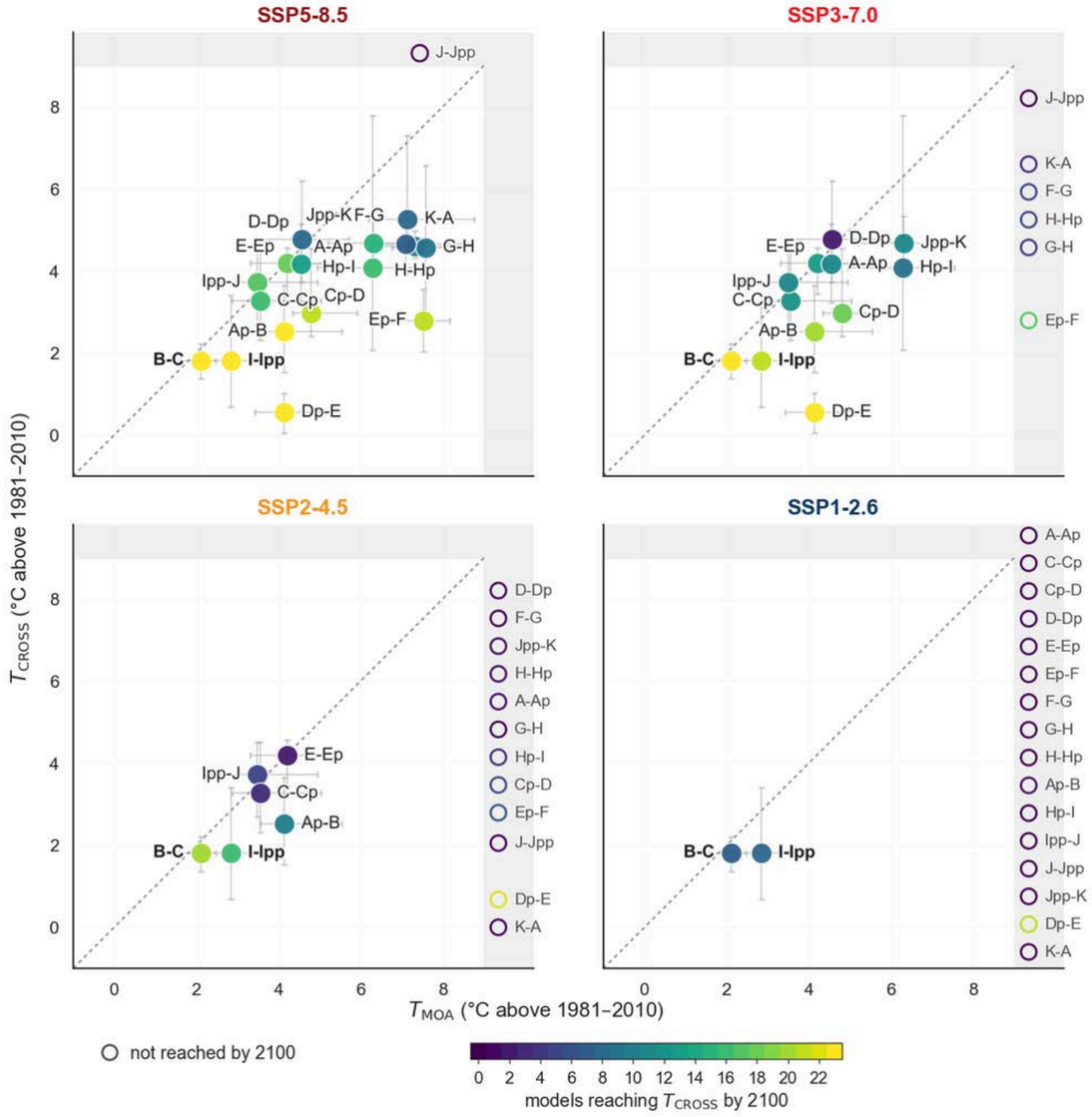
Wind-driven snow impact on meltwater pond formation thresholds

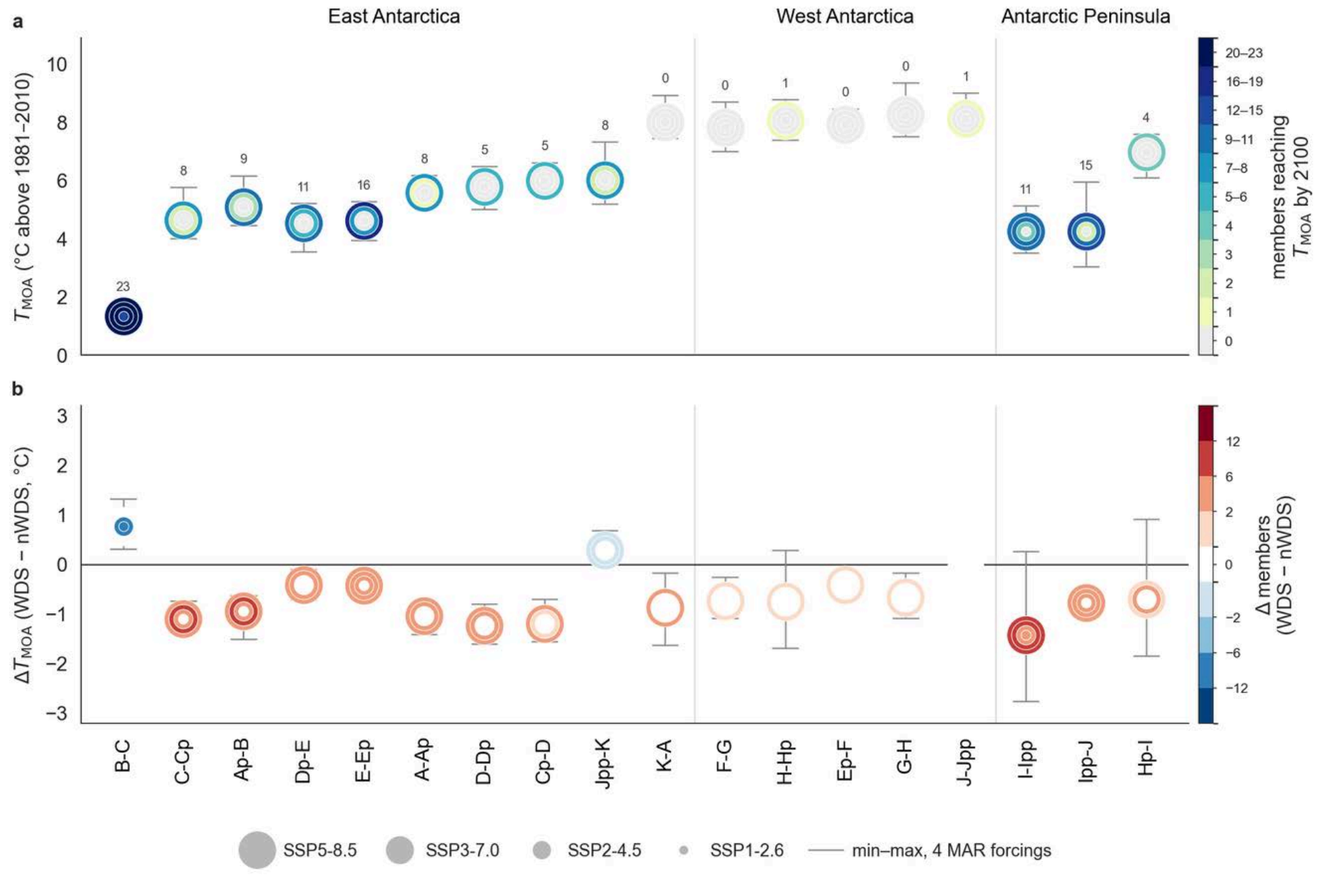


WDS lowers T_moa almost everywhere

16/18 basins

CMIP6 ensemble and lower emission scenarios





B-C and **I-Ipp** reached in every scenario

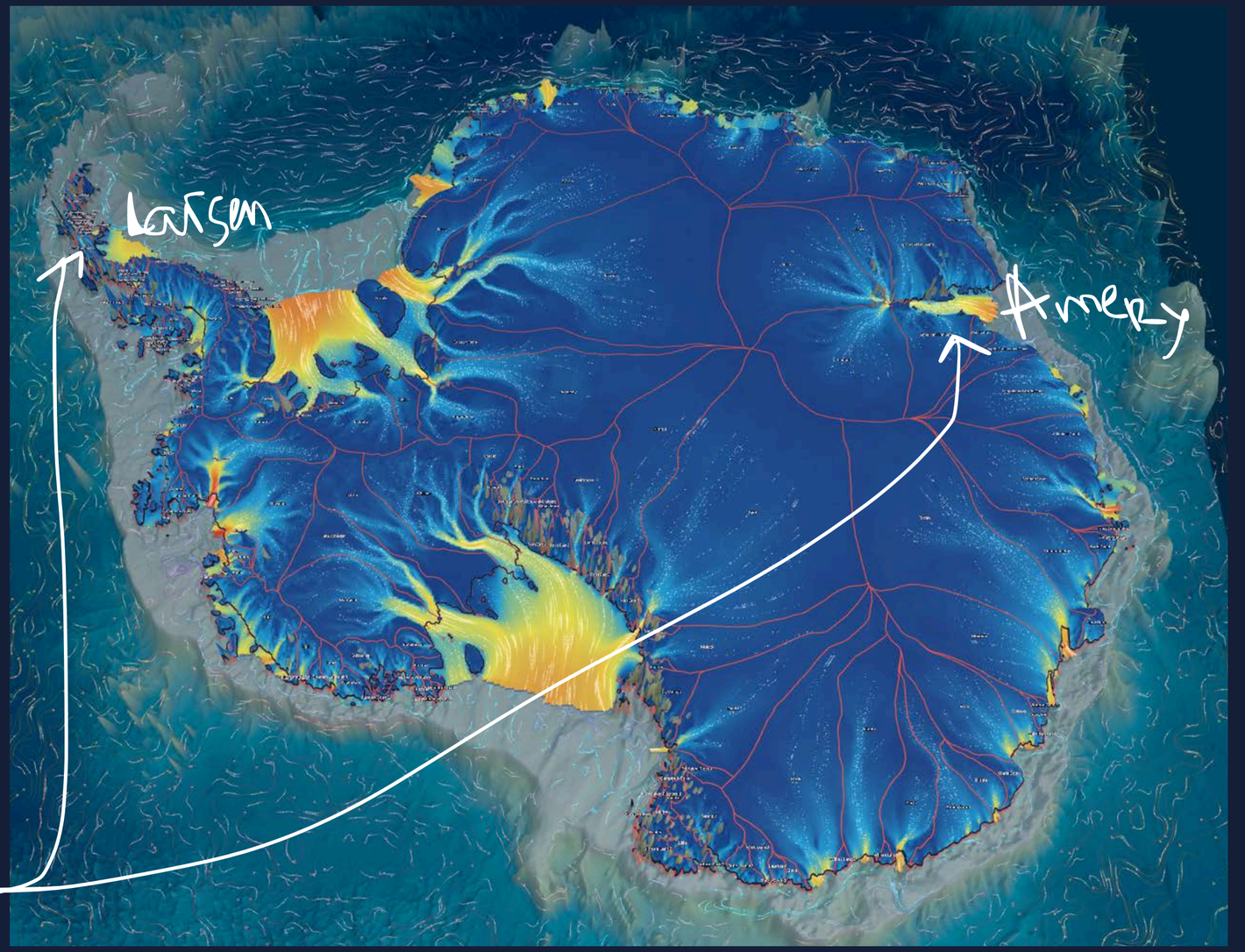
Sum up

On grounded ice margins meltwater ponding threshold depends on the amount of melt + firn left

Including WDS in models is essential for a more accurate assesment of exposure

EAIS's *Lambert-Amery* system meets the exposure criteria under all the frameworks applied and in several independant studies

Source:3d-ice.com



Next: WDS coupled atmosphere–ice–ocean simulations with the focus on

article in prep. : C. Amory, V.Favier, M.Santolaria-Otín, C.Kittel, D.Kan


Thank you!

supplement

Wind-driven snow impact

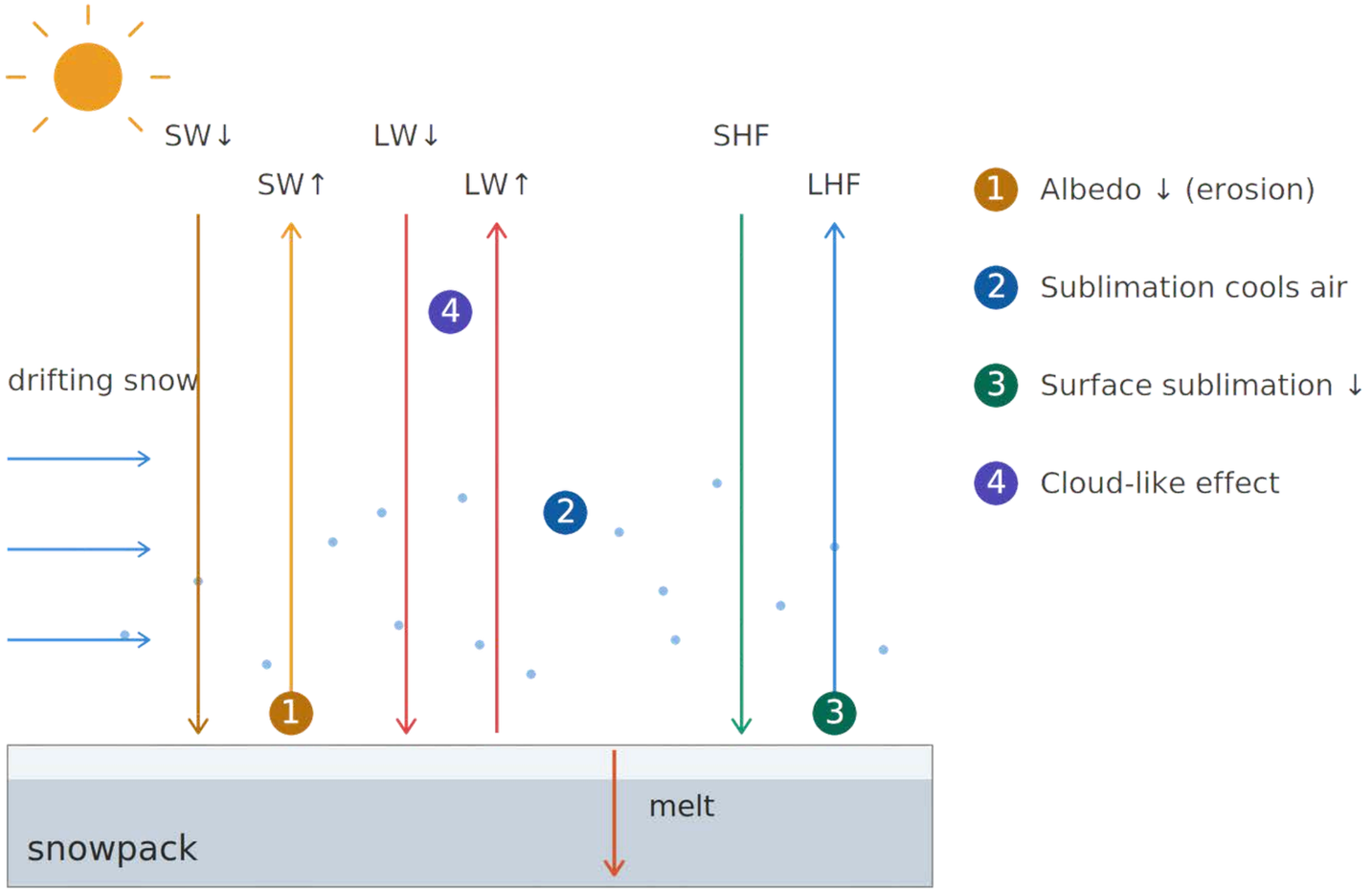
grounded ice

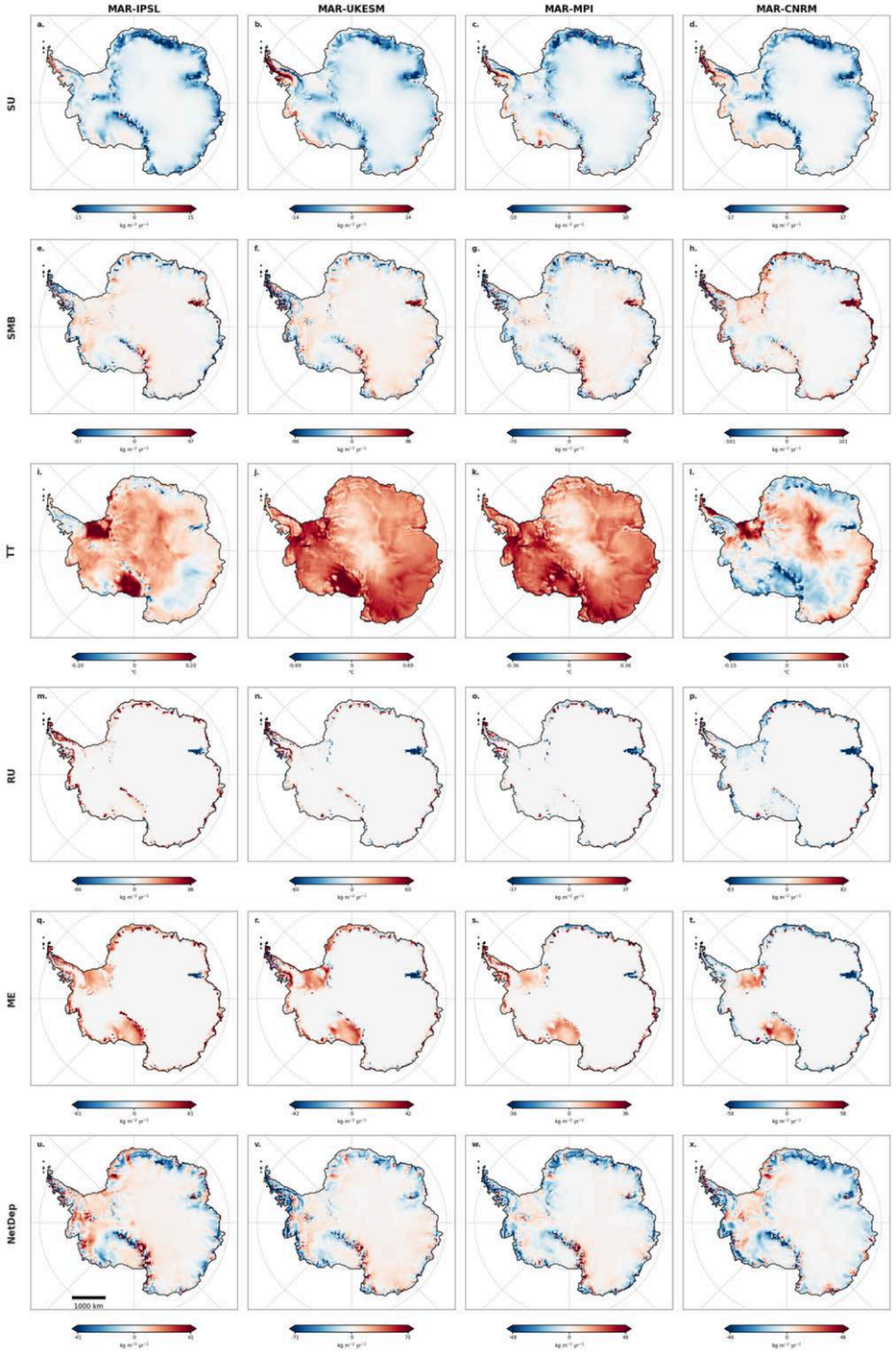
Model	ME	RU	SMB	SU
CNRM	-0.04	-0.05	0.02	-1.51
IPSL	0.31	0.44	0.01	-2.96
MPI	0.22	0.32	-0.13	-1.35
UKESM	0.008	0.14	0.07	-1.76

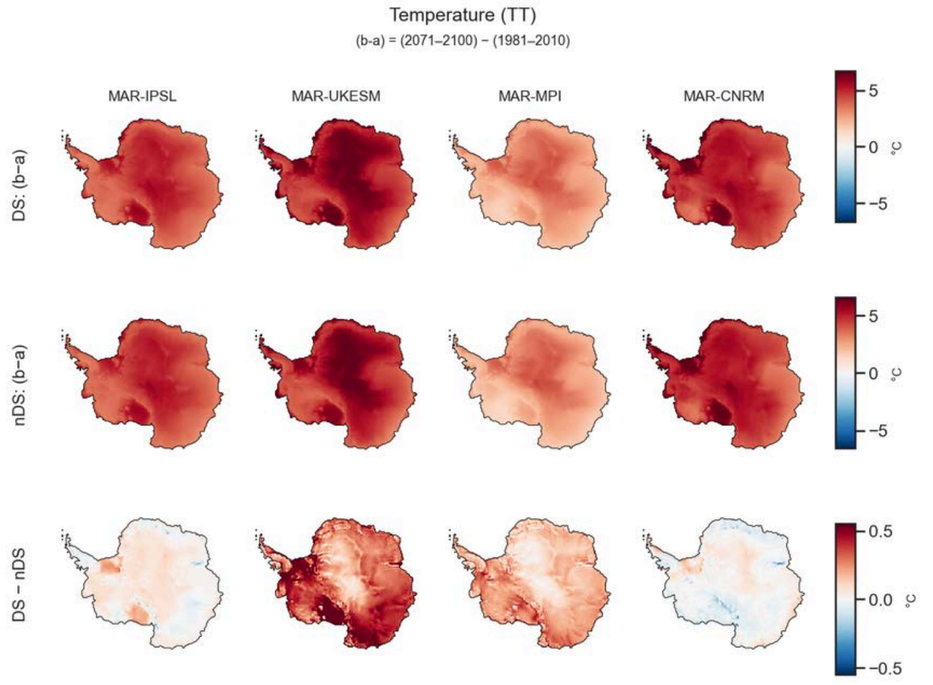
ice shelves

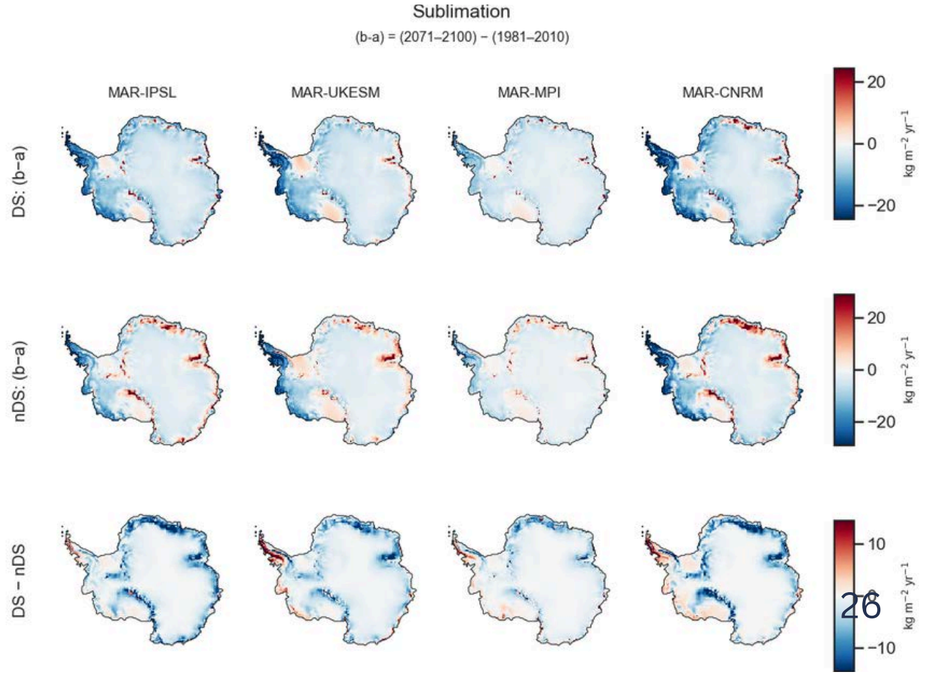
CNRM	-0.02	-0.15	0.23	-0.34
IPSL	0.28	0.22	-0.18	-1.97
MPI	0.26	0.05	-0.23	-0.61
UKESM	0.15	0	-0.01	-0.49

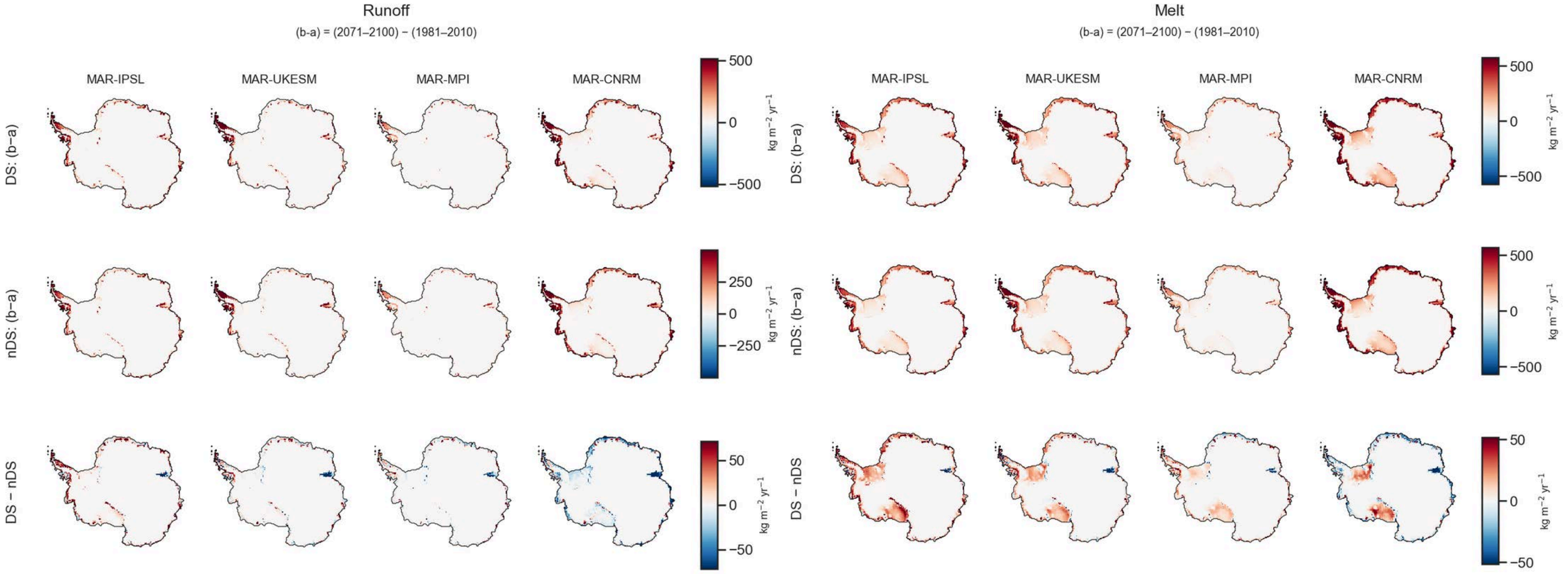
ds-nds / std (x2071-2100)nds

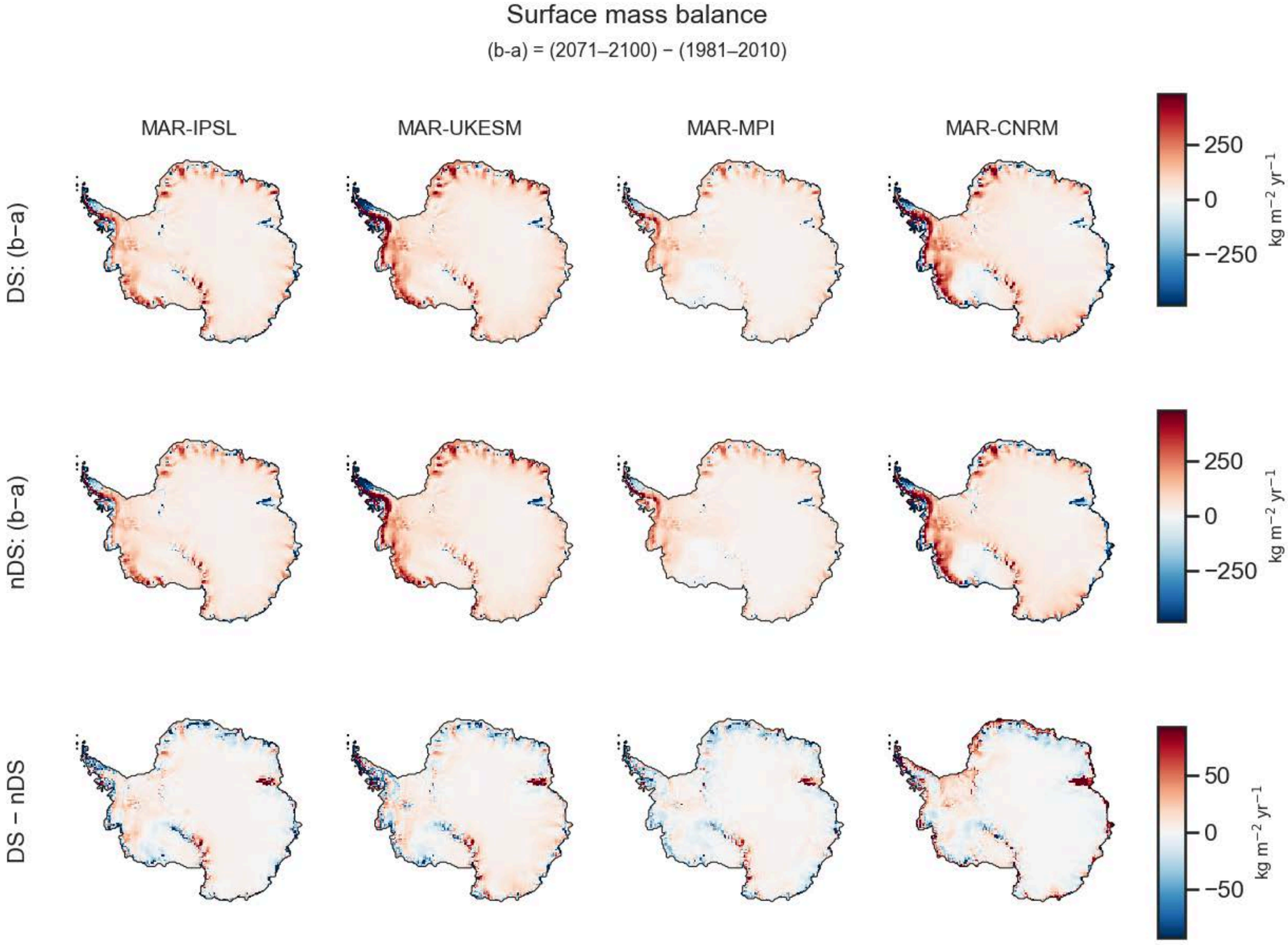


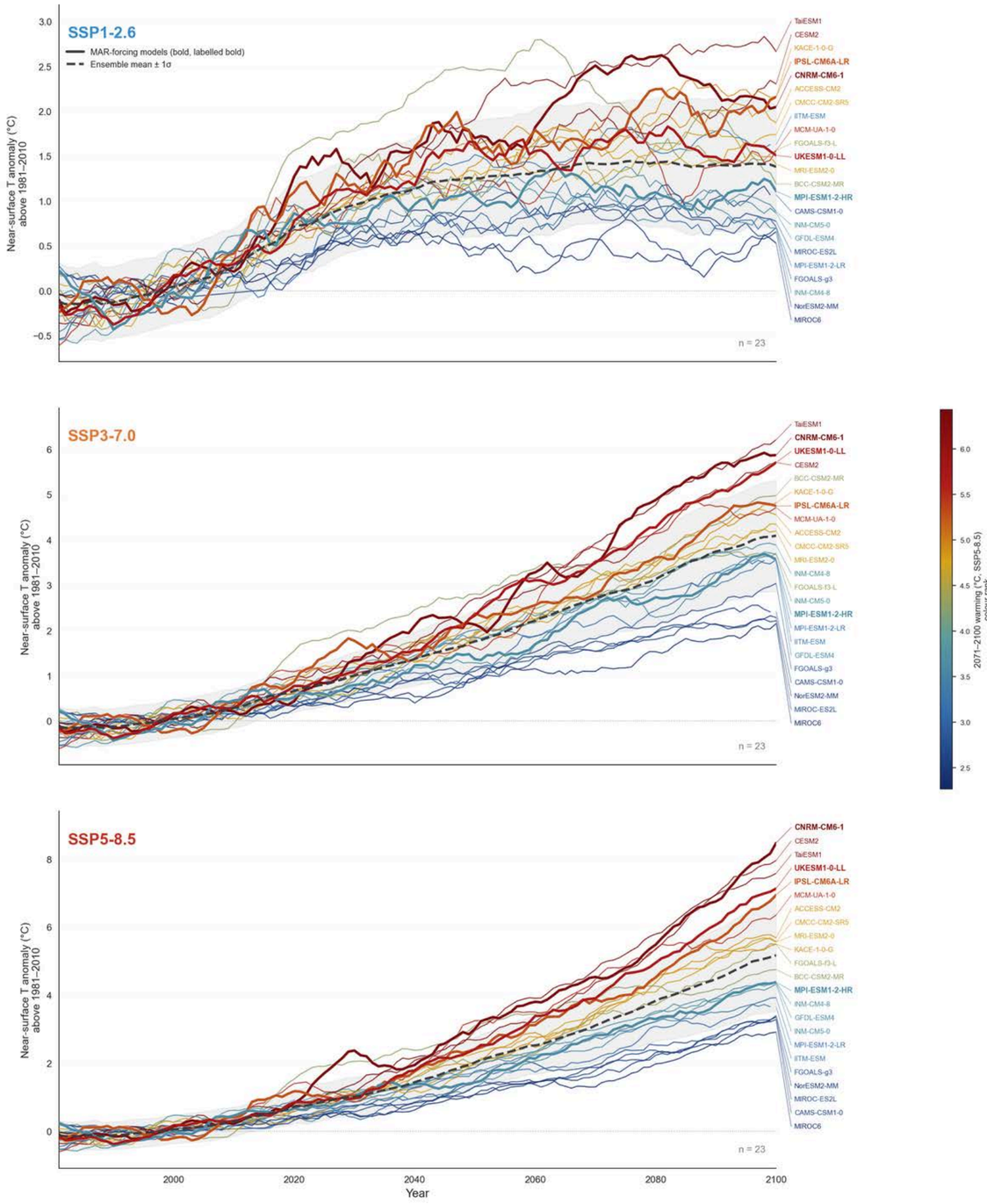

MAR-IPSL
MAR-UKESM
MAR-MPI
MAR-CNRM
SU
SMB
TT
RU
ME
NetDep
1000 km


Temperature (TT)
(b-a) = (2071–2100) − (1981–2010)
MAR-IPSL
MAR-UKESM
MAR-MPI
MAR-CNRM
DS: (b−a)
nDS: (b−a)
DS − nDS
°C


Sublimation
(b-a) = (2071–2100) − (1981–2010)
MAR-IPSL
MAR-UKESM
MAR-MPI
MAR-CNRM
DS: (b−a)
nDS: (b−a)
DS − nDS
kg m⁻² yr⁻¹


Runoff
(b-a) = (2071–2100) − (1981–2010)
Melt
(b-a) = (2071–2100) − (1981–2010)
MAR-IPSL
MAR-UKESM
MAR-MPI
MAR-CNRM
DS: (b−a)
nDS: (b−a)
DS − nDS
500
0
−500
250
−250
50
−50
kg m⁻² yr⁻¹


Surface mass balance
(b-a) = (2071–2100) − (1981–2010)
MAR-IPSL
MAR-UKESM
MAR-MPI
MAR-CNRM
DS: (b−a)
nDS: (b−a)
DS − nDS
250
0
−250
kg m−2 yr−1
250
0
−250
kg m−2 yr−1
50
0
−50
kg m−2 yr−1


SSP1-2.6
MAR-forcing models (bold, labelled bold)
Ensemble mean ± 1σ
Near-surface T anomaly (°C)
above 1981–2010
n = 23
SSP3-7.0
SSP5-8.5
Year
2071–2100 warming (°C, SSP5-8.5)
colour rank