SMB from RCMs: structural uncertainties in sea level projections from both ice sheets

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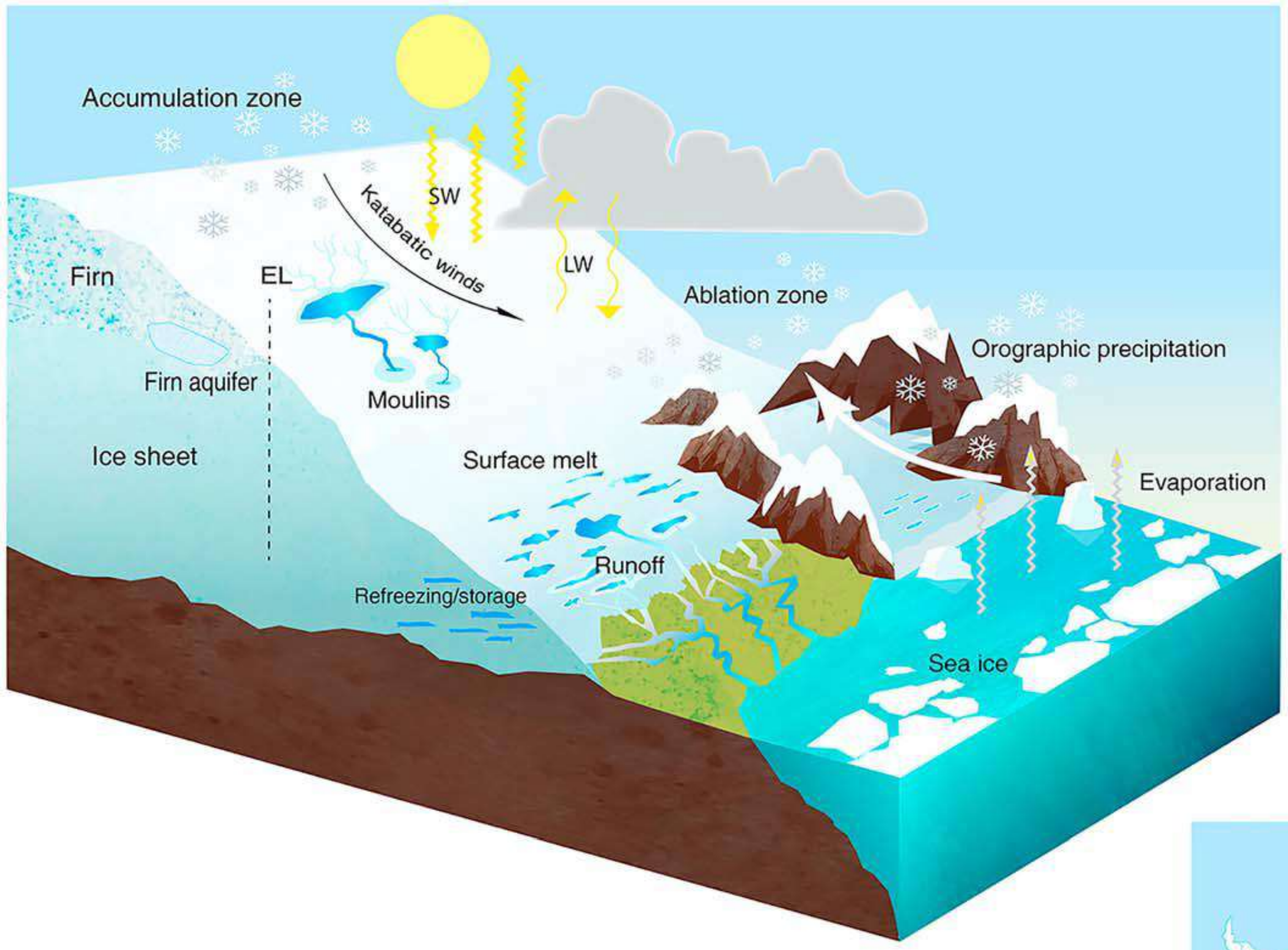
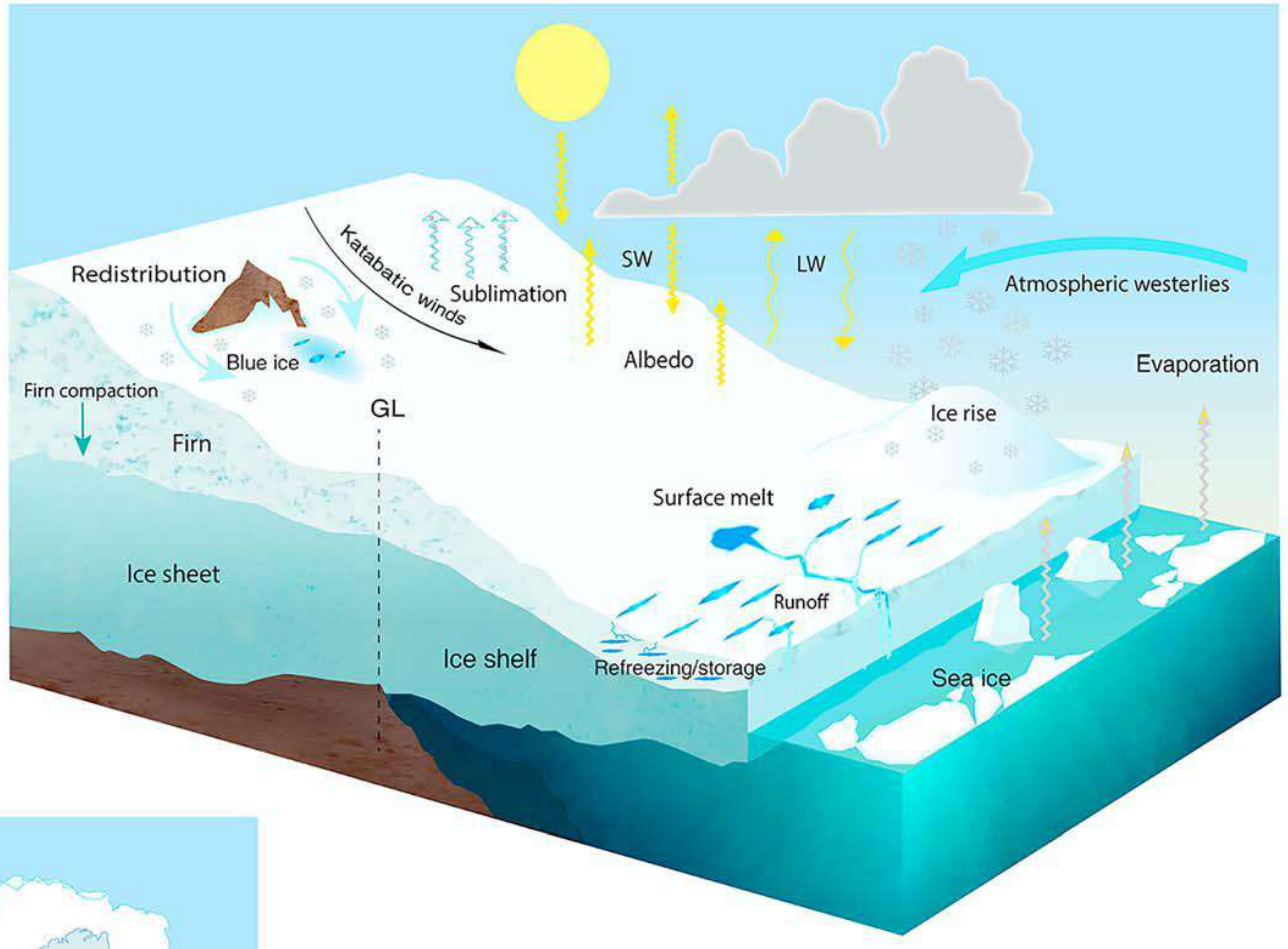
Surface Mass balance of ice sheets: atmospheric and surface coupling



Greenland Ice Sheet



Antarctic Ice Sheet

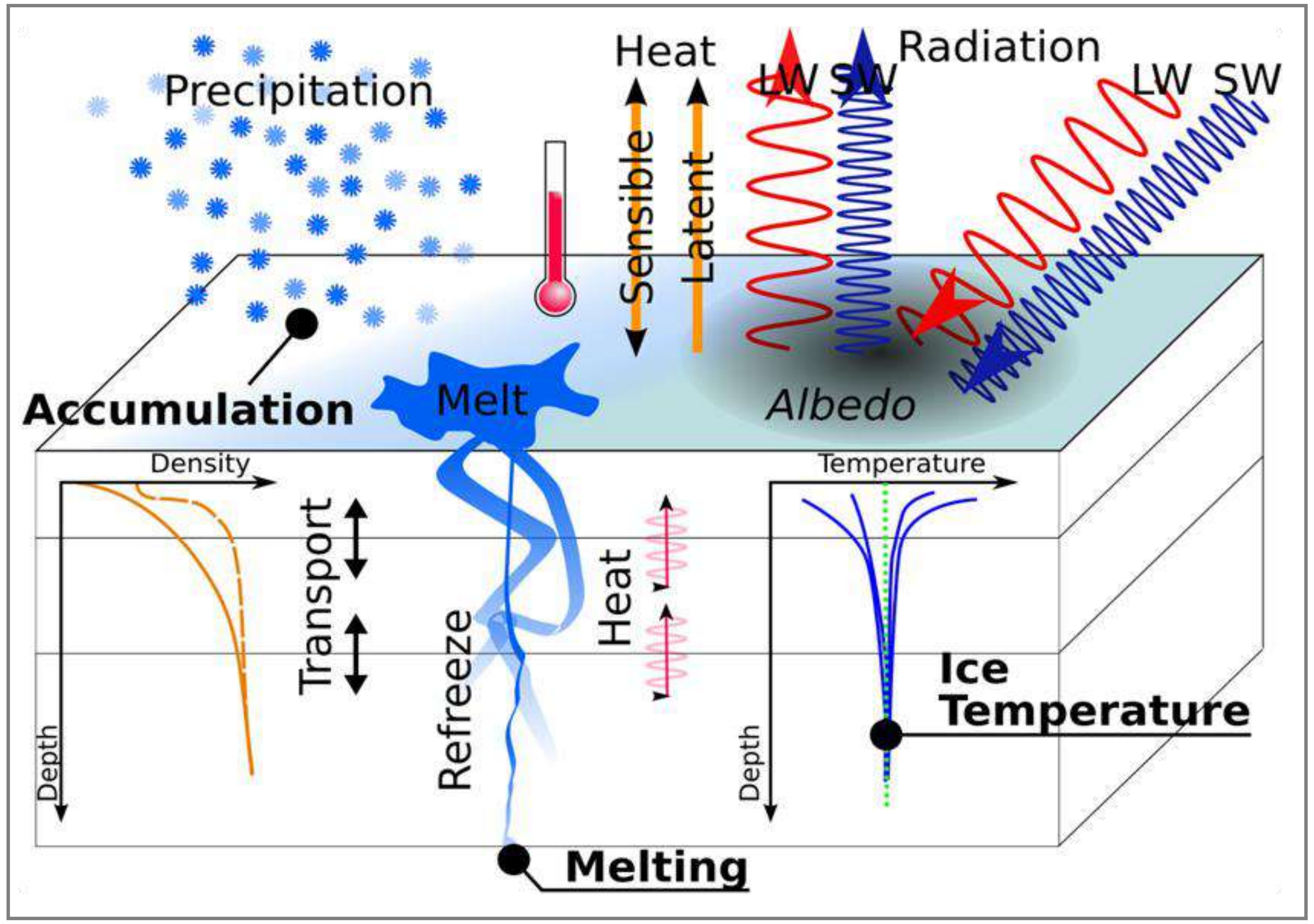
Lenaerts et al., 2018 (Credit: Marlo Garnsworthy, Wordy Bird Studio).

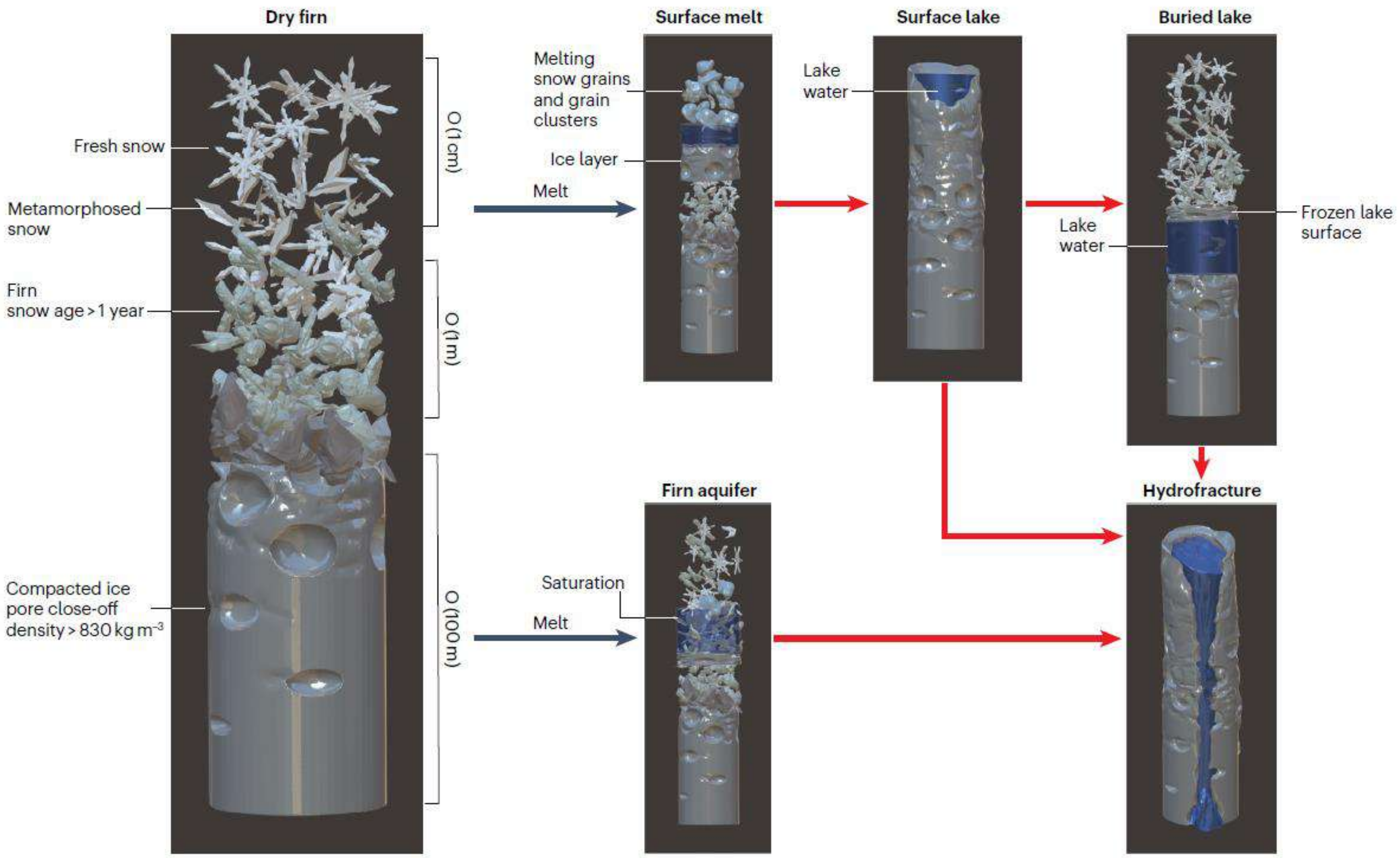
Atmosphere, snow and firn processes required for SMB:

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

$$Runoff = Melt + Rainfall + Condensation - Retention - Refreeze$$

$$SEB = SWD - SWU + LWD - LWU + SHF + LHF + GHF$$





Firn Symposium team, NREE, 2024

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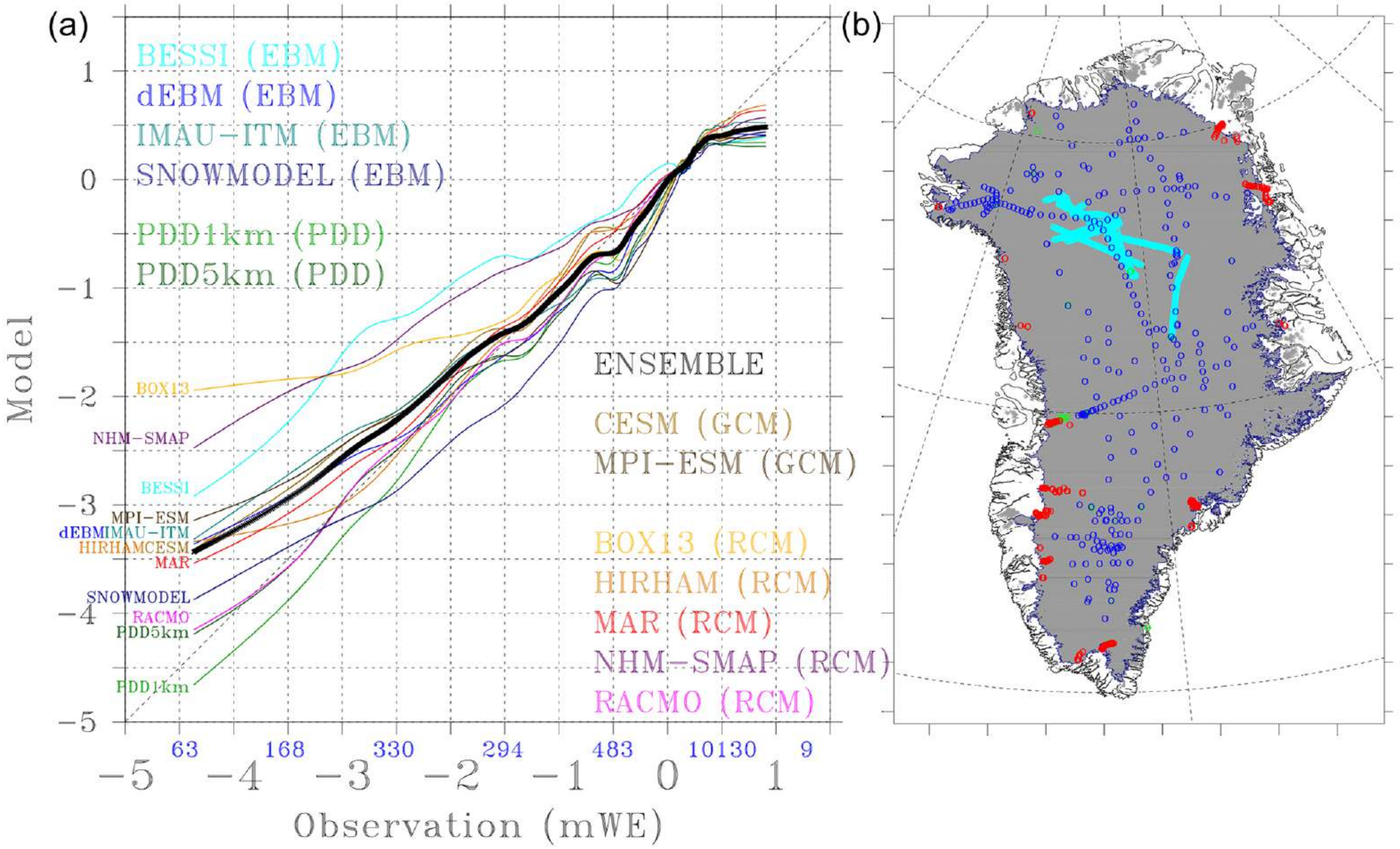
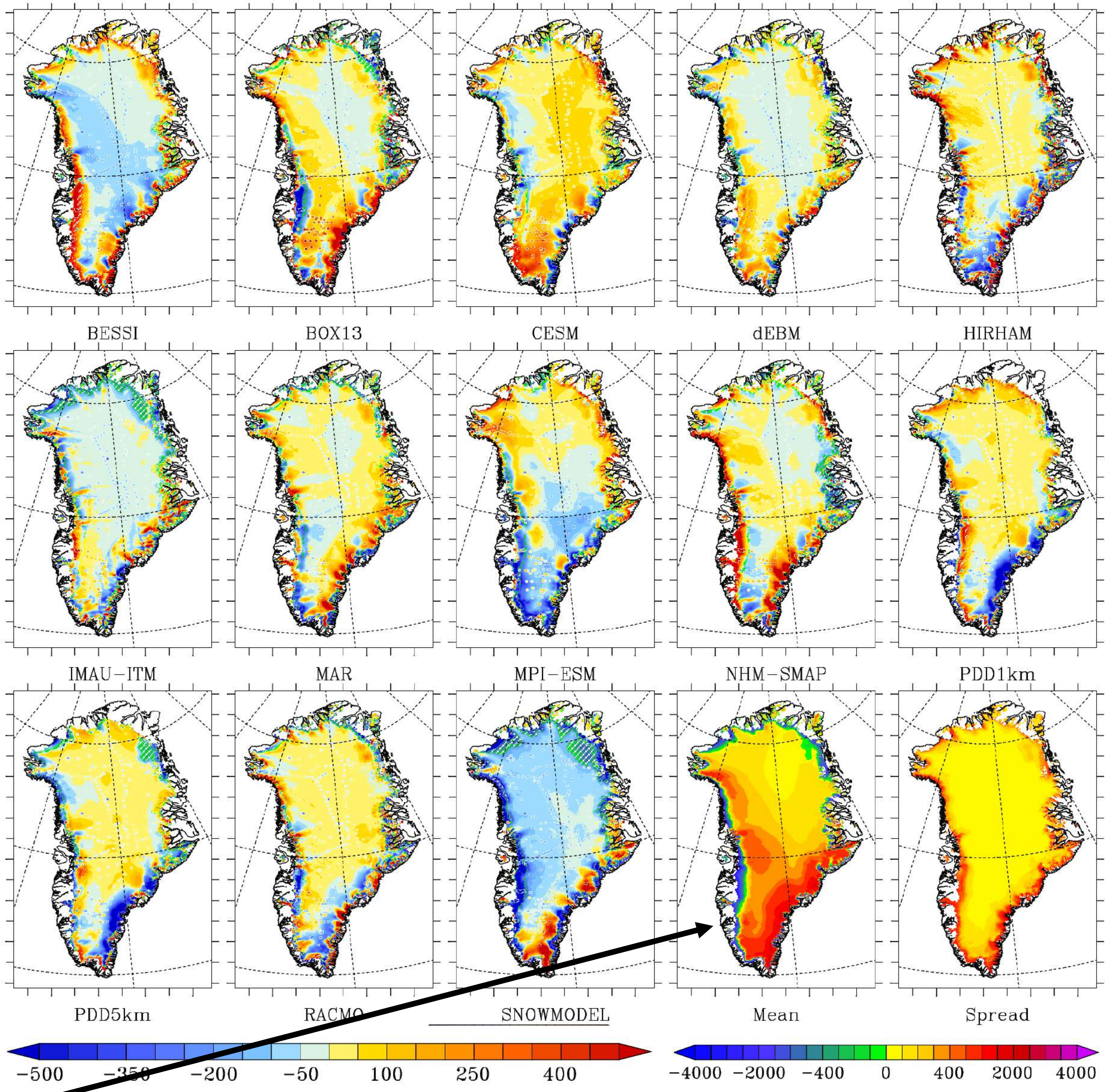
Present Day SMB from RCMs with Climate Reanalysis: GrIS

	SMB			Snowfall			Runoff		
	Mean	SD	Trend	Mean	SD	Trend	Mean	SD	Trend
BESSI	387	80	−4.1	566	54	0.3	134	52	4.2
BOX13	426	99	−6.5	718	61	−0.3	508	118	9.1
CESM	421	87	−3.1	668	59	0.1	276	66	4.0
dEBM	359	121	−8.1	604	59	−0.1	280	108	8.6
HIRHAM	398	109	−7.3	701	63	−1.5	491	123	8.2
IMAU-ITM	281	129	−8.7	638	62	0.4	382	122	9.5
MAR	372	122	−7.8	640	55	−0.5	302	107	8.0
MPI-ESM	284	101	−3.5	558	59	0.5	336	70	4.0
NHM-SMAP	429	99	−4.3	807	81	1.3	260	79	6.1
PDD1km	332	101	−6.3	519	55	0.2	230	87	7.0
PDD5km	285	111	−6.8	534	56	0.3	278	97	7.5
RACMO	357	115	−7.2	667	59	−0.7	306	90	6.7
SNOWMODEL	96	179	−12.9	665	65	0.3	469	171	13.4
ENSEMBLE	338	111	−7.3	642	59	0.0	331	102	8.0



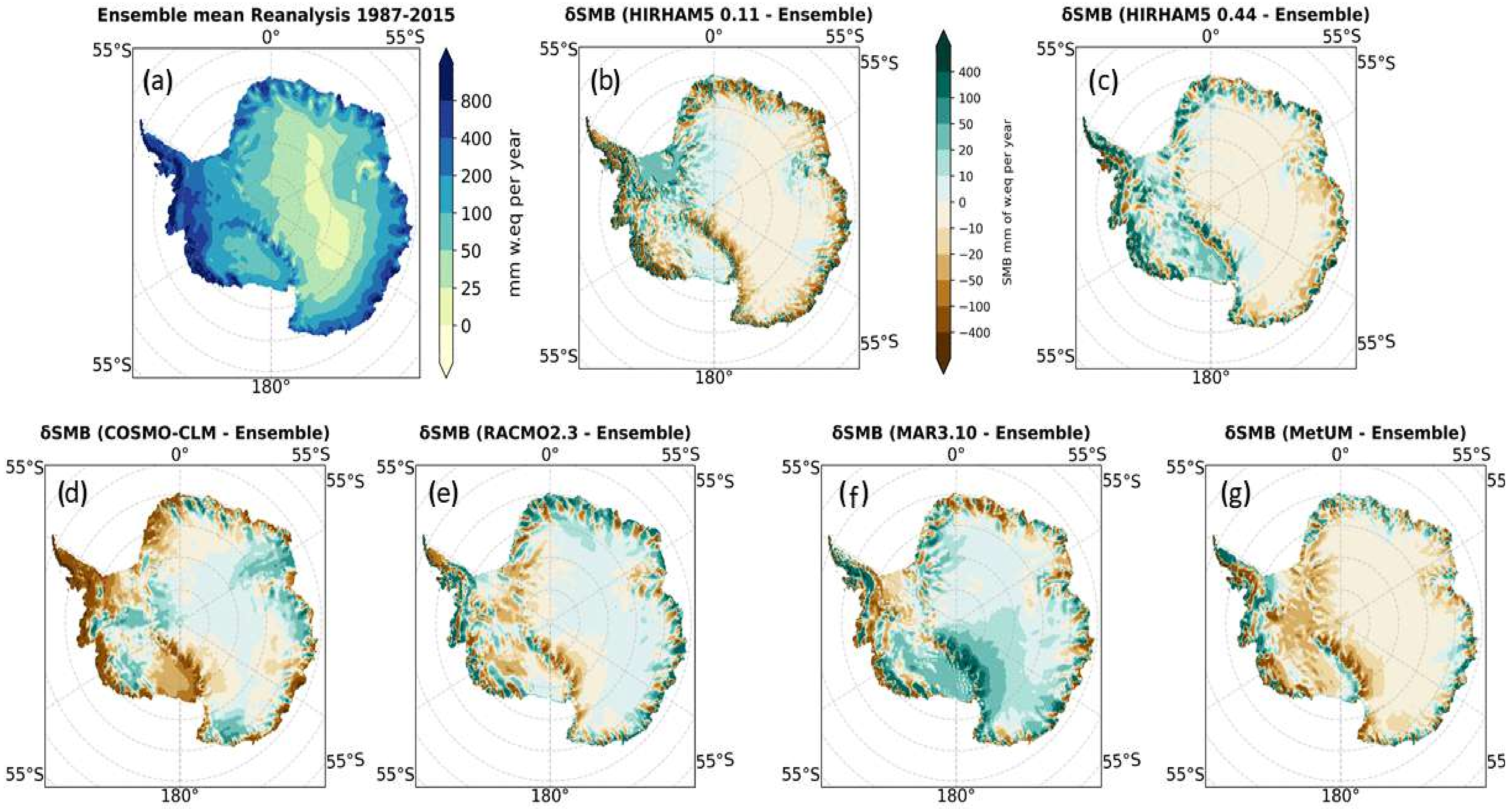


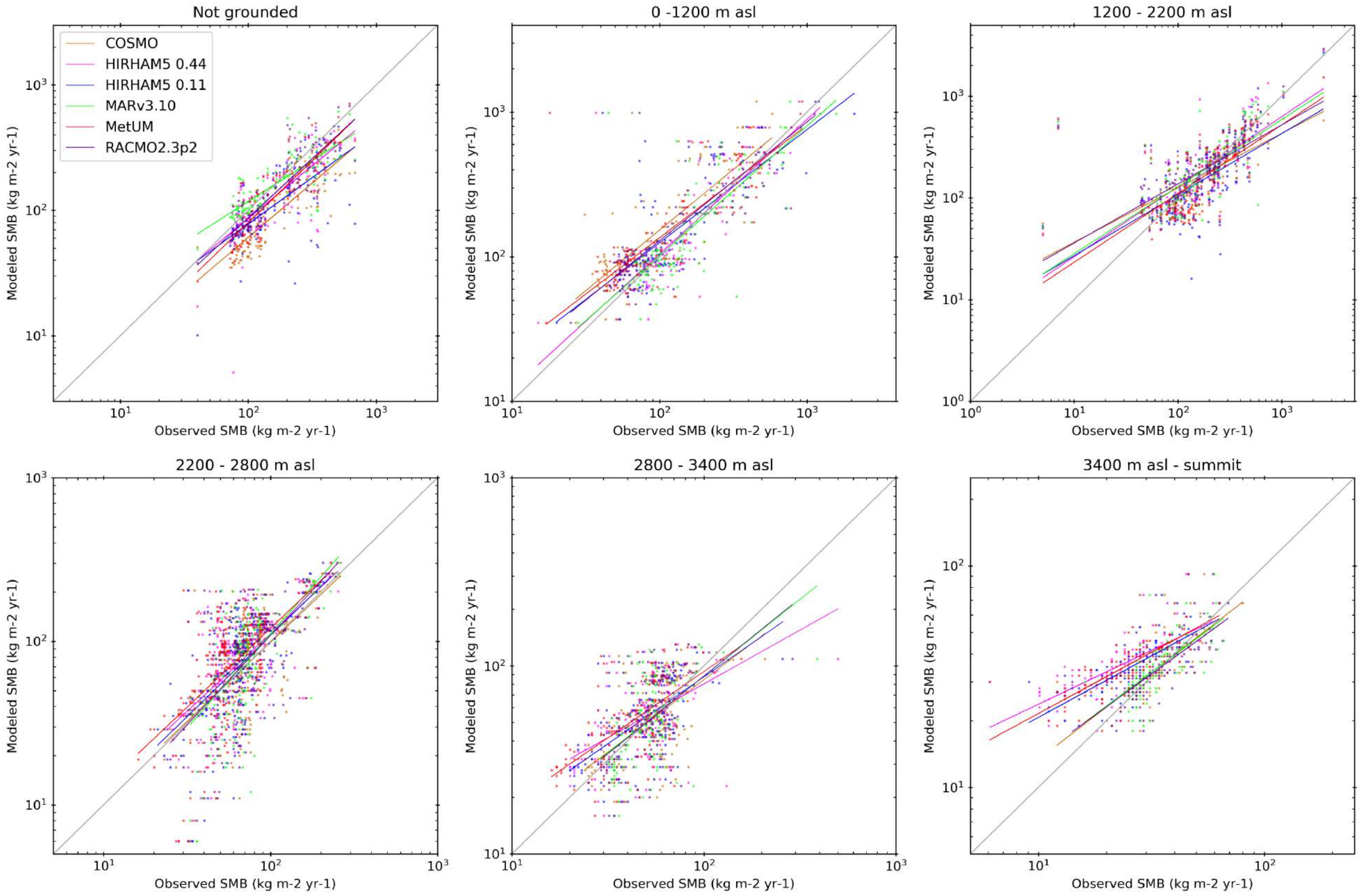
Ensemble Mean

Fettweis et al., 2020

Present Day SMB from RCMs with Climate Reanalysis: AIS

Ensemble Mean





Model	GrIS ($\mathrm{Gt\,yr^{-1}}$)	IS ($\mathrm{Gt\,yr^{-1}}$)	ToTIS ($\mathrm{Gt\,yr^{-1}}$)	Area ($10^6\,\mathrm{km^2}$)
RACMO2.1	1929	471	2391	13.85
RACMO2.3p2	2132	430	2555	13.85
RACMO2.3p1	2032	437	2462	13.85
MARv3.10	2227	413	2633	13.92
MARv3.6	2156	395	2545	13.92
HIRHAM5 0.44	2323	437	2752	13.87
HIRHAM5 0.11	2233	434	2657	13.83
MetUM	1883	452	2327	13.82
COSMO-CLM	1743	287	2023	13.84
Ensemble mean	2073	417	2483	13.86
Ensemble Σ	306	77	266	0.085

With the same forcing, RCMs produce similar SMB values at present day, though with some geographical differences, but the observational data is sparse

Mottram et al., 2021

Greenland Regional Climate Models:

MAR

15km resolution

Albedo scheme adjusts for snow properties and clouds constant in bare ice zone at 0.55.

Irreducible water saturation = 7%

RACMO2.3p2

11km resolution

Snow albedo based on snow impurities, zenith angle, and metamorphism, bare ice albedo is derived from a MODIS 5% lowest values, averaged over 2000-2015.

Irreducible water saturation = 2%

HIRHAM5

5km resolution

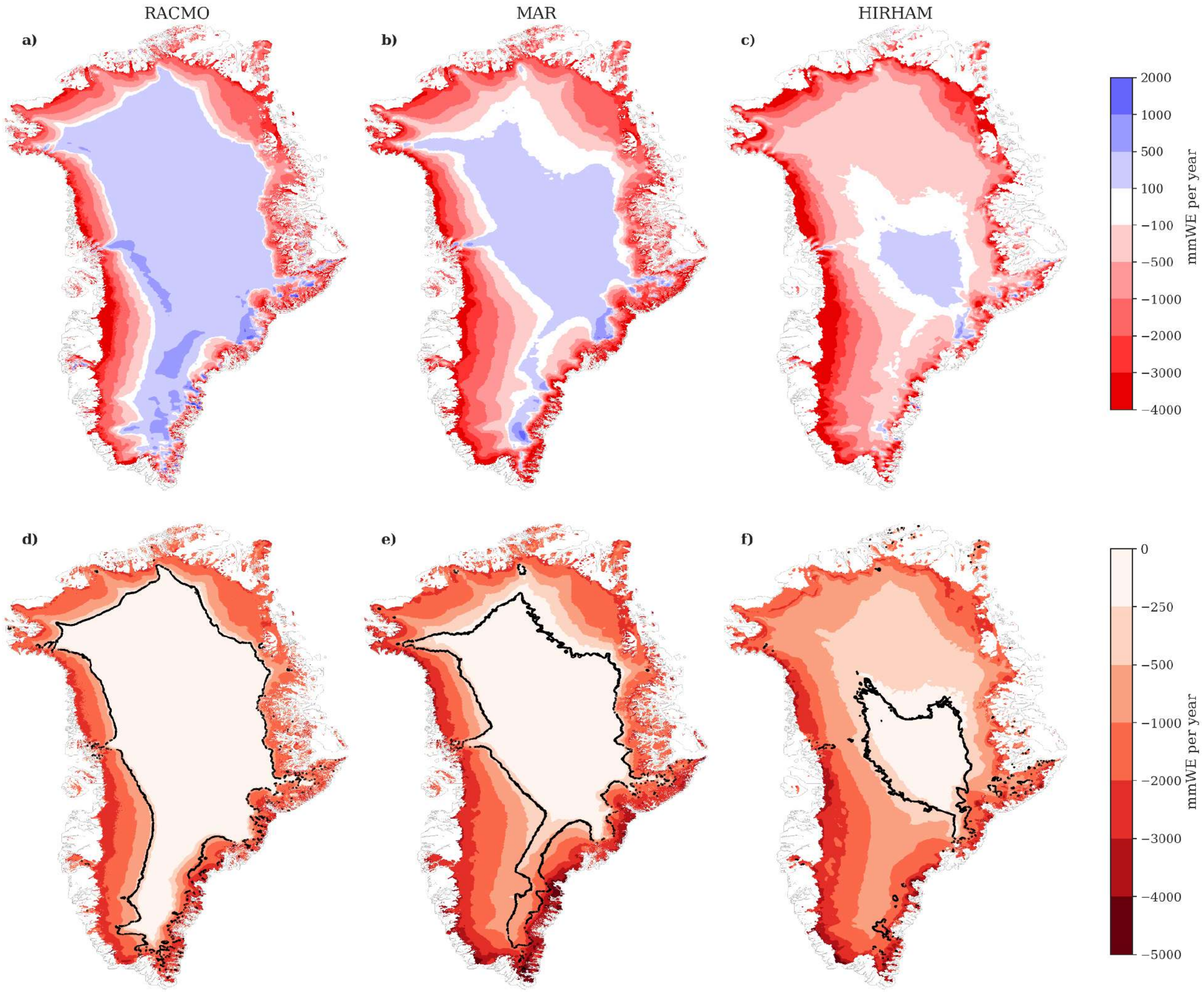
Albedo: linear ramping of snow albedo ranging from 0.85 below −5 °C to 0.65 at 0 °C, bare ice remains constant at 0.4 with transition albedo is determined for thin snow layers on ice.

Irreducible water saturation = 7%

CMIP6 model	ssp126	ssp245	ssp585/rcp8.5
CESM2	RACMO2,MAR, HIRHAM5	RACMO2, MAR	RACMO2, MAR, HIRHAM5
CNRM-CM6-1			MAR
MPI-ESM1-2-HR	MAR	MAR	MAR
UKESM1-0-LL	HIRHAM5	HIRHAM5	HIRHAM, MAR
CNRM-ESM2			MAR
EC-EARTH v3	HIRHAM5		,HIRHAM5
NorESM2	HIRHAM5	MAR	MAR HIRHAM5

A range of future projections are available..

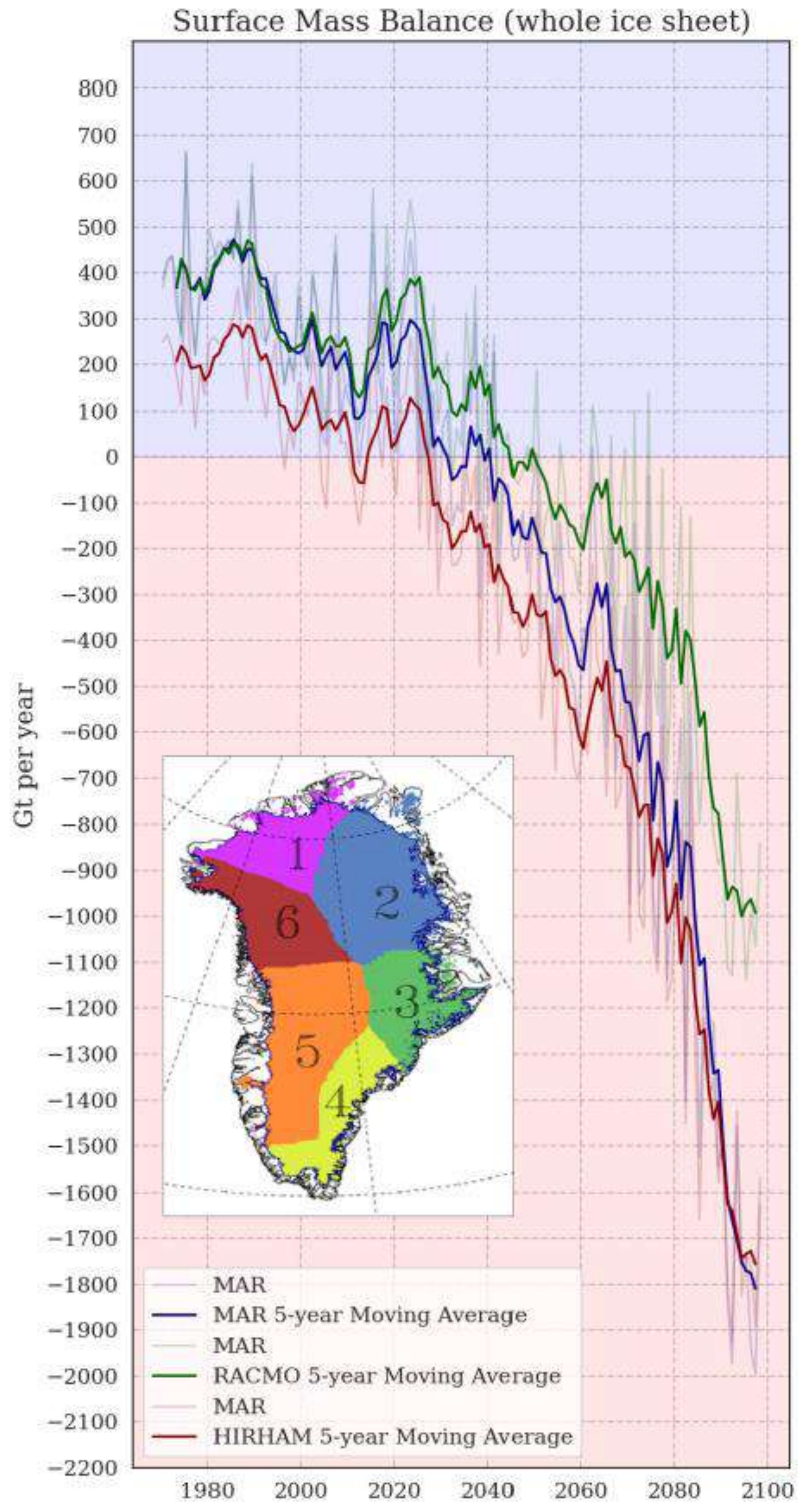
CESM2 SSP5-8.5 as common forcing: GrIS



Mean annual SMB

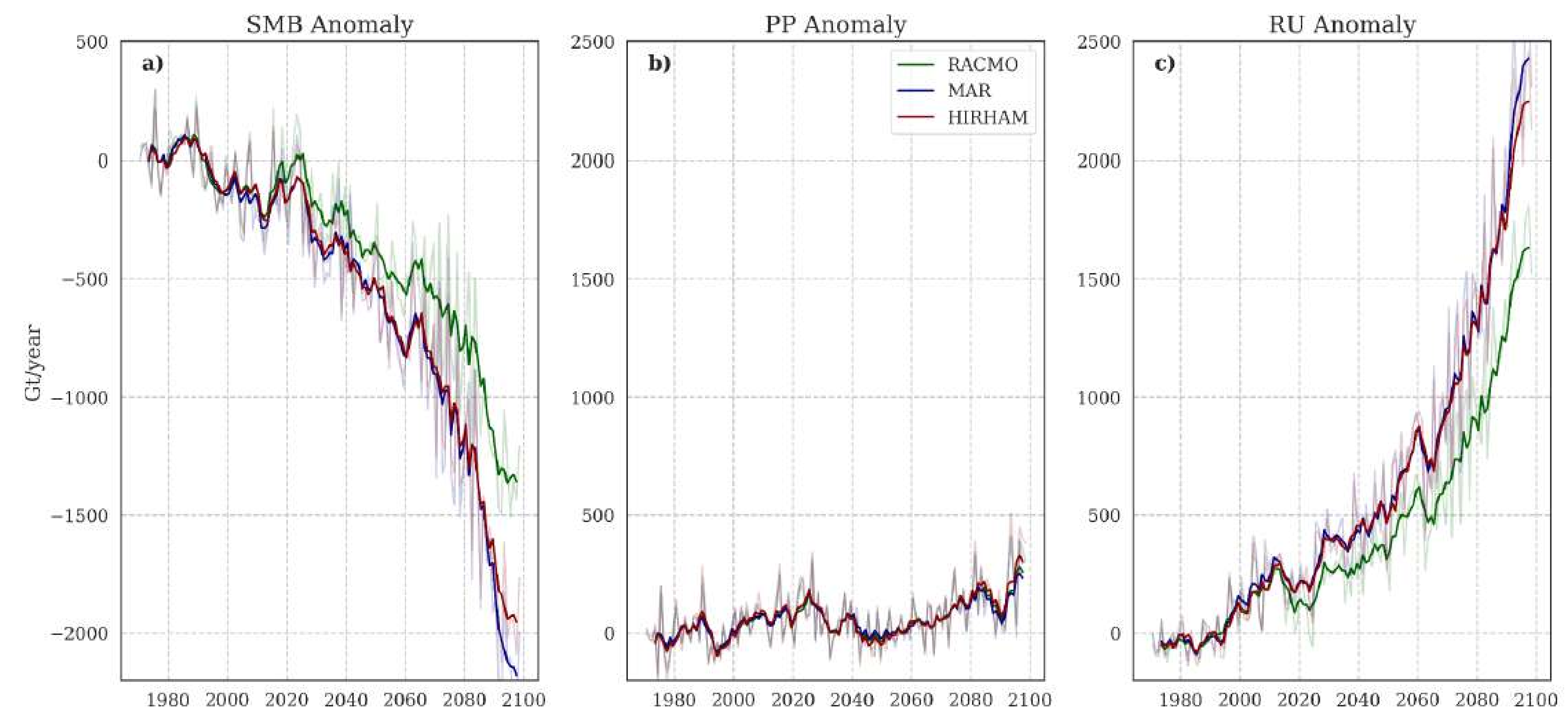
2081- 2100

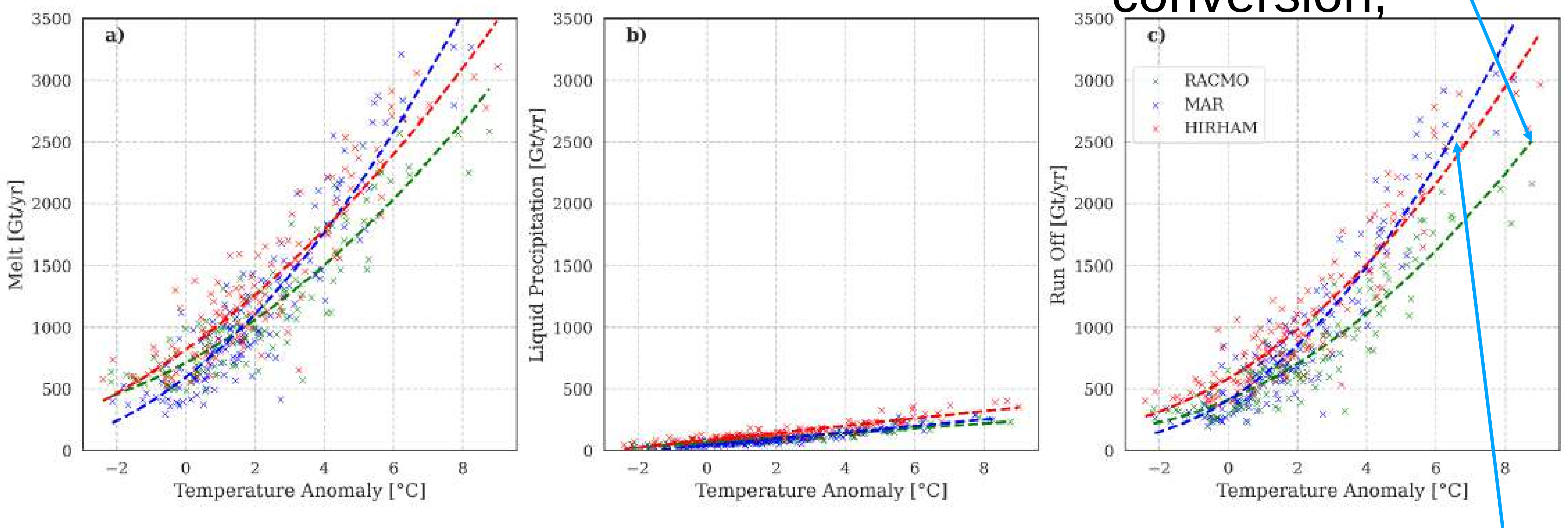
SMB Anomaly relative to 1980-1999



From Quentin Glaude

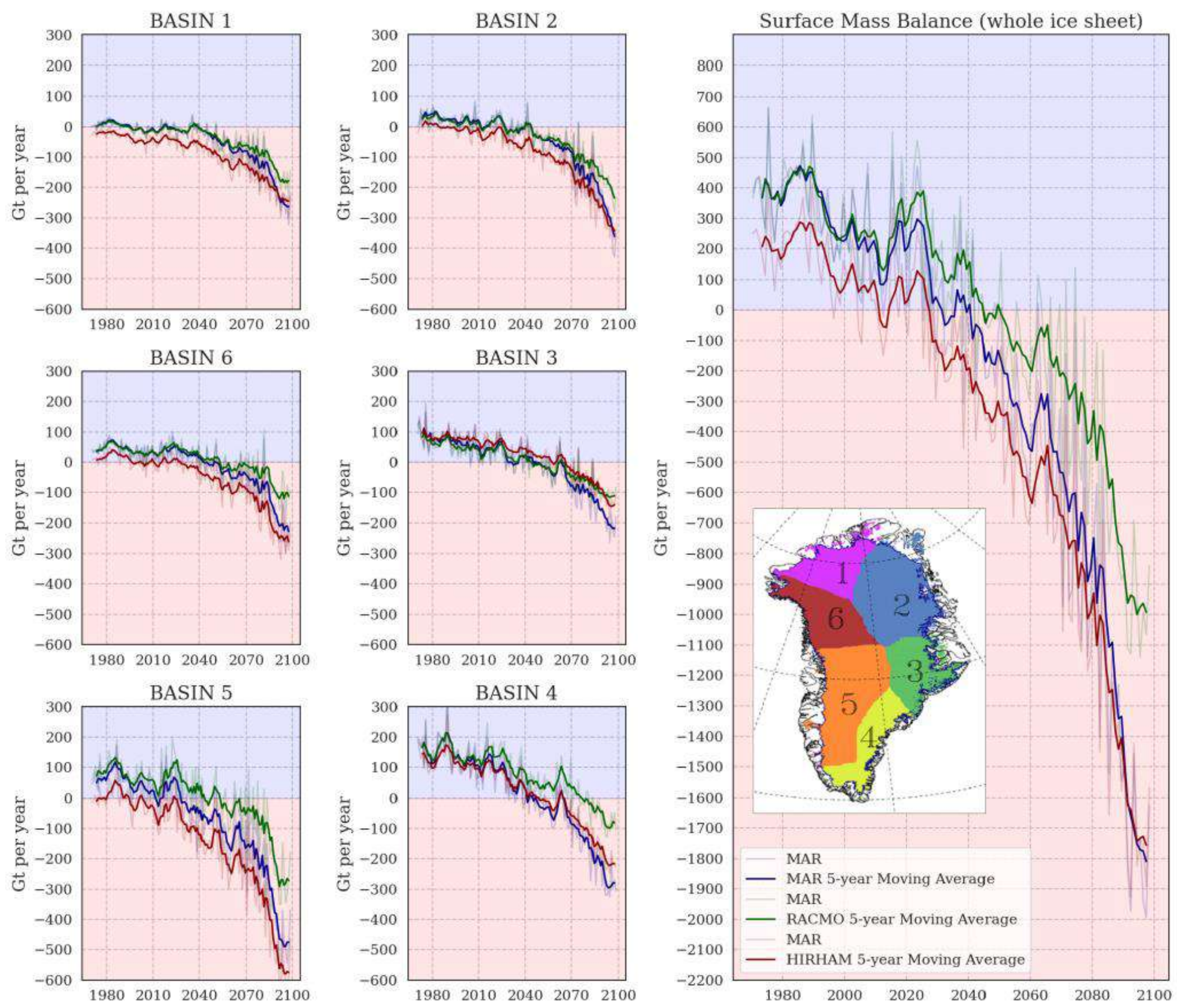
Differences between models are driven by melt and runoff





RACMO: 82% melt to runoff conversion,

HIRHAM 94% of melt converted to runoff.



RCMs have non-uniform response to temperature anomalies.

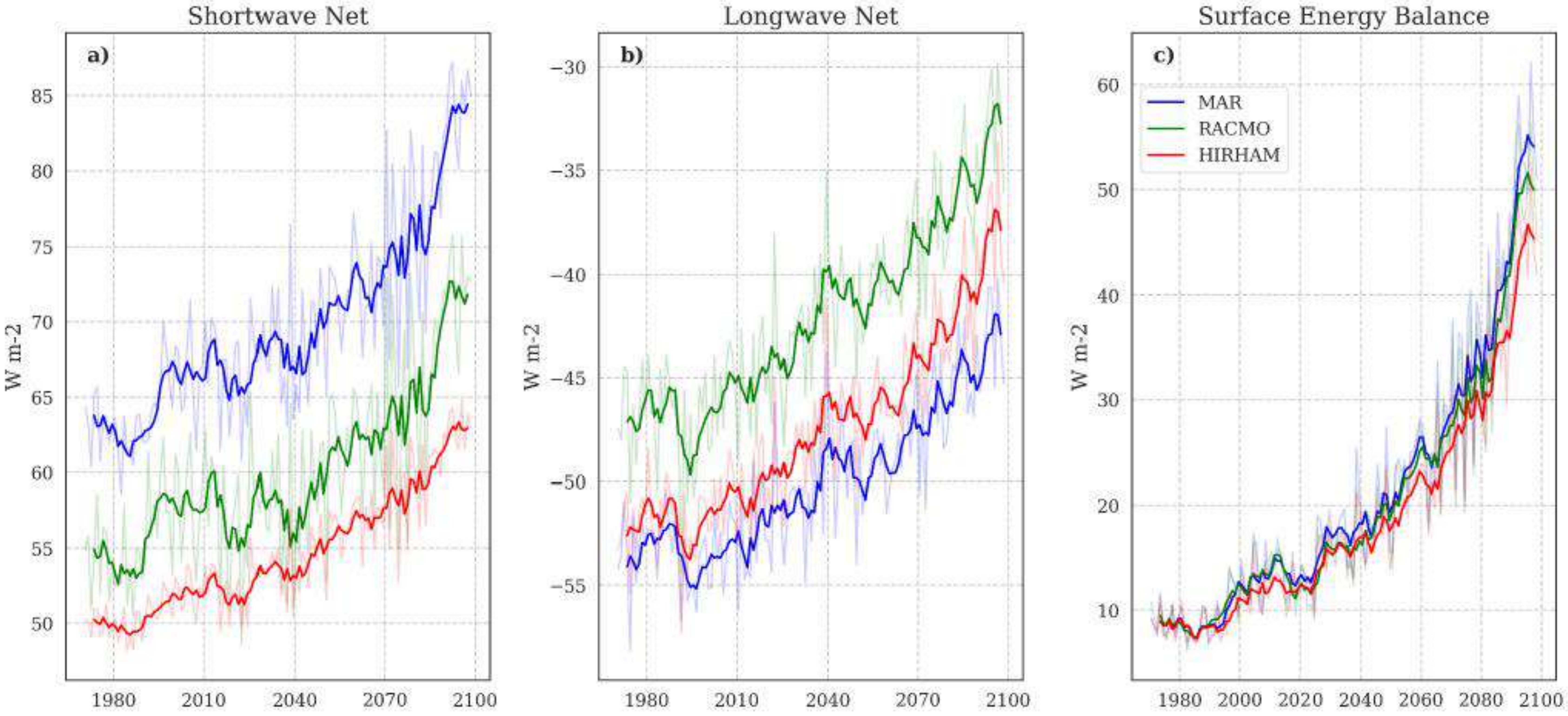
RACMO and HIRHAM are higher than MAR at low temperatures but MAR has steeper curve up at higher temperatures

From Quentin Glaude

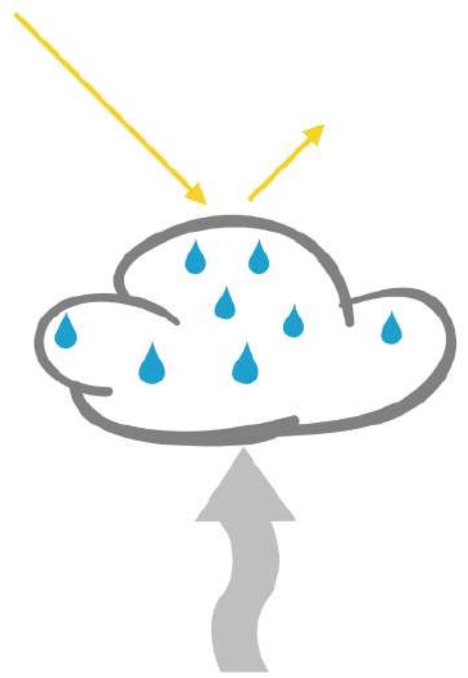
Surface Energy Budgets have compensating errors (GrIS)

Radiation and cloud parameterisations likely account for some differences:

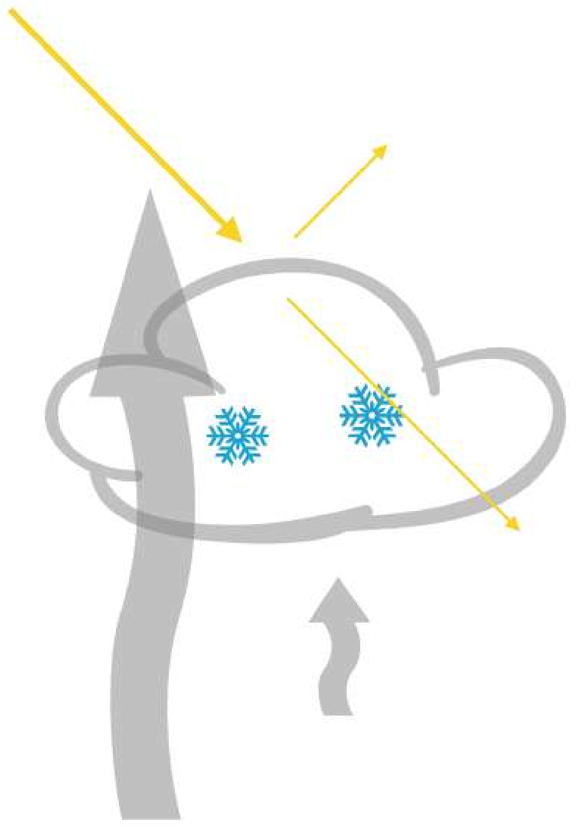
- Mixed phase clouds (cloud cover and cloud optical depth)
- Surface albedo scheme differences



Liquid clouds reflect SWin and absorb LWout radiation

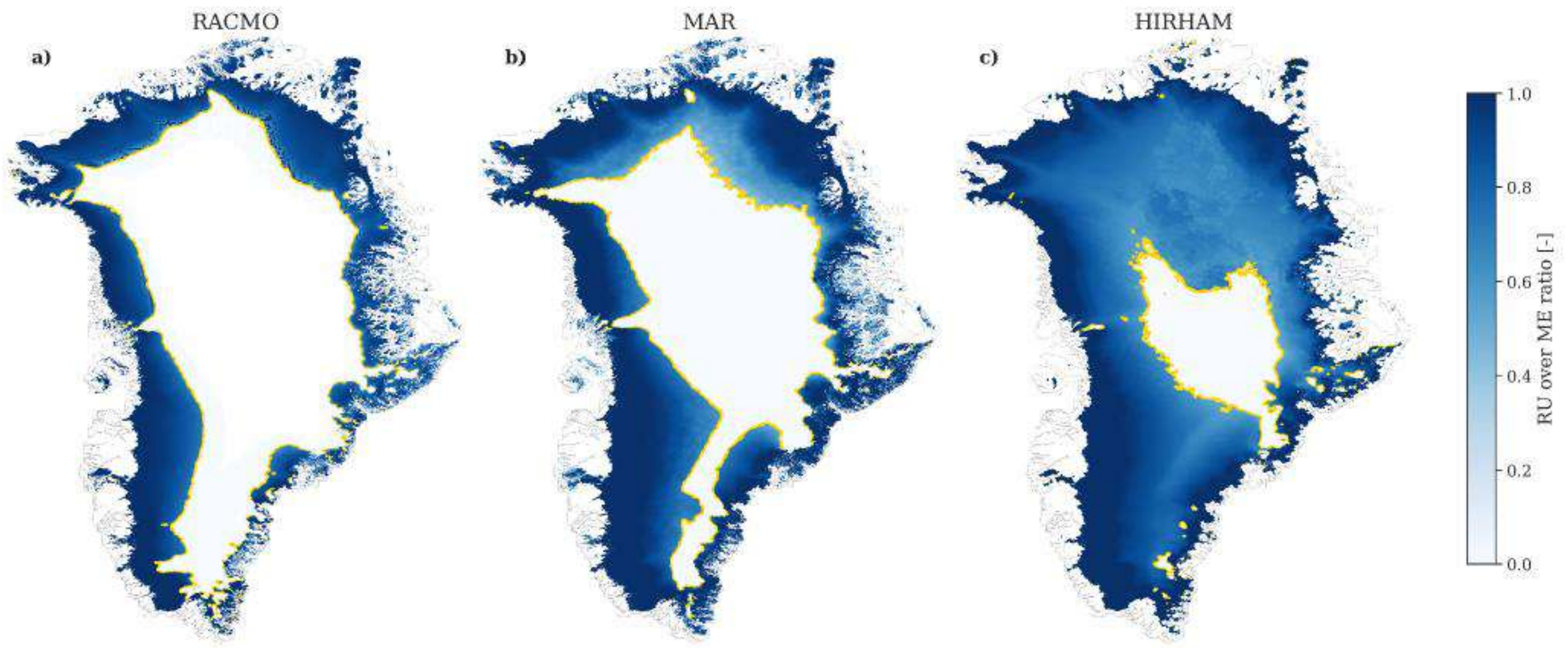


Ice clouds reflect less SWin and absorb less LWout radiation



From Quentin Glaude

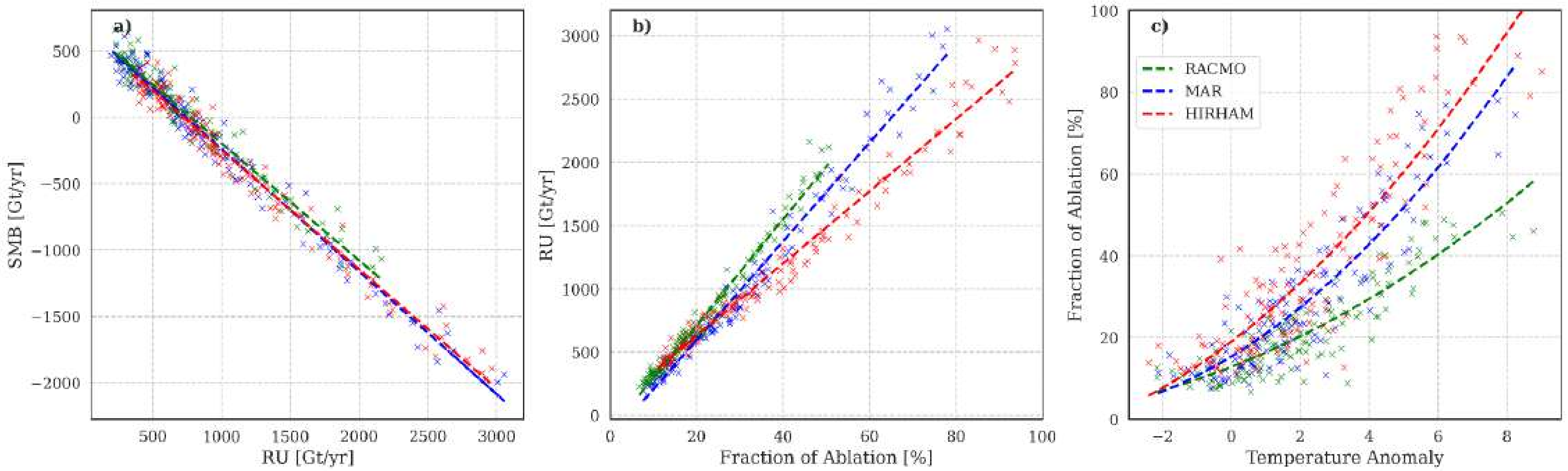
Different model sensitivities to temperature change

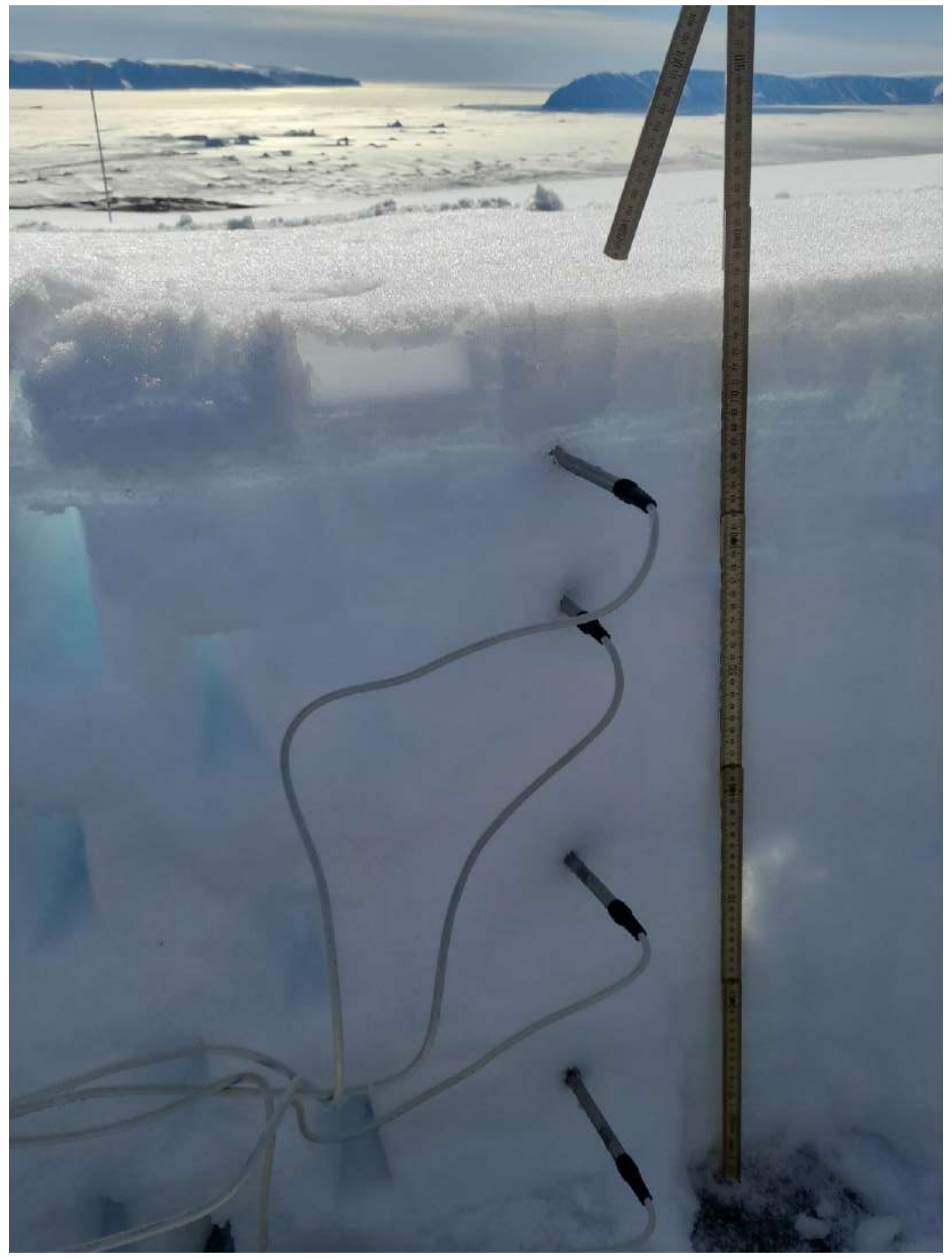


Melt – albedo feedback, but also IWS is key!

Ablation area has different sensitivities to temperature

RACMO: higher runoff from smaller fraction of area





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Preprint out now:

A Factor Two Difference in 21st-Century Greenland Ice Sheet Surface Mass Balance Projections from Three Regional Climate Models for a Strong Warming Scenario (SSP5-8.5)

Quentin Glaude[1], Brice Noël[2], Martin Olesen[3], Michiel R. van den Broeke[4], Willem Jan van de Berg[5], Ruth Mottram[3], Nicolaj Hansen[3], Alison Delhasse[1], Charles Amory[6], Christoph Kittel[7], Heiko Goelzer[8], and Xavier Fettweis[9]

[1]Universite de Liege
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[9]University of Liege, Belgium

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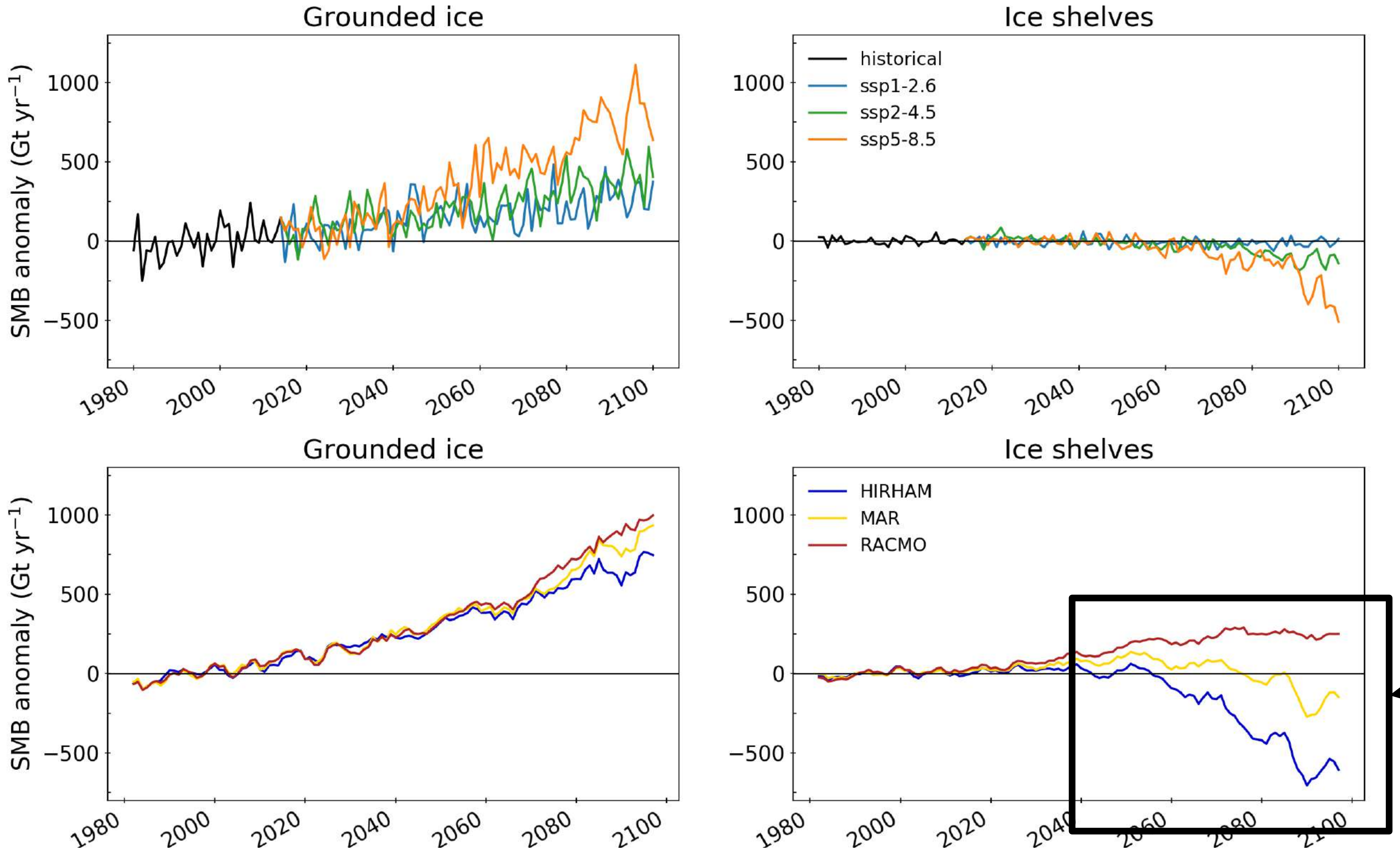
doi.org/10.22541/essoar.172537578.84386972/v

DMI

Diverging future projections over Antarctic ice shelves



3 different pathways

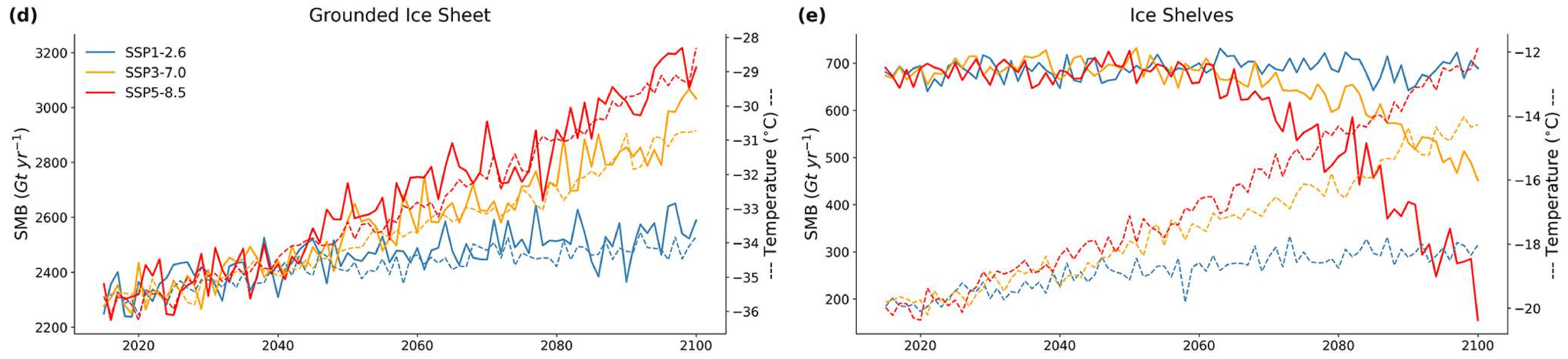
CESM2 downscaled by MAR

3 different RCMs

ssp5-8.5

CESM2

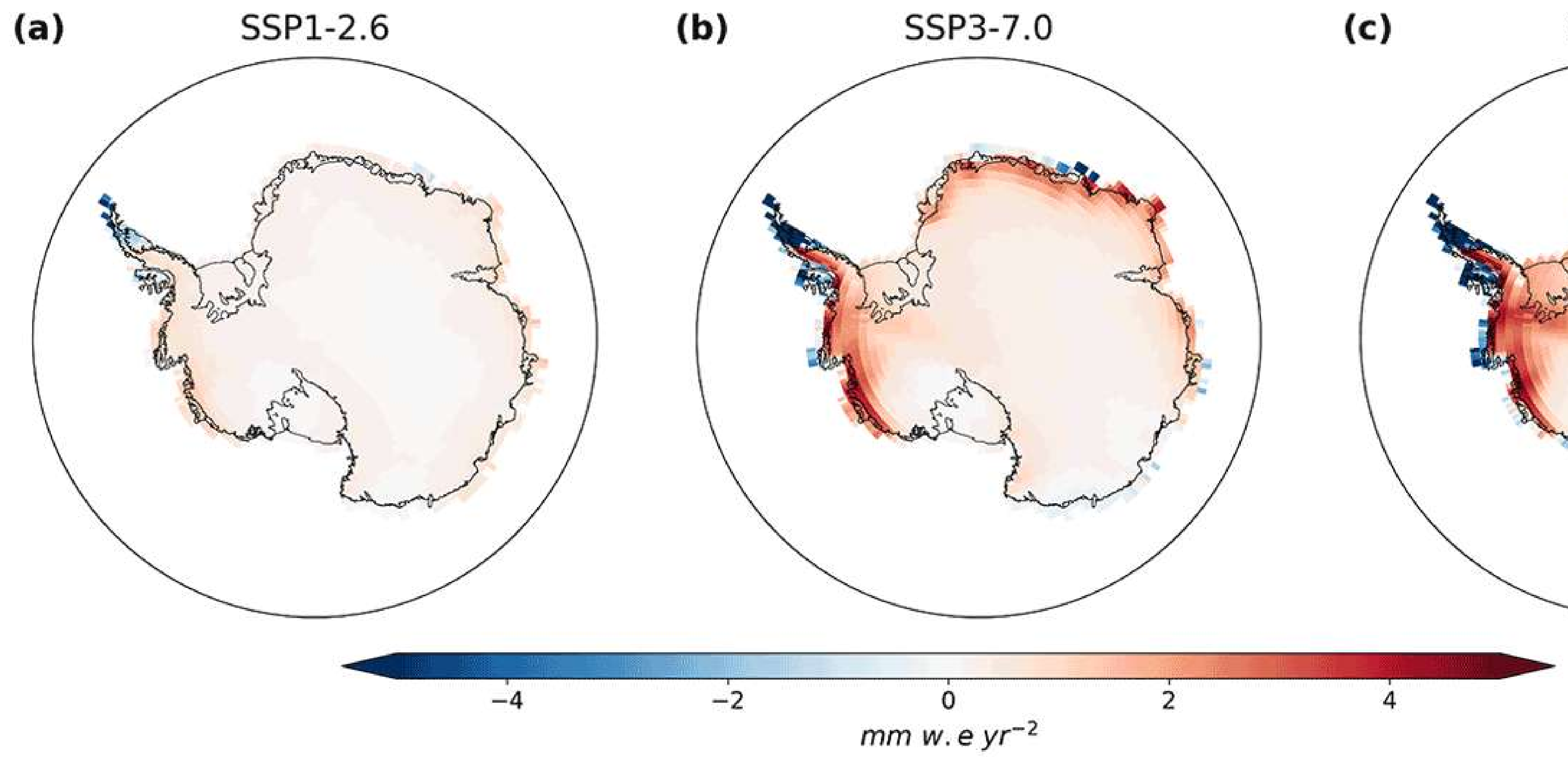
RCMs start diverging in ~2050



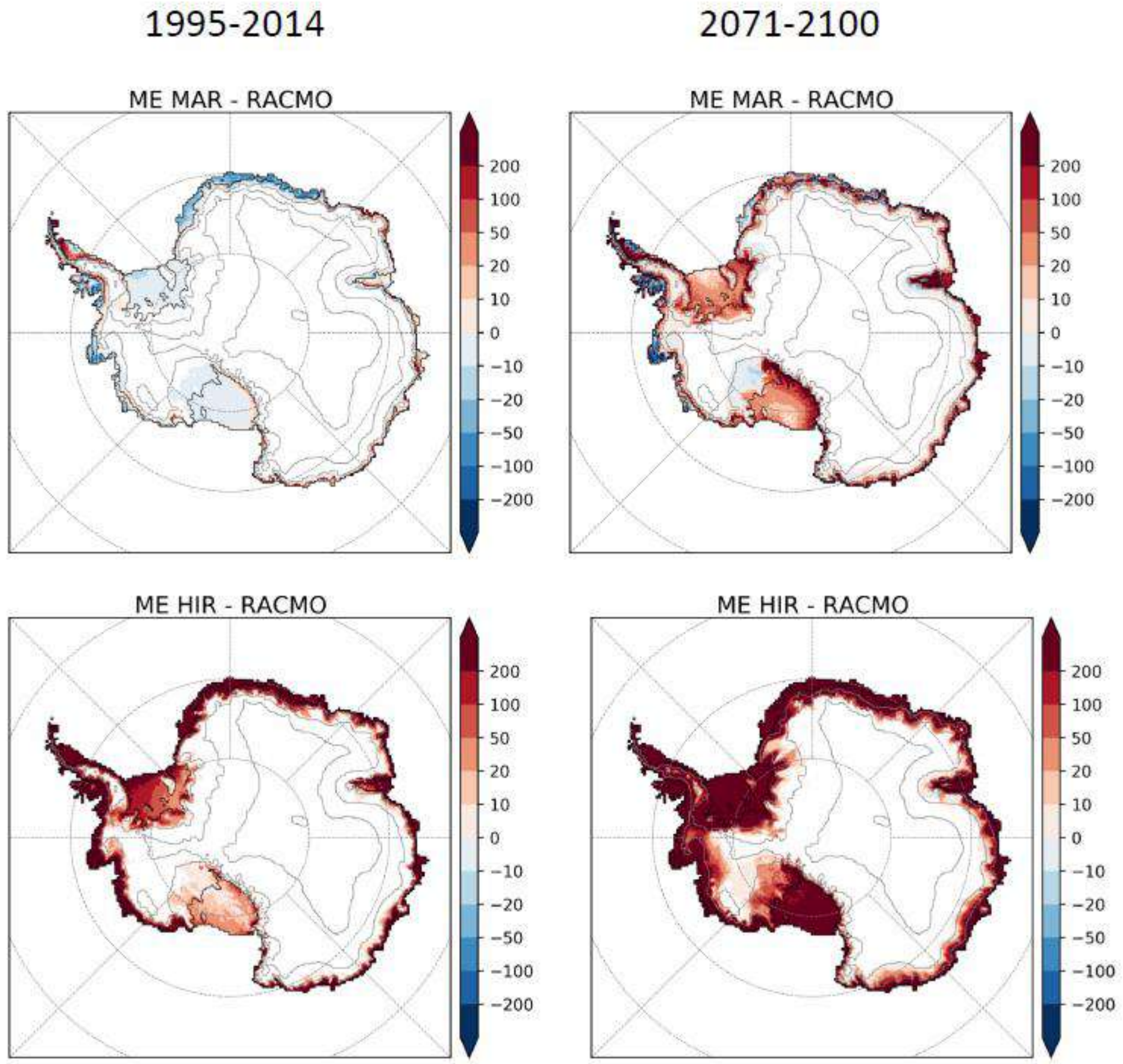
CESM2 internally calculated SMB (Dunmire et al., 2022)

From Charles Amory

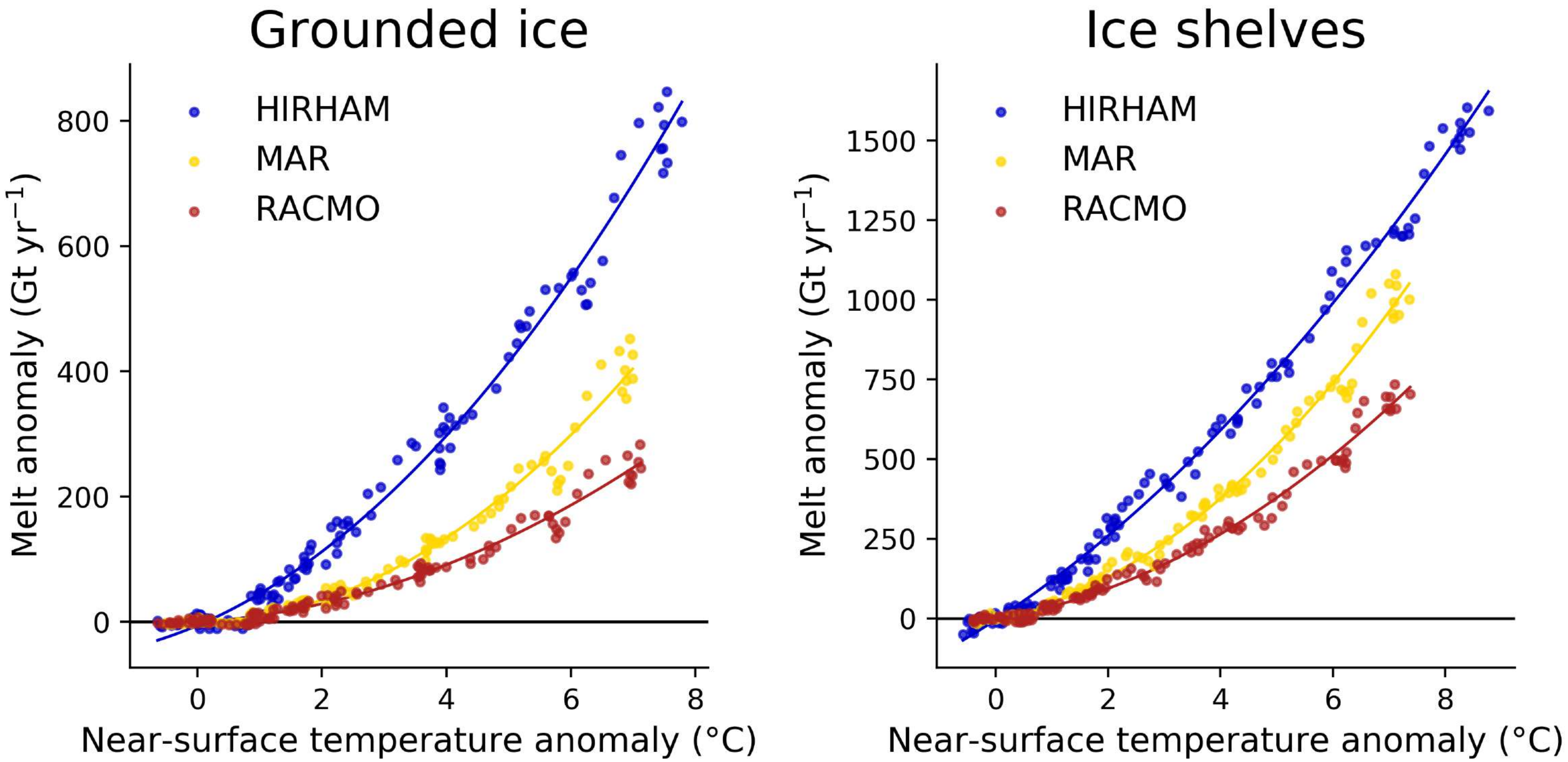
Different model sensitivities to temperature change



CESM2 SMB output (Dunmire et al., 2022)

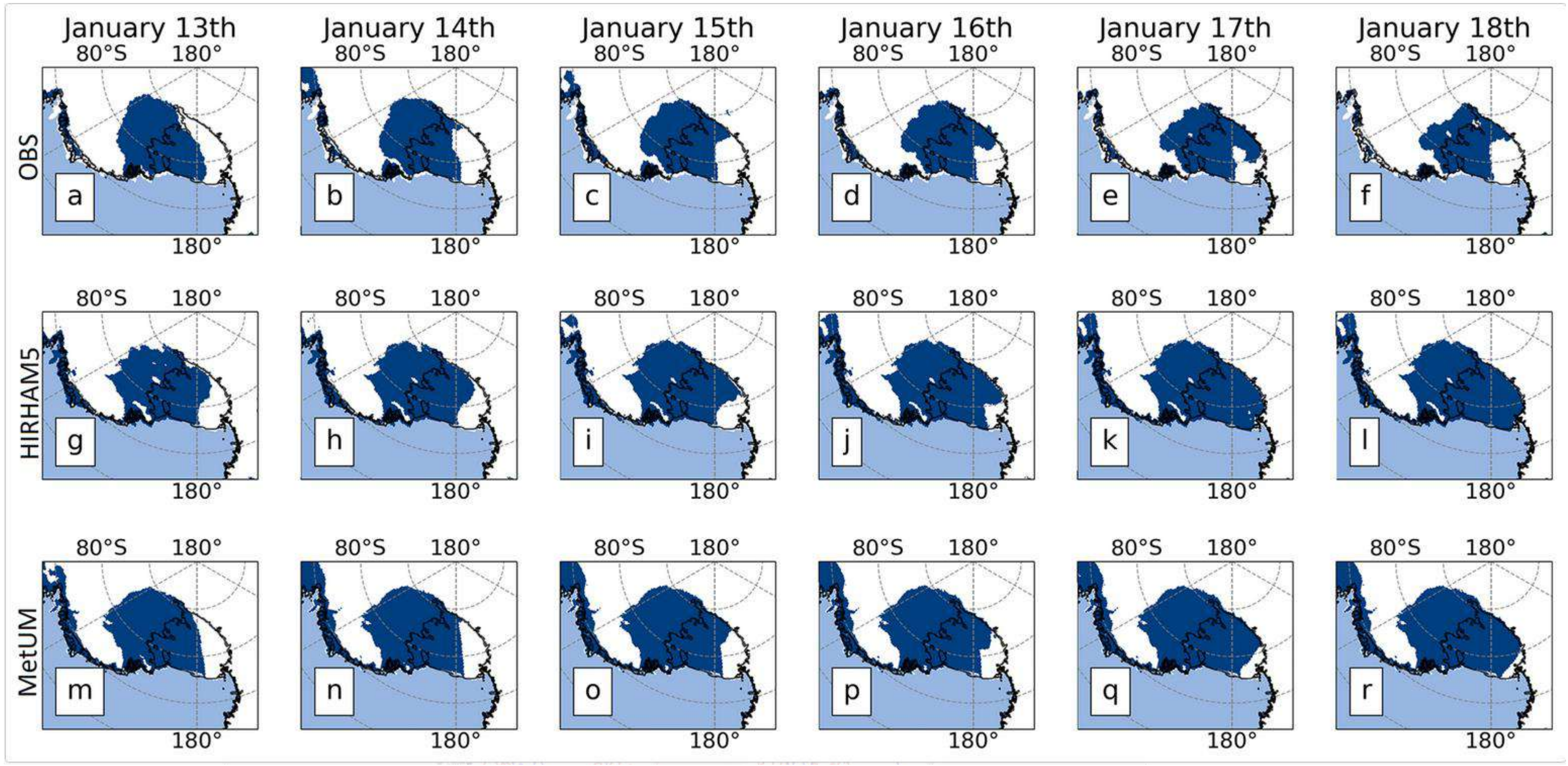


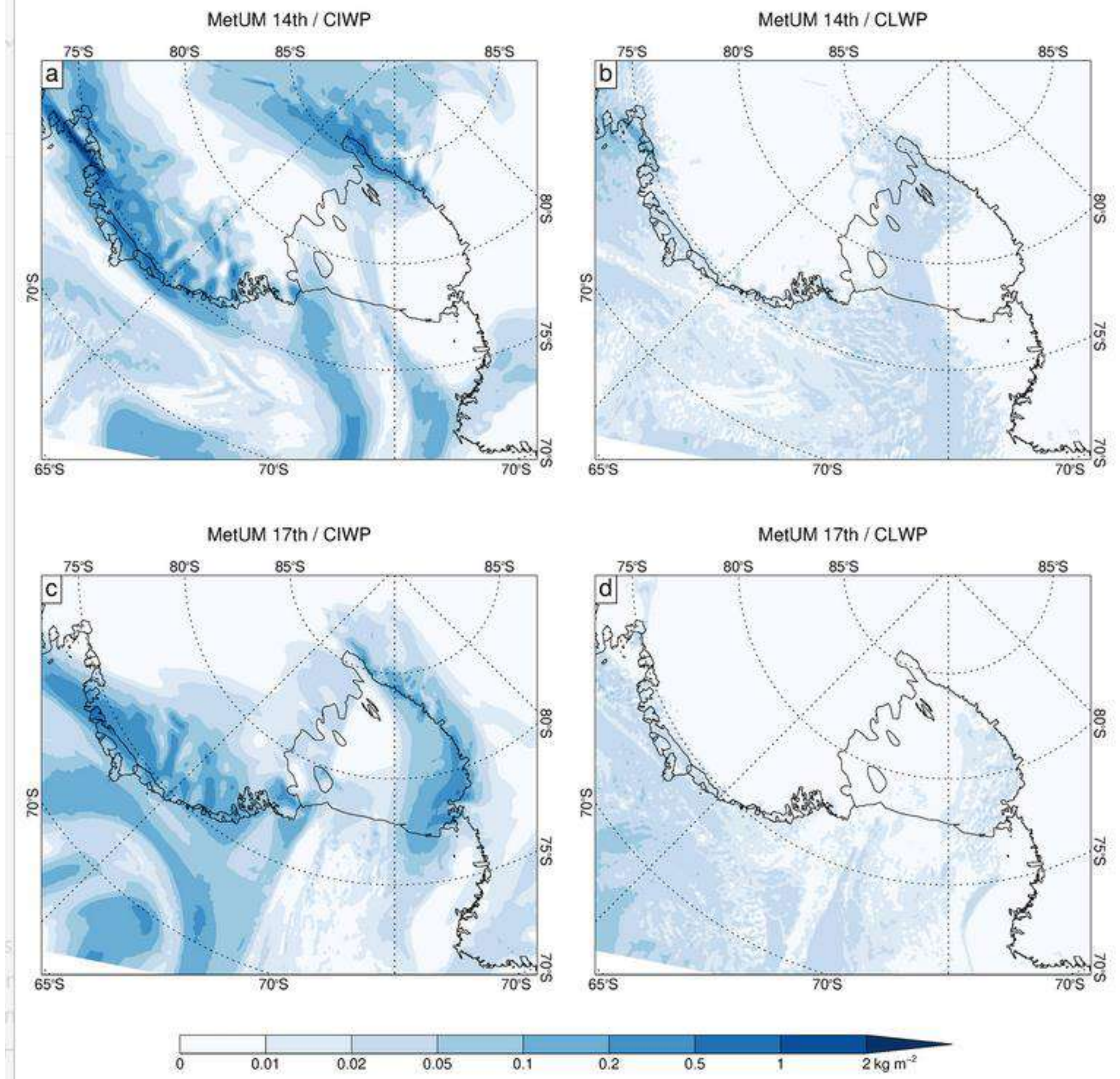
Intensification of present day SMB: more precipitation but also more melt over especially ice shelves, likely due to albedo and IWS differences

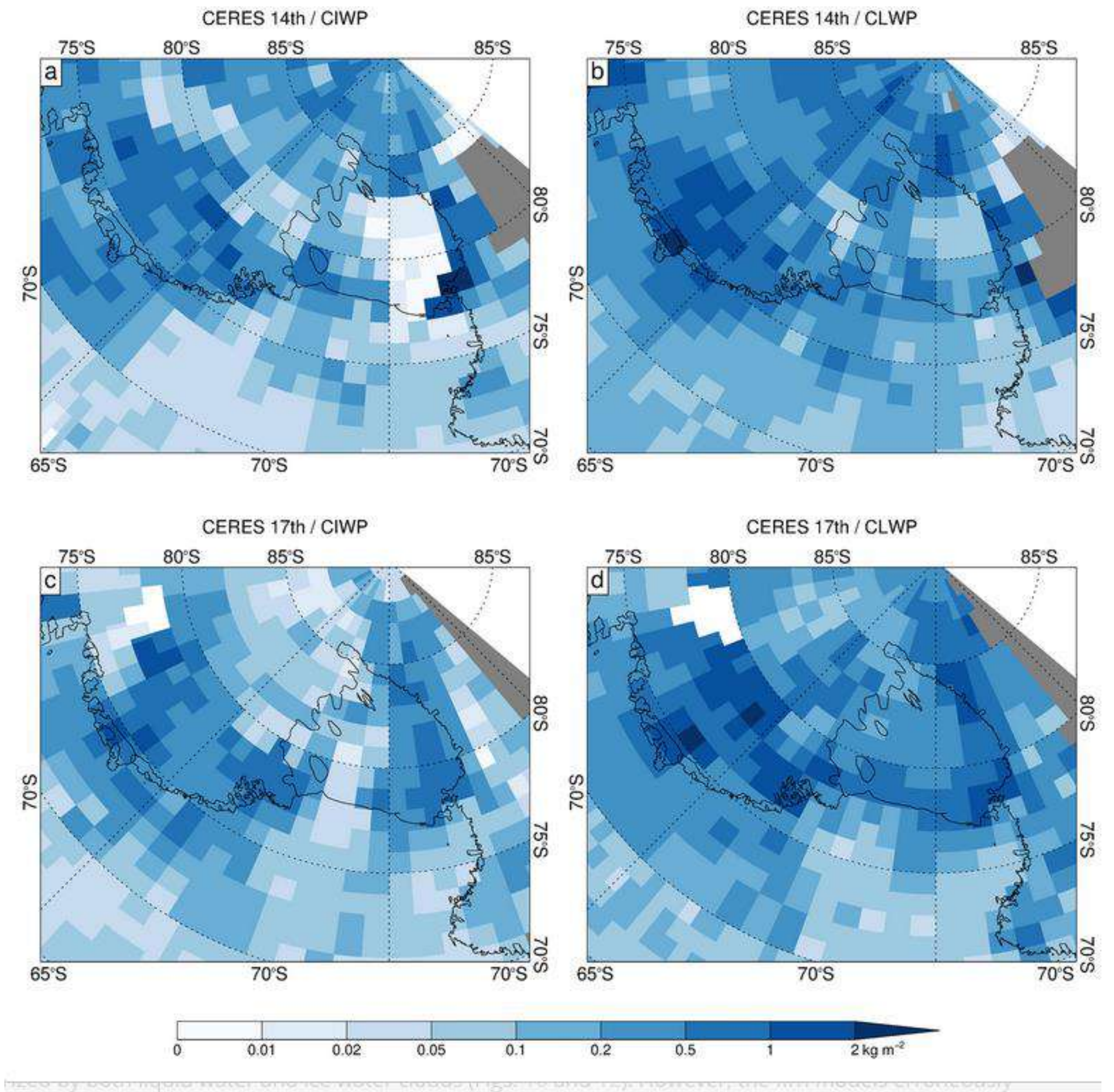


From Charles Amory

Surface melt and Cloud phases







From Hansen et al 2024

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Key Points

Global climate models rarely produce SMB over ice sheets and regional climate simulations produce similar SMB values at present day

Small differences between regional climate model physics parameterisatons can lead to large long-term large differences in SMB projections, outside of driving climate induced uncertainty

Differences in radiation schemes and cloud parameterisations are important but s mall differences in firn and snowpack parameterisations can lead to long-term differences in retention, refreezing and runoff

We have a *large* amount of RCM projections over both Greenland and Antarctica forced by CMIP6 all publically available for analysis

SMB emulation and new model parameterisations under development for CMIP7