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Modelling the surface mass balance of the Greenland Ice Sheet under past and future climate conditions with the energy balance model dEBM

Uta Krebs-Kanzow, Paul Gierz, Shan Xu, Hu Yang, Gerrit Lohmann

Technical Tour
slides 10-16

Bonus Tour
(glacial ice sheets)
slides 17-20

References
slide 21

The diurnal Energy Balance Model dEBM

an SMB model for Earth System Modelling

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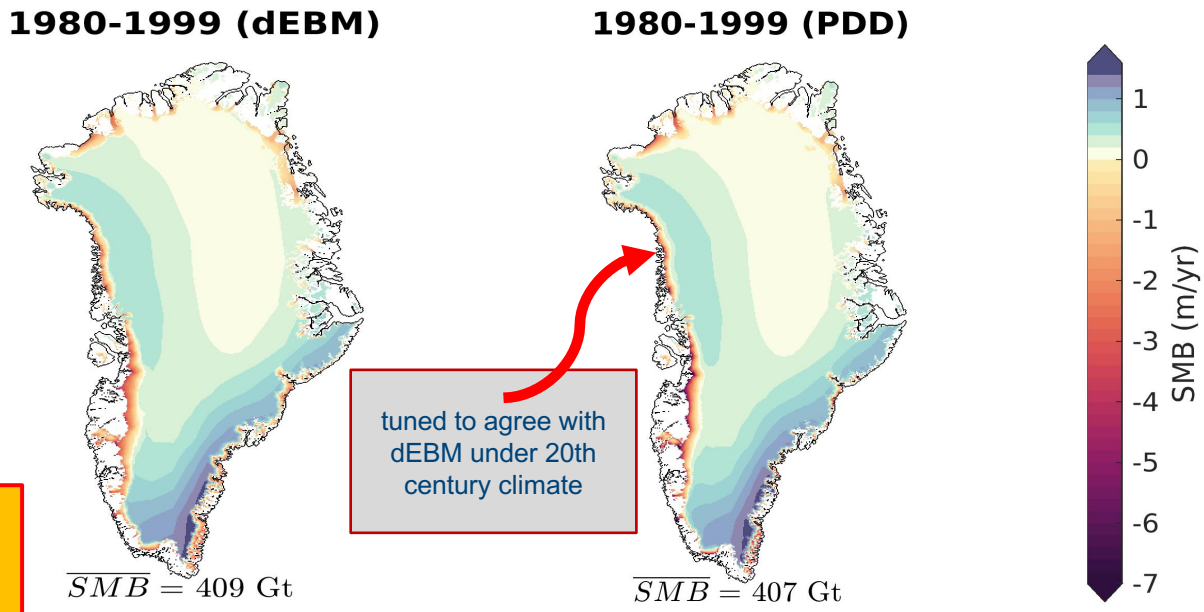
dEBM is an energy balance model to estimates the surface mass balance of ice sheets

- **efficient:** requires only monthly forcing, monthly timestep
- **physics based:** parameters are well constrained and largely globally valid
- **applicable to past and future climates:** accounts for radiation and cloud cover

➔ more universally valid than empirical temperature index methods (e.g. PDD model)

➔ suitable for Earth System modelling on long time scales and changing climate conditions

We aim to test whether the temperature – melt relation changes in different climates



Approach:
we consider the Greenland Ice Sheet (GrIS) under

- global warming (i.e. changing longwave radiation)
- mid-Holocene climate (i.e. intensified shortwave radiation)

we compare dEBM with an empirical PDD model, which assumes the same temperature melt relation for all climates

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SMB of the present GrIS
model intercomparison for ERA-Interim period

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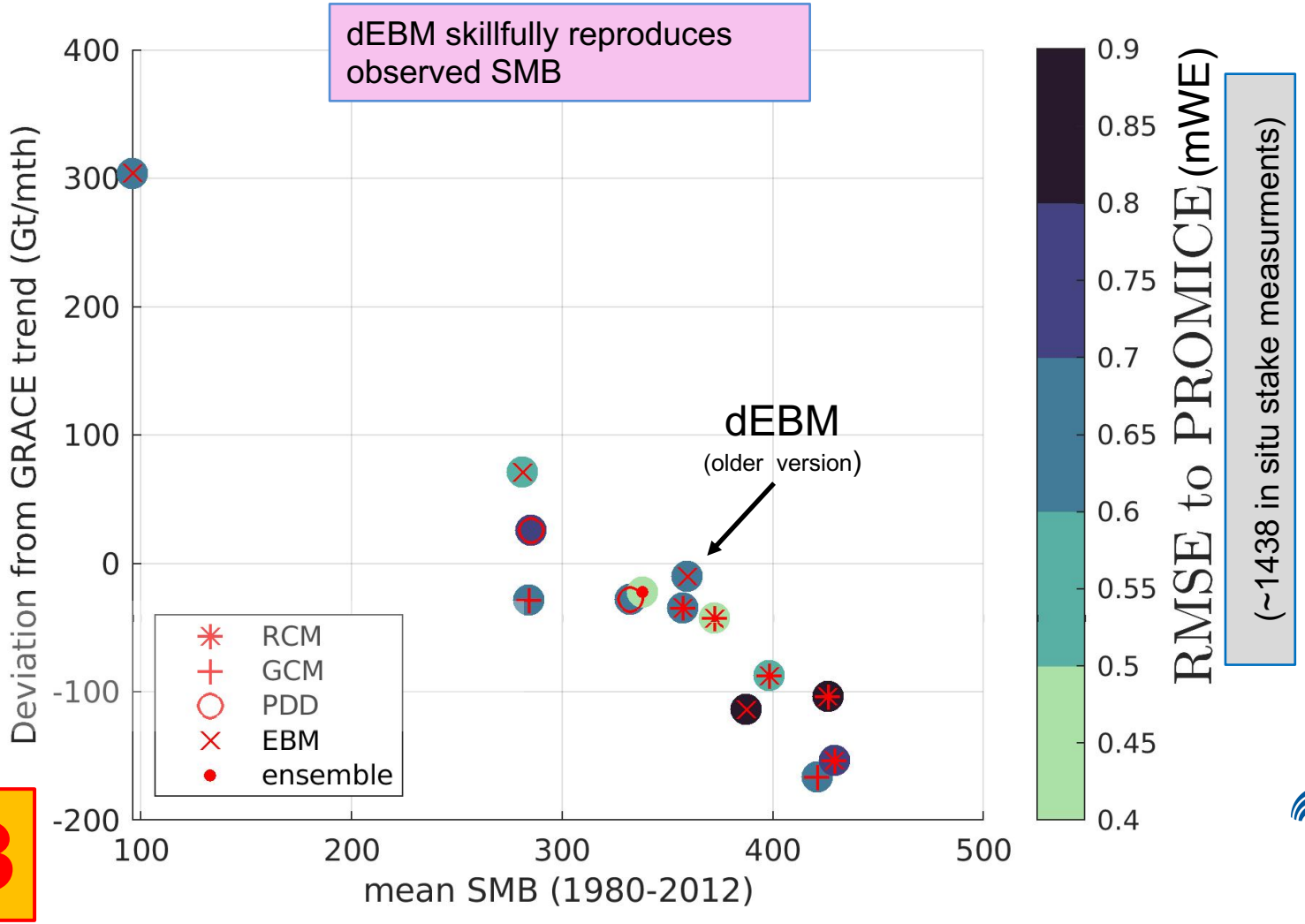
GrSMBMIP: Intercomparison of the modelled 1980-2012 surface mass balance over the Greenland Ice sheet *(Fettweis et al. 2020)*

The Cryosphere Discussions — Open Access — EGU



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1850-2100 GrIS surface mass balance:
sensitivity to global warming

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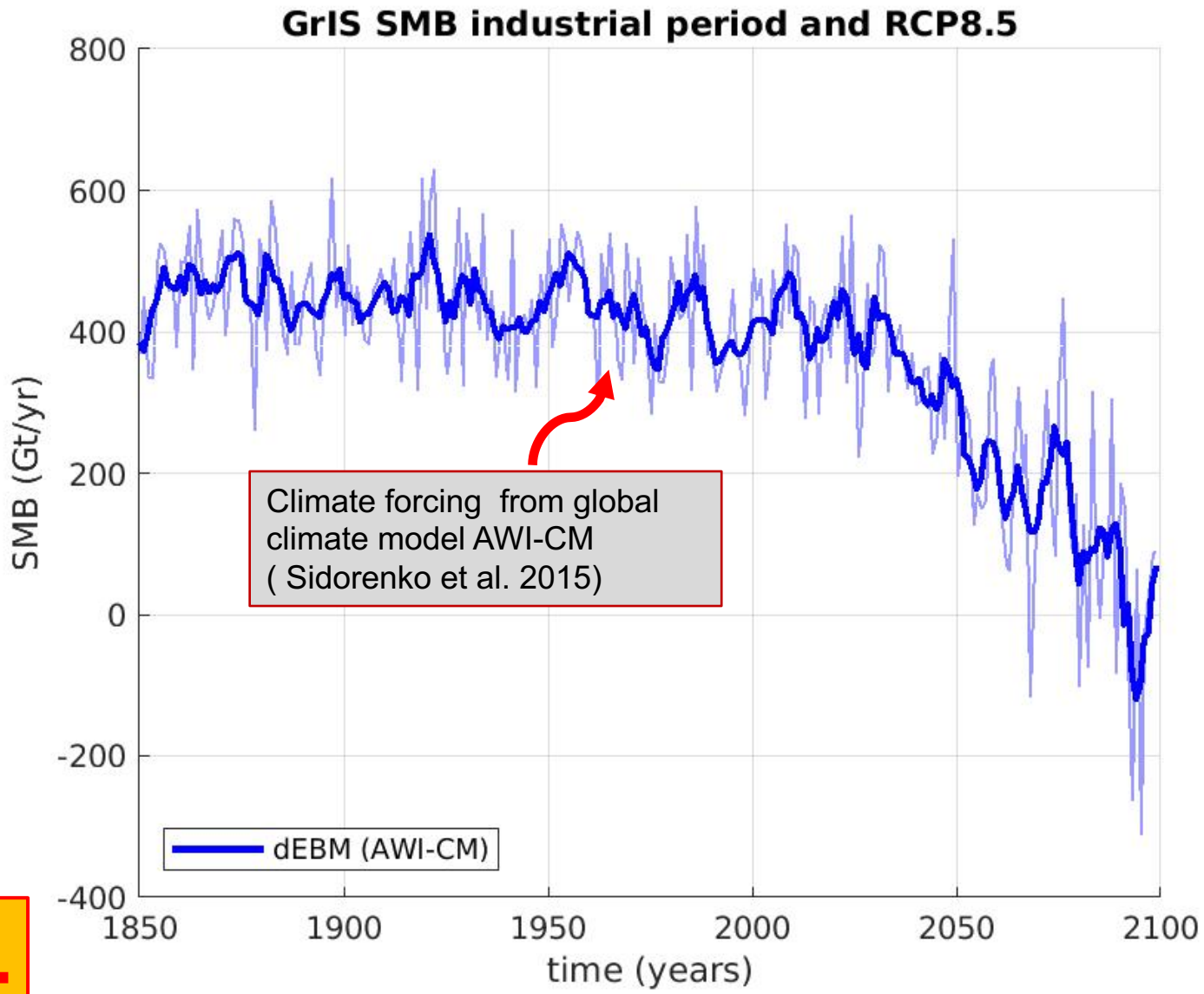

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1850-2100 GrIS surface mass balance:
sensitivity to global warming

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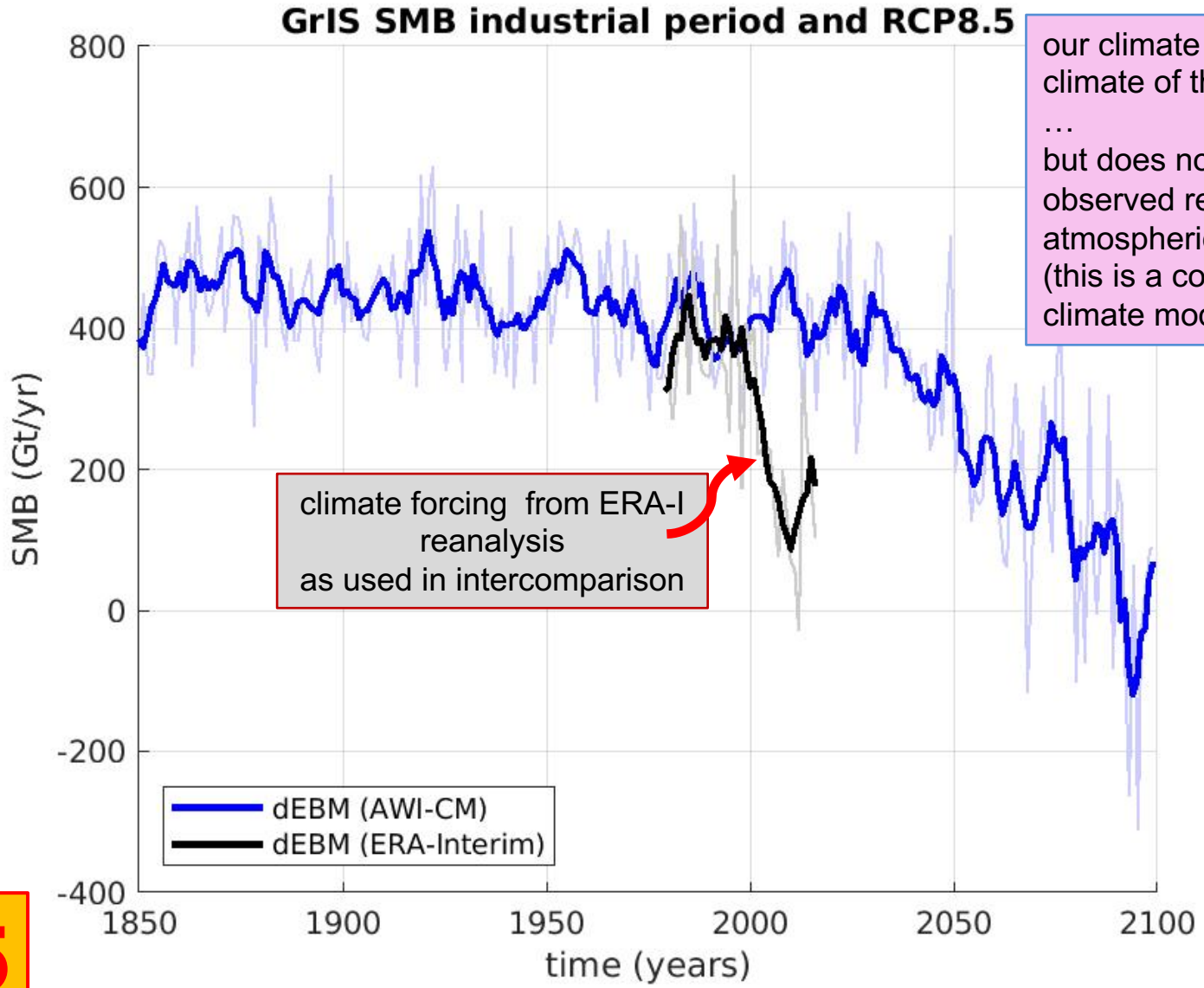

our climate model reproduces the climate of the 20th century
…
but does not reproduce the observed recent changes in atmospheric circulation (blocking) (this is a common problem of global climate models)

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1850-2100 surface mass balance:
Comparison to empirical PDD scheme

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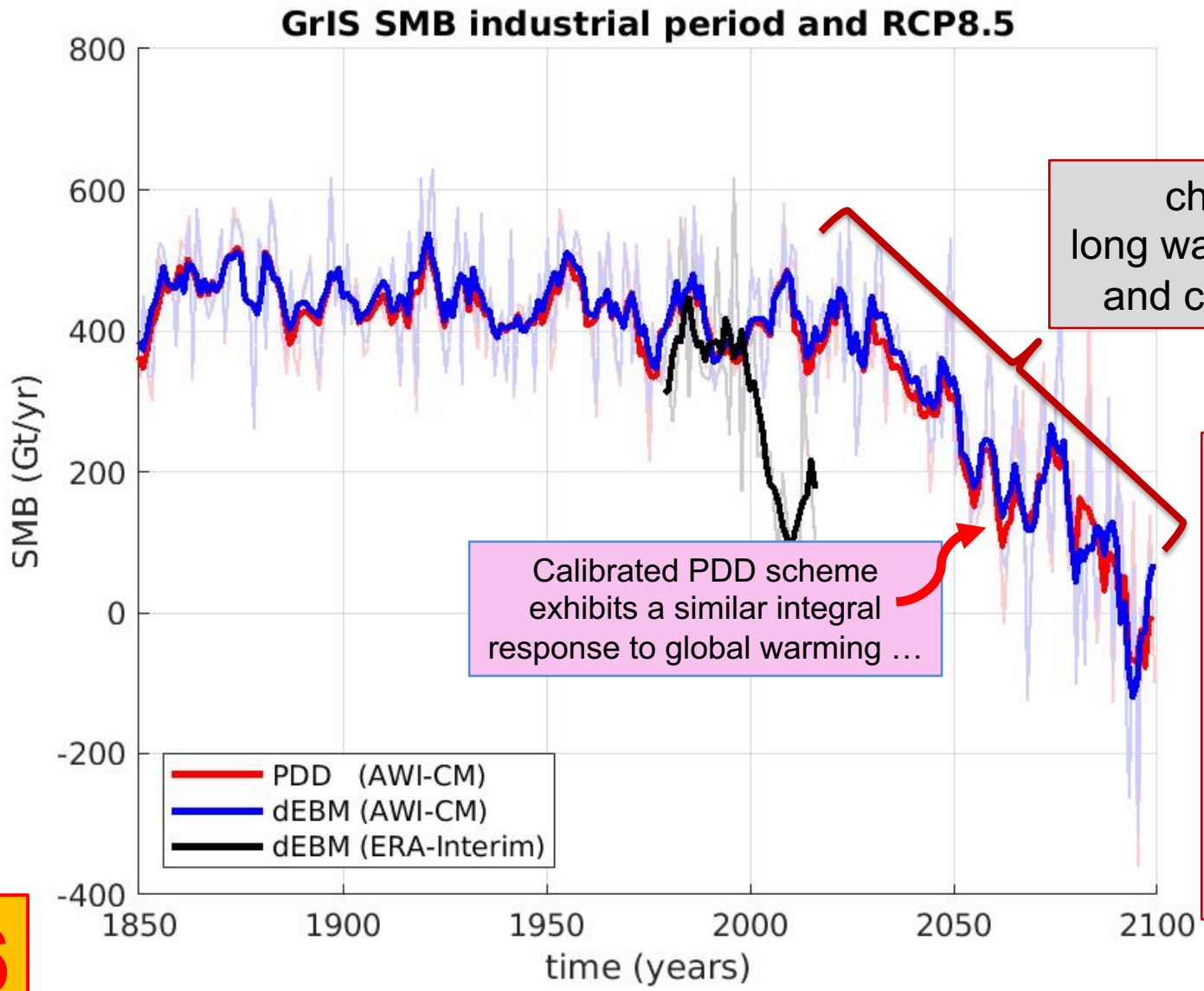

changing
long wave radiation
and cloud cover

Calibrated PDD scheme
exhibits a similar integral
response to global warming …

The PDD scheme calculates melt only on the basis of air temperature and cannot account for changes in radiative fluxes.

It here serves as reference to test whether the temperature – melt relationship changes in different climates

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1850-2100 GrIS surface mass balance:
Comparison to empirical scheme

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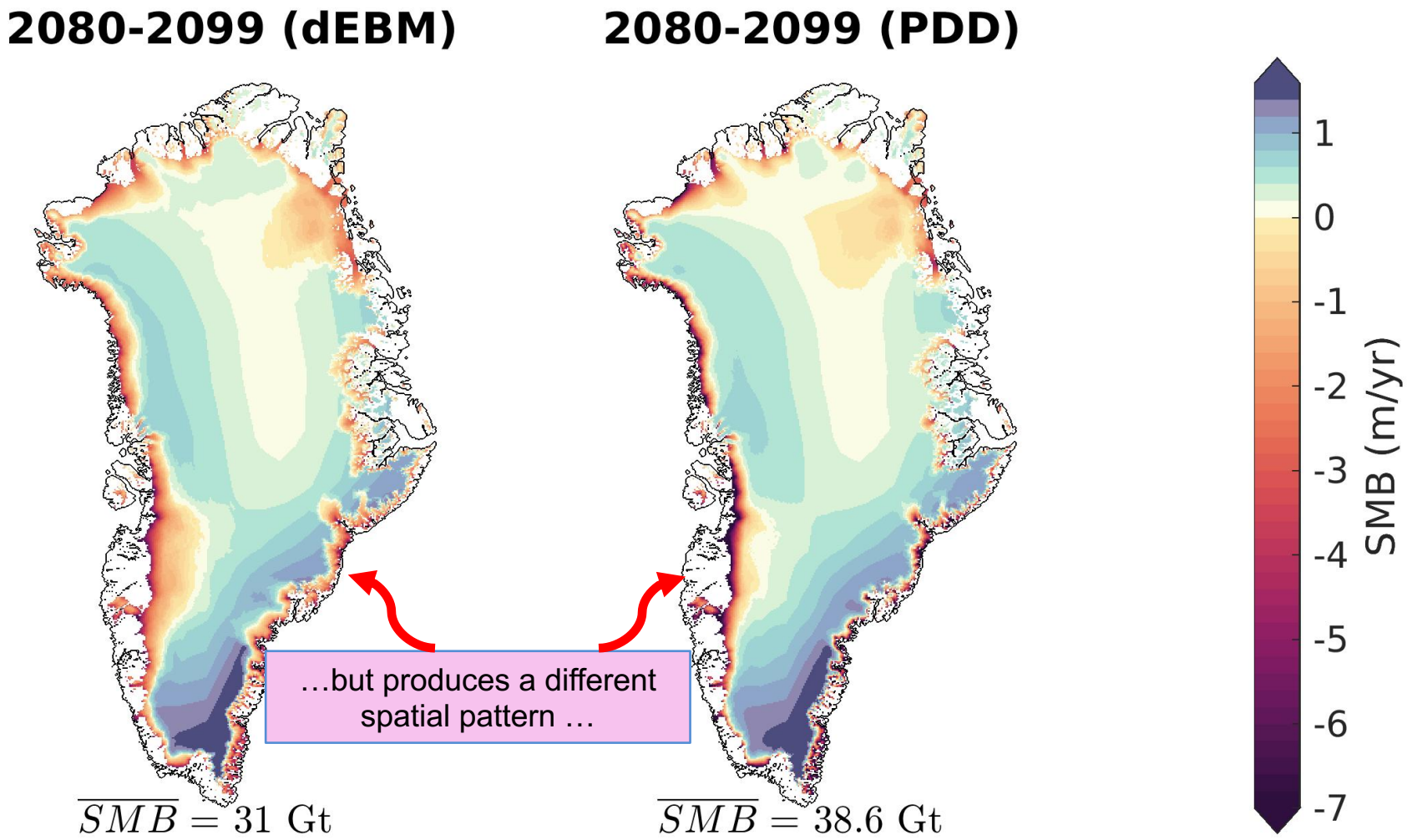

the spatial pattern may influence the dynamic response and retreat of the ice sheet‘s margins

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Mid Holocene SMB:
Effect of intensified summer insolation

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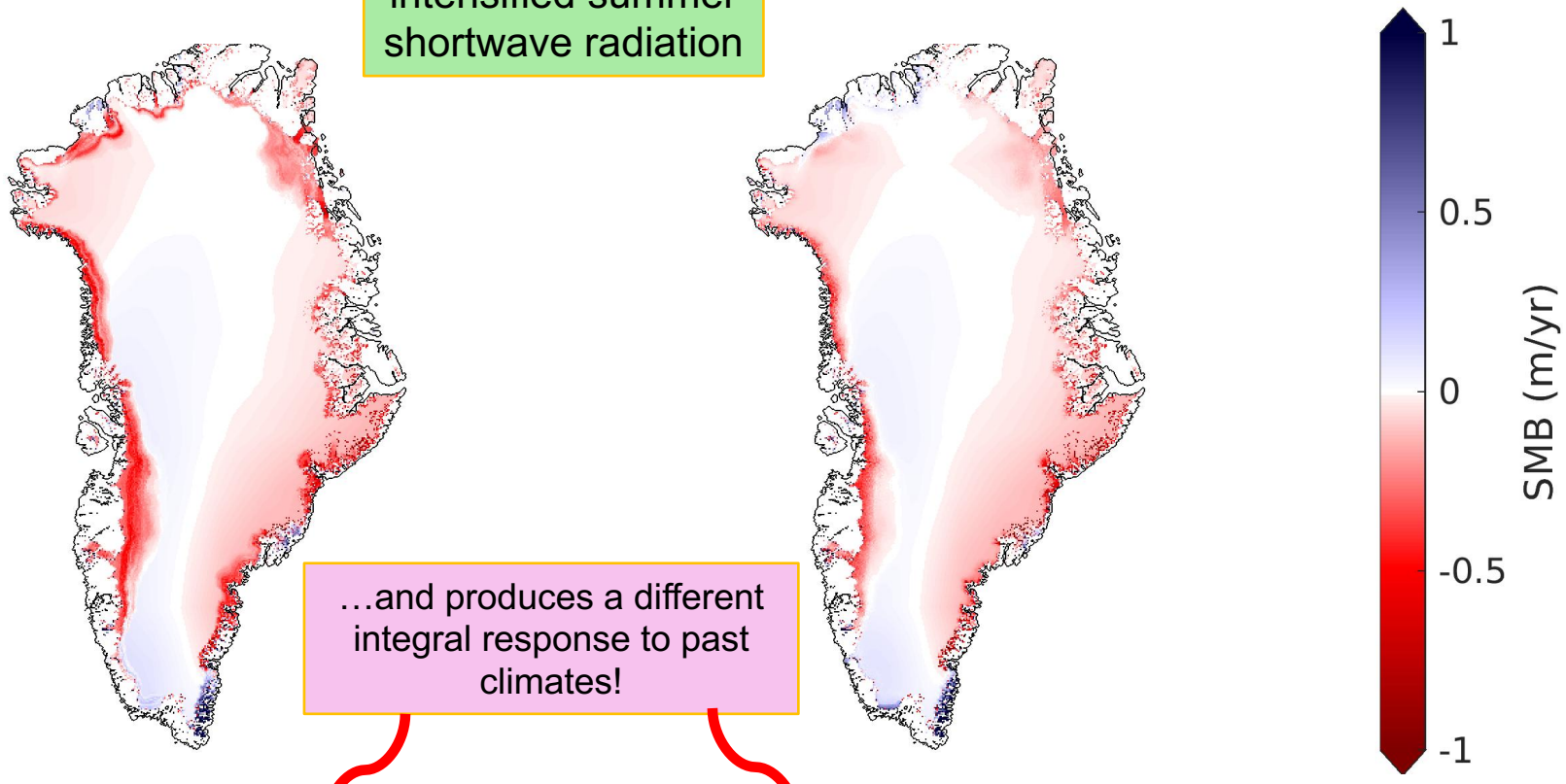
Mid Holocene SMB anomaly

dEBM

intensified summer shortwave radiation

PDD



…and produces a different integral response to past climates!

Δ SMB = -84 Gt

Δ SMB = -49 Gt

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Summary

dEBM

- downscaling of coarse resolution, monthly mean forcing (→ Technical Tour)
- good skill in reproducing observational data
- temperature-melt relationship is particularly sensitive to changes in shortwave radiation
- PDD scheme exhibts a similar integral but different spatial response to global warming
- dEBM indicates a complex response to glacial climate (→ Bonus Tour)

→ **empirical PDD-like schemes** are limited to conditions similar to today

Technical Tour:
Why downscaling is necessary

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dEBM is based on the surface energy balance,
Forcing: monthly mean precipitation, air temperature, cloud cover, shortwave and longwave radiation
unresolved spatial and temporal scales are downscaled

Surface mass balance
SMB = **Acc**umulation – **M**elt + **R**efreezing

Melt rate M related to surface energy flux:

$$M = \max\left[0,\ \left((1-A)\,SW\downarrow - LW_{net}\uparrow + H_{turb}\right)\,\Delta t / Lf\right]$$

introduces non-linearity

spatial or temporal means may bias results

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Why downscaling is necessary
spatial downscaling

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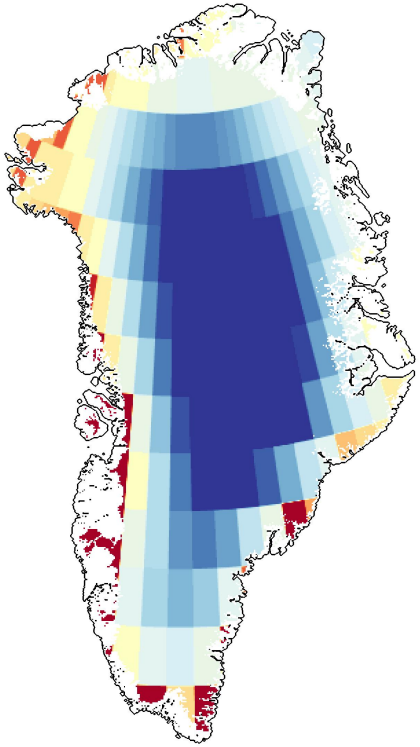
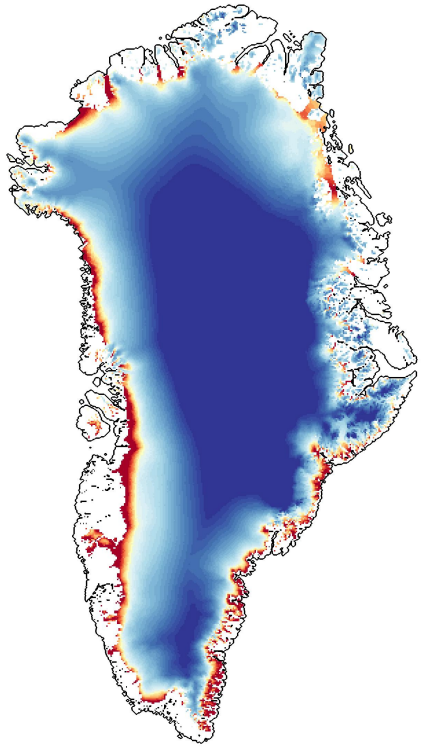
T63



lapse rate correction
to high resolution topography

T63 downscaled



2m air temperature (^{o} C)

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Why downscaling is necessary
spatial downscaling

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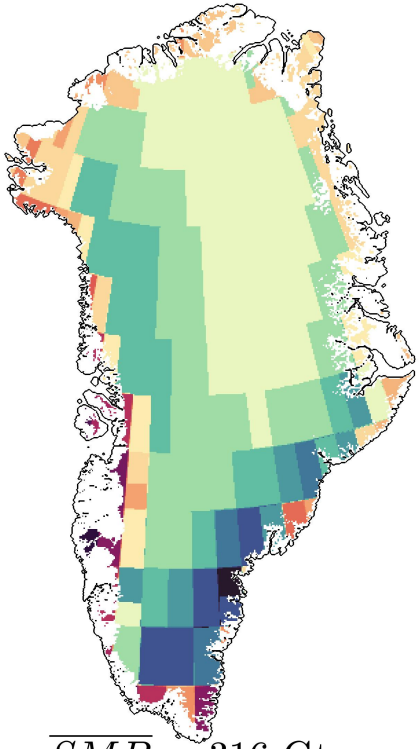
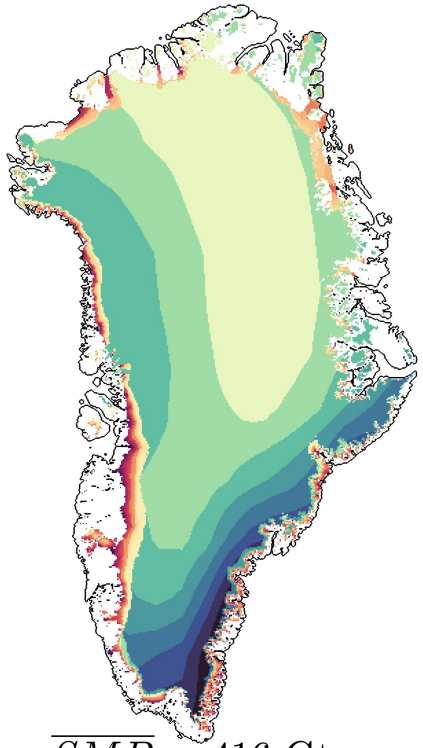


$\overline{SMB} = 316$ Gt

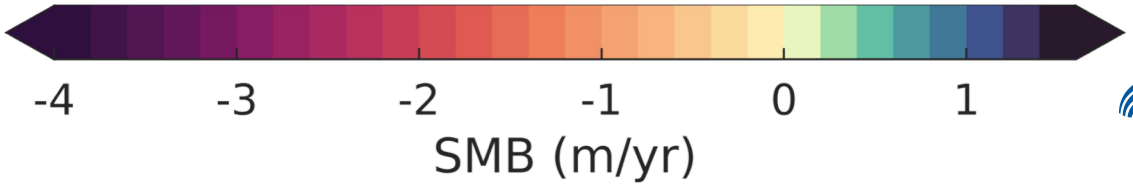
coarse resolution bias of

Δ SMB $\approx$ 25%

T63 downscaled



$\overline{SMB} = 416$ Gt



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Temporal downscaling

Diurnal cycle

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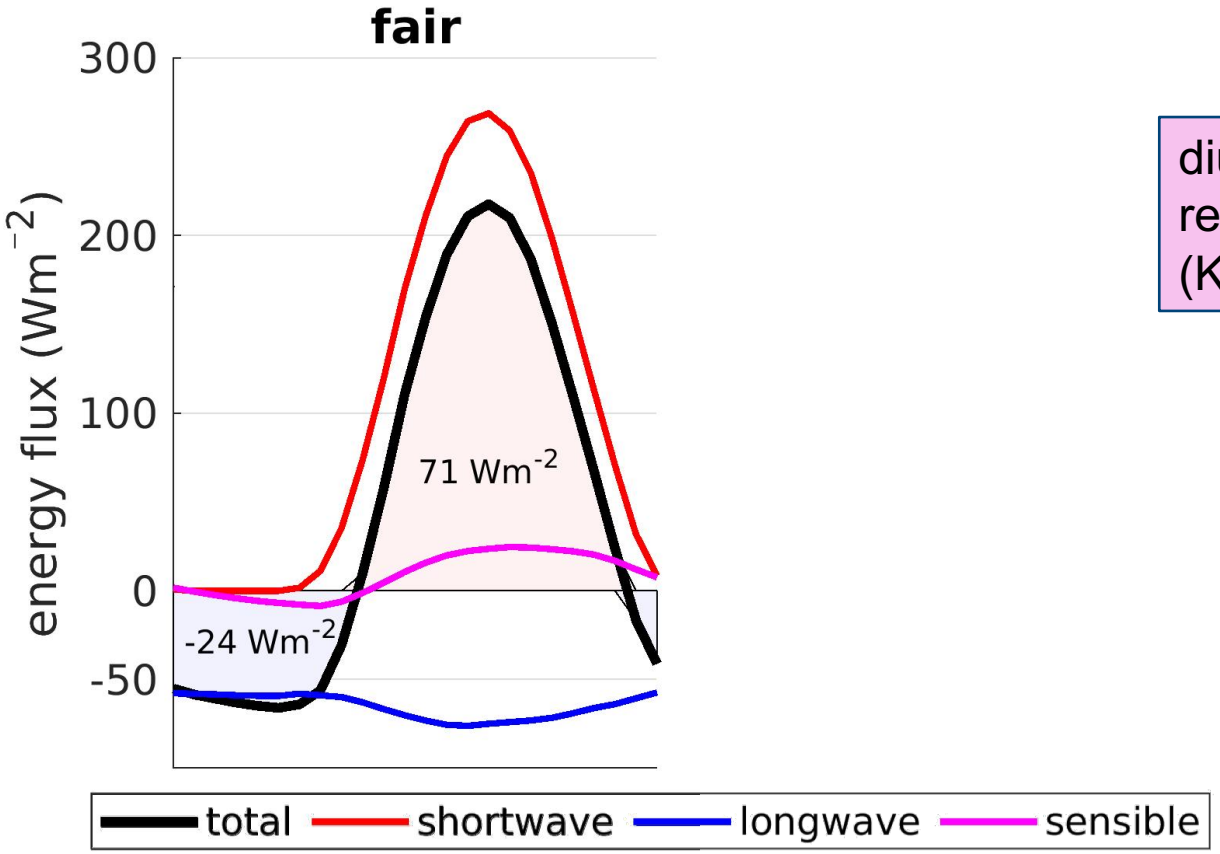

diurnal freeze-melt periods represented implicitely (Krebs-Kanzow et al. 2018)

Temporal downscaling

Submonthly variations in cloud cover

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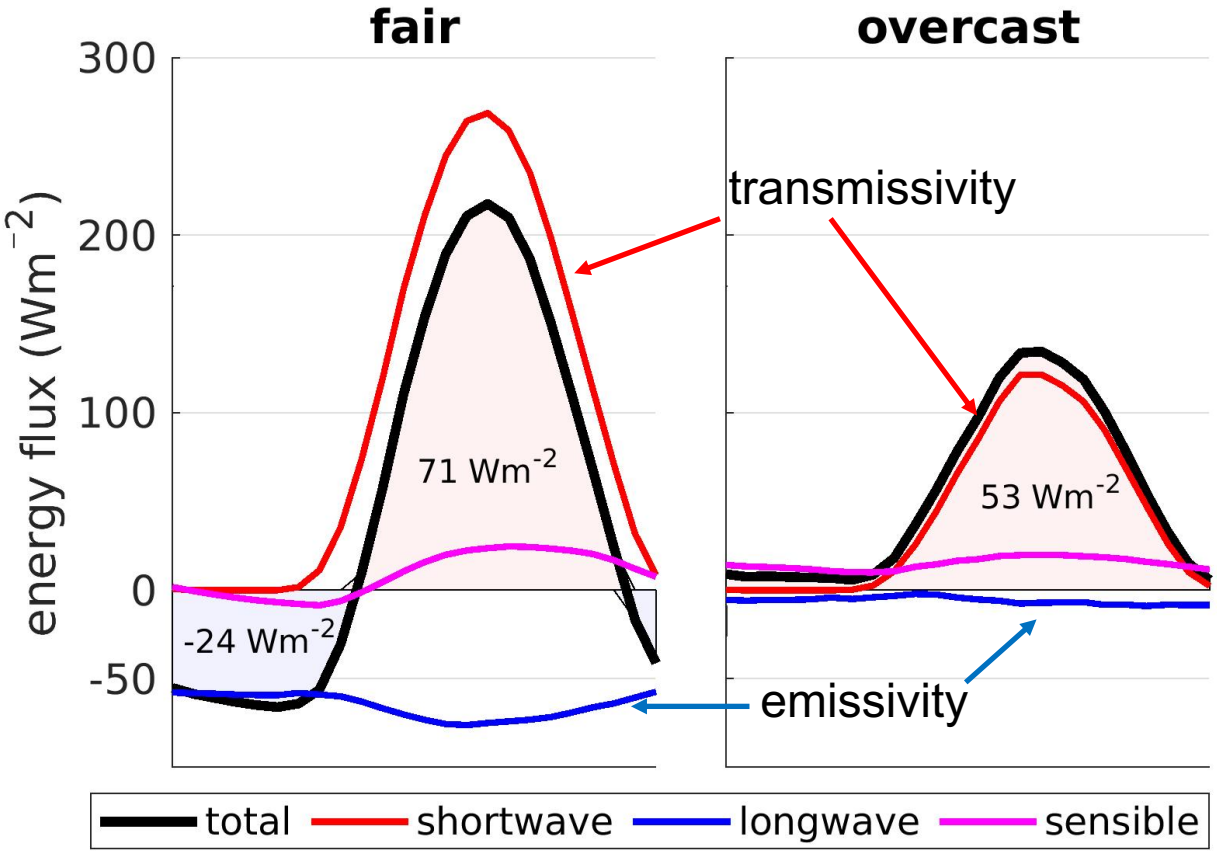

no diurnal freeze-melt periods under overcast conditions

Temporal scales

Submonthly variations in cloud cover

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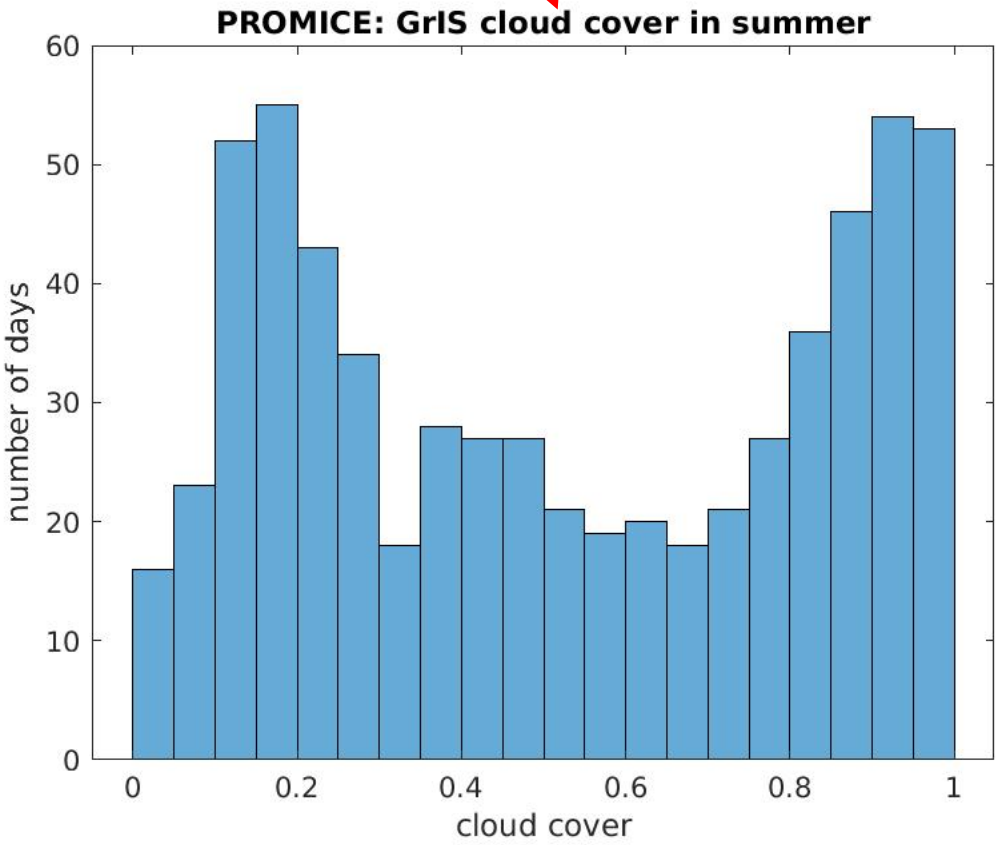
automatic weather station observations



daily cloud cover is not normally distributed:
We use monthly mean cloud cover to statistically represent submonthly variations in cloud cover by two distinct modes with…

Temporal scales

Downscaling submonthly variations

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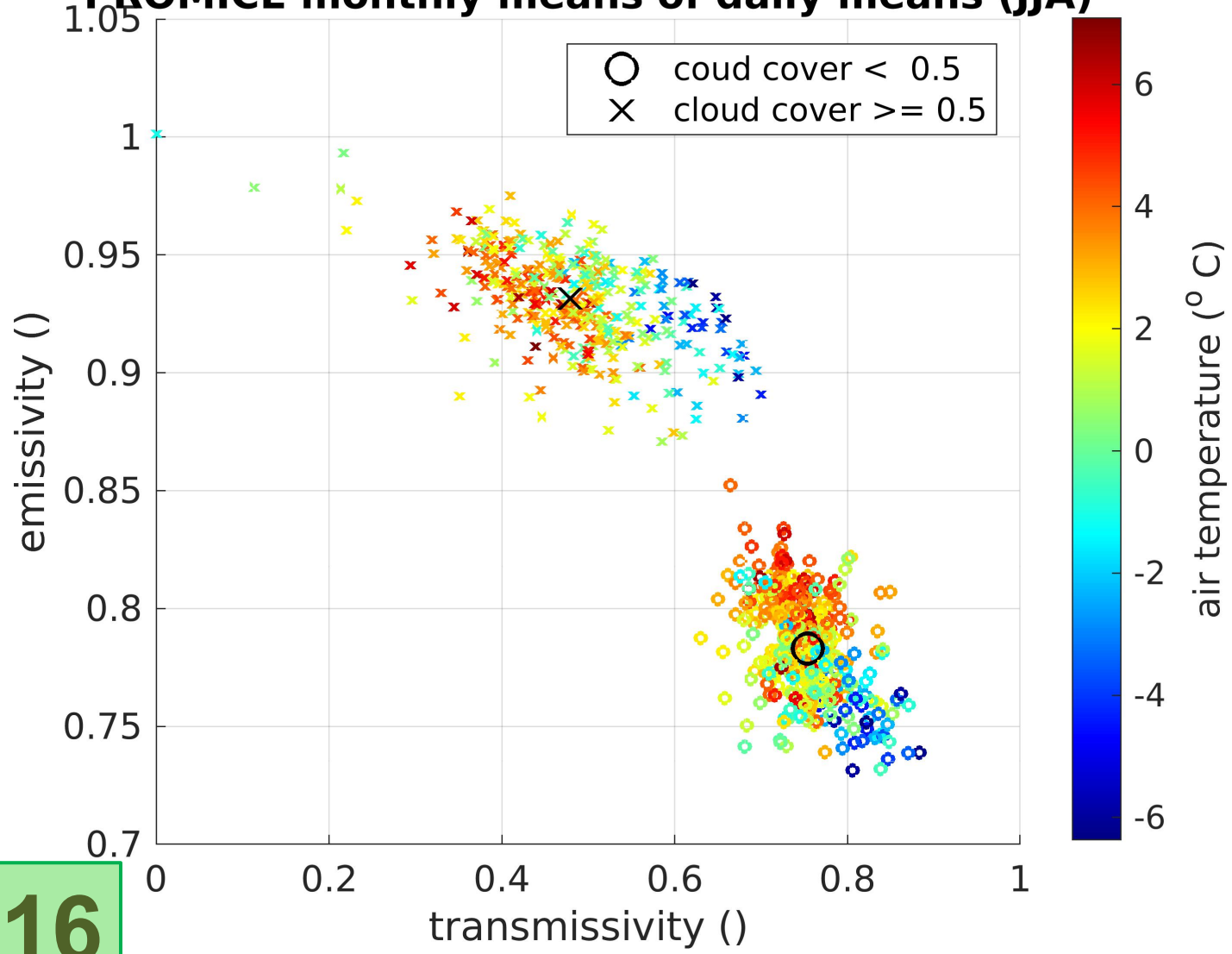
PROMICE monthly means of daily means (JJA)



… with distinct optical / radiative properties which can be diagnosed from observation

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Bonus: Last Glacial Maximum

SMB outside of Greenland

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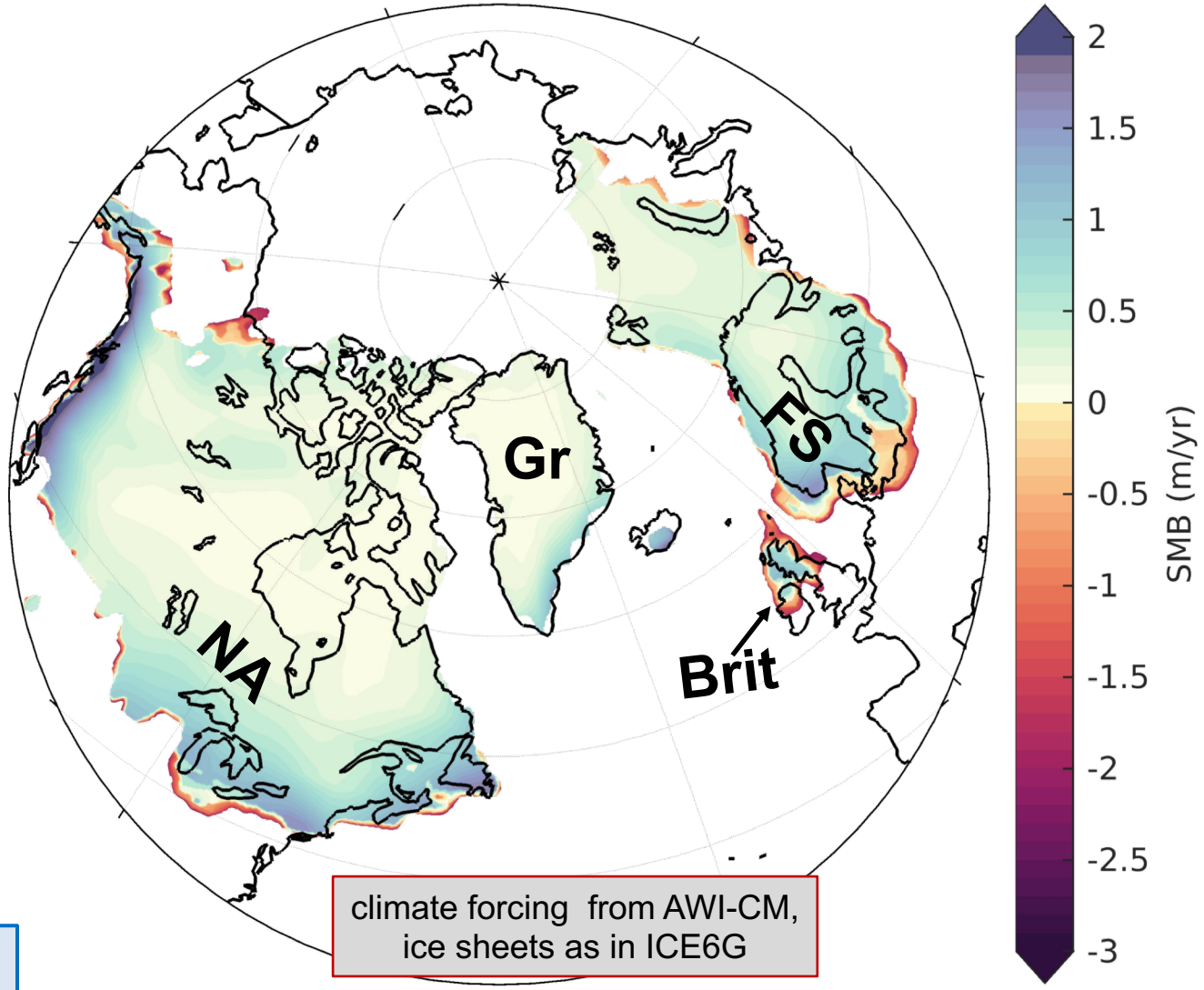

climate forcing from AWI-CM, ice sheets as in ICE6G

Last Glacial Maximum:
Sensitivity to radiation

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$dEBM, 21ka$		ice sheet	runoff anomaly		
SMB (Gt)	runoff (Gt)		PDD, 21ka	dEBM, 14ka	dEBM, A-0.05
5594	4902	TOTAL	−10 %	+17 %	+18 %
4675	2359	NA	−15 %	+8 %	+17 %
449	< 1	Gr			
1014	1400	FS	−23 %	+35 %	+24 %
-604	1134	Brit	+15 %	+13 %	+14 %

PDD scheme produces less runoff for most ice sheets

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Last Glacial Maximum:
Sensitivity to radiation

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Changing insolation to deglacial (14ka) insolation increases runoff (LGM temperatures unchanged)

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Last Glacial Maximum:
Sensitivity to radiation

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Changing ice albedo
increases runoff
(to estimate dust feedback)

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References

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Krebs-Kanzow, U. Gierz, P., Lohmann, G.: Brief communication: An ice surface melt scheme including the diurnal cycle of solar radiation, The Cryosphere, 12, 3923–3930, https://doi.org/10.5194/tc-12-3923-2018, 2018.

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