Laboratoire de Climatologie et Topoclimatologie

LIÈGE université

Comparison of the surface mass and energy balance of CESM and MAR forced by CESM over Greenland: present and future

Charlotte Lang[1], C. Amory[1], A. Delhasse[1], S. Hofer[2], C. Kittel[1], L. van Kampenhout[3], W. Lipscomb[4], X. Fettweis[1]

Corresponding author: charlotte.lang@uliege.be

(1) Université de Liège, Département de Géographie, Liège, Belgium
(2) School of Geographical Sciences, University of Bristol, UK
(3) Institute for Marine and Atmospheric research Utrecht, Utrecht University, the Netherlands
(4) National Center for Atmospheric Research, Boulder, CO, USA

EGU General Assembly 2020 – May 7th 2020

D2553 - EGU2020-18037

Context of the study

- Prior to this study:

GCMs/ESMs used to force the lateral boundaries of an RCM (Regional Climate Model, here MAR) couldn’t simulate the surface mass balance (SMB) of an ice sheet

The potential added value of an RCM could only be evaluated by comparing atmospheric variables in both models

- In this study:

Land/snow module of CESM simulating the surface mass and energy balance at the surface of the snow pack allows us for the first time to directly compare the SMB and its components in both models as well as the sensitivity of the snow module of both models to the projected temperature increase

Simulations setup

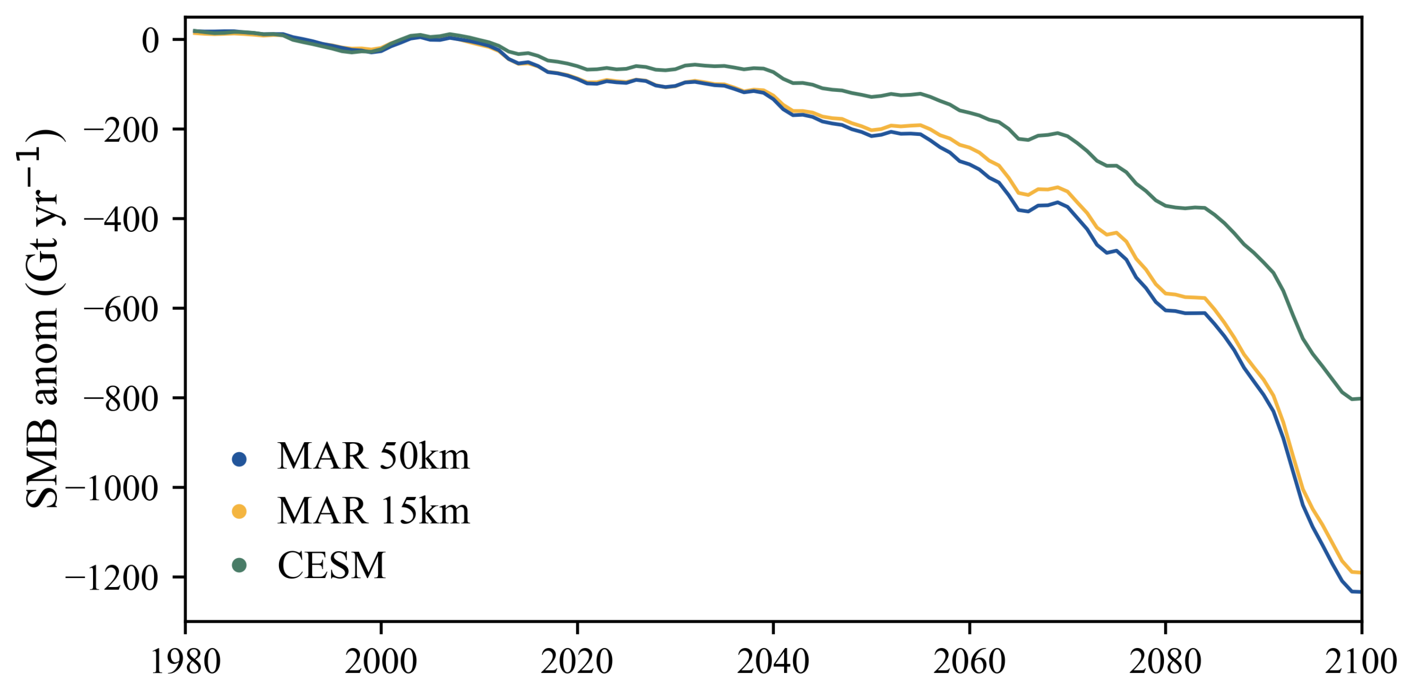
Period: 1981 – 2100
Scenario: SSP585
Model 1: CESM2 (Community Earth System Model), same version as in CMIP6
Model 2: MAR (Modèle Atmosphérique Régional) v3.11 forced by CESM

Aim of the study is to show the sensitivity of the snow module of both models to the projected climate change, not an ***who's the best*** contest

→ No correction at the MAR lateral boundaries in this study (e.g. to match MAR Greenland reference run (15km forced by ER5))

Initially two spatial resolutions for MAR runs (15 and 50 km) to highlight potential differences due to spatial resolution rather than used model

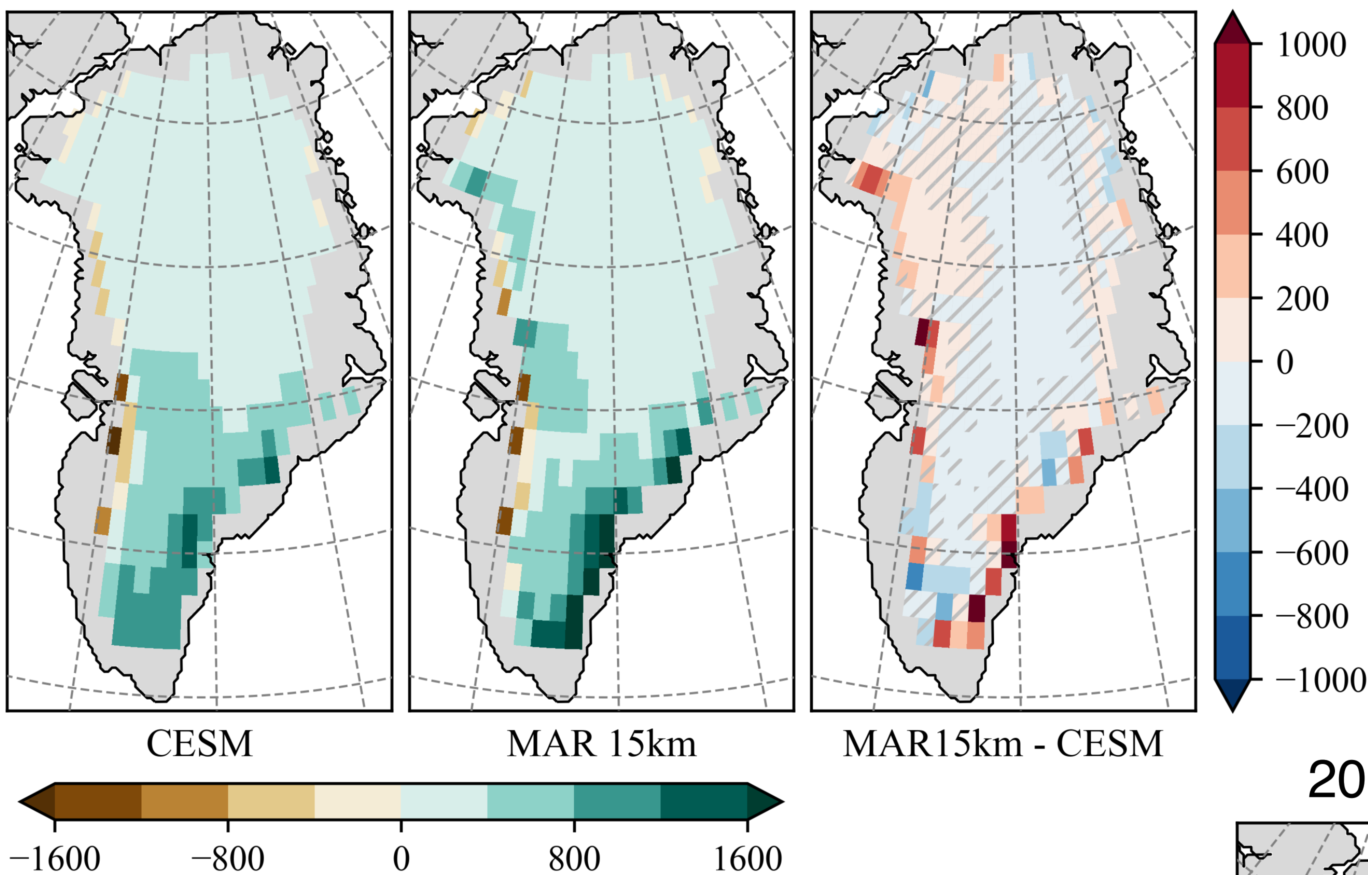
→ Differences between future anomalies: MAR vs MAR << MAR vs CESM
Only the MAR 15km simulation is used afterwards



Temporal evolution of SMB anomaly with respect to the 1981 – 2010 average

2071 – 2100 mean SMB anomaly

1981 – 2010 average SMB (mm we yr^{-1})

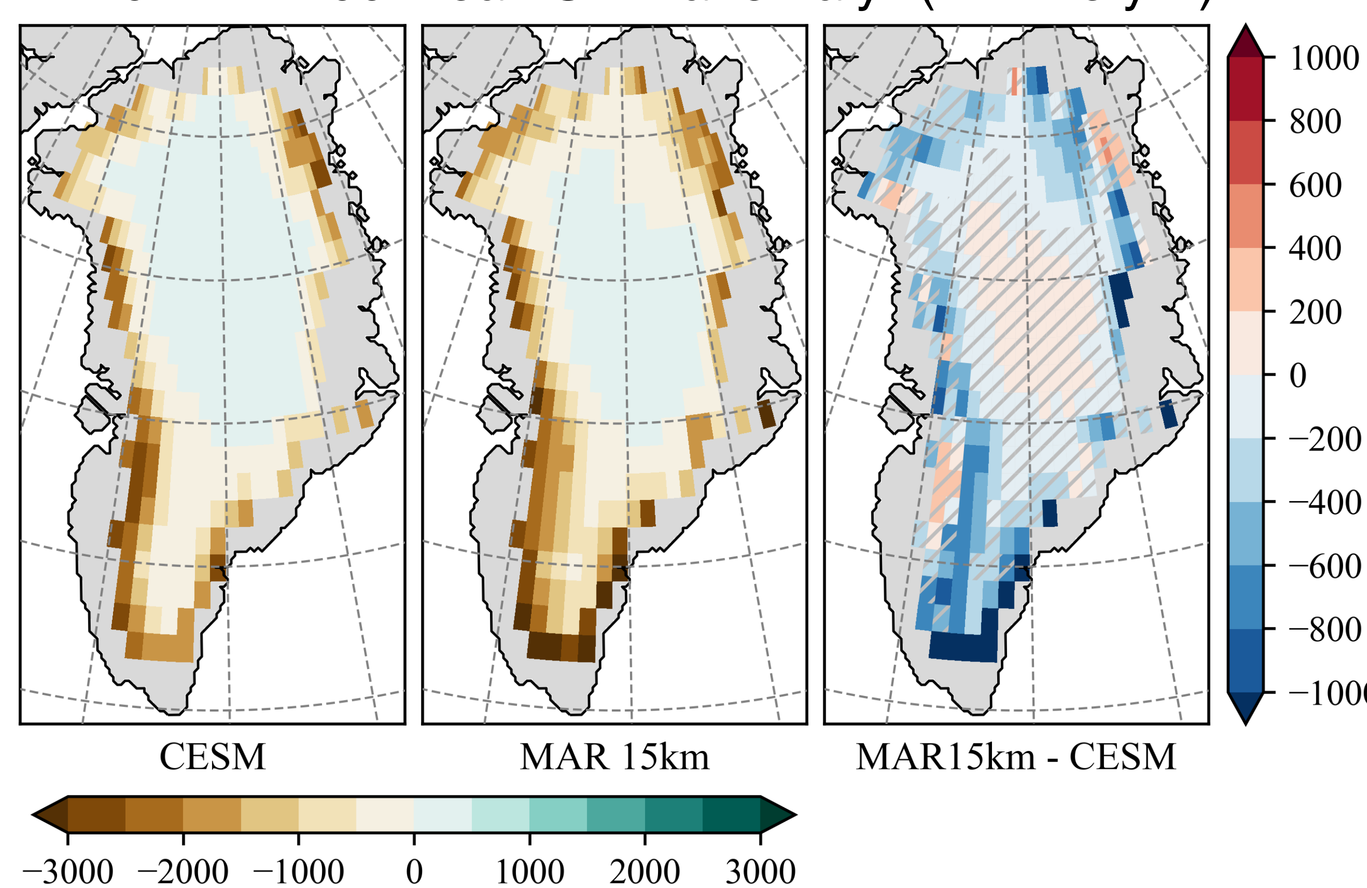


Significantly different

Not significantly different

*Anomaly = difference with respect to the 1981 – 2010 average

2071 – 2100 mean SMB anomaly* (mm we yr^{-1})

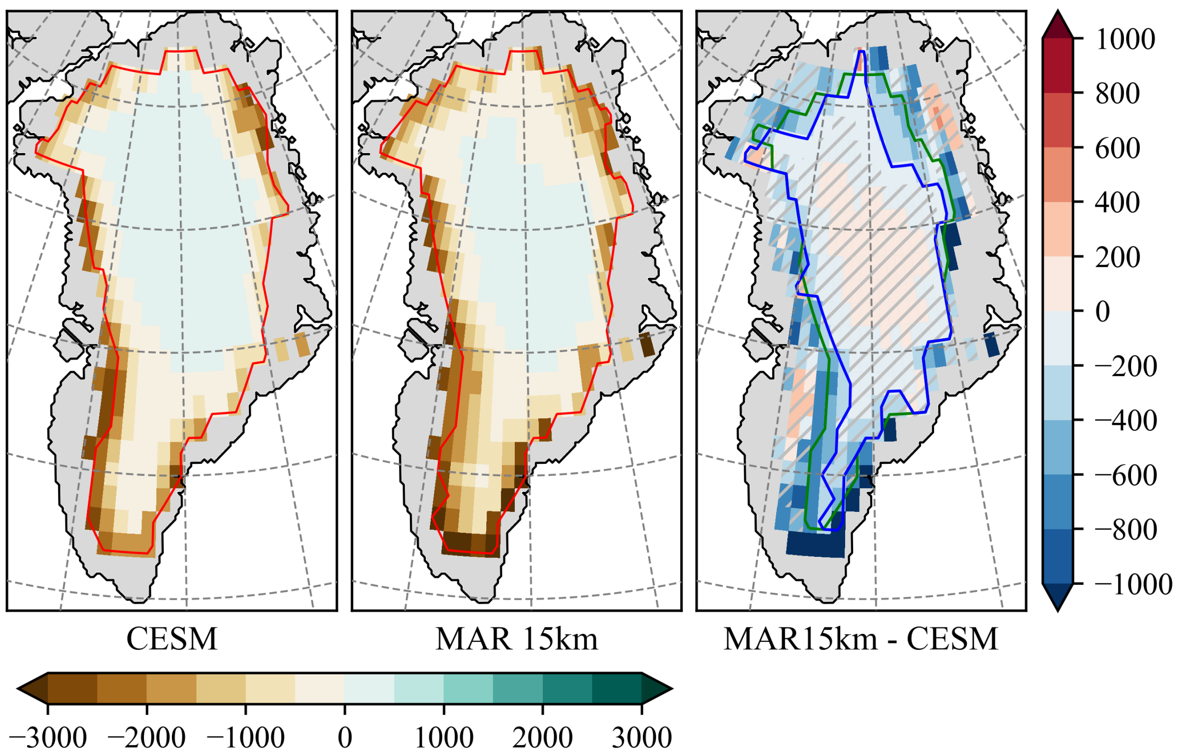


	MB ± SD
1981 – 2010	+29 ± 240
2071 – 2100 anom	-238 ±328

MB = Mean bias (mm we yr^{-1})

SD = Standard deviation (mm we yr^{-1})

2071 – 2100 mean SMB anomaly

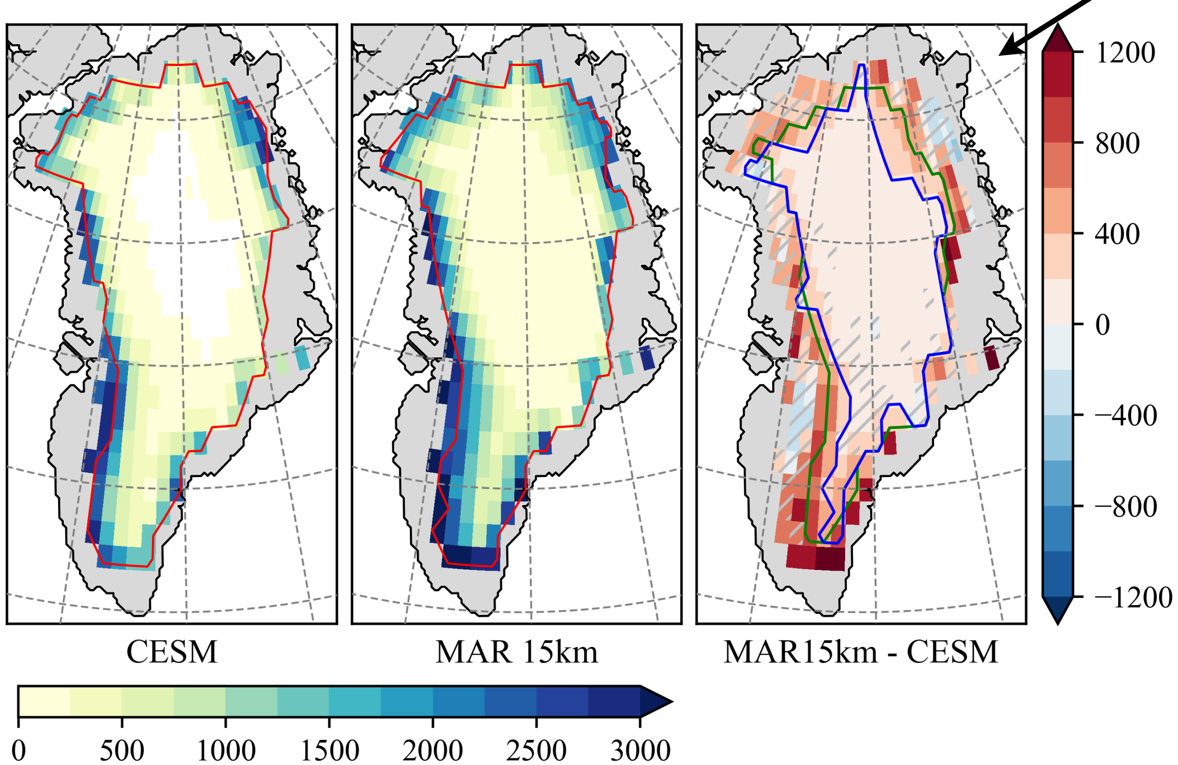


Most of the SMB anomaly between MAR and CESM comes from the runoff anomaly (total amount and pattern)

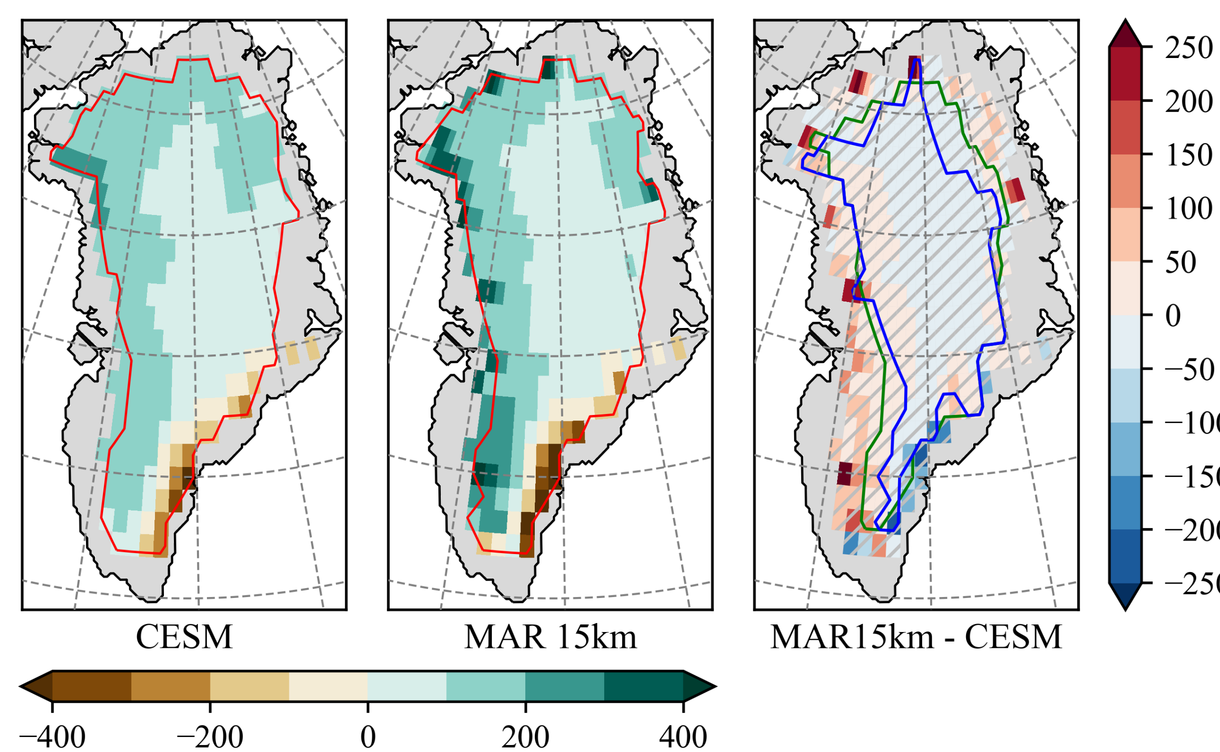
	MB ± SD
SMB	-238±328
RU	272±322
SF+RF (=P)	10±63
	R^2
SMB vs RU	0.96
SMB vs P	0.02

1981–2010 eq. line
2071–2100 CESM eq. line
2071–2100 MAR eq. line

Significantly different over 75% of the ice covered area

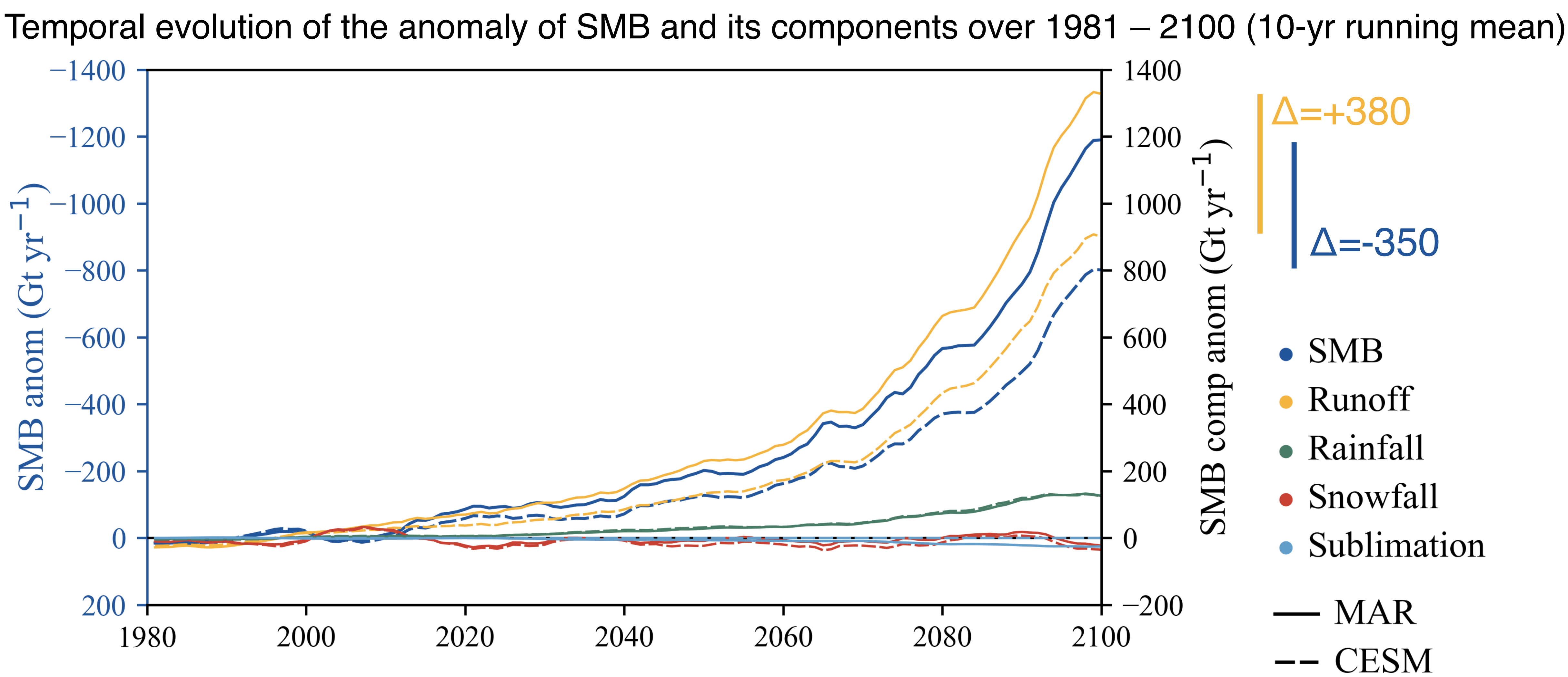


2071 – 2100 mean runoff anomaly (mm we yr^{-1})



2071 – 2100 mean precipitation anomaly (mm we yr^{-1})

SMB components anomalies: temporal evolution



	Difference (Gt yr⁻¹)*
SMB	-350
Runoff	380
Sublimation	25
Snowfall	10
Rainfall	0

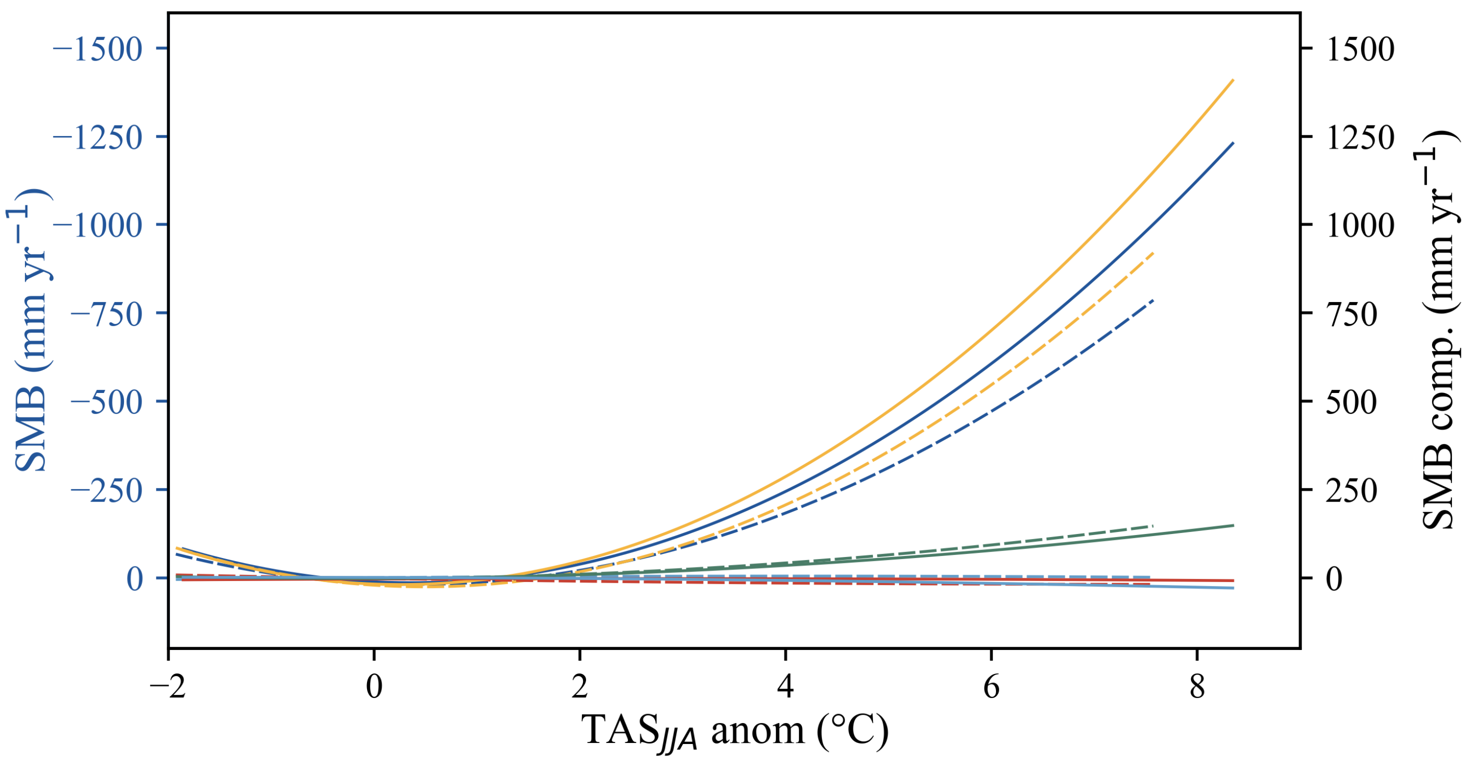
/15 (Runoff vs. Sublimation)

* MAR–CESM anomaly difference averaged over 2091 – 2100

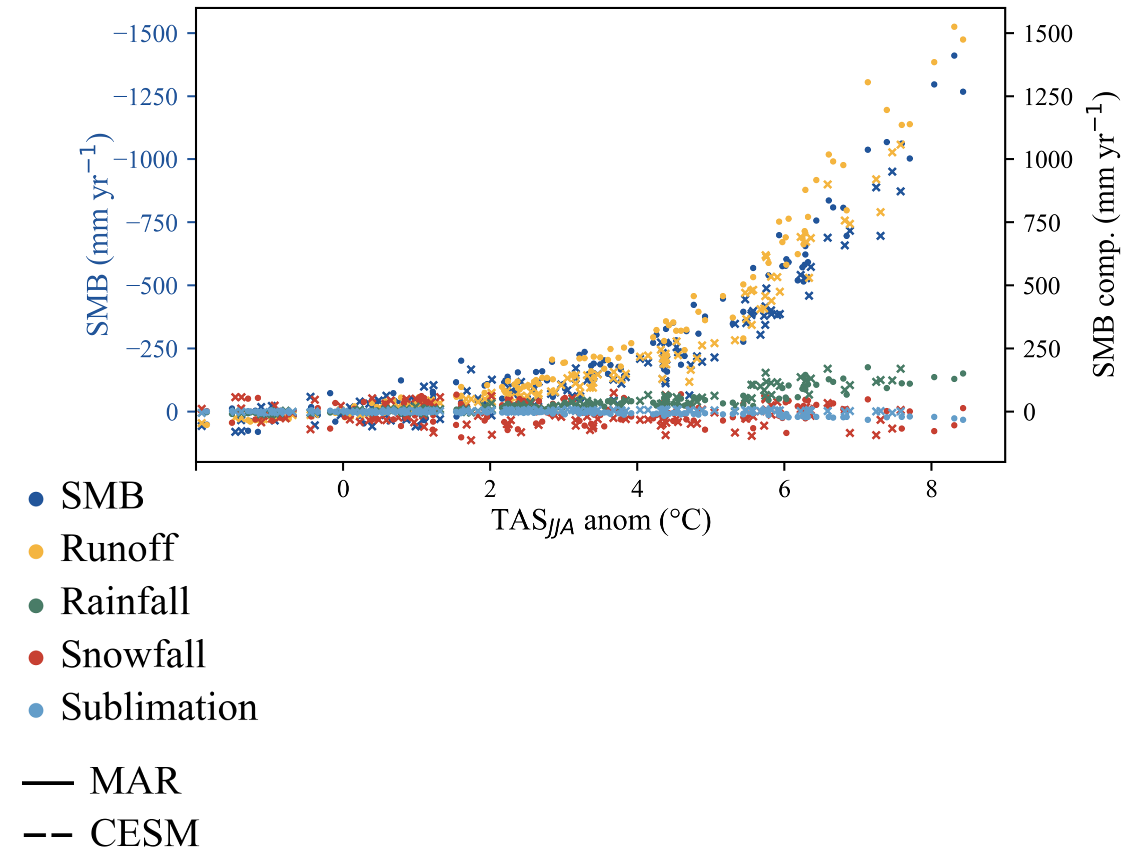
Factor >10 between RU MAR-CESM difference and SU difference (next largest difference) at the end of the century

SMB components anomalies vs temperature anomalies

Quadratic fit of SMB vs temperature anomaly



SMB and its components anomaly vs near-surface temperature anomaly



1/ For the same temperature increase, SMB/RU decreases/increases more in MAR than in CESM
2/ Temperature increases more in MAR than in CESM

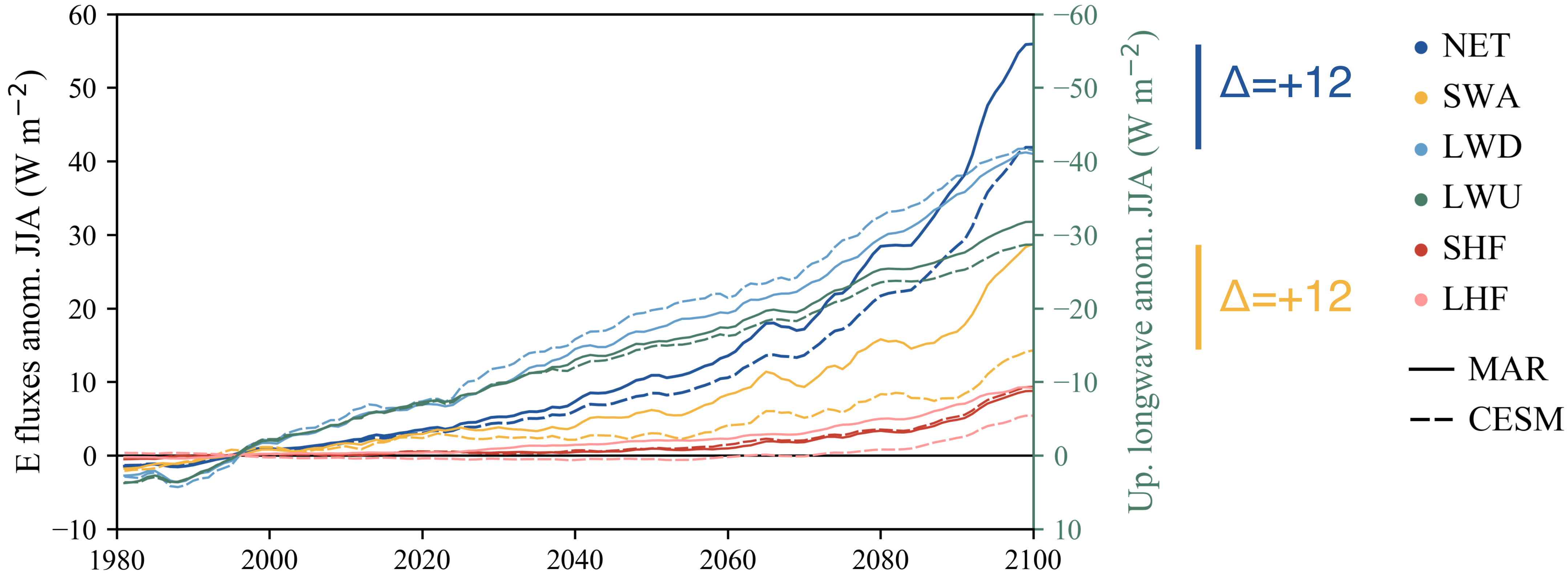
Half of SMB/RU anomaly at the end of the century comes from **sensitivity to temperature** increase
Half of SMB/RU anomaly at the end of the century comes from **larger temperature** increase in MAR

R^2 of quadratic fit

	CESM	MAR
SMB	0.91	0.95
RU	0.94	0.96
RF	0.84	0.85
SF	0.03	0.001
SU	0.77	0.87

Energy balance components anomalies: temporal evolution

Temporal evolution of the anomaly of energy balance components over 1981 – 2100 (10-yr running mean)



	Difference (W m^{-2})*
Net radiation (NET)	12
Absorbed shortwave (SWA)	12
Down. longwave (LWD)	-1
Up. longwave (LWU)	-3
Sensible heat flux (SHF)	-0.5
Latent heat flux (LHF)	4

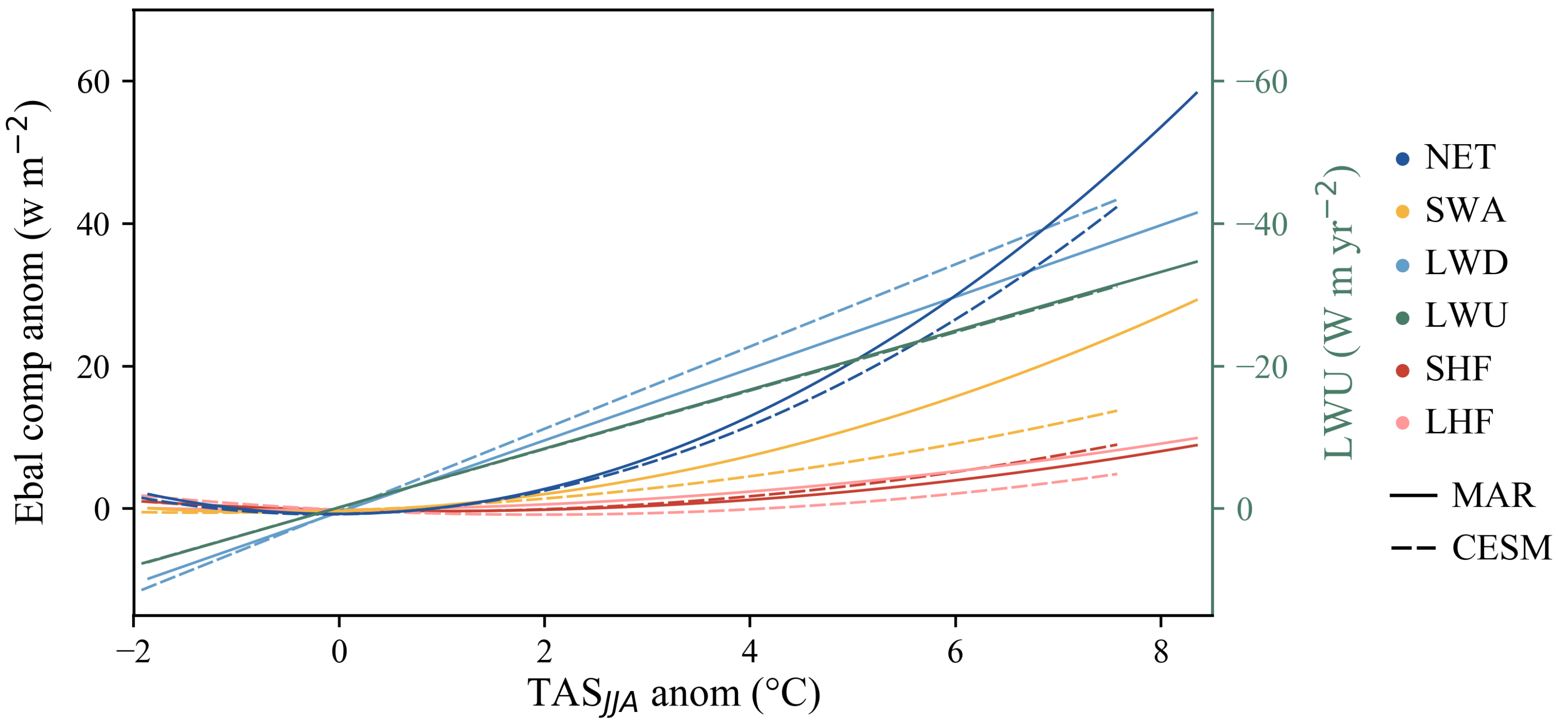
* MAR–CESM anomaly difference averaged over 2091 – 2100

NET = SWA + LWD - LWU + SHF + LHF
SWA = SWD (1-a)
SWD = incoming solar radiation at the surface
a = albedo

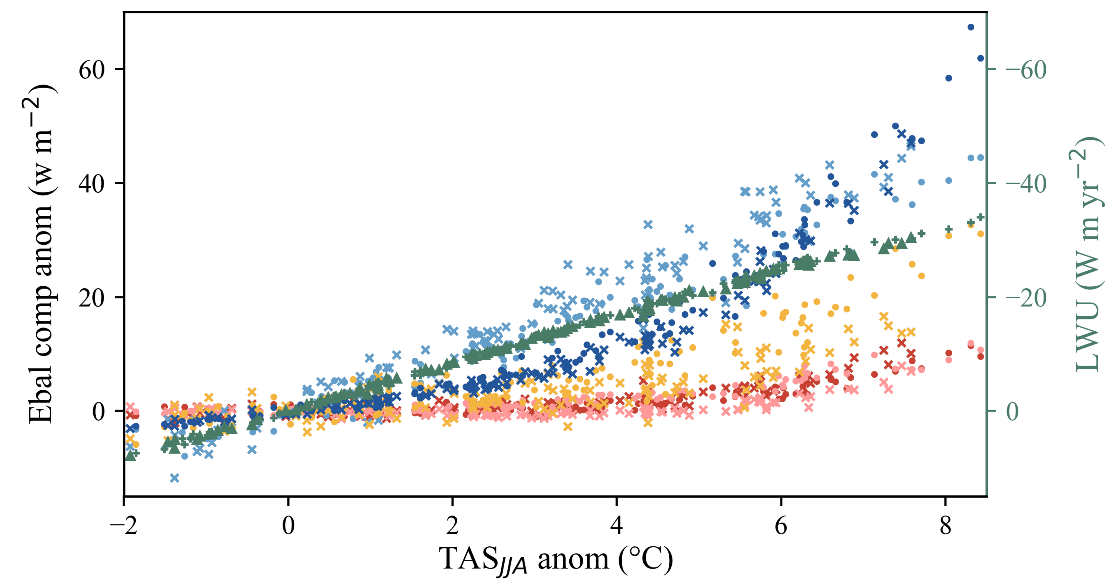
- NET MAR-CESM difference at the end of the century mostly driven by SWA differences, and, to a lesser extent, by LHF and LWU
- SHF difference is negligible
- LWD difference reduced towards the end of the century

Energy balance components anomalies vs temperature anomalies

Quadratic fit of energy balance vs temperature anomaly



Energy balance and its components anomaly vs near-surface temperature anomaly



Sensitivity to temperature change or larger temperature increase?

NET	40/60
SWA	70/30
LWD	Cancel out
LWU	T increase
SHF	Cancel out
LHF	70/30

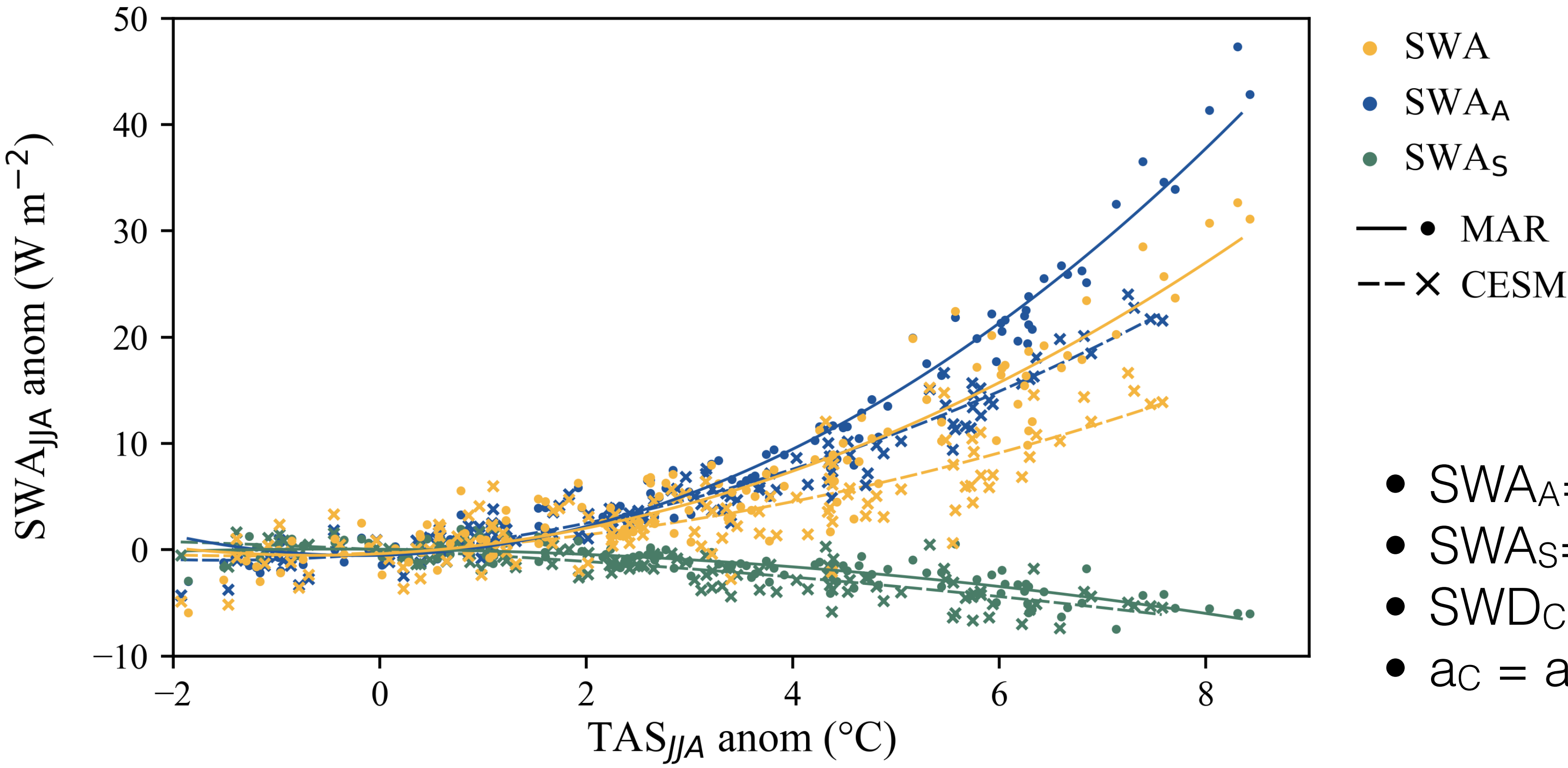
R^2 of quadratic fit

	CESM	MAR
NET	0.97	0.97
SWA	0.66	0.88
*LWD**	*0.94*	*0.96*
*LWU**	*0.998*	*0.998*
SHF	0.82	0.85
LHF	0.79	0.91

** Linear fit*

Absorbed shortwave radiation: albedo vs SWD

Absorbed shortwave radiation anomaly vs temperature anomaly



R² of quadratic fit	CESM	MAR
SWA_A	0.94	0.97
SWA_S	0.67	0.73
SWA	0.66	0.88

- $SWA_A = SWD_C * (1-a)$
- $SWA_S = SWD * (1-a_C)$
- SWD_C = SWD averaged over 1981–2010
- a_C = a averaged over 1981–2010

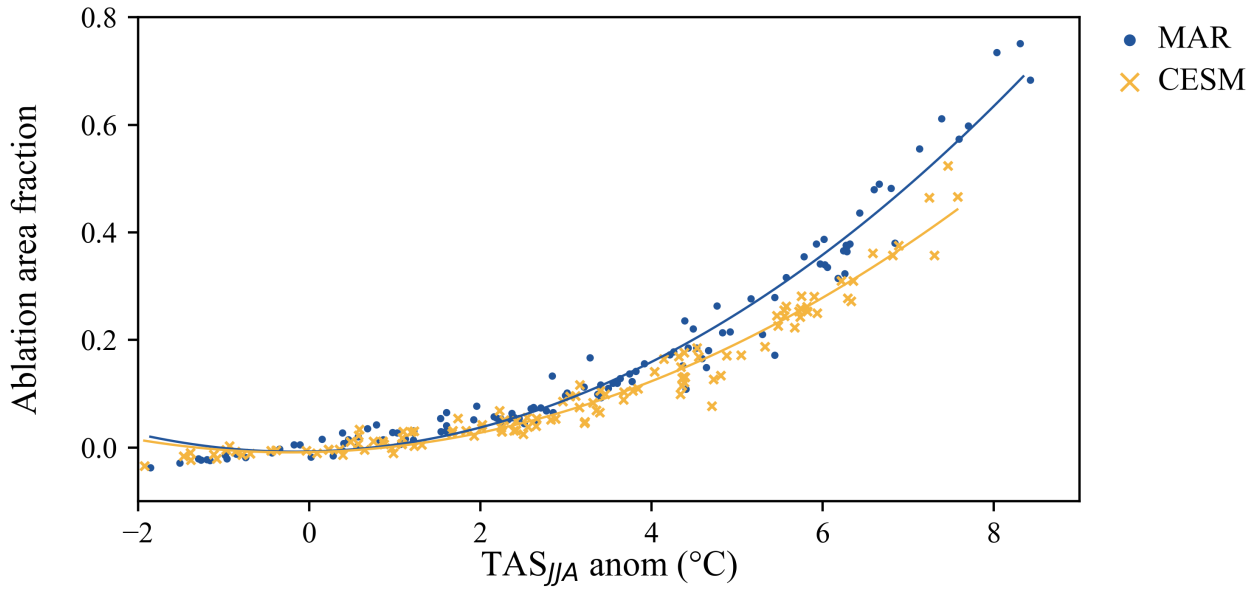
SWA_A = Absorbed SW with incoming **solar radiation** kept **constant** in time. Shows **influence of albedo changes** on SWA

SWA_S = Absorbed SW with **albedo** kept **constant** in time. Shows the **influence of incoming shortwave radiation** changes on SWA

Larger sensitivity of SWA to temperature change in MAR driven by larger sensitivity of albedo to temperature change

Absorbed shortwave radiation: albedo vs SWD

Fraction of the GrIS in the ablation zone vs temperature anomaly



Ablation area area sensitivity to temperature rise is slightly larger in MAR than in CESM

→ Larger retreat of equilibrium line in MAR

Largest albedo (and therefore SWA) differences where GrIS is in the ablation area in both models and mostly non-significant differences in the accumulation area

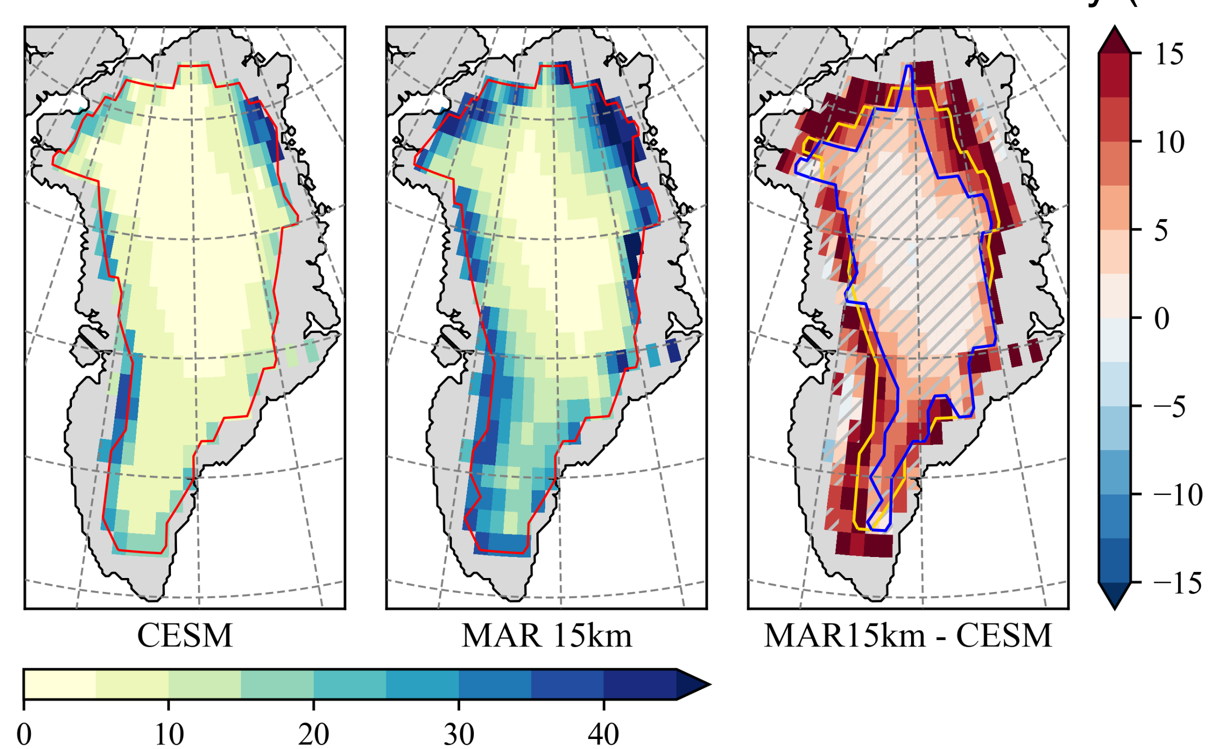
→ Transition from snow to ice faster in MAR (? TBD)

1981–2010 eq. line

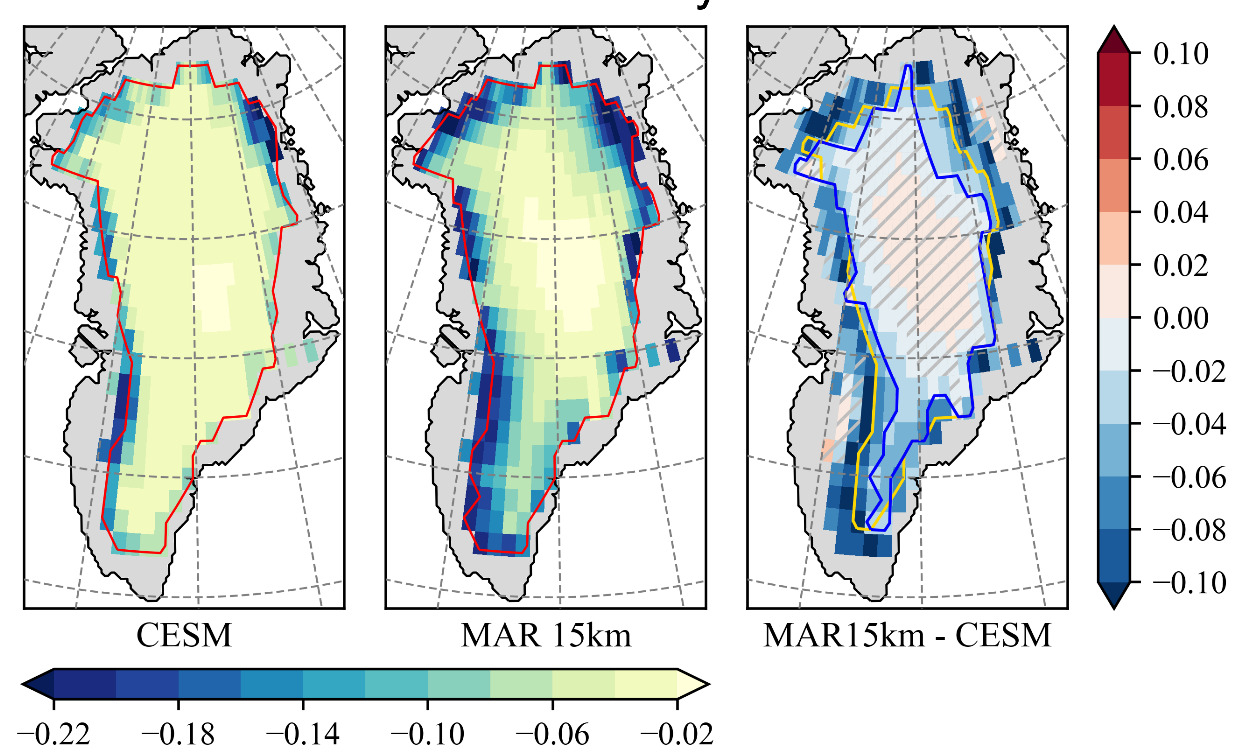
2071–2100 CESM eq. line

2071–2100 MAR eq. line

2071 – 2100 absorbed shortwave radiation anomaly (W m^{-2})



2071 – 2100 albedo anomaly



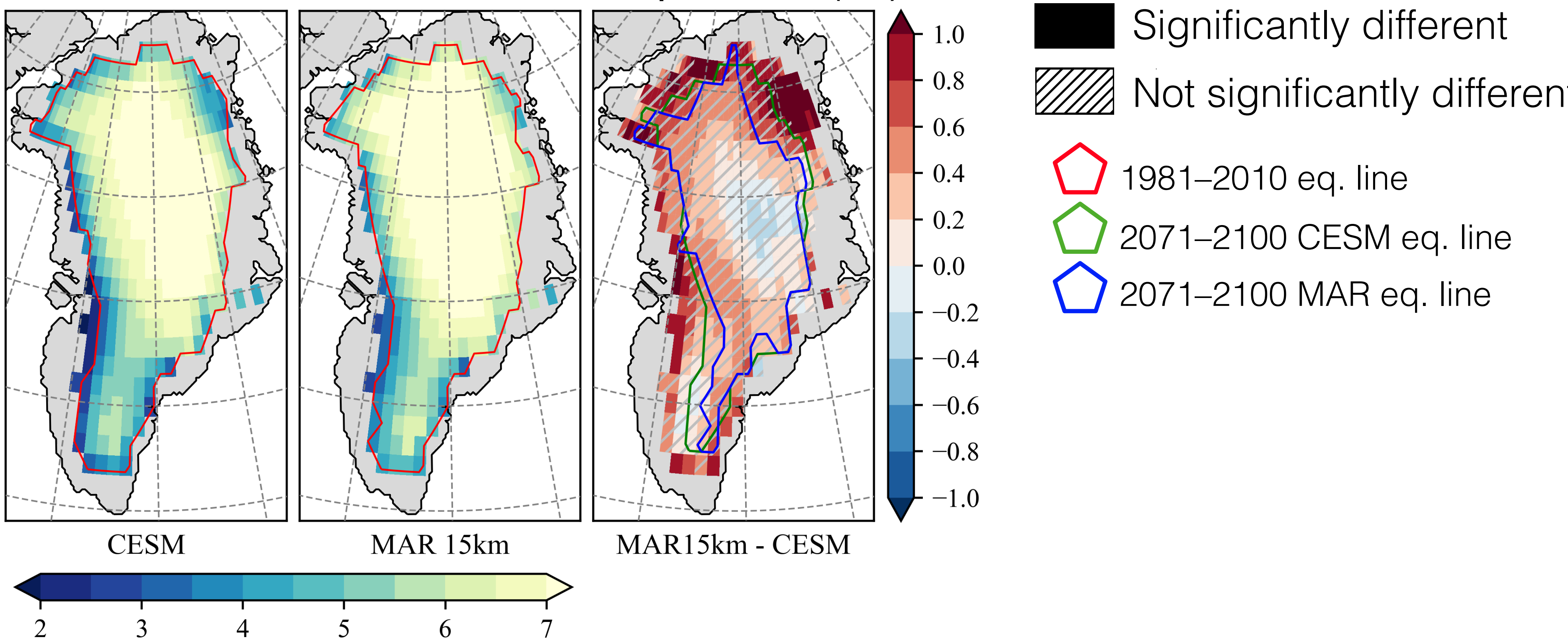
Conclusions and perspective

1. First time that we can compare the sensitivities of the snow modules of MAR and the model used to force the atmosphere at the MAR domain boundaries
2. **SMB** and **runoff** simulated by **MAR** appear to be **more sensitive** than CESM's to the projected **temperature increase**
3. **Main cause** is the higher sensitivity of the MAR **albedo** (snow density increase) to temperature increase through its effect on the absorbed incoming radiation
4. Other causes for more minor different sensitivities in MAR and CESM might include:
    - Differences in parametrisations for sensible and latent heat fluxes
    - Effect of cloud cover on incoming shortwave and long wave radiation

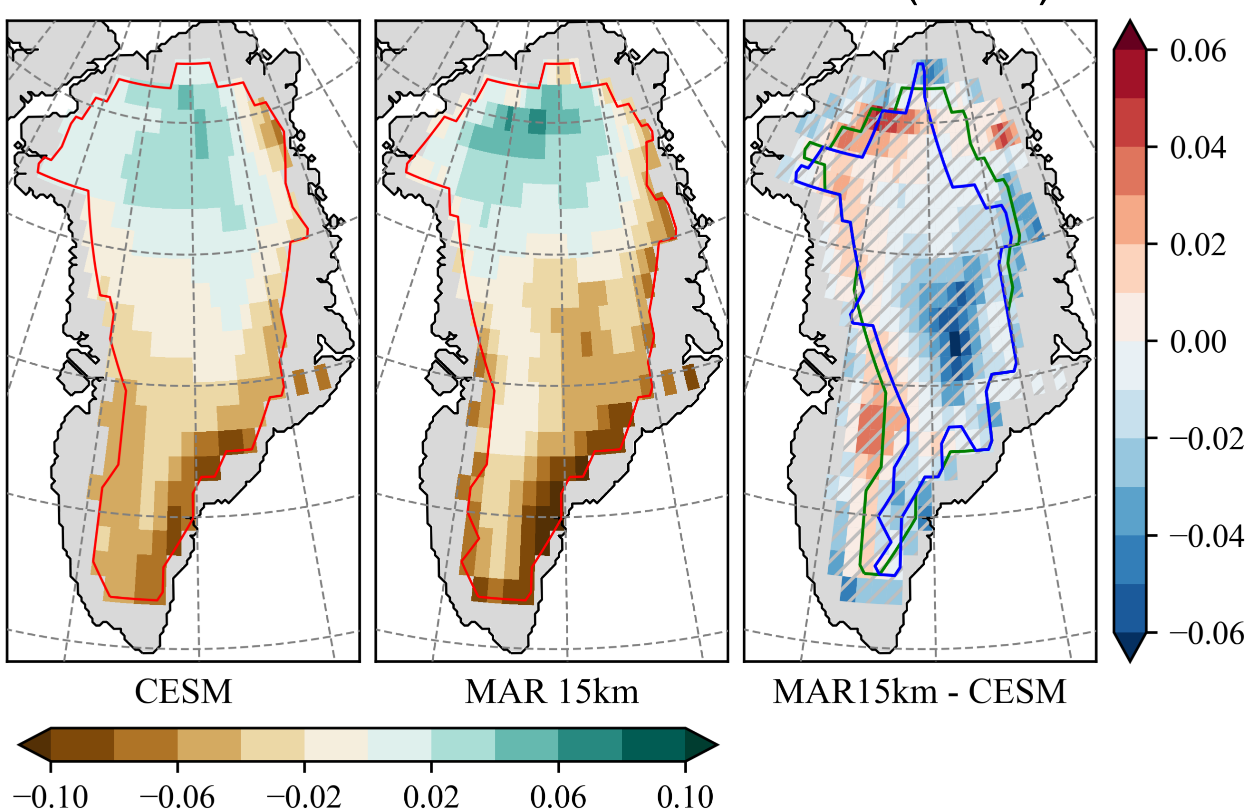
Next step: try and determine which processes/parametrisations cause the sensitivity differences in both models

Supplementary material

2071 – 2100 JJA near surface temperature (°C)



2071 – 2100 JJA cloud cover fraction (0 – 1)



Temporal evolution of the anomaly of cloud cover fraction 1981 – 2100 (10-yr running mean)