High-resolution, Fully-coupled Simulations of the Greenland Ice Sheet in a Future, Strong Warming Scenario

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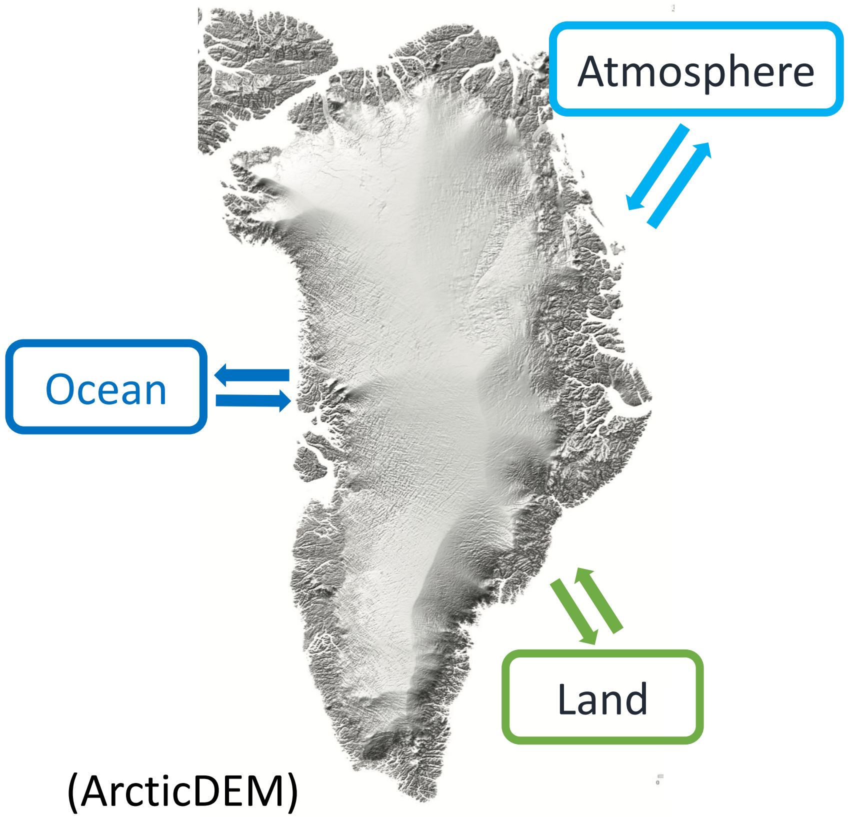
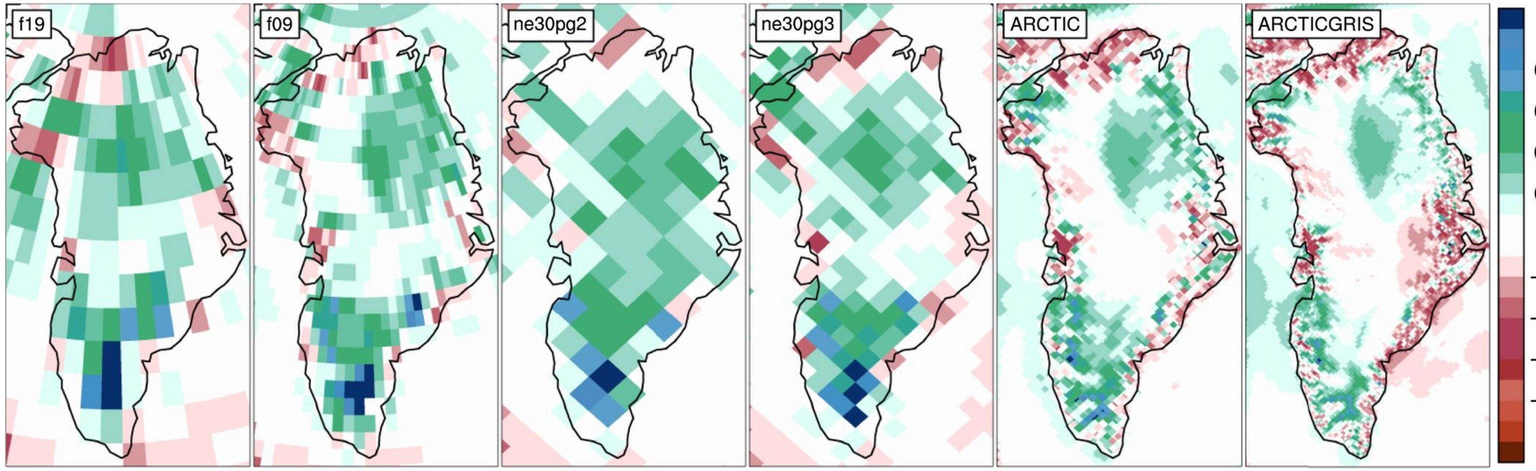
Background



(ArcticDEM)
https://www.pgc.umn.edu/data/arcticdem/

Greenland clouds/precipitation is sensitive to resolution



(Herrington et al. 2022)

A fine spatial resolution to resolve narrow ablation zones and topographic gradients

+

A coupled framework to model interactions / feedbacks

Coupled CESM2.2-CISM2.1 & variable resolution grid

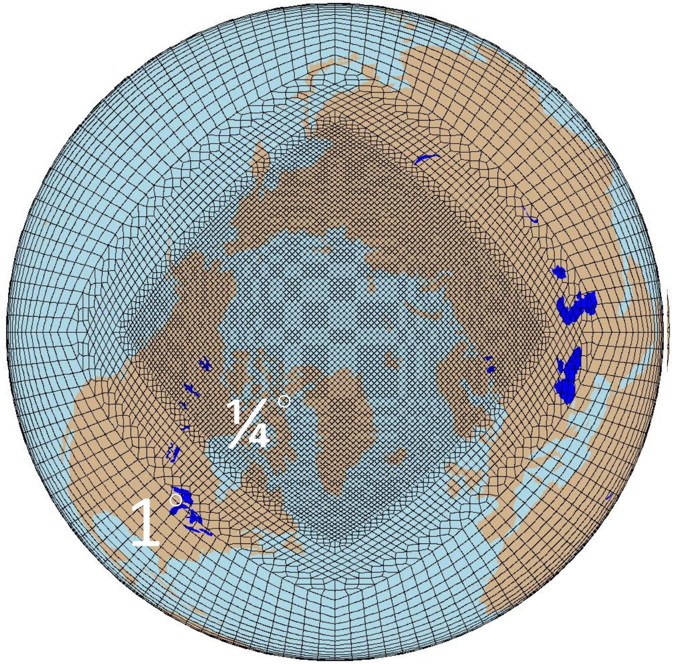
- Atmosphere/land: VR grid 'Arctic'
- Ice sheet: 4km
- Ocean: 1 °
- 32 hybrid σ-p vertical atmospheric levels

- Regional high resolution (¼ °)
- A unified, coupled model infrastructure
- Reduce computational cost

Compare to CMIP6 1 ° workhorse (CESM2.1)

- **Muntjewerf et al. (2020)**
- **New simulation**

'Arctic' grid



(Herrington et al. 2022)

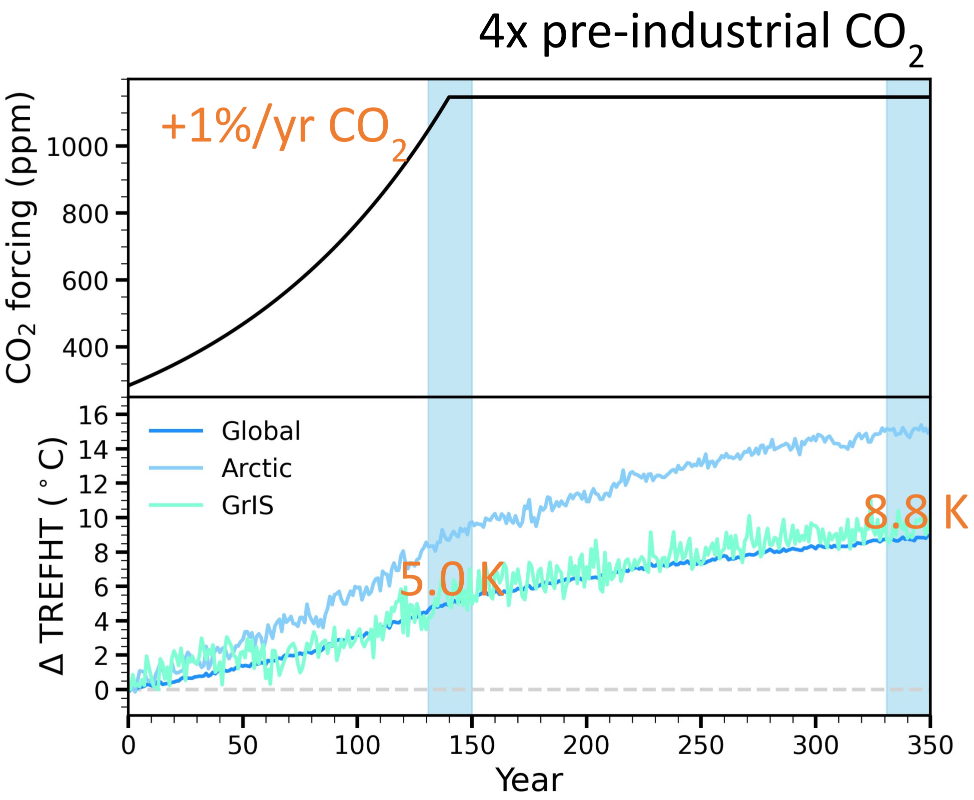
Δx_{eq}(km)	Δx_{fine}(km)	Δt_{phys}(s)	cost(8192 processors)
111	28	450	30403.91

10 times more expensive than 1 ° run

Experiment setup

Branched from the BG7 control of Lofverstrom et al. (2020)

piControl
(180yrs)



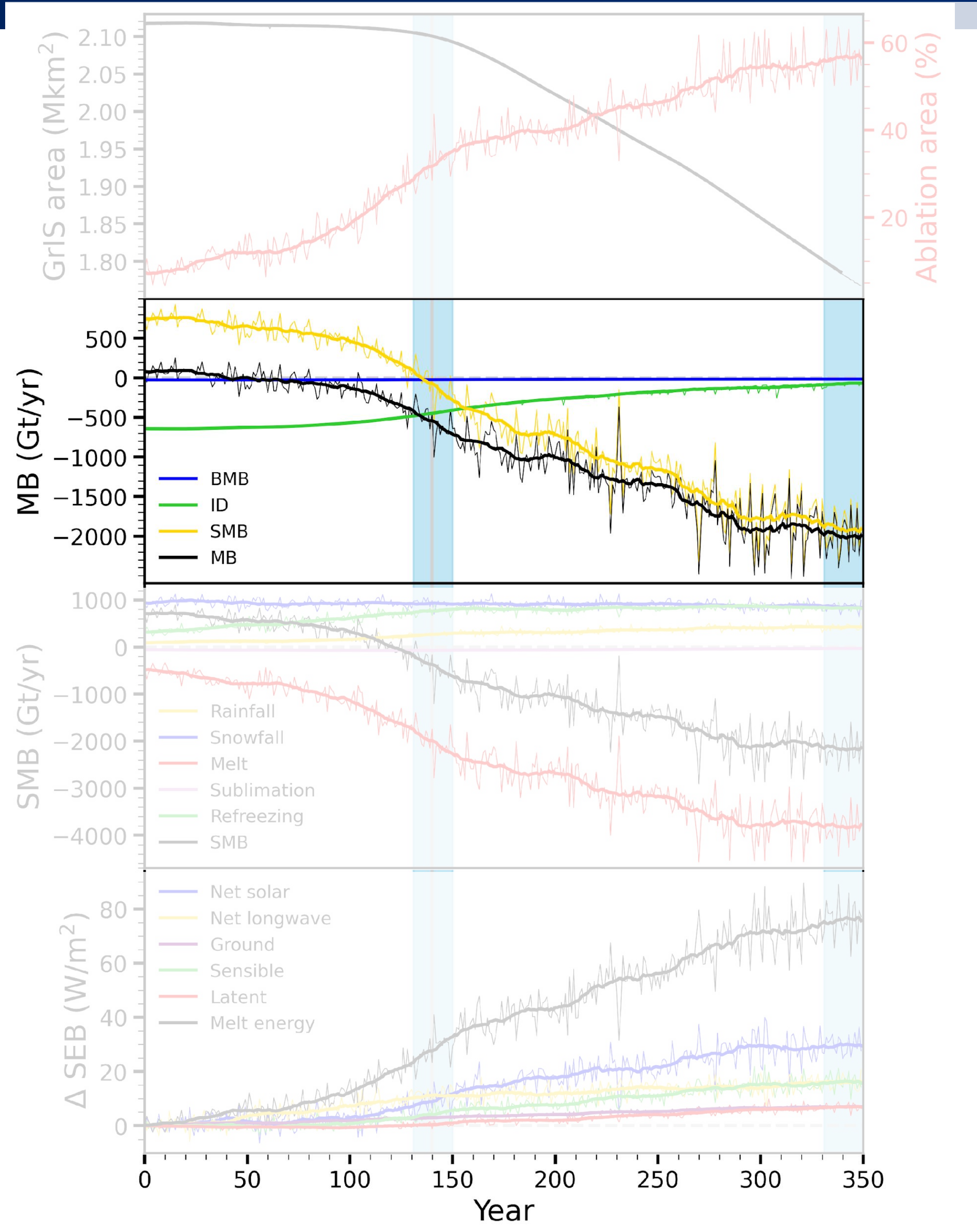
Arctic amplification (1.8)

Greenland amplification (1.1)

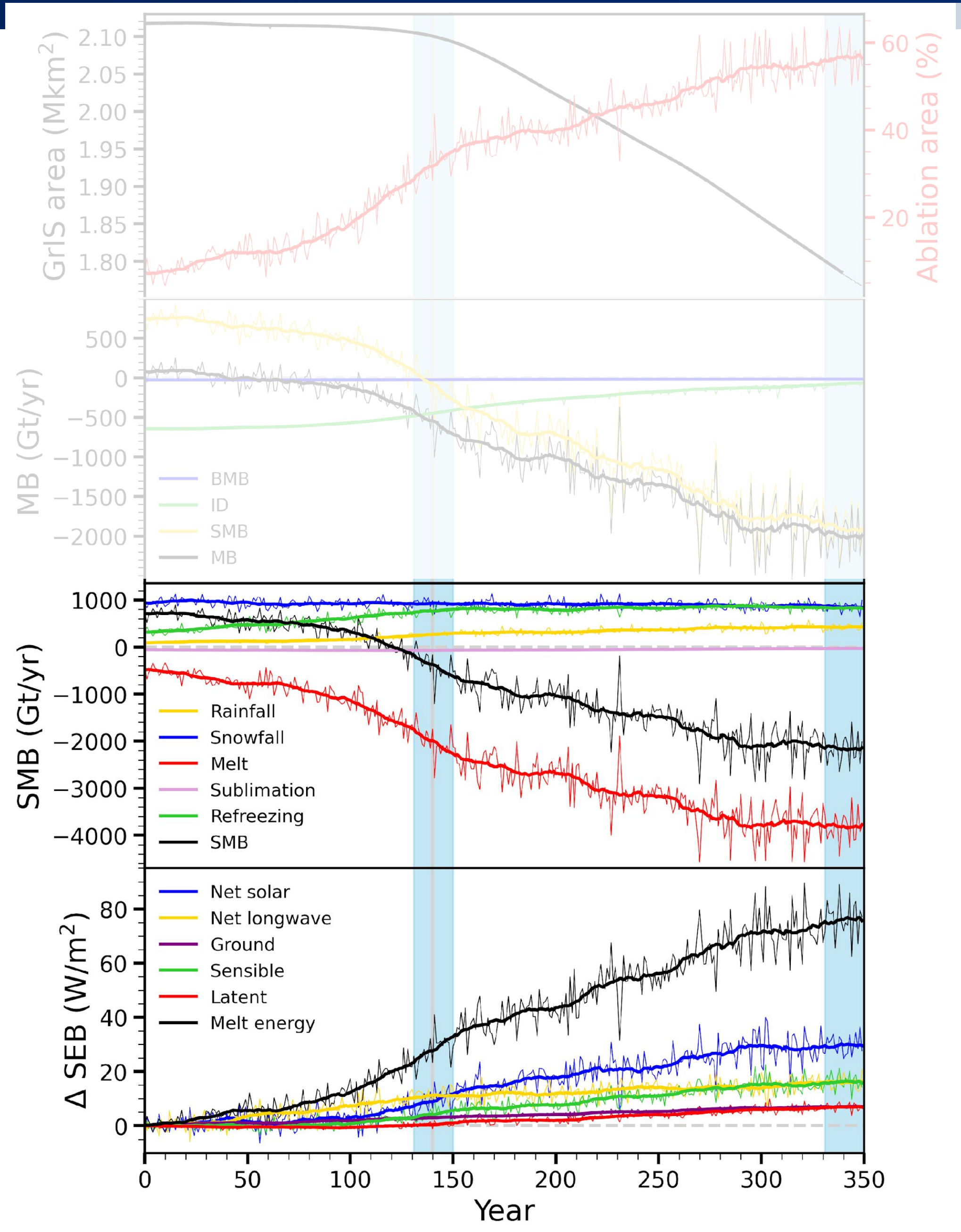
Evolution of MB & SMB

- Mass loss accelerates at ~ yr 100
- SMB dominates mass loss trend

- Melting dominates SMB trend

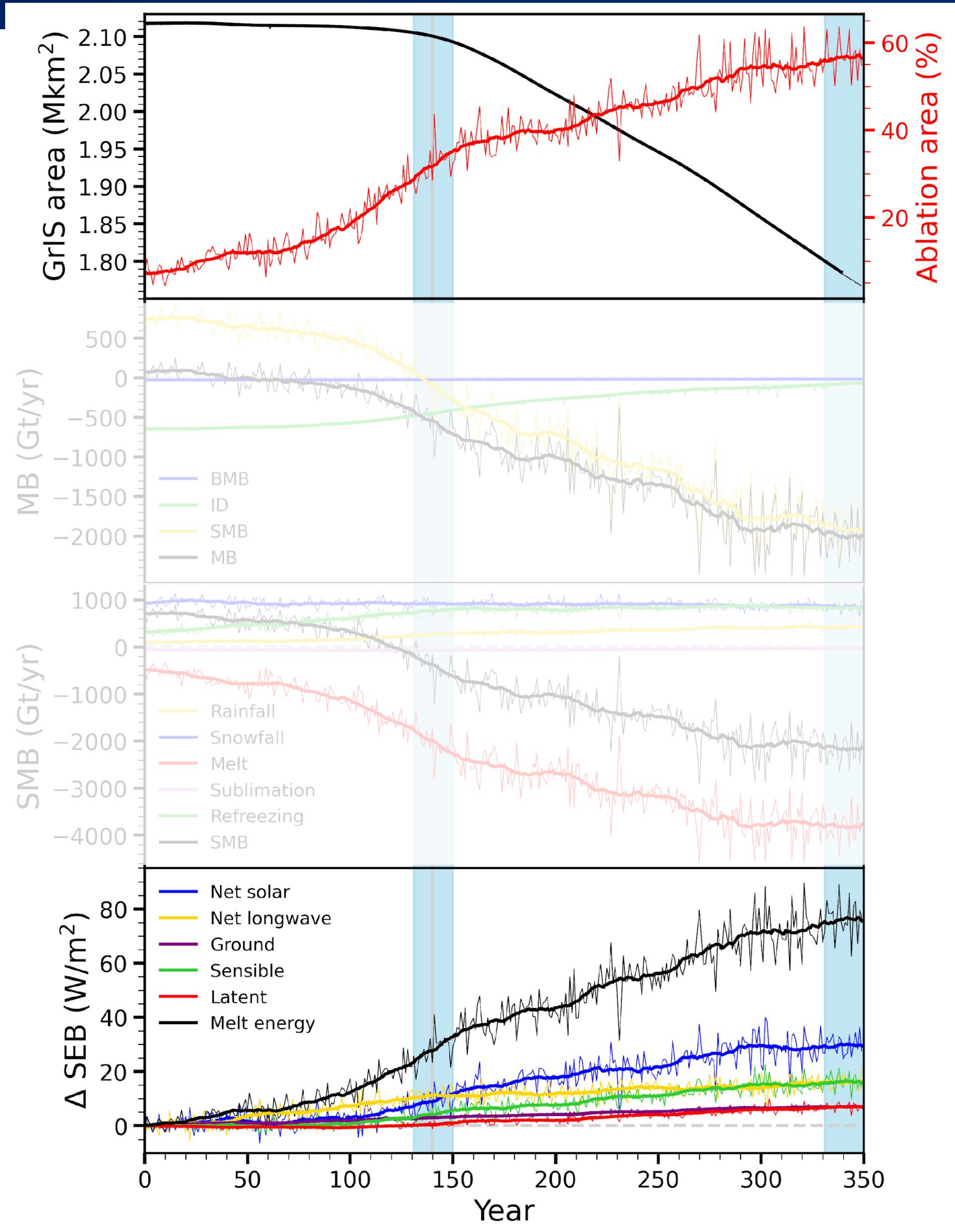


Evolution of MB & SMB



- Melting dominates SMB trend
- Net solar radiation provides most of the melting energy

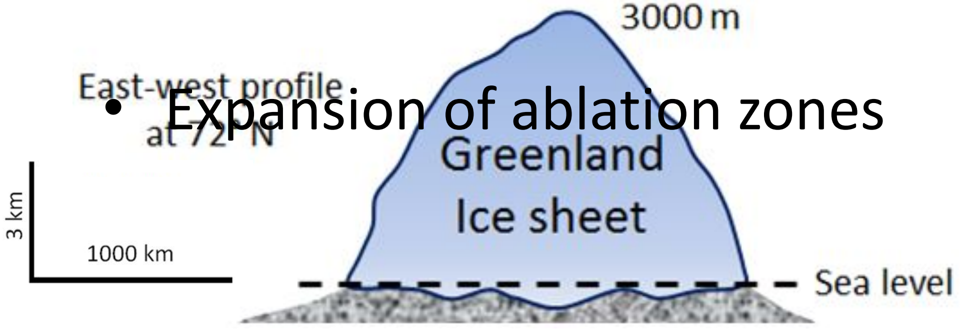
Evolution of MB & SMB



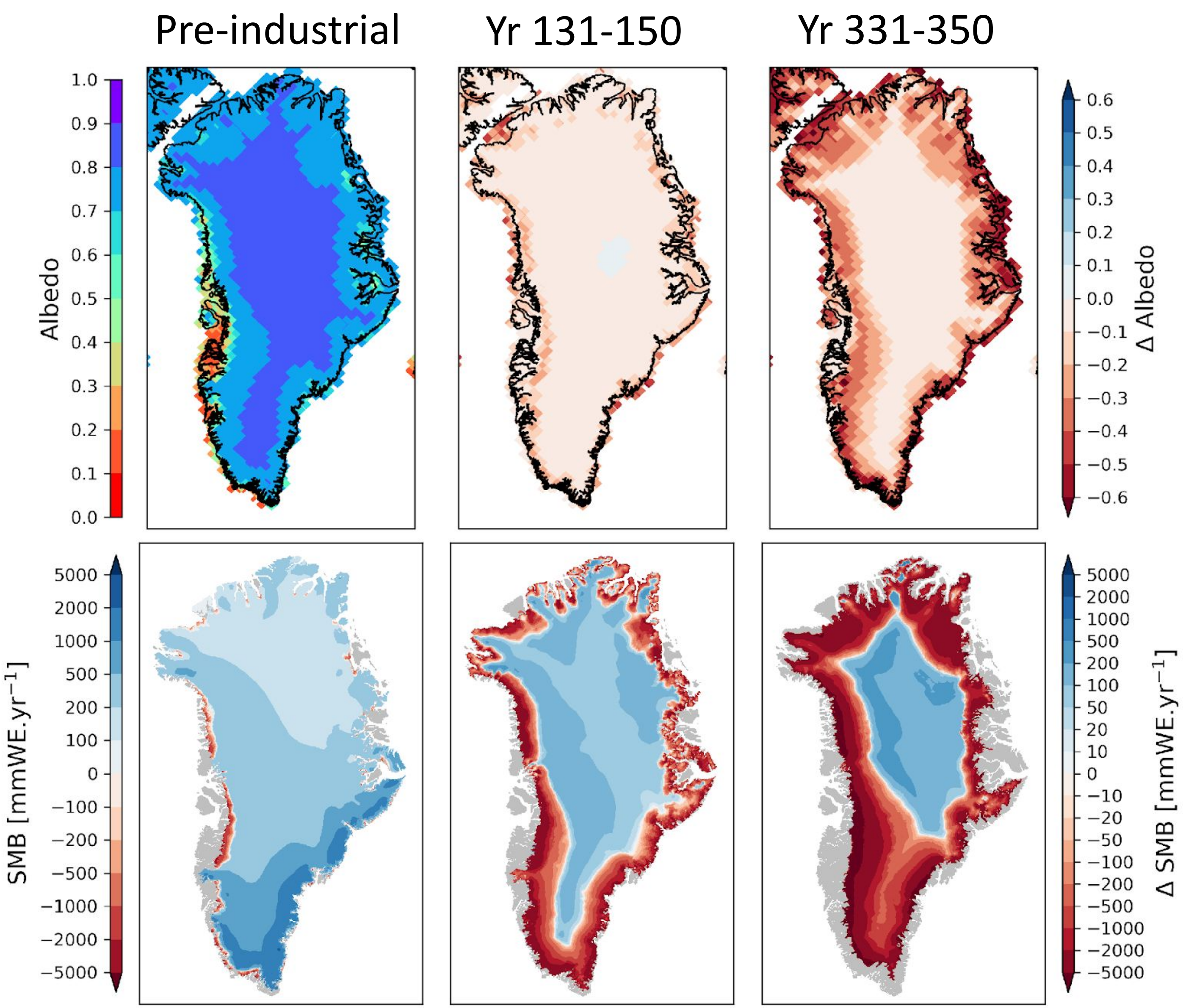
- Net solar radiation provides most of the melting energy

Ice/albedo feedback is triggered

- Surface albedo decreases especially around the margins
- Expansion of ablation zones

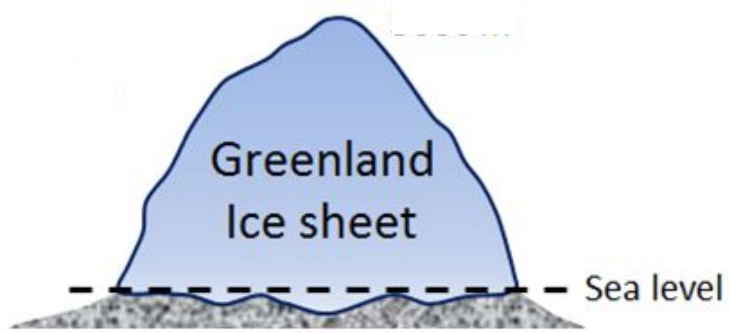


(Earle 2015)

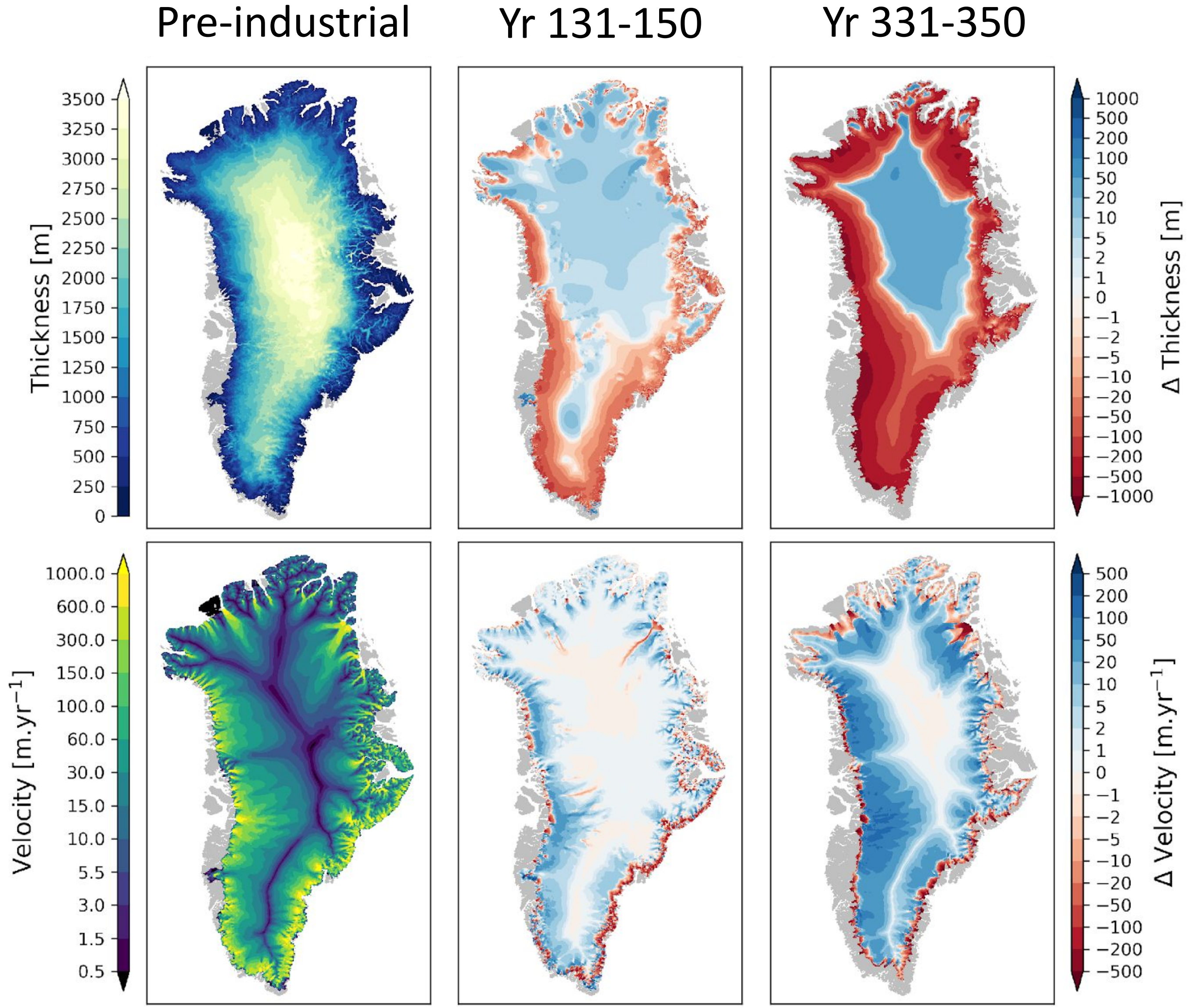


SMB & ice dynamics coupling

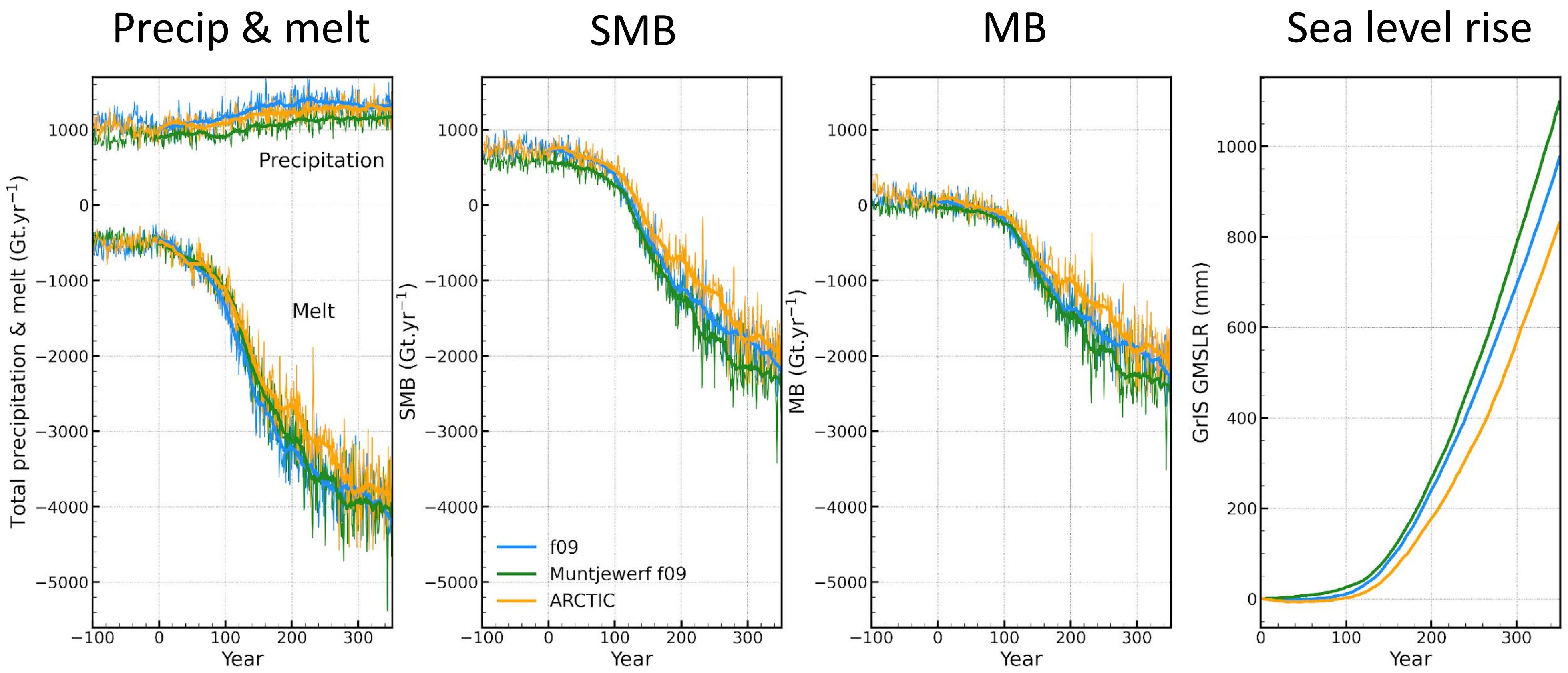
- Extensive thinning over ablation zones



- Increased ice flow from interior towards margins due to steeper slopes



Compared to 1 ° resolution runs



f09 ~ 1100 mm sea level equiv.

f09 ~ 975 mm sea level equiv.

ARCTIC ~ 825 mm sea level equiv.

ARCTIC exhibits a smaller increase in melting

Thanks also to Miren Vizcaino and Kate Thayer-Calder for help with reproducing these results

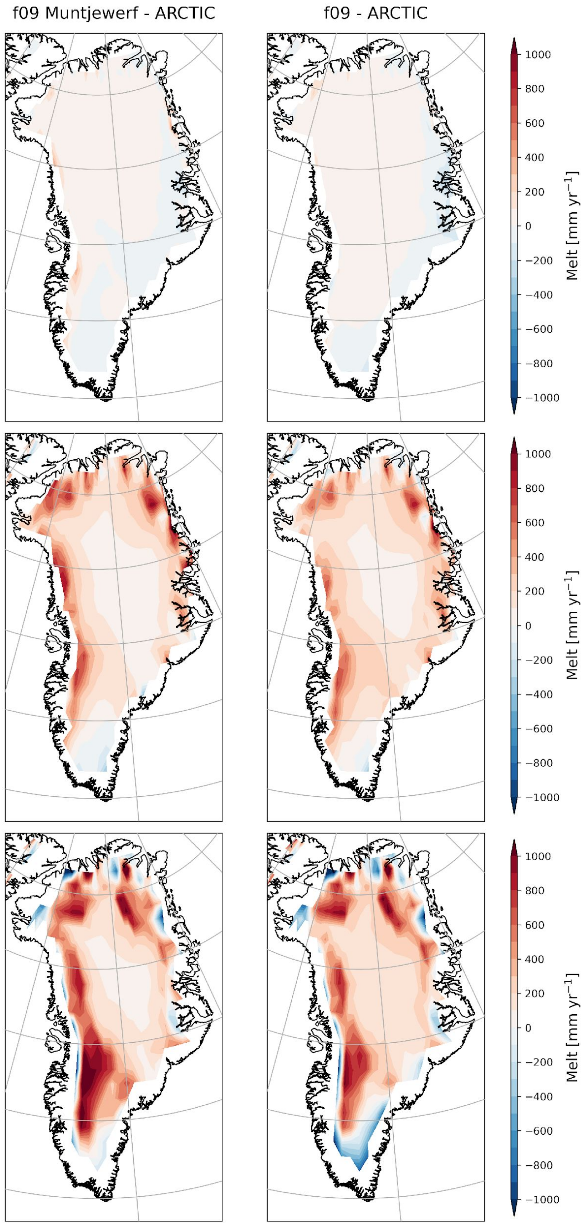
Smaller melt increase of the ARCTIC run

JJA melt differences

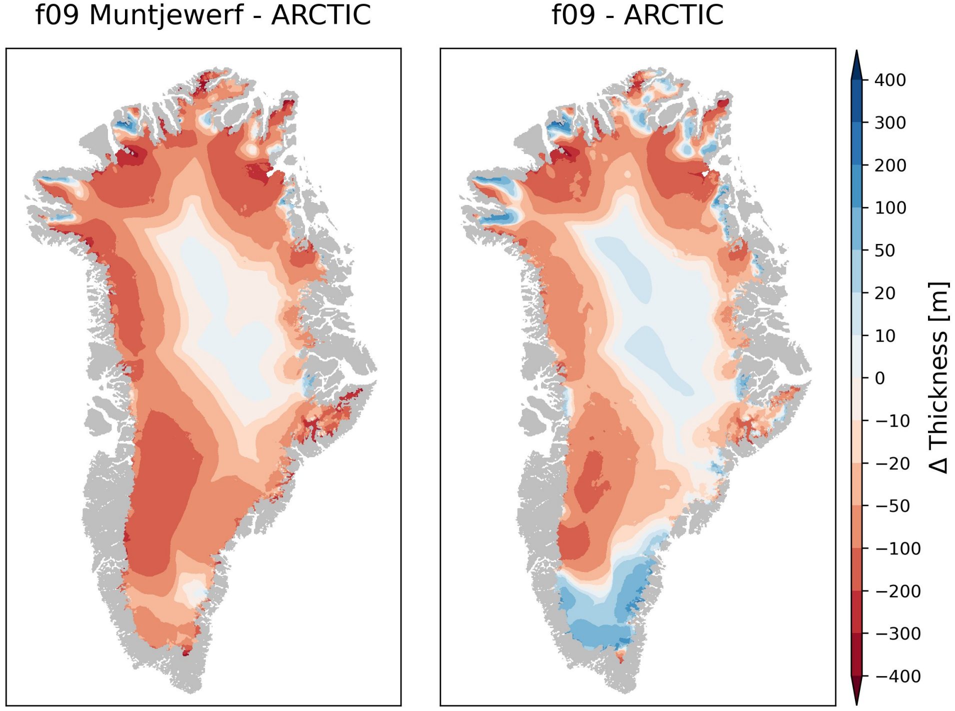
Pre-industrial

CO_2 stabilization

End of simulation



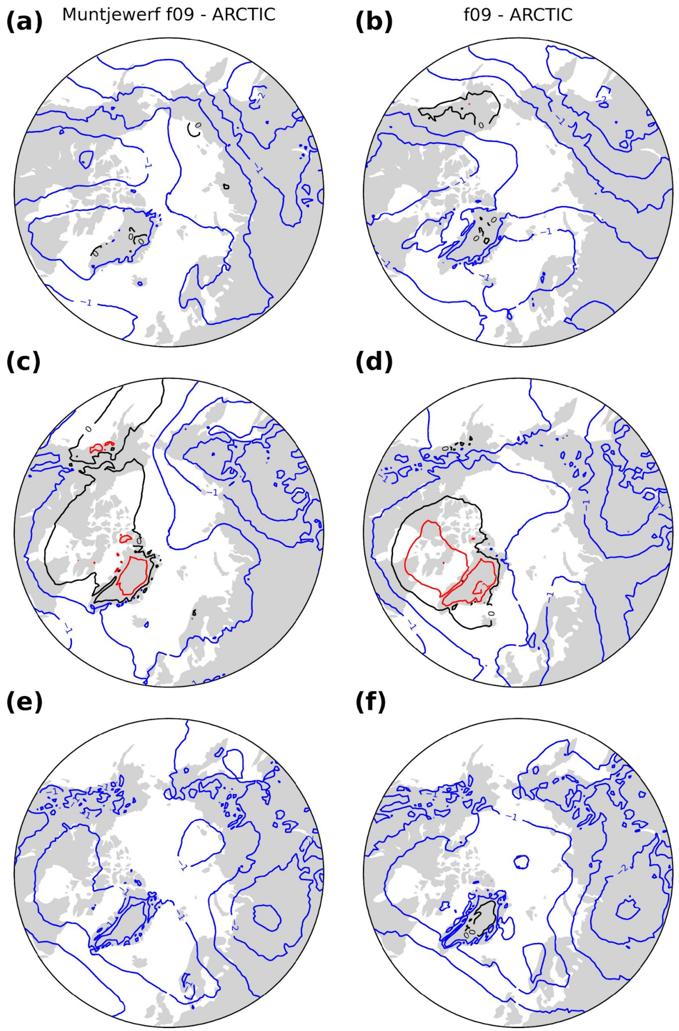
Ice thickness change differences



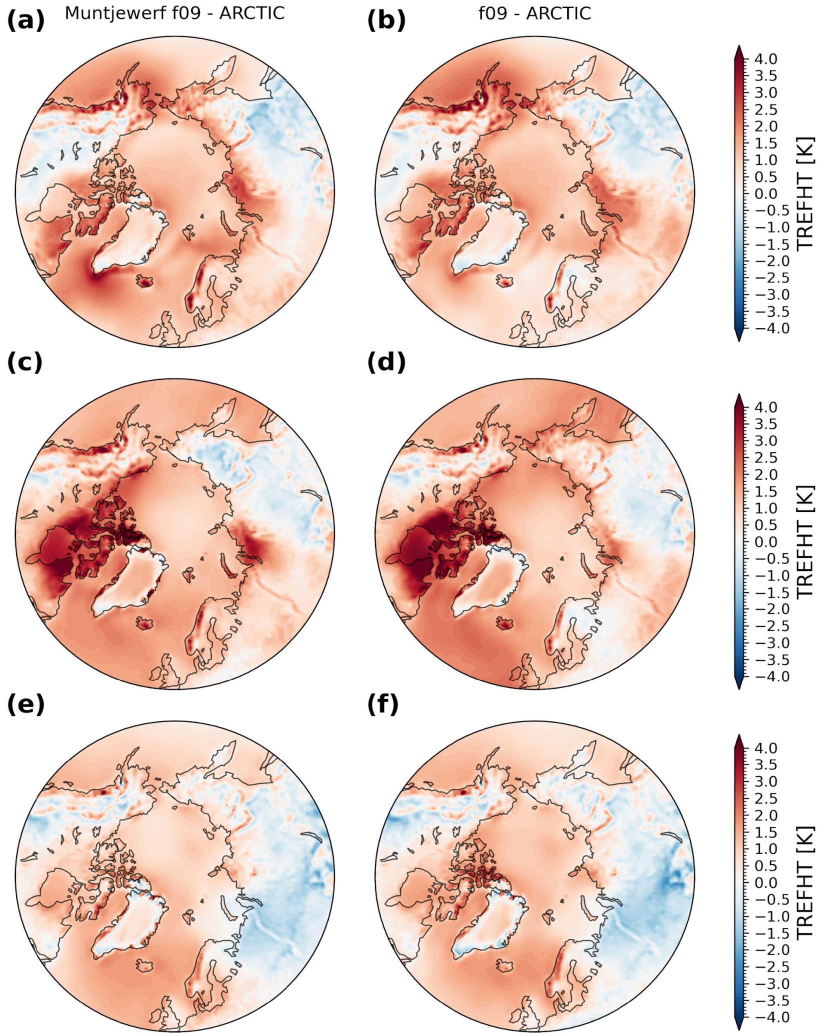
What causes the smaller melt increase of ARCTIC?

Tropospheric & near surface temperatures

Lower troposphere JJA virtual temperature differences



JJA 2m air temperature differences

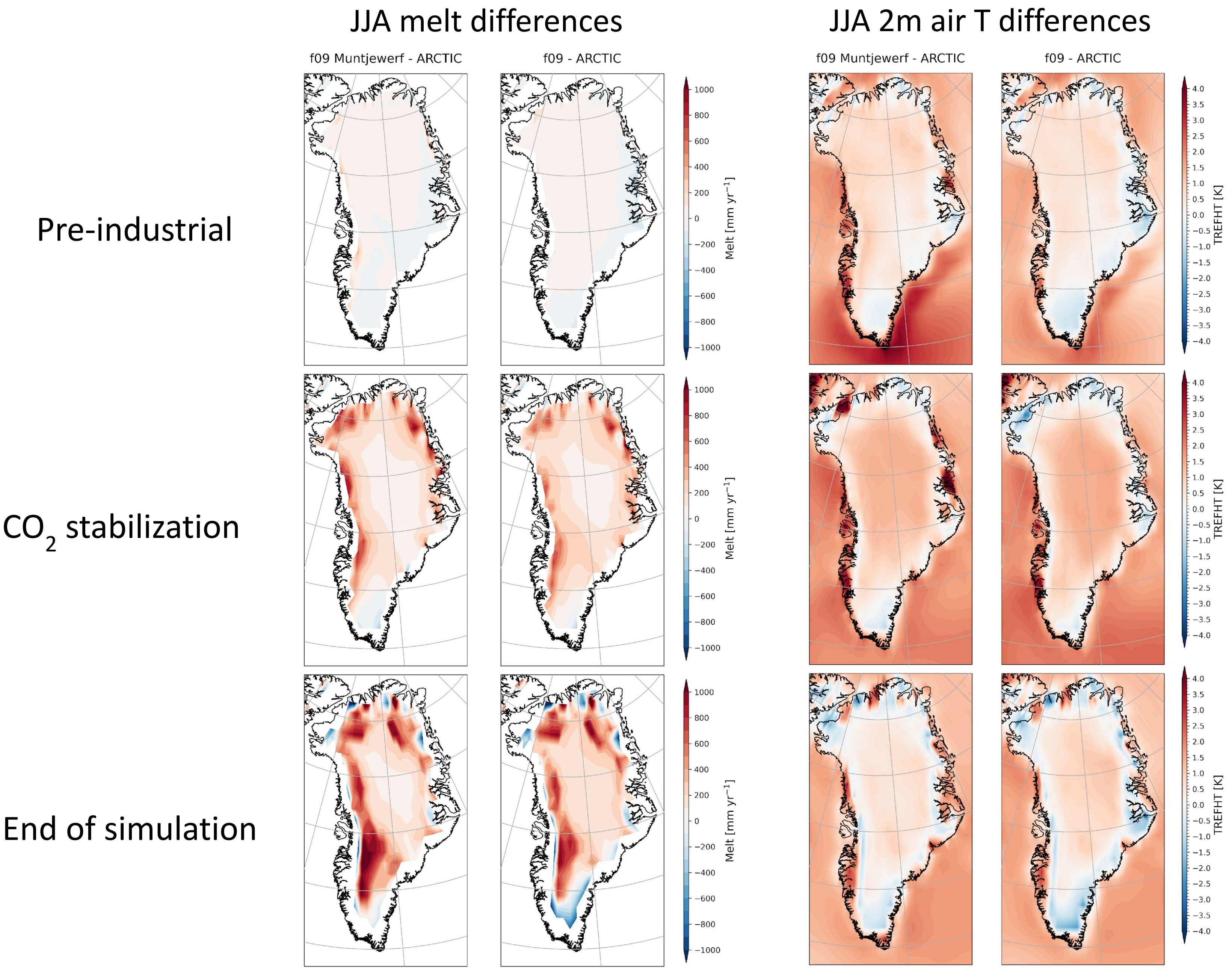


Pre-industrial

CO_2 stabilization

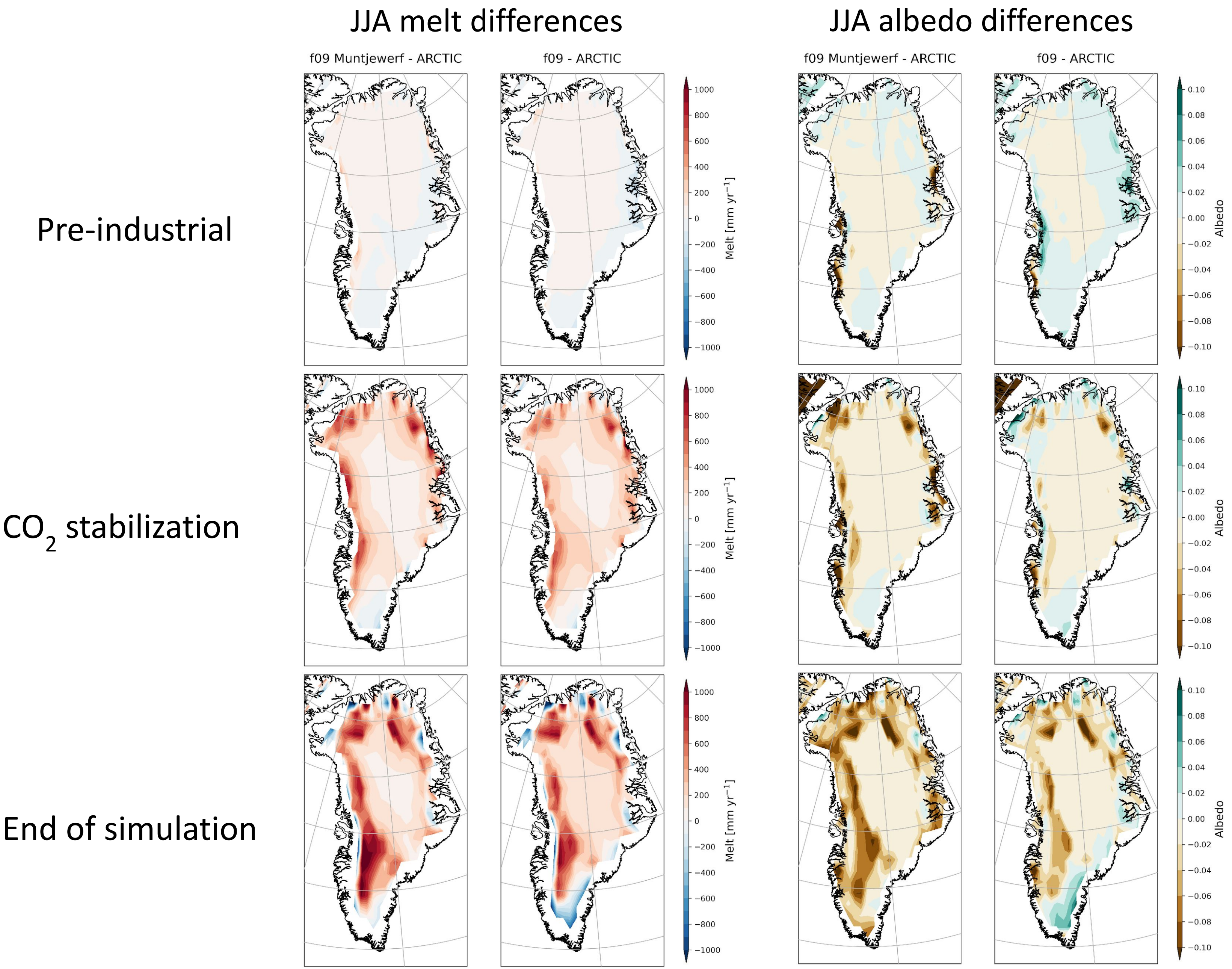
End of simulation

Near surface temperatures



Warmer temperature is not the dominant factor that causes the larger melt of f09 runs

Solar radiation changes



The lower surface albedo of f09 enhances the absorbed solar radiation, causing the larger melt

Conclusions & Next steps

- Similar to Muntjewerf et al. (2020), the GrIS mass loss accelerates after ~ 100 years, which is caused by rapidly increasing surface melt as the ablation area expands and the associated ice/albedo feedback

- Compared to 1° resolution runs, the ARCTIC grid run has smaller summer melt, thus slower mass loss. This is due to a smaller ice/albedo feedback and we are currently looking into the causes for this difference.

- Further compare with the 1° resolution runs and explain the differences

- Include other interactions (effects on atmospheric and oceanic circulation ……)

References

Herrington, A. R., Lauritzen, P. H., Lofverstrom, M., et al. (2022). Impact of grids and dynamical cores in CESM2.2 on the surface mass balance of the Greenland Ice Sheet, Journal of Advances in Modeling Earth Systems

Muntjewerf, L., Sellevold, R., Vizcaino, M., et al. (2020). Accelerated Greenland ice sheet mass loss under high greenhouse gas forcing as simulated by the coupled CESM2.1- CISM2.1. Journal of Advances in Modeling Earth Systems, 12, e2019MS002031

Lofverstrom, M., Fyke, J. G., Thayer-Calder, K., et al. (2020). An efficient ice sheet/Earth system model spin-up procedure for CESM2-CISM2: Description, evaluation, and broader applicability. Journal of Advances in Modeling Earth Systems, 12, e2019MS001984

Muntjewerf, L., Sacks, W. J., Lofverstrom, M., et al. (2021). Description and demonstration of the coupled Community Earth System Model v2 – Community Ice Sheet Model v2 (CESM2-CISM2). Journal of Advances in Modeling Earth Systems, 13, e2020MS002356.

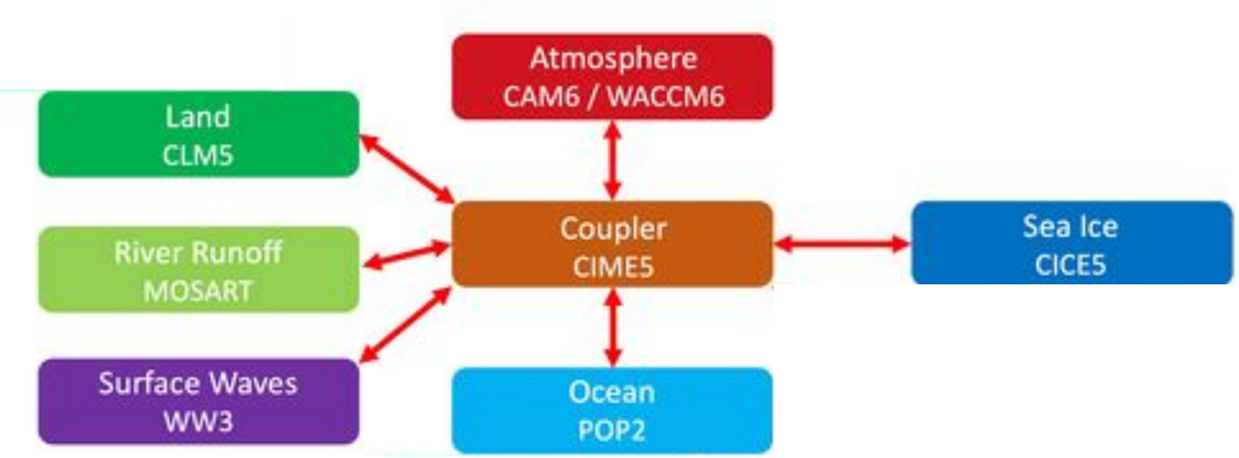
Earle, S (2015). Physical Geology, BCcampus

Coupled climate-ice sheet modeling

Community Earth System Model version 2

(available at www.cesm.ucar.edu:/models/cesm2/)

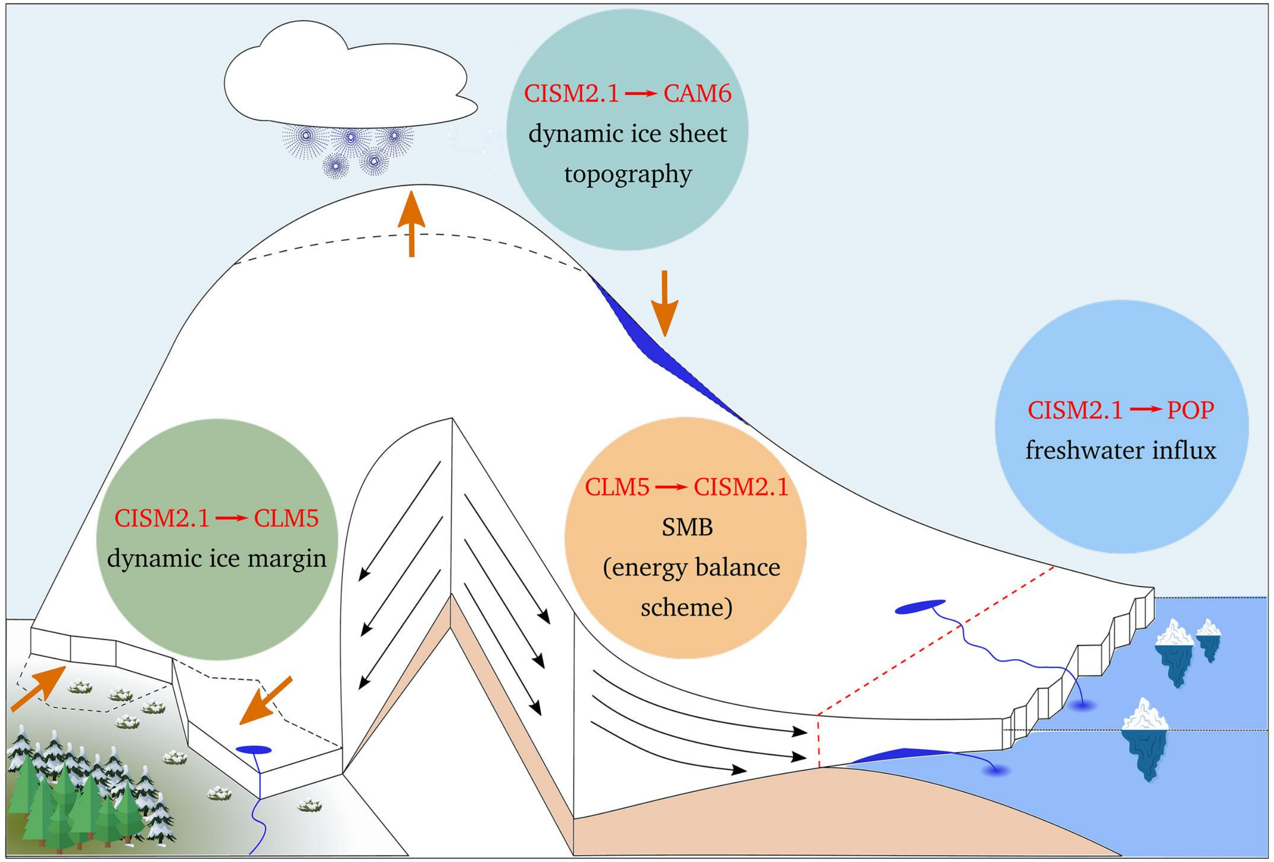
CESM2 components



Community Ice Sheet Model v2

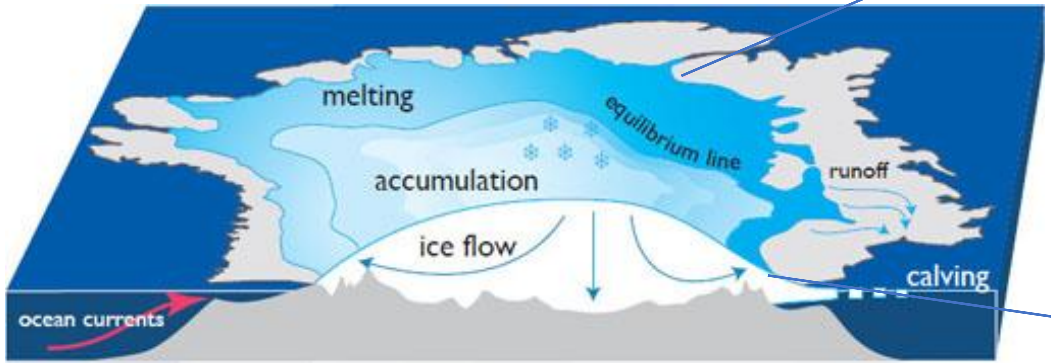
(Danabasoglu et al. 2020)

Coupled CESM2.2-CISM2.1

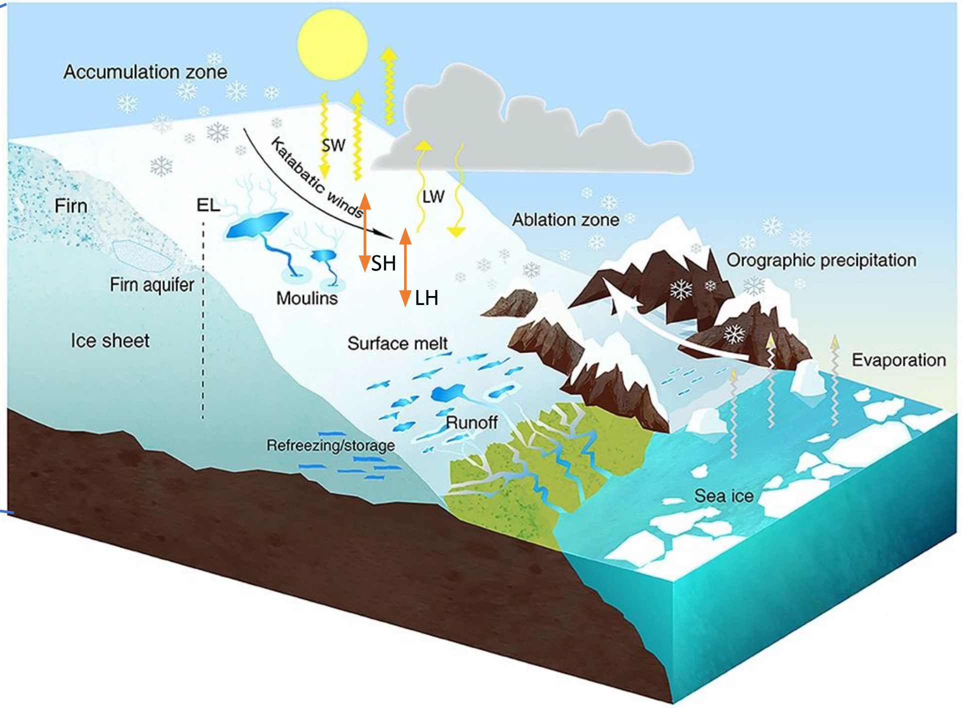


(Muntjewerf et al. 2021)

Ice sheet mass balance & surface mass balance



(National Research Council. 2012)



(Lenaerts et al. 2019)

MB = SMB + BMB - ID

MB: mass balance
SMB: surface mass balance
BMB: bottom mass balance
ID: ice discharge

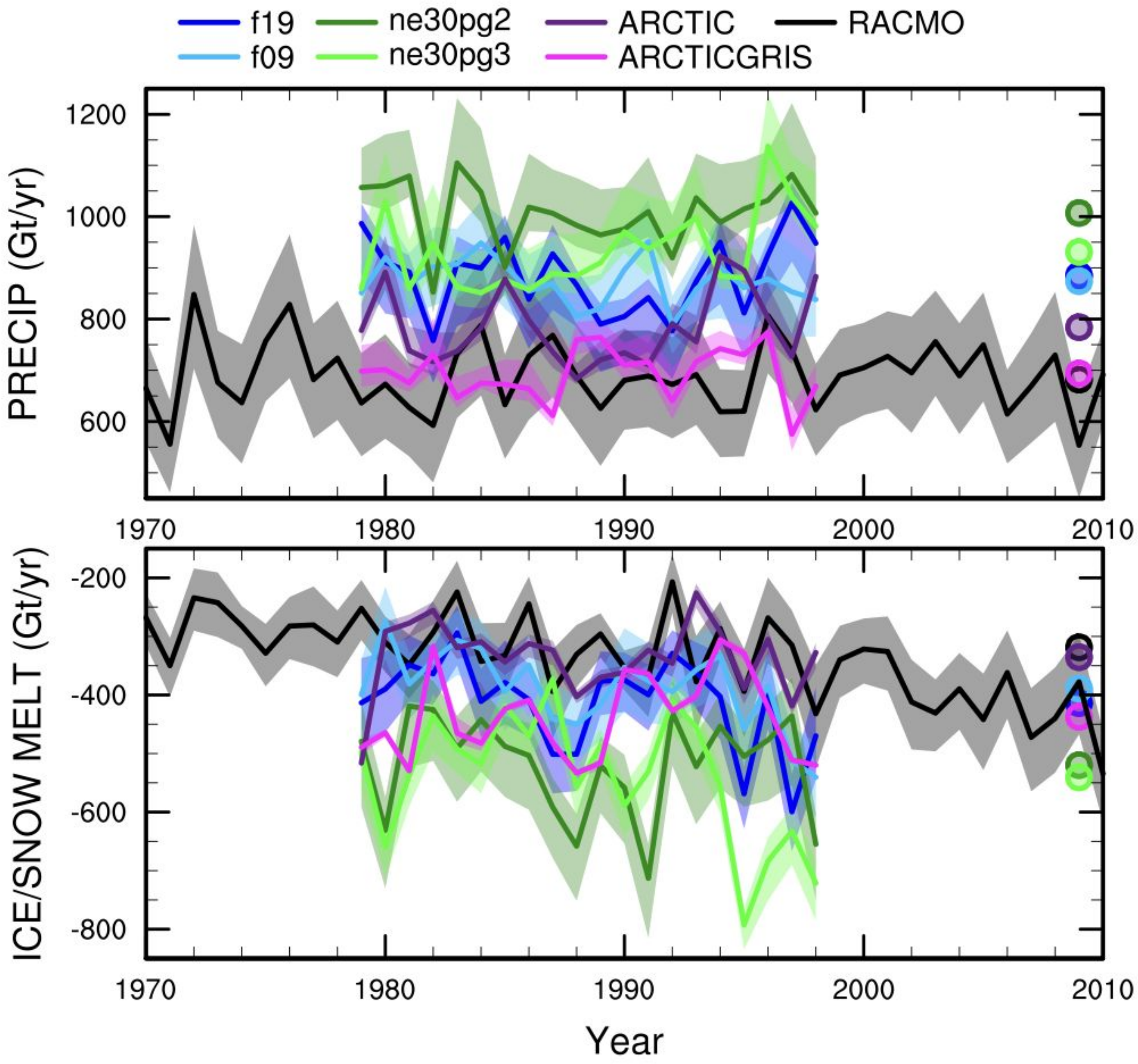
SMB = (Snowfall + Rain) - Runoff - Sublimation

SMB = Snowfall + Refreezing - Melt - Sublimation

Refreezing = Rain + Melt - Runoff

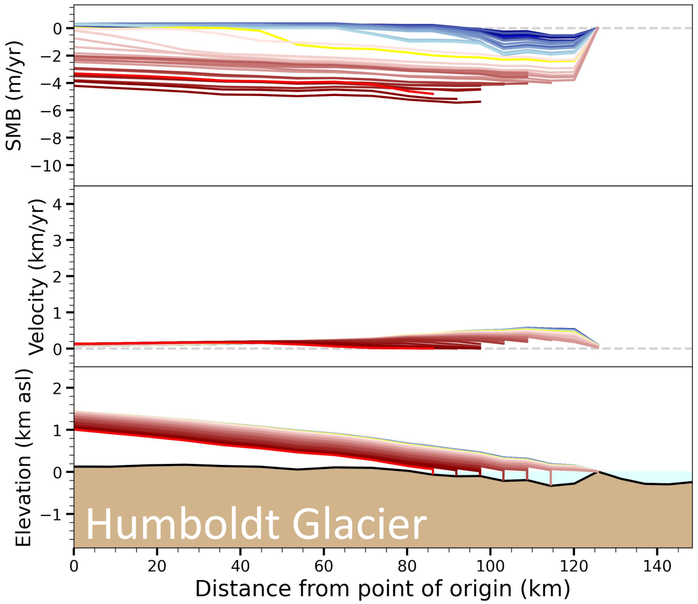
Melt energy = $LW_{net} + SW_{net}$ + Latent heat + Sensible heat + Ground heat

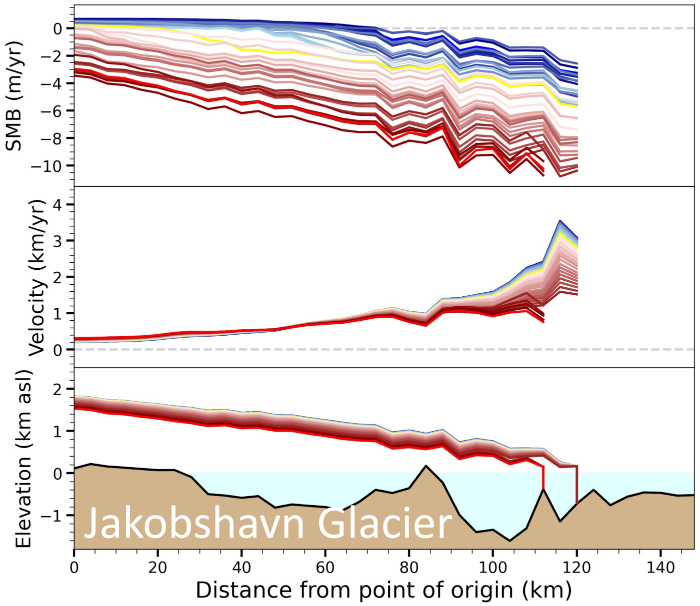
Dynamical core or grid resolution

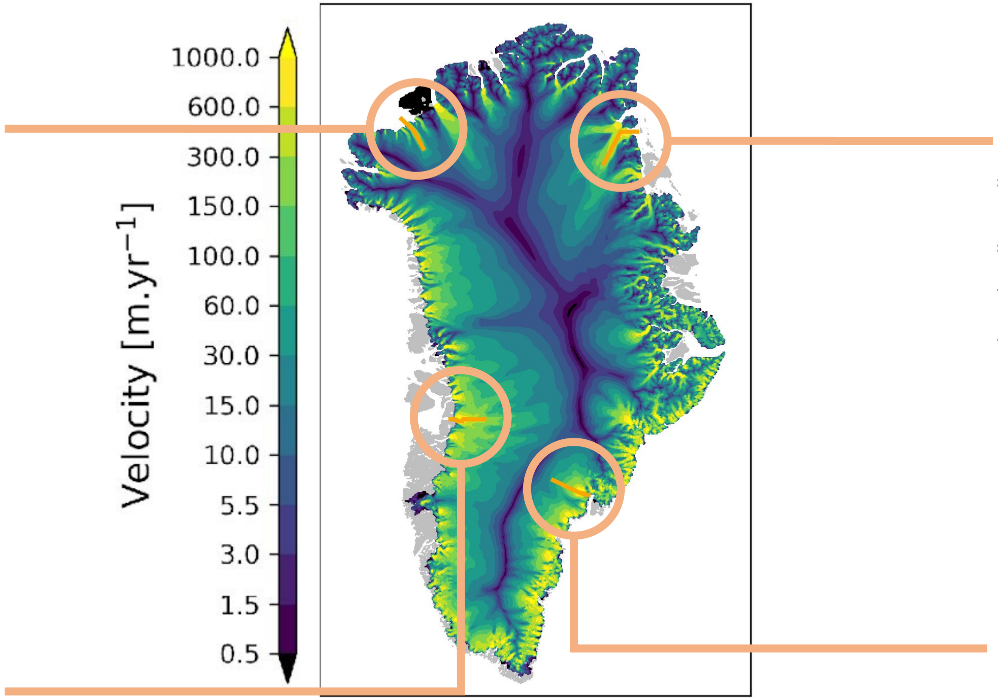


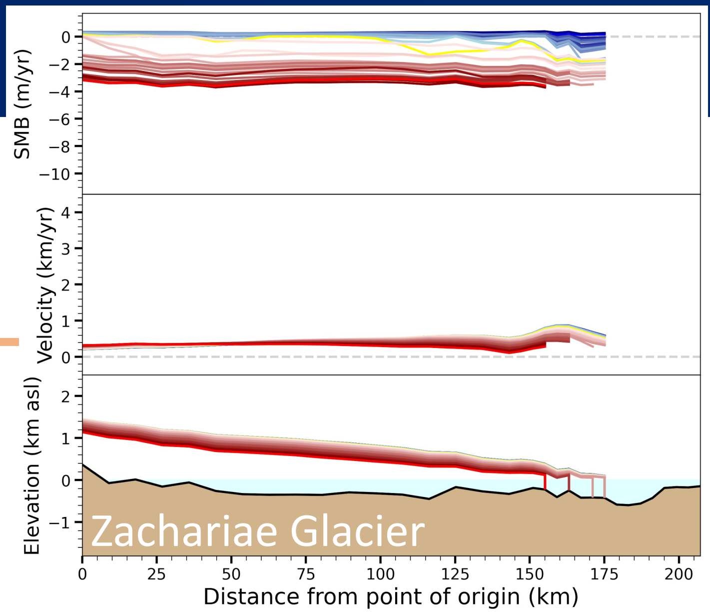
(Herrington et al. 2022)

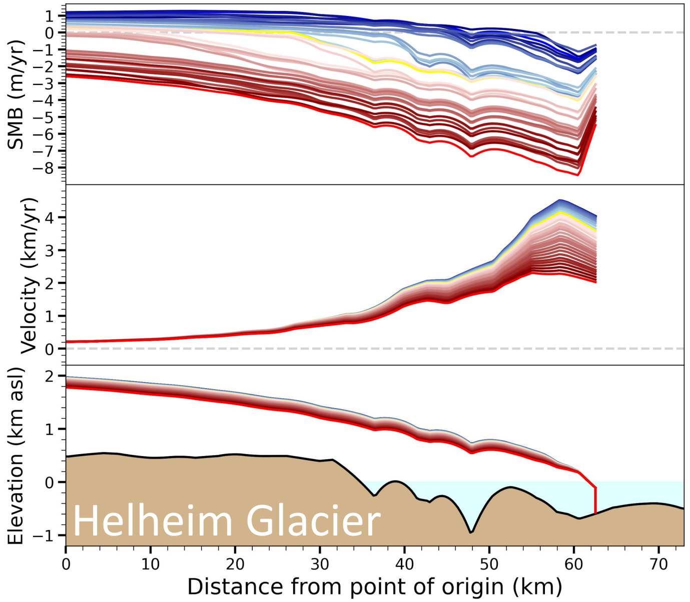
Glacier flowlines

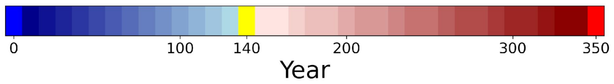








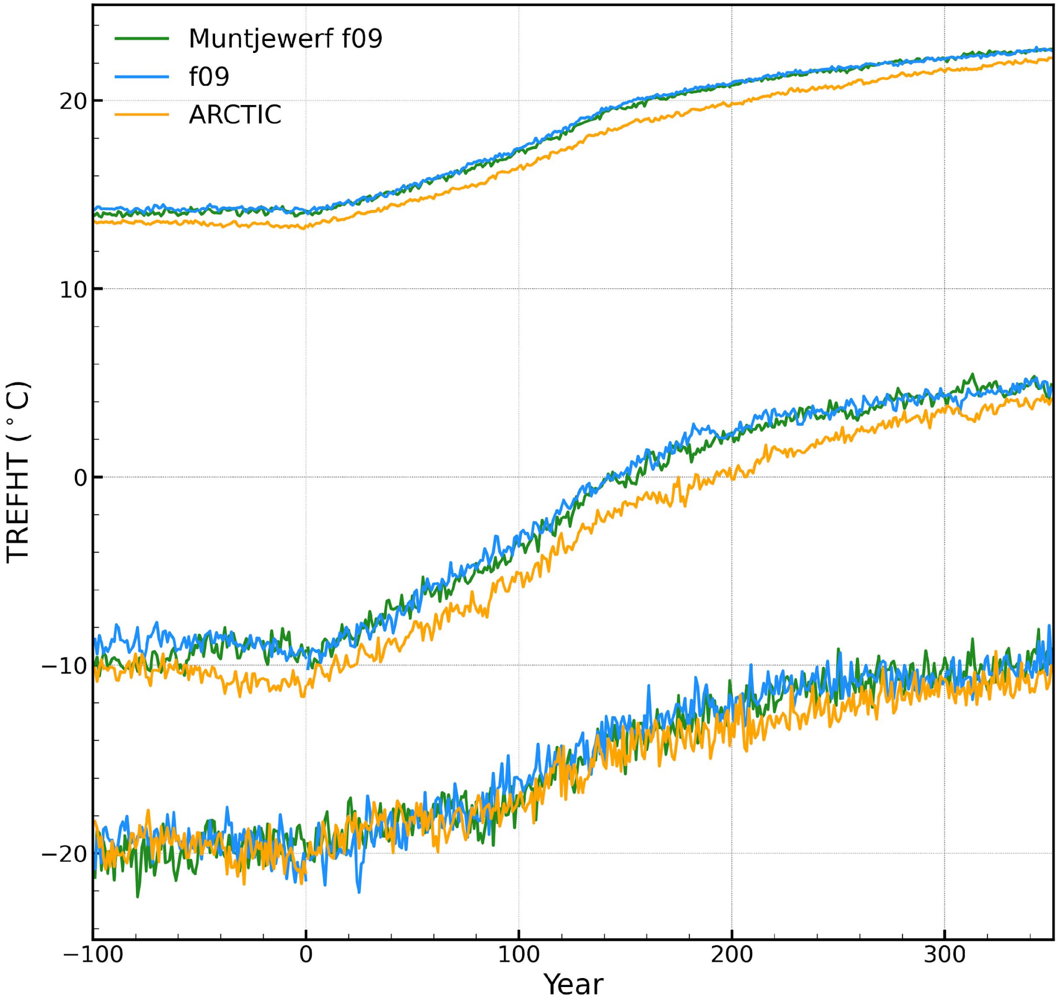




Heterogeneous sensitivity of these outlet glaciers to the simulated climate change, with glaciers in the northern basin retreating the most

Flowline coordinates courtesy of Michele Petrini

Mean temperature evolution

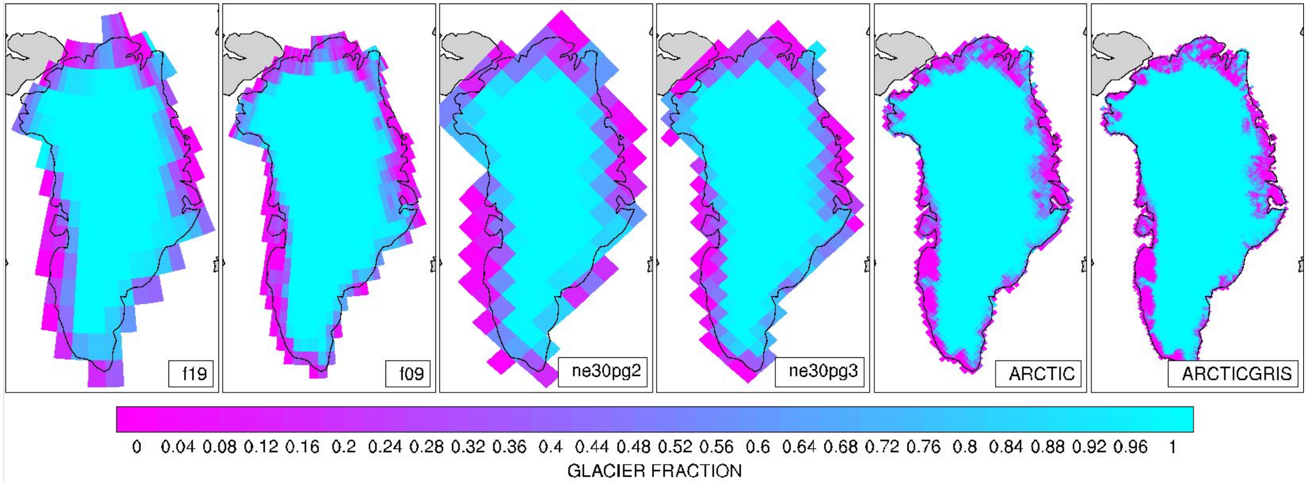


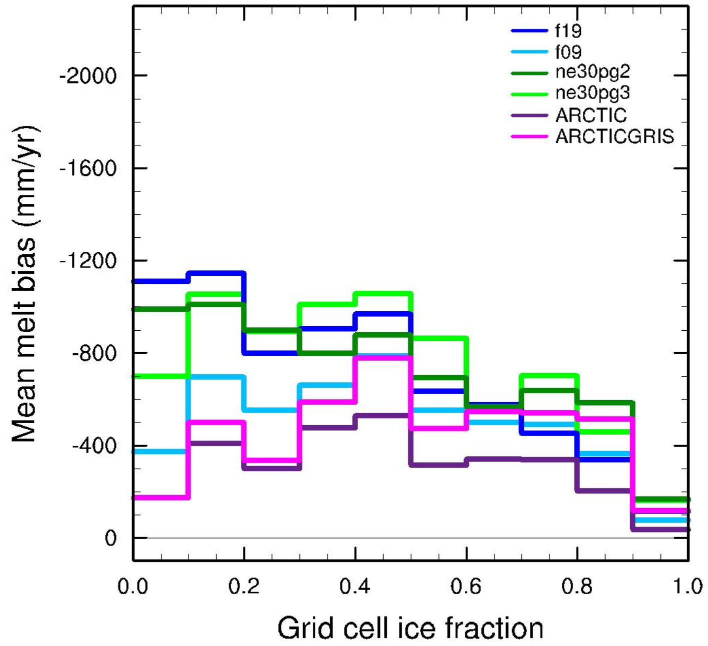
Global mean

Arctic mean

Greenland mean

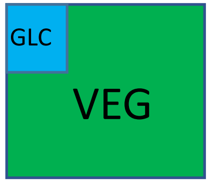
Problem with mixed land surface types



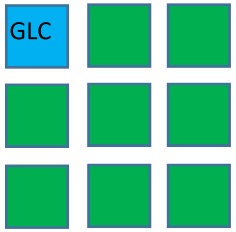


(Herrington et al. 2022)

1˚-2˚ models



1/4˚ to 1/8˚ models

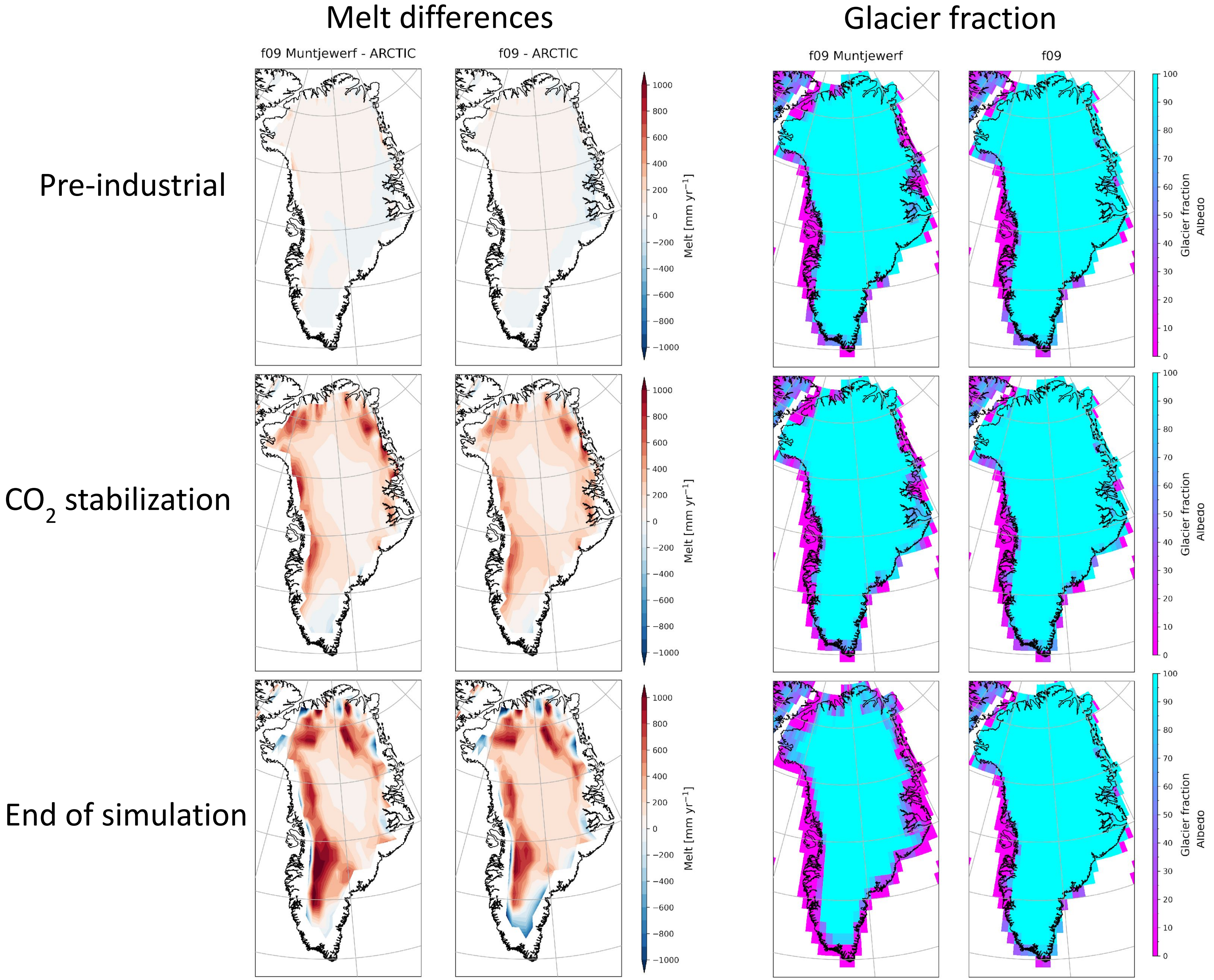


- **Smaller grid cell ice fractions have larger (more negative) melt biases**
- **1/4˚ and 1/8˚ alleviates this dependence of melt bias on ice fraction, because it largely resolves the ice margin**

Melt bias vs. grid cell ice fraction plot

- Map all runs to the coarsest grids (f19/ne30pg2)
- Bin melt bias by grid cell ice fraction (on coarse f19/ne30pg2 ice masks)

Compared to 1° resolution runs



Better resolved orographic precipitation