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

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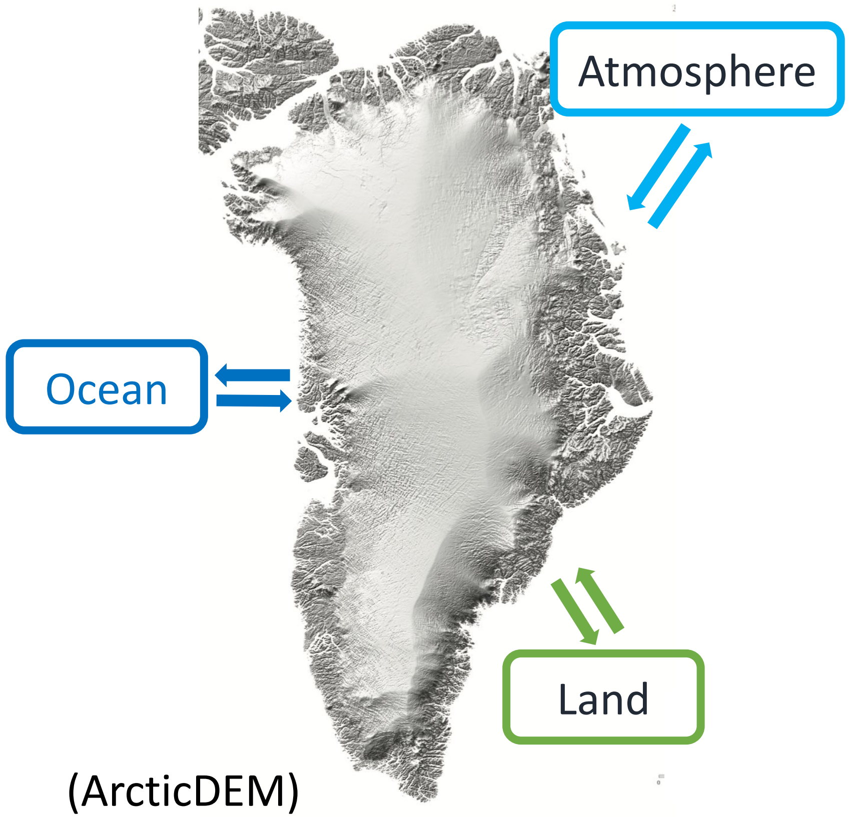
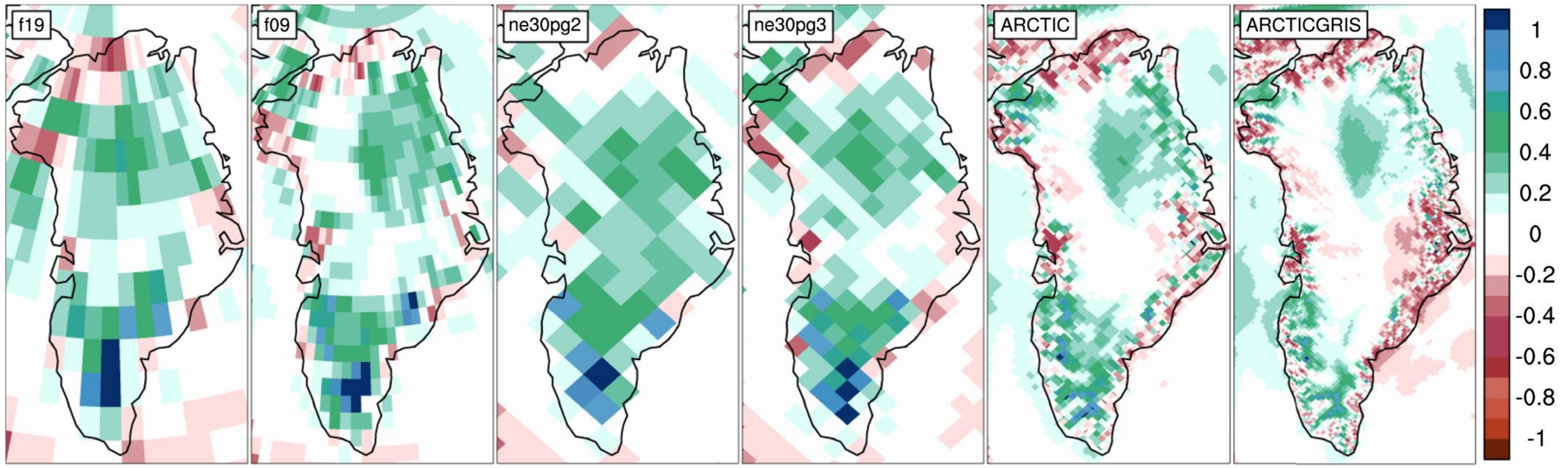
Background



(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

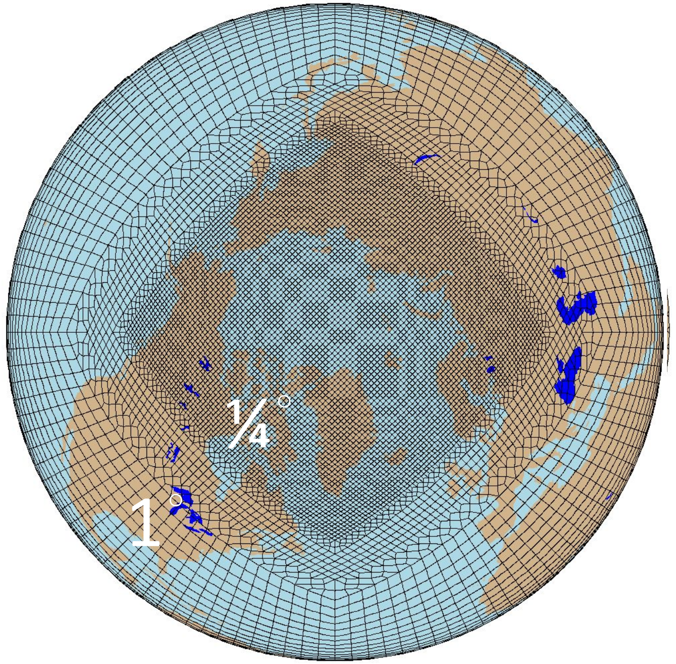
- Atmosphere/land: VR grid 'Arctic'
- Ice sheet: 4km
- Ocean: 1 $^\circ$
- 32 hybrid σ-p vertical atmospheric levels

- Regional high resolution (¼ $^\circ$)
- A unified, coupled model infrastructure
- Reduce computational cost

Compare to CMIP6 1 ˚ workhorse (CESM2.1)

- **Muntjewerf et al. (2020) and …**

'Arctic' grid



(Herrington et al. 2022)

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

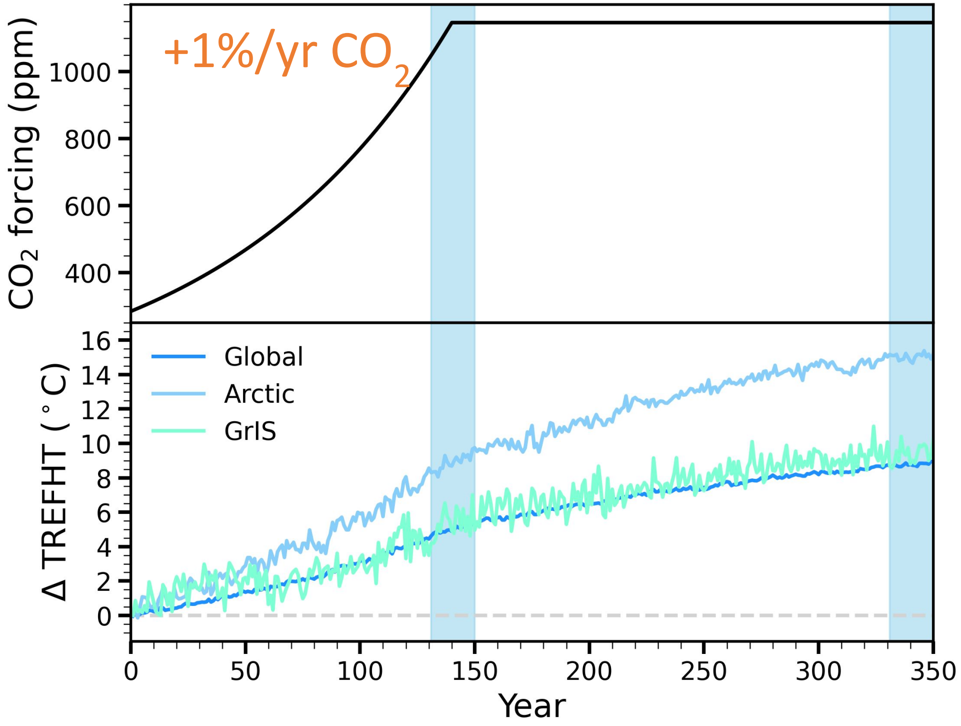
10 times more expensive than 1 $^\circ$ run

Experiment setup

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

piControl
(180yrs)

4x pre-industrial CO_2



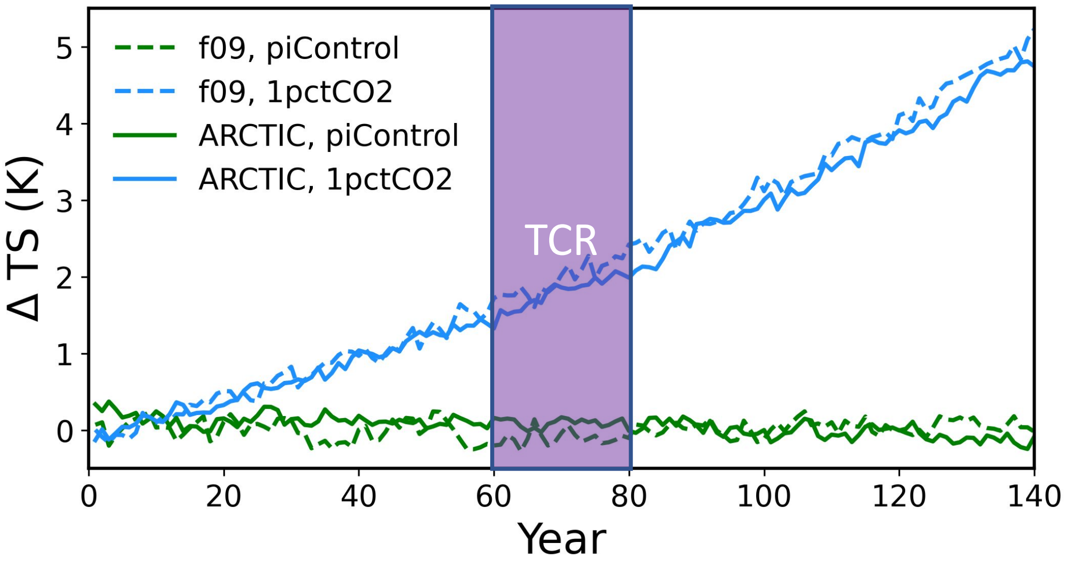
Arctic amplification (1.8)

Greenland amplification (1.1)

Compare to f09 in Muntjewerf et al. (2020)

First results: lower TCR*

- f09: 1.95 K
- ARCTIC: 1.65-1.78 K

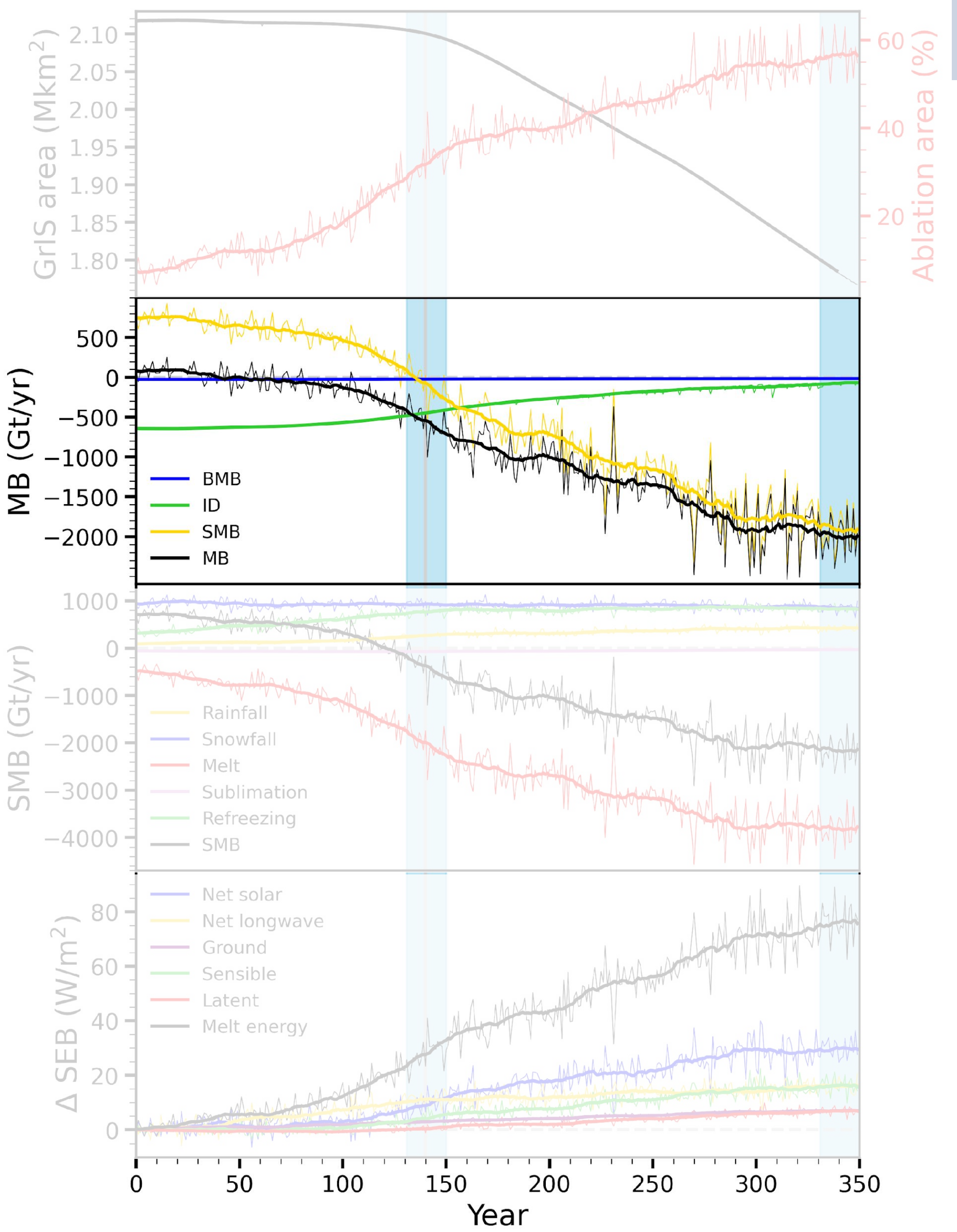


*Transient Climate Response (TCR) is the avg sfc temperature change in the 20-year period when the CO_2 concentration doubles in a 1%CO_2 experiment

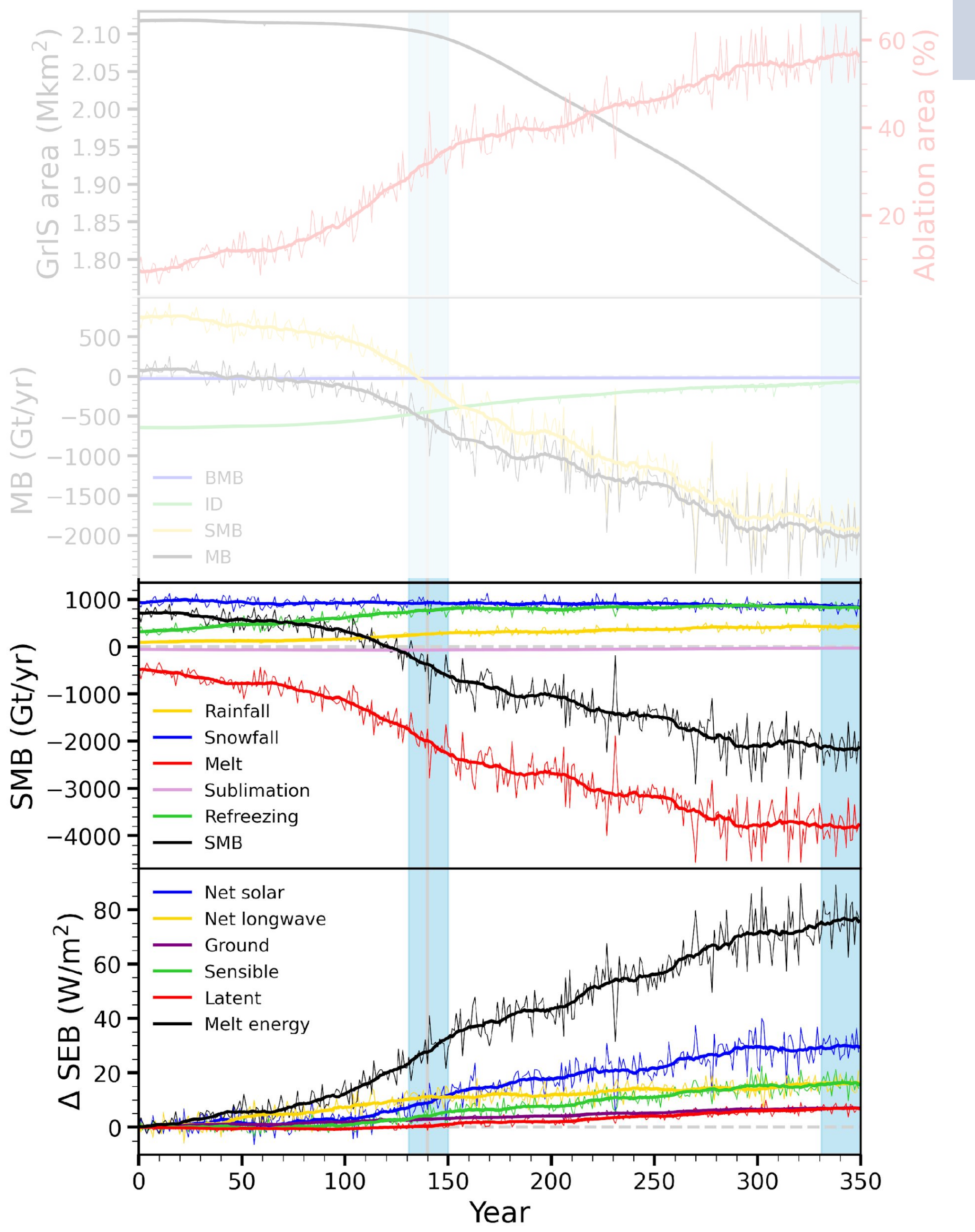
Evolution of MB & SMB

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

SMB = Snowfall + Refreezing - Melt - Sublimation



Evolution of MB & SMB



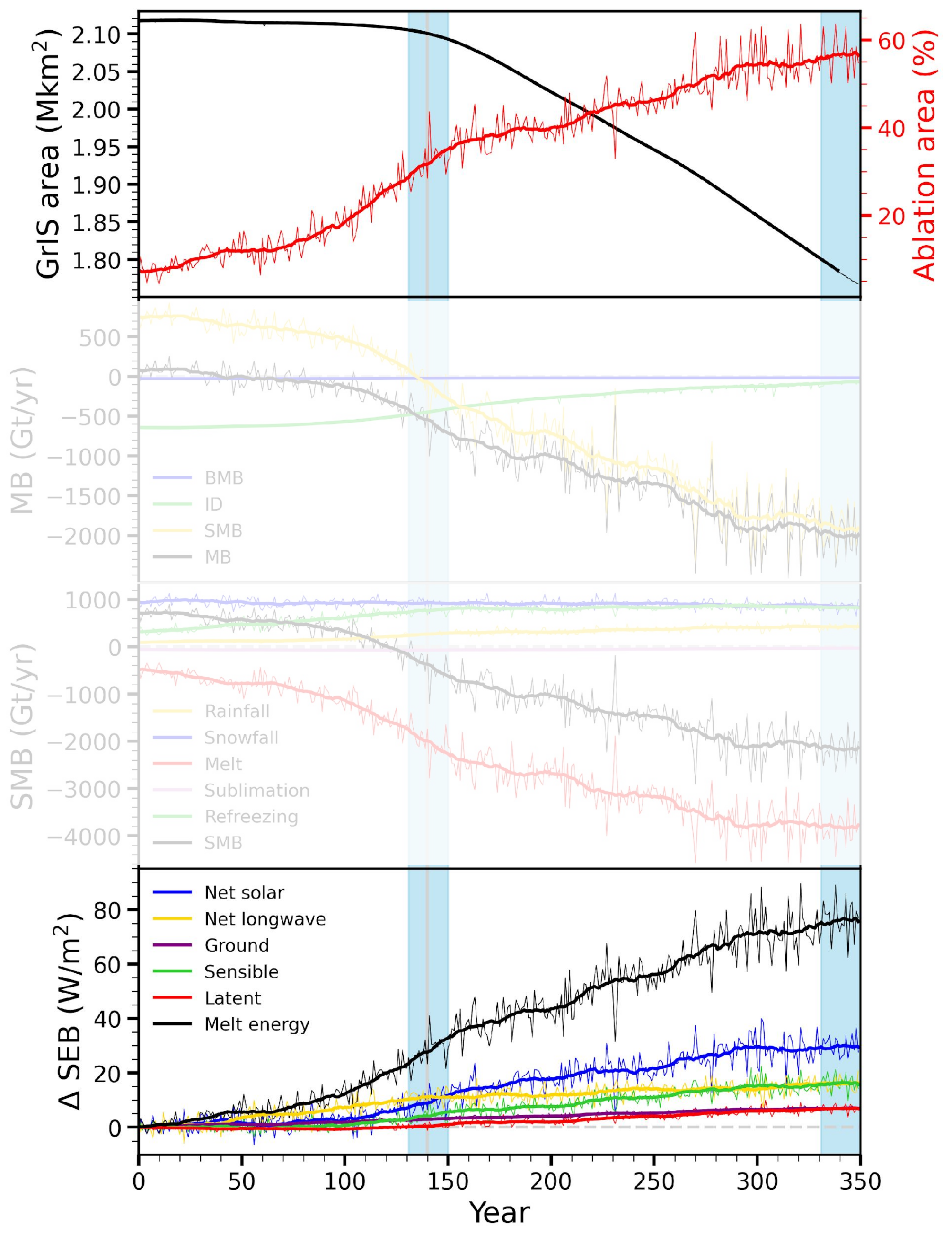
- Melting dominates SMB trend

Melt energy = $LW_{net} + SW_{net} + LH + SH + GH$

- Net solar radiation provides most of the melting energy

Evolution of MB & SMB

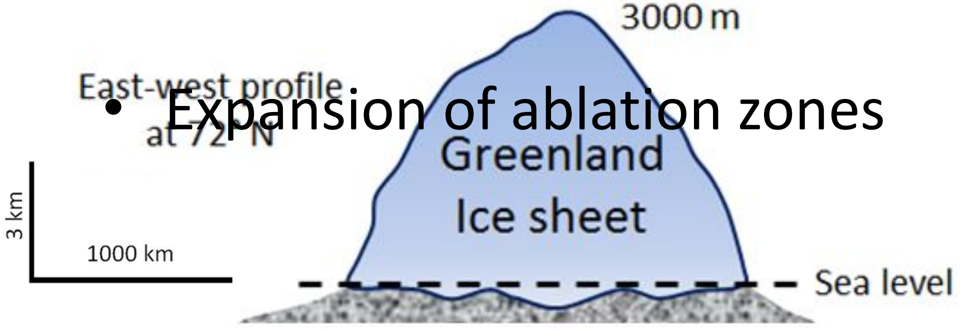
- Net solar radiation provides most of the melting energy



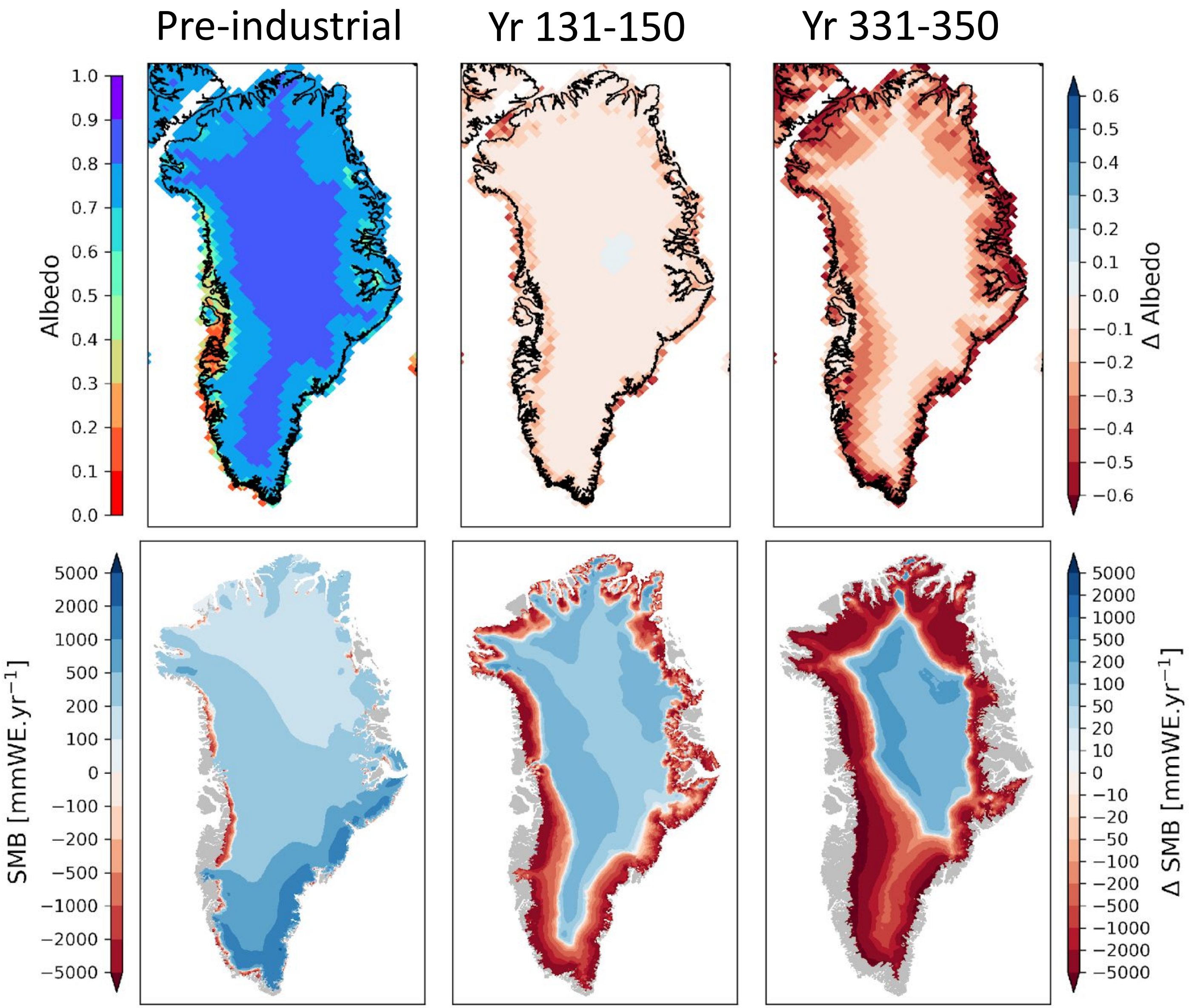
Ice/albedo feedback is triggered

- Surface albedo decreases especially around the margins

- Expansion of ablation zones

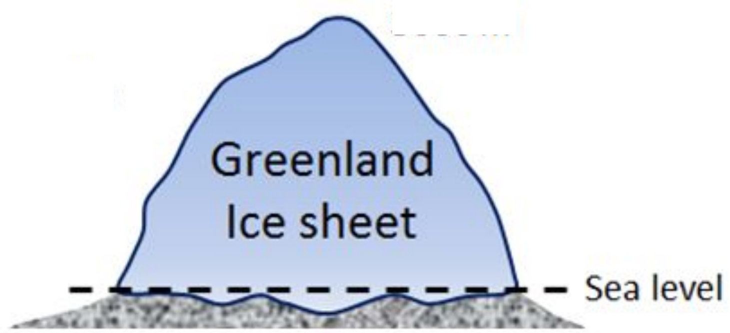


(Earle 2015)

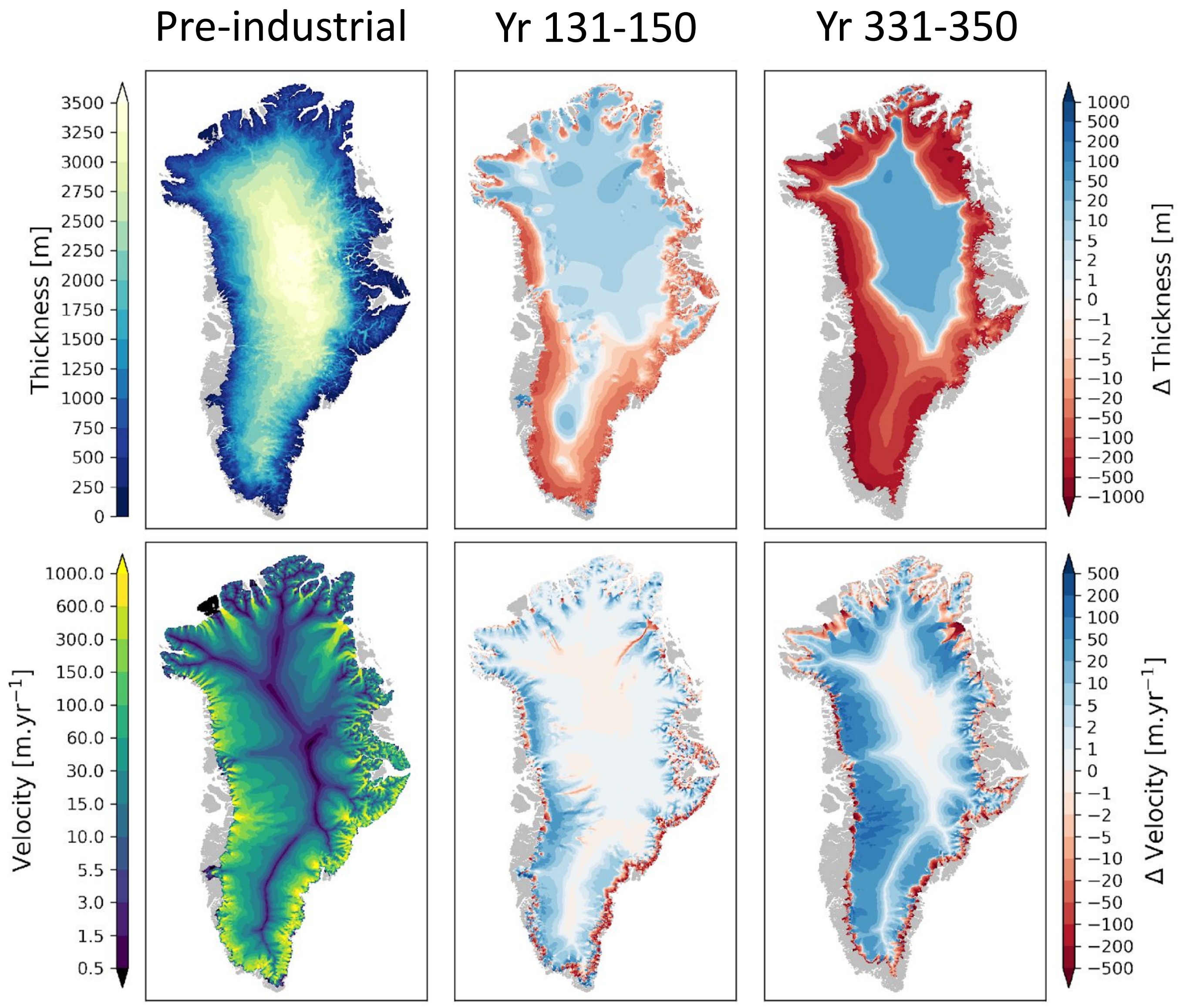


SMB & ice dynamics coupling

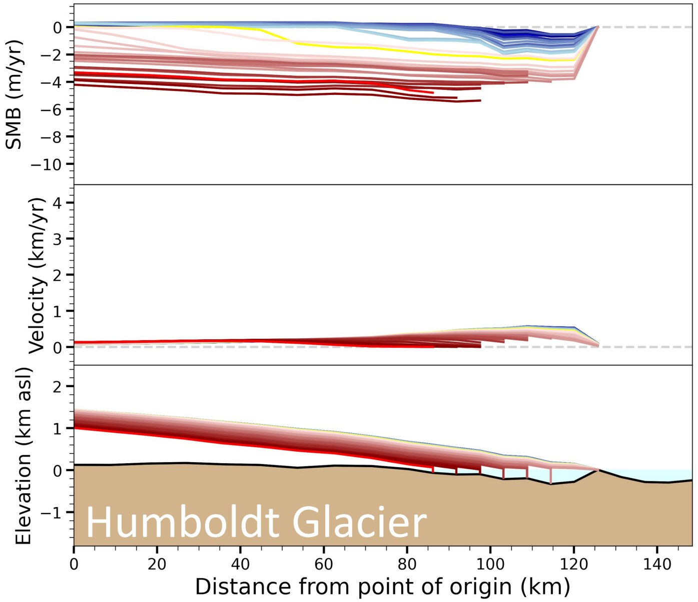
- Extensive thinning over ablation zones

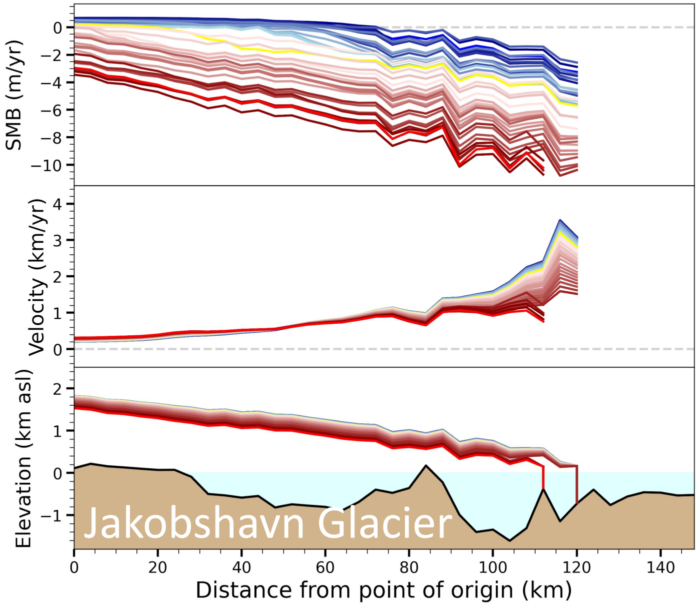


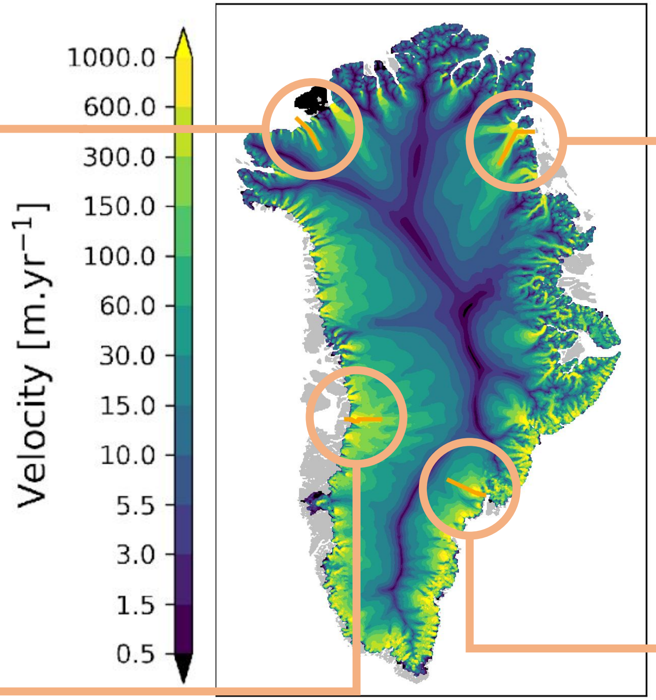
- Increased ice flow from interior towards margins due to steeper slopes

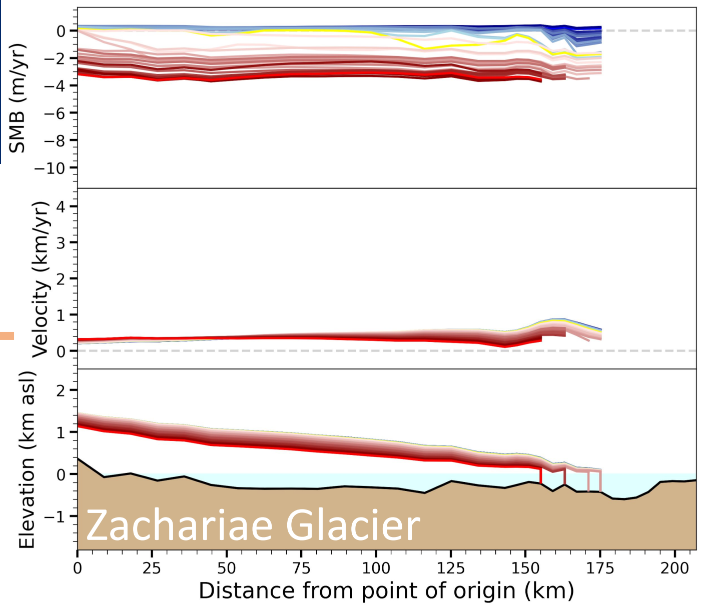


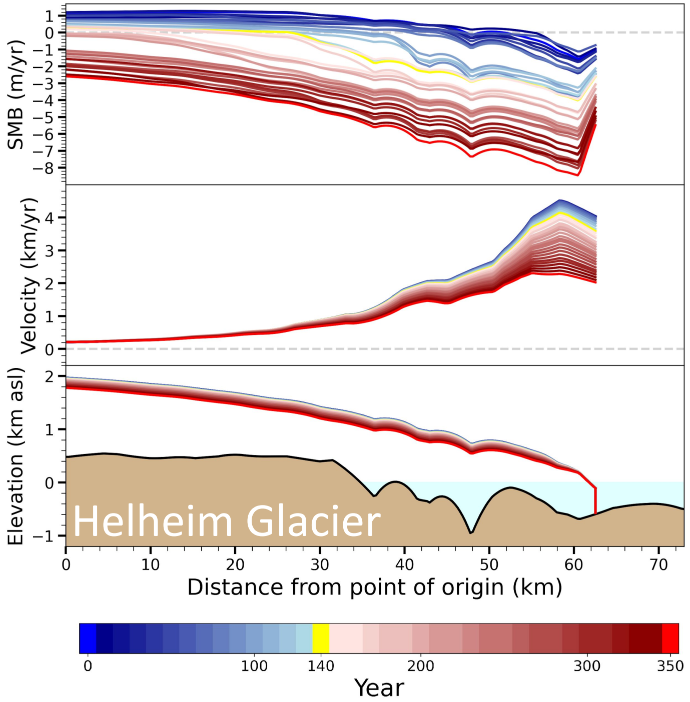
Glacier flowlines









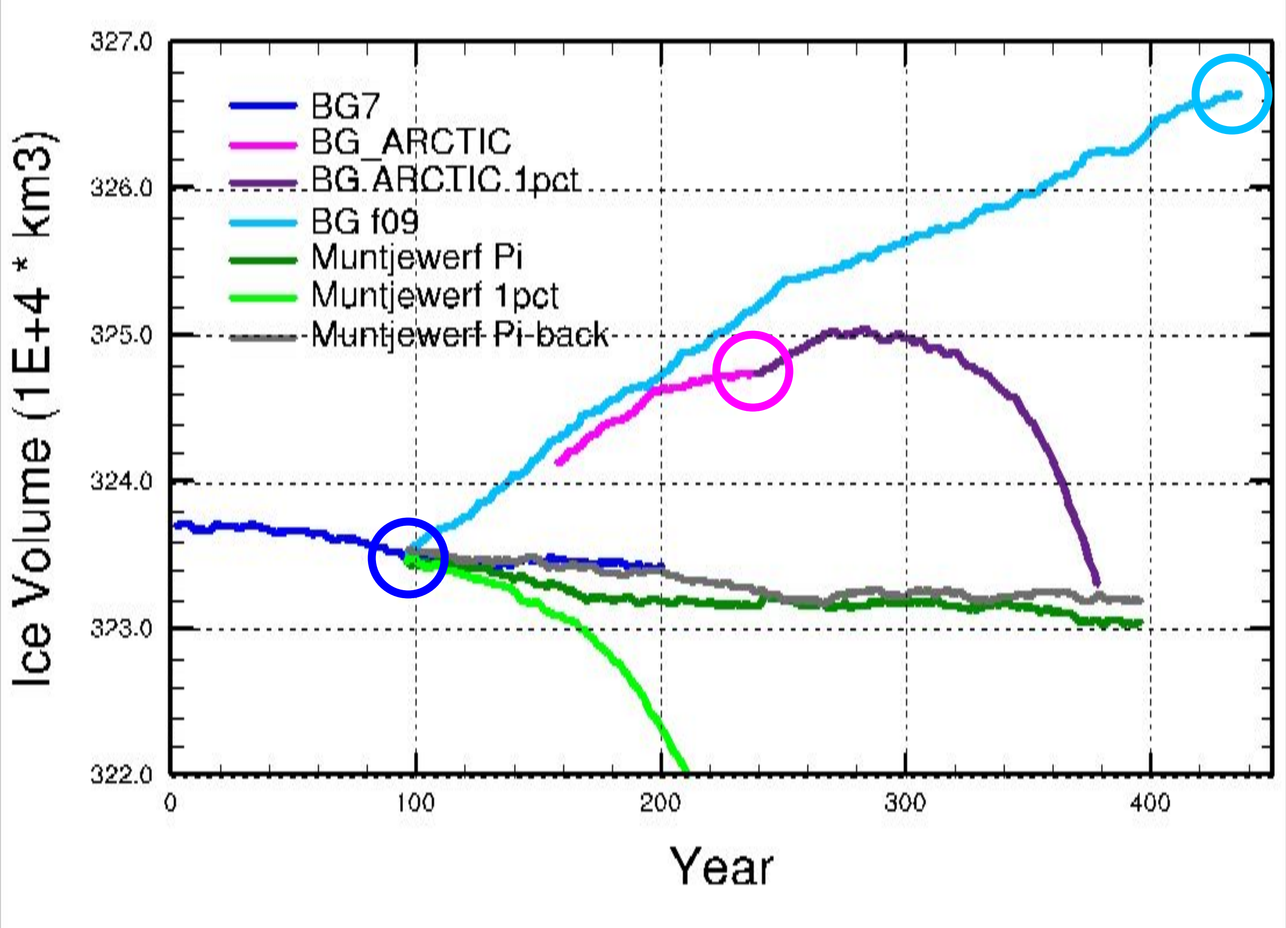


Heterogeneous sensitivity of these outlet glaciers to the simulated climate change, with glaciers in the northern basin retreating the most

Flowline coordinates courtesy of Michele Petrini

Impact of horizontal resolution

Compare to CMIP6 1 ° workhorse (CESM2.1)



New f09

- ~~Artificially elevated drag~~
- ~~Cold rain -> runoff~~

Muntjewerf f09

- Artificially elevated drag
- Cold rain -> runoff

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

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
- The two-way interaction between SMB and ice dynamics is important for modeling the evolution of the GrIS and also outlet glaciers

- Compare with lower resolution run to explore the impact of enhanced resolution
- Include other interactions/feedbacks (elevation feedback, effects on atmospheric and oceanic circulation ……)
- Integrate with data science/ ML methods (tipping points detection, causality, downscaling ……)

References

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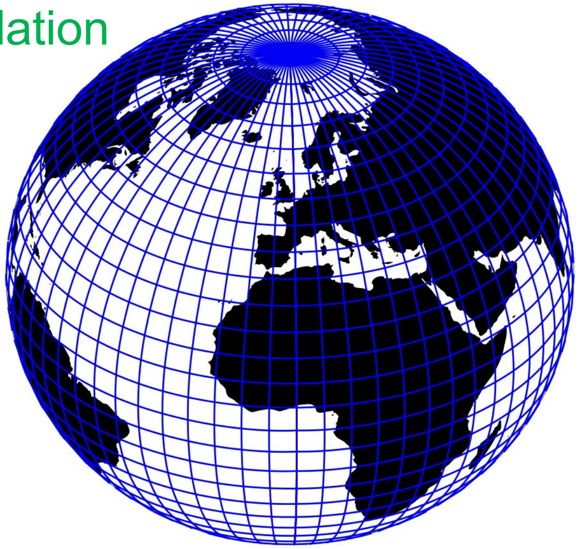
CESM is transitioning from conventional lat-lon grids towards unstructured quasi-uniform grids

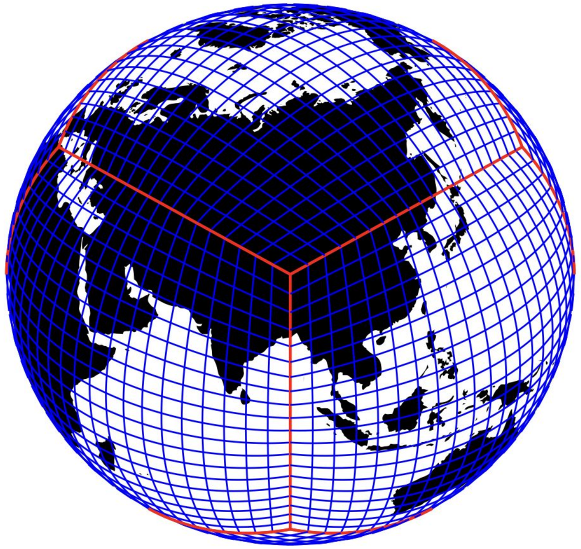
Dycore: **Finite Volume (FV)** **Spectral Element (SE)**

- Aligned with zonally circulation
- Need polar filter

(a) Regular latitude-longitude



(b) Cubed-sphere



- Better performance on parallel system
- Flexible mesh-refinement
- No pole problem
- Harder for analyzing

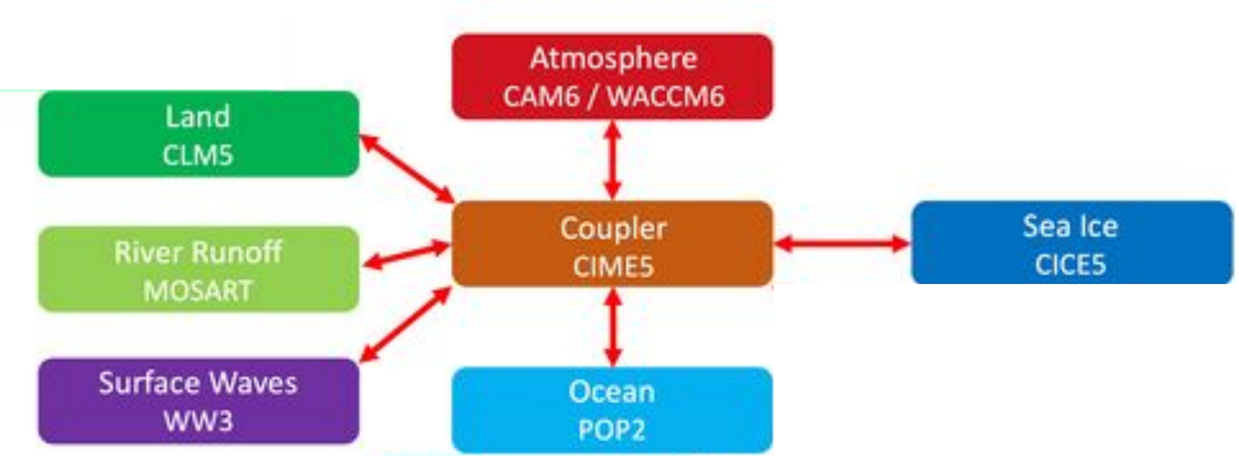
(Lauitzen et al. 2009)

Coupled modeling

Community Earth System Model version 2

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

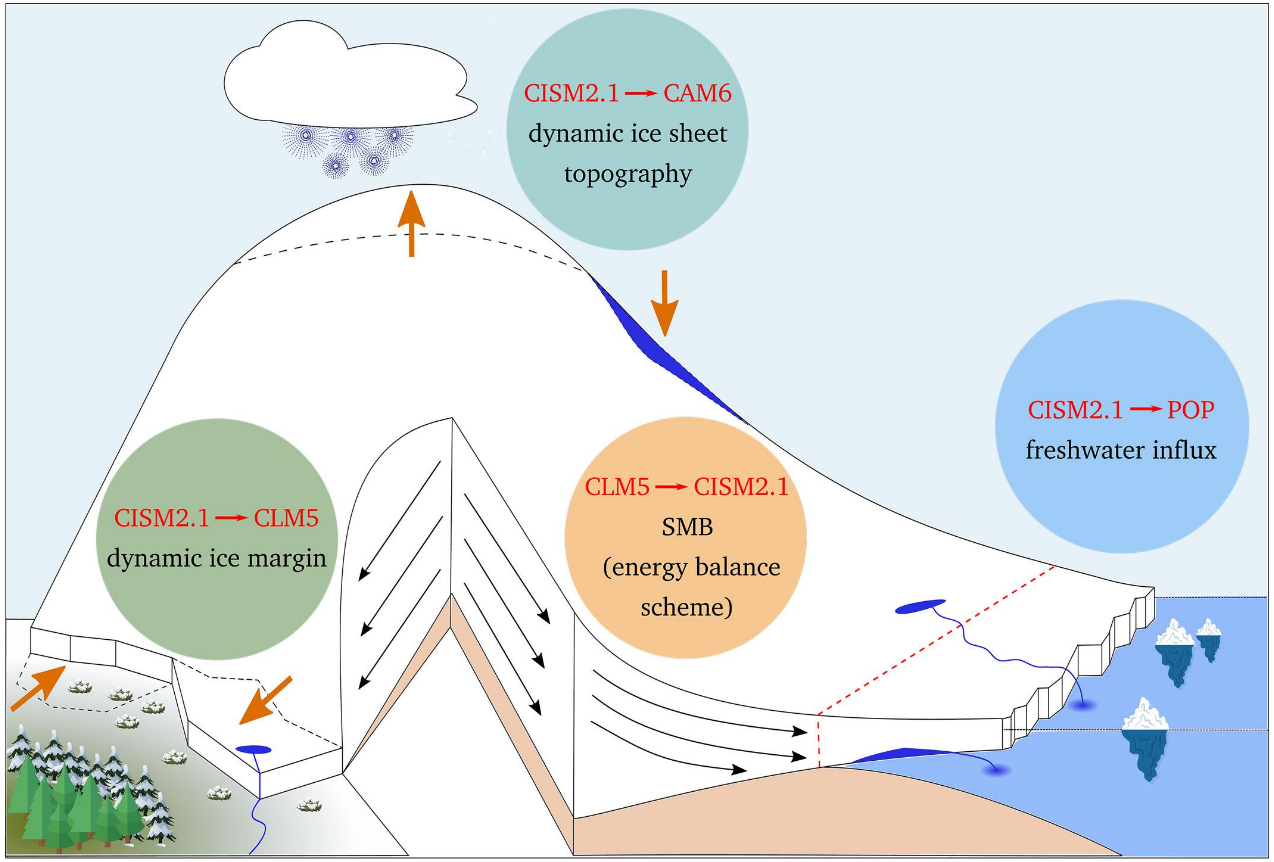
CESM2 components



Community Ice Sheet Model v2

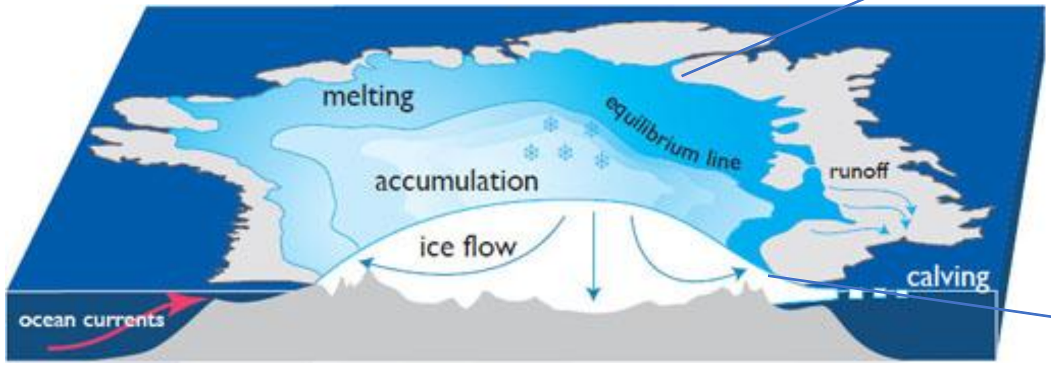
(Danabasoglu et al. 2020)

Coupled CESM2.2-CISM2.1

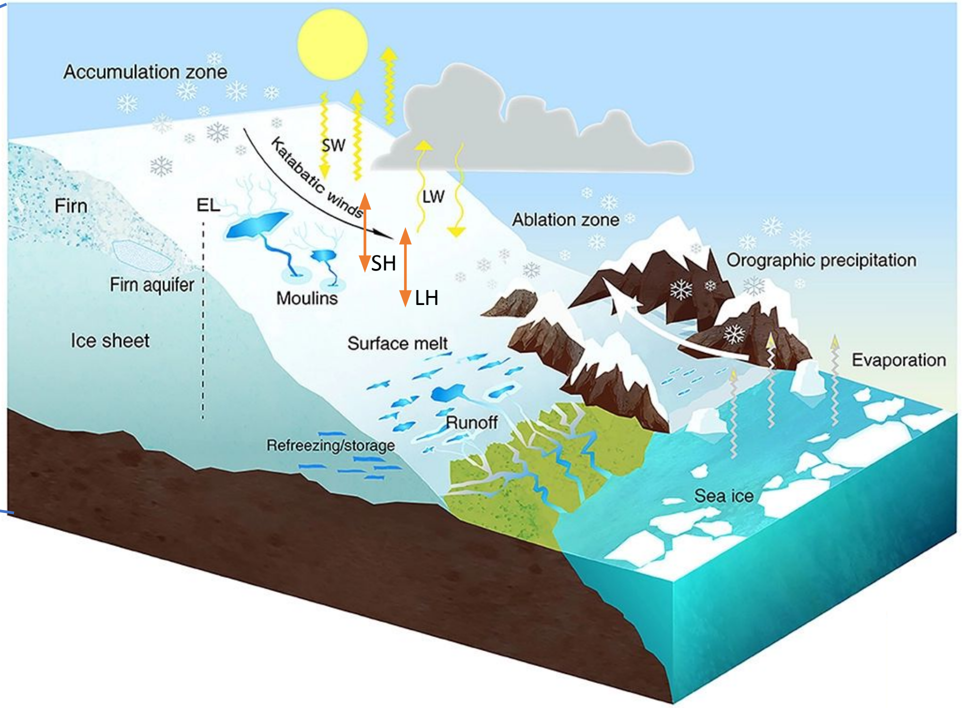


(Muntjewerf et al. 2021)

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 / Snowfall + Refreezing - Melt - Sublimation

Refreezing = Rain + Melt - Runoff

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