Effects of elevation feedback and climate mitigation on future Greenland ice sheet melt

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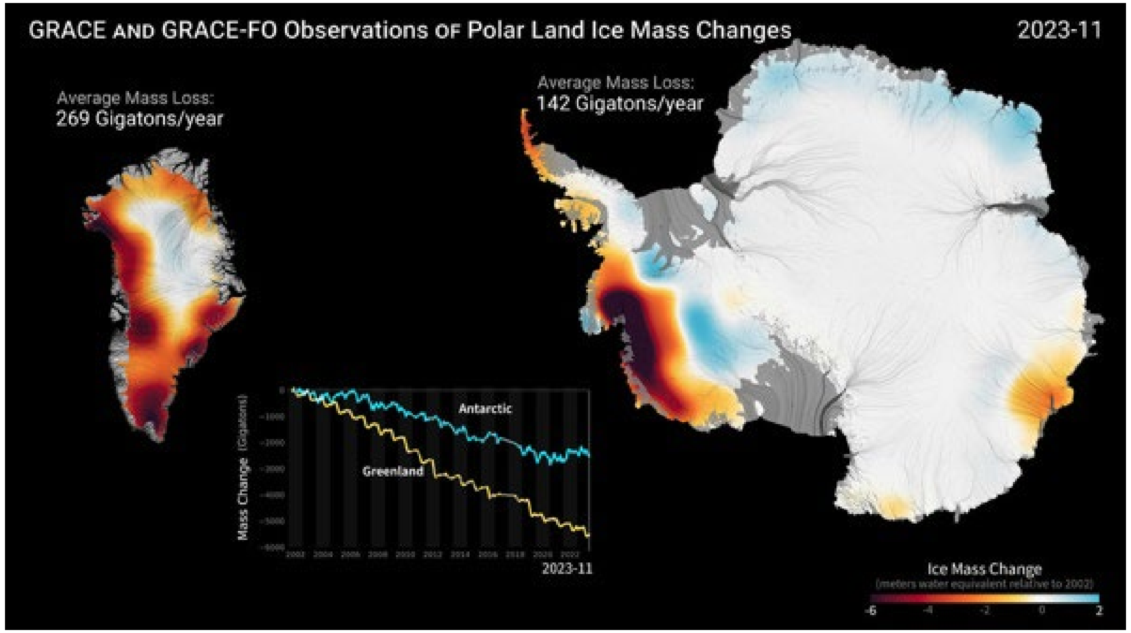
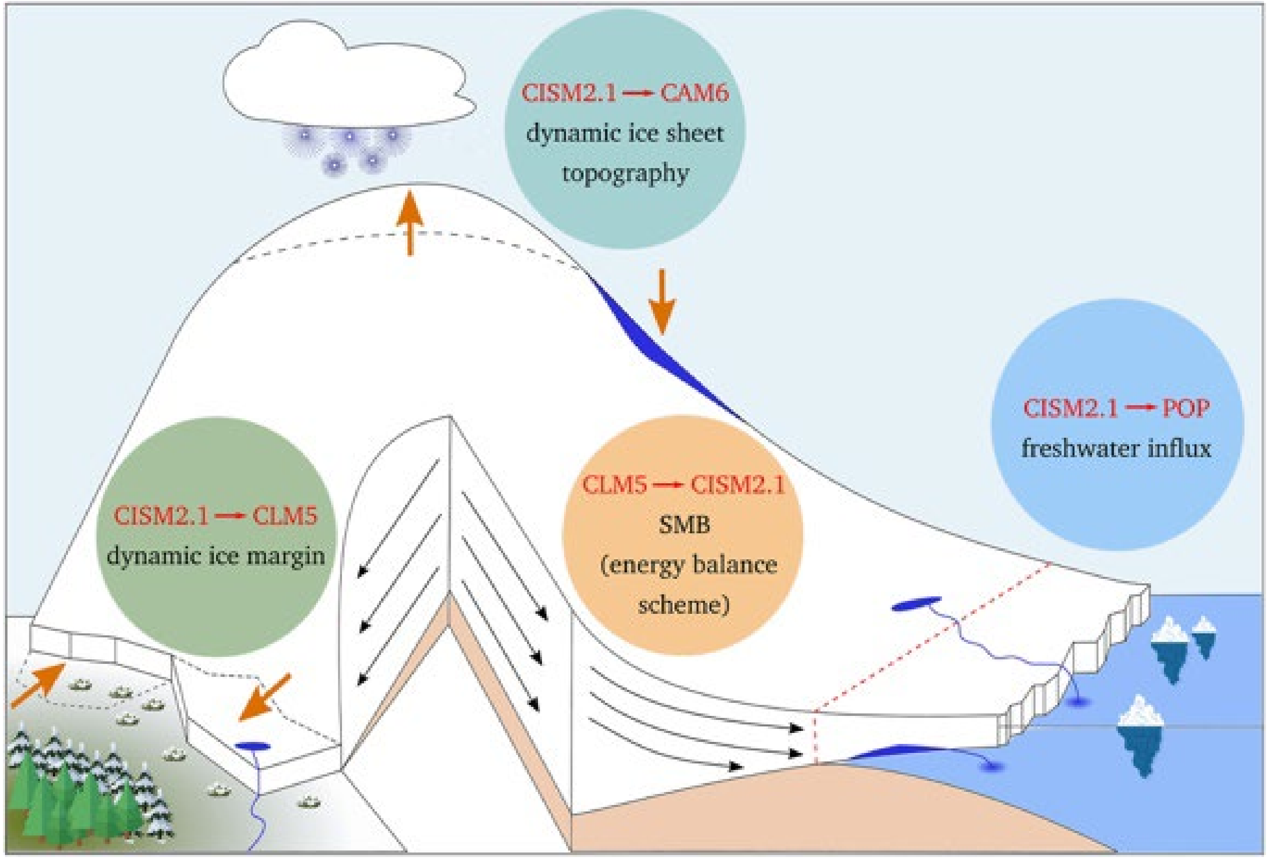
Ice sheet change in a changing climate

- The Greenland and Antarctic ice sheets are losing mass at an accelerated pace in response to atmospheric and ocean warming
- State-of-the-art projections are mostly based on ice sheet models forced with the output of climate models
- This prevents the direct representation of ice-climate interaction including feedbacks
- ISMIP6 – one coupled model
- ISMIP7 aiming to several coupled estimates (ISMIP7-ESM)



CESM2-CISM2: first CMIP6 model with interactive ice sheet



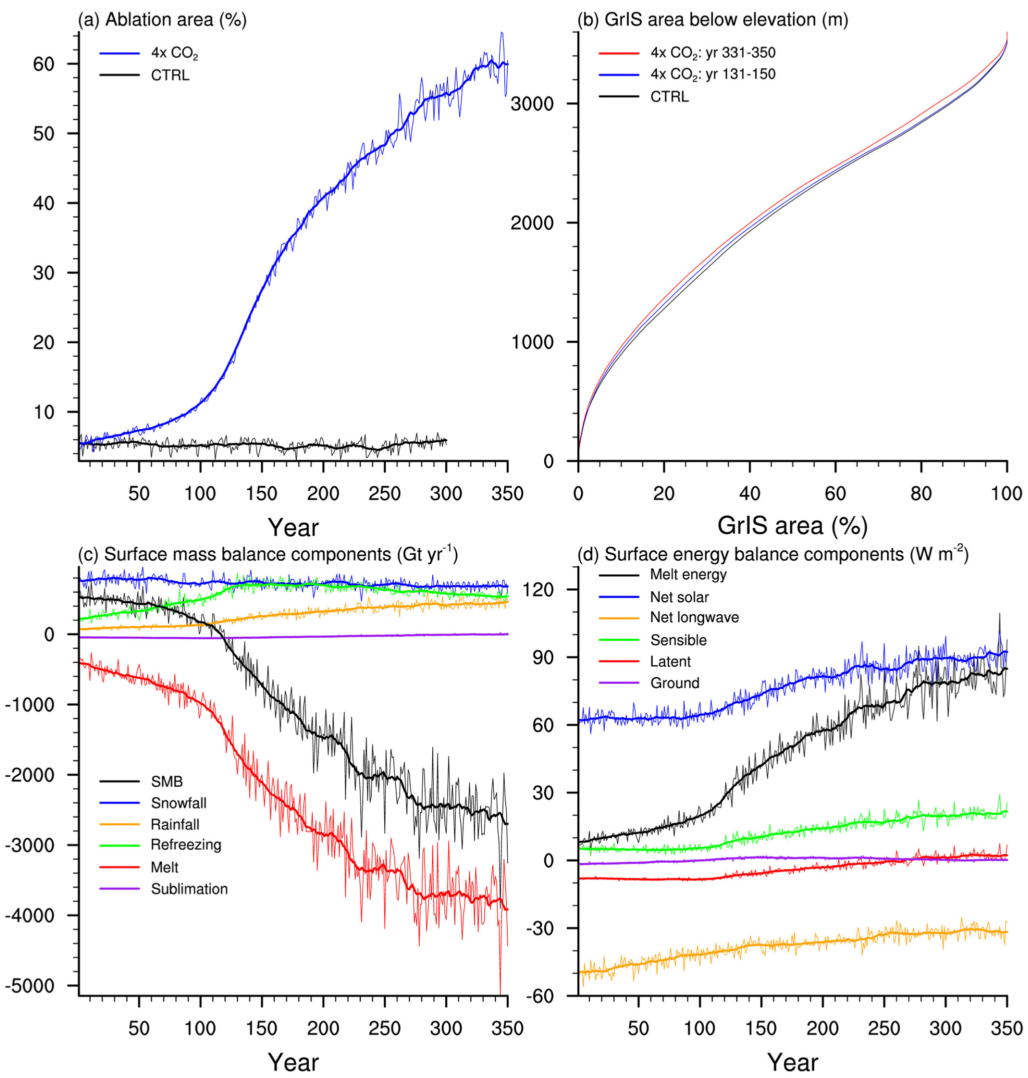
Realistic surface mass balance calculation (van Kampenhout et al, 2021)

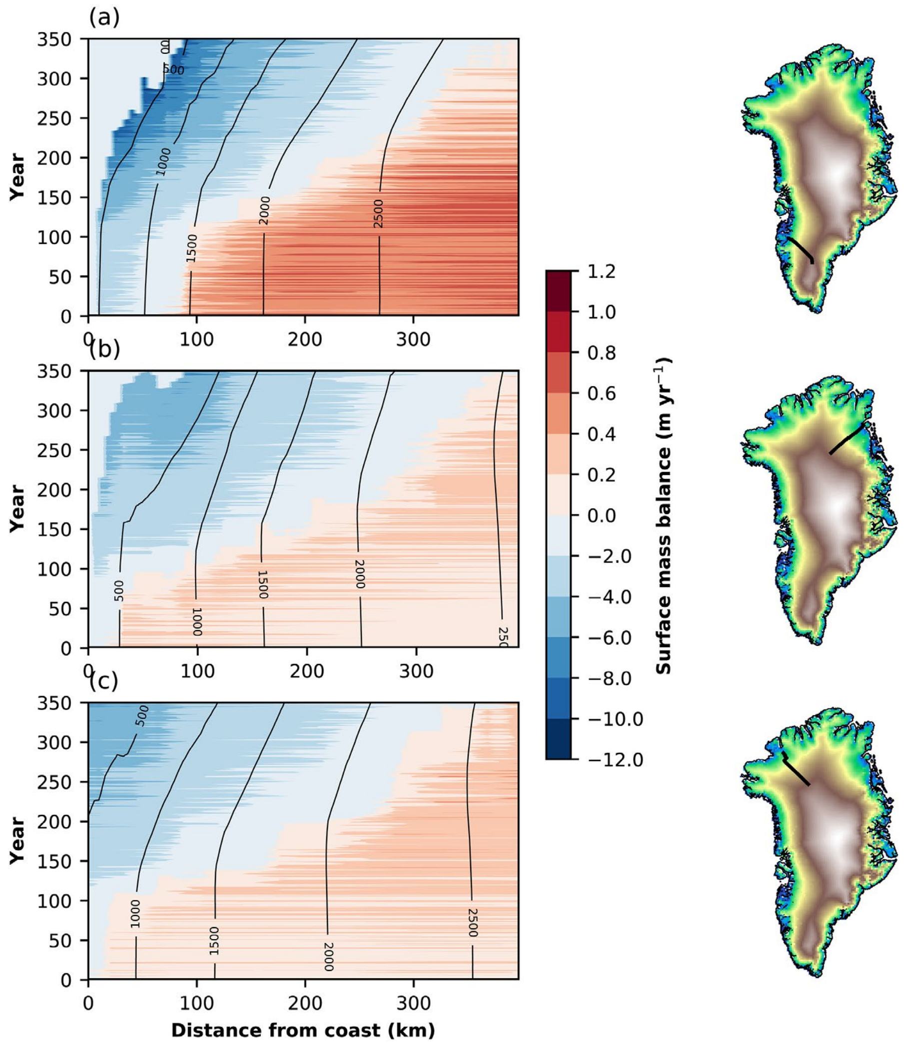
- Model contains advance snow and firn simulation developed at UU
- Surface melt is downscaled to the 4 km ice sheet grid through multiple melt calculations at 10 elevation bins and posterior vertical and horizontal interpolation

Coupling

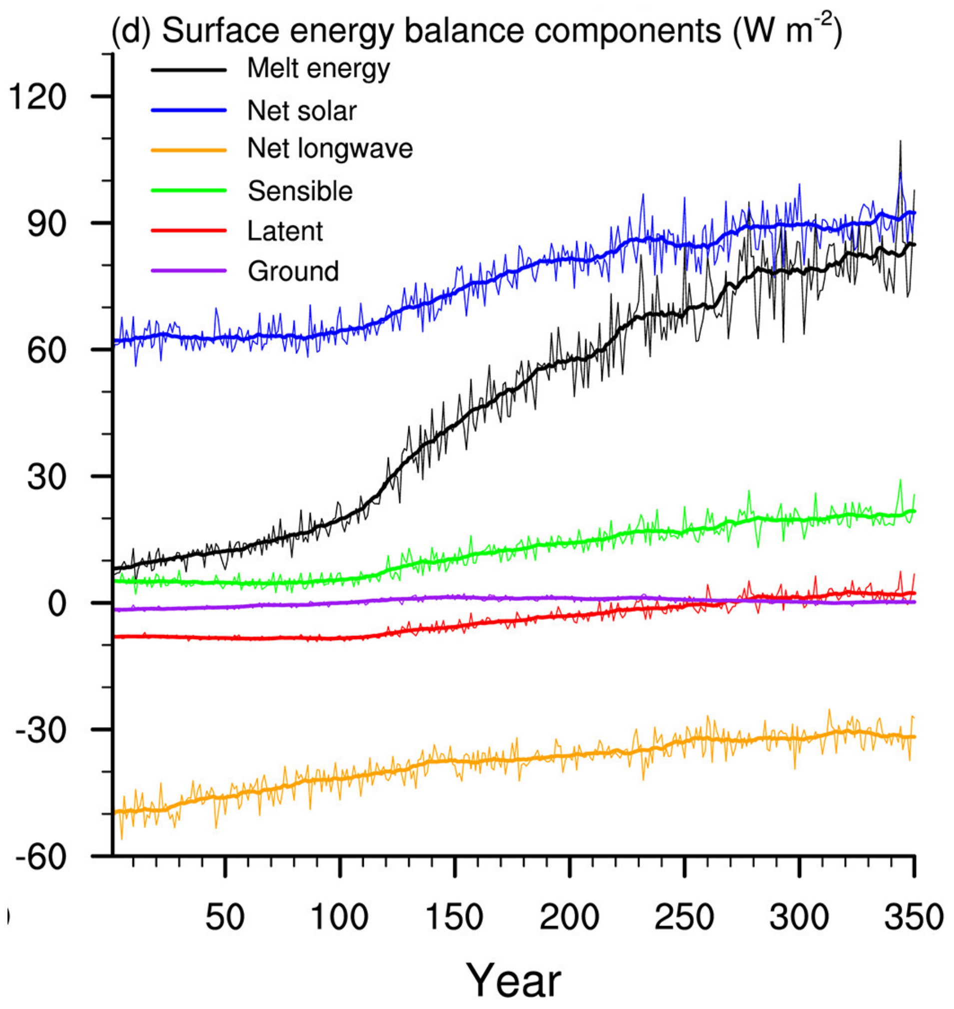
- Ice sheet changes in topography and meltwater are communicated to the atmosphere, land and ocean in (non standard) two-way coupled simulations

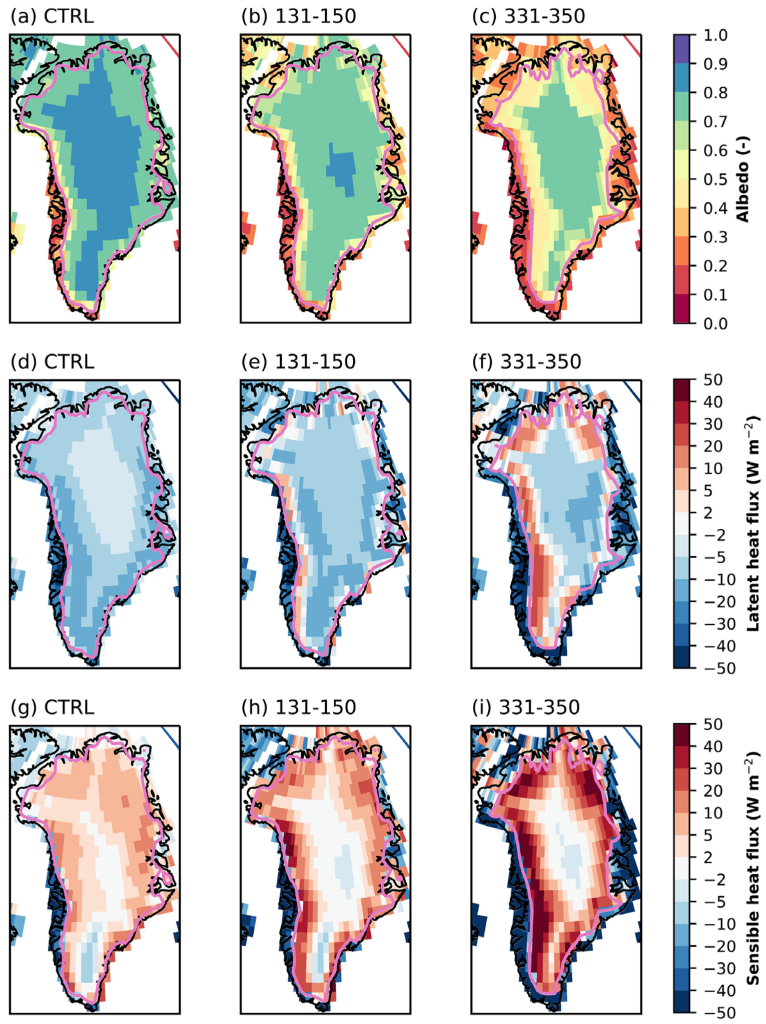
Large melt acceleration at year 120 under 1% to 4xCO_2 forcing *(Muntjewerf et al, JAMES, 2021)*





Evolution of melt contributors



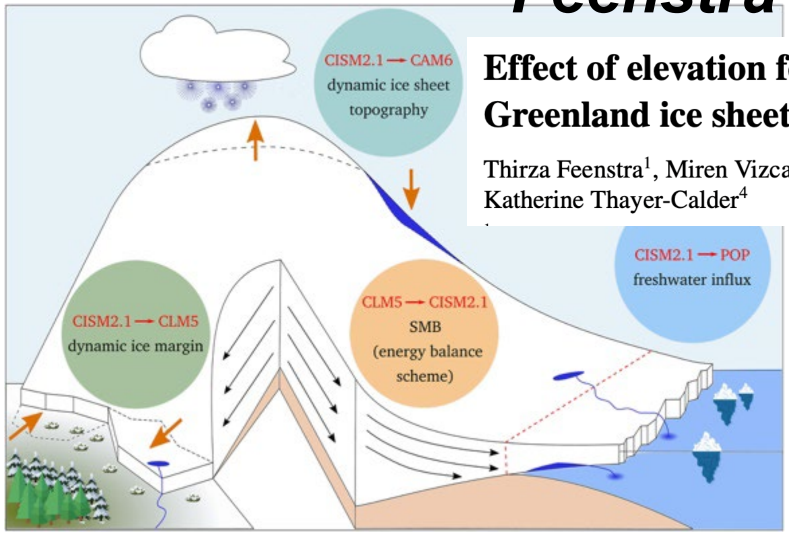


Surface albedo largely decreases as the ablation area expands

Contribution of turbulent atmosphere-ice flux largely increases over the lower parts of the ice sheet

Comparing one-way and two-way 4xCO2 simulation

Feenstra et al, TC, accepted



Effect of elevation feedbacks and climate mitigation on future Greenland ice sheet melt

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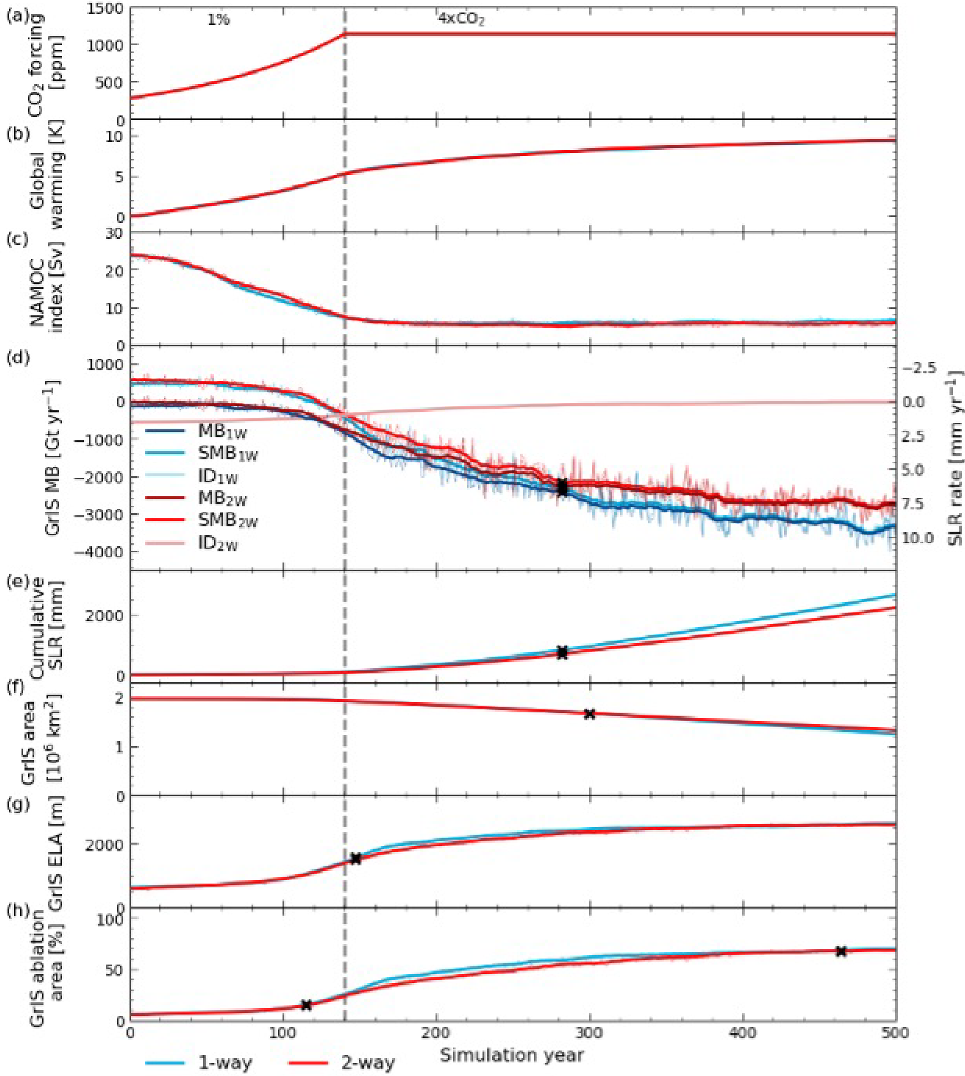
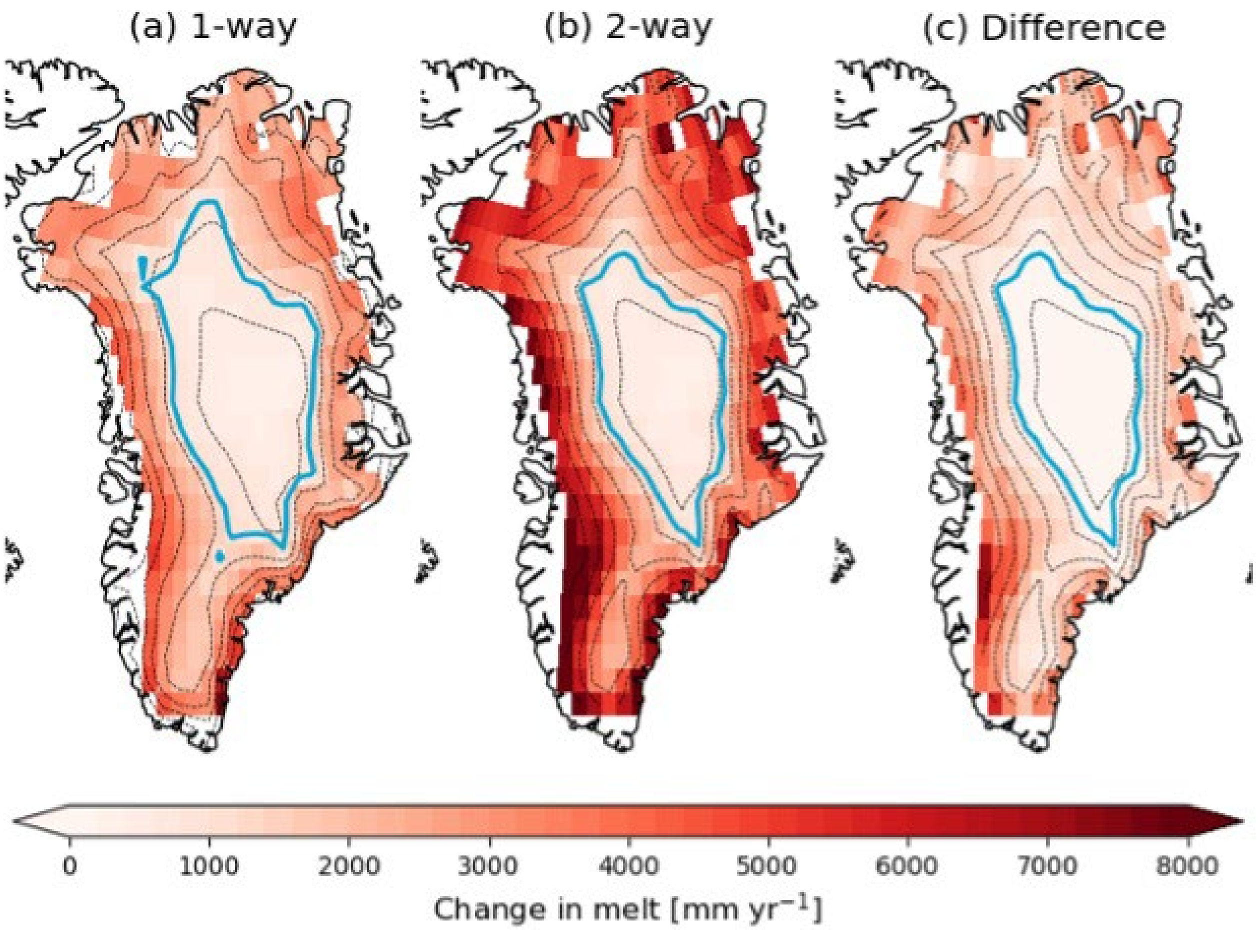


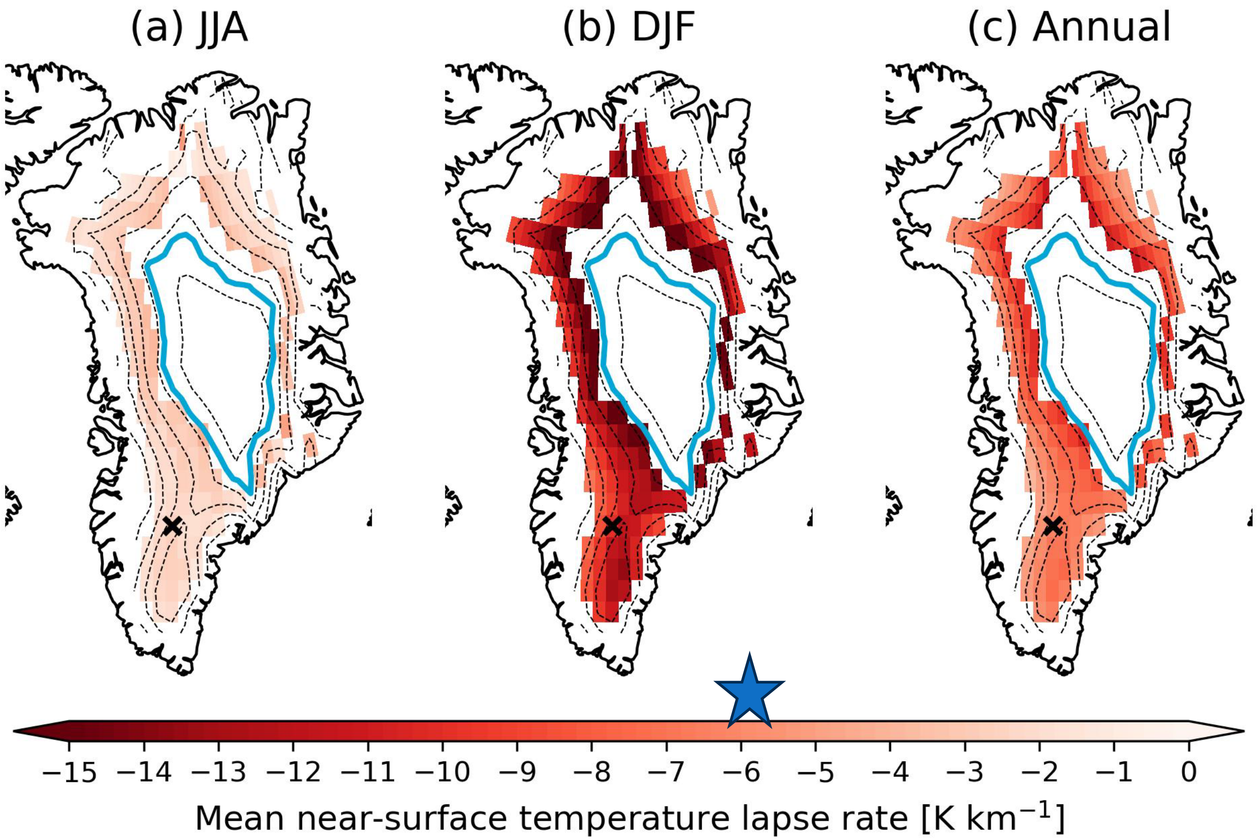
- **First evaluation of feedbacks with a CMIP6 model**
  - 1-way: topo & meltwater prescribed as pre-industrial
  - 2-way: topo & meltwater are communicated to CESM2
- Global temperature and **NAMOC show similar evolution in both simulations** (panel c)
- Consistently with previous work with simpler coupled models, the **one-way simulation overestimates ice sheet mass loss [**as calculated by the dynamical ice sheet model]

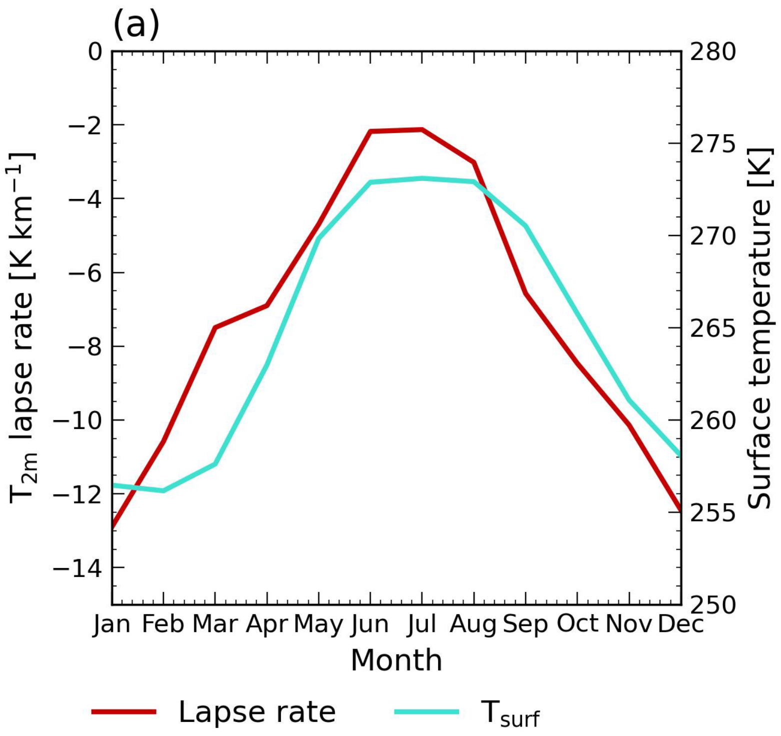
Evaluation of elevation feedback on melt



Results correspond to year 500

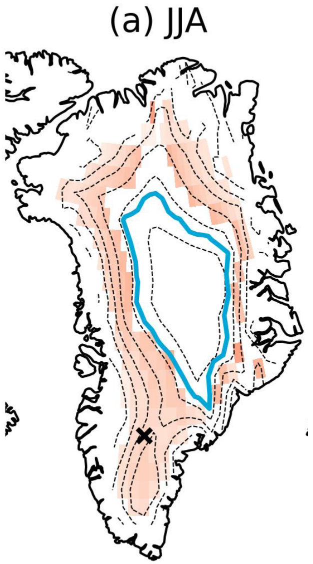
Elevation feedback on melt is possibly overestimated in state-of-the-art uncoupled models

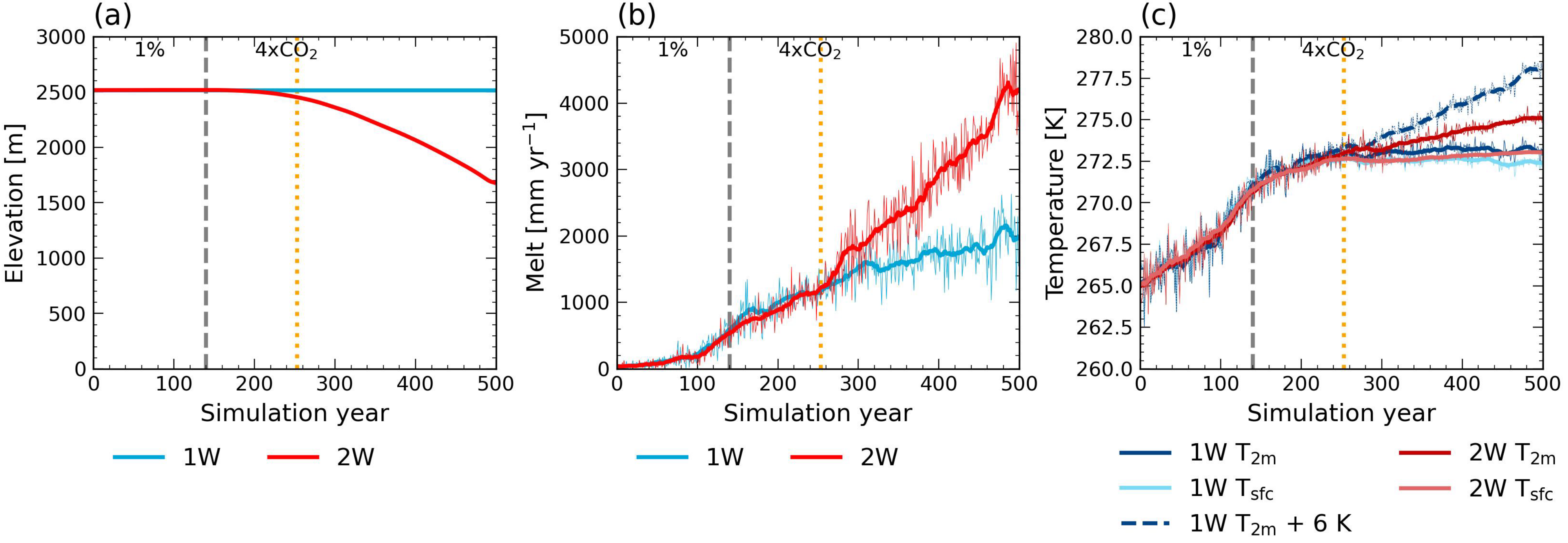




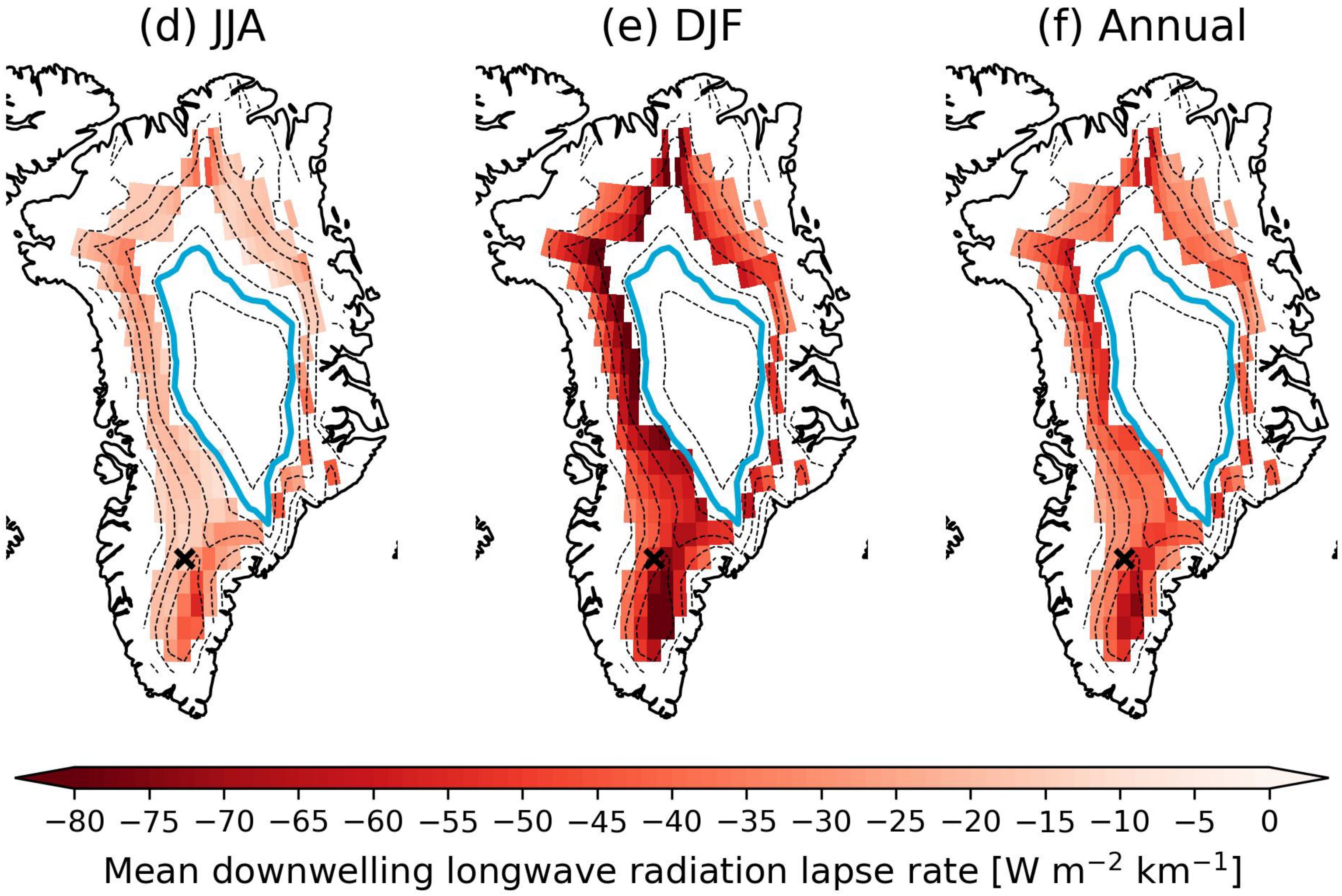
- **Summer T_{2m} change with elevation reduction is much less than 6 K per km**, widely used in uncoupled projections of GrIS melt, potentially explaining melt overestimation in those.

Evaluation of elevation feedback on melt, southern Greenland

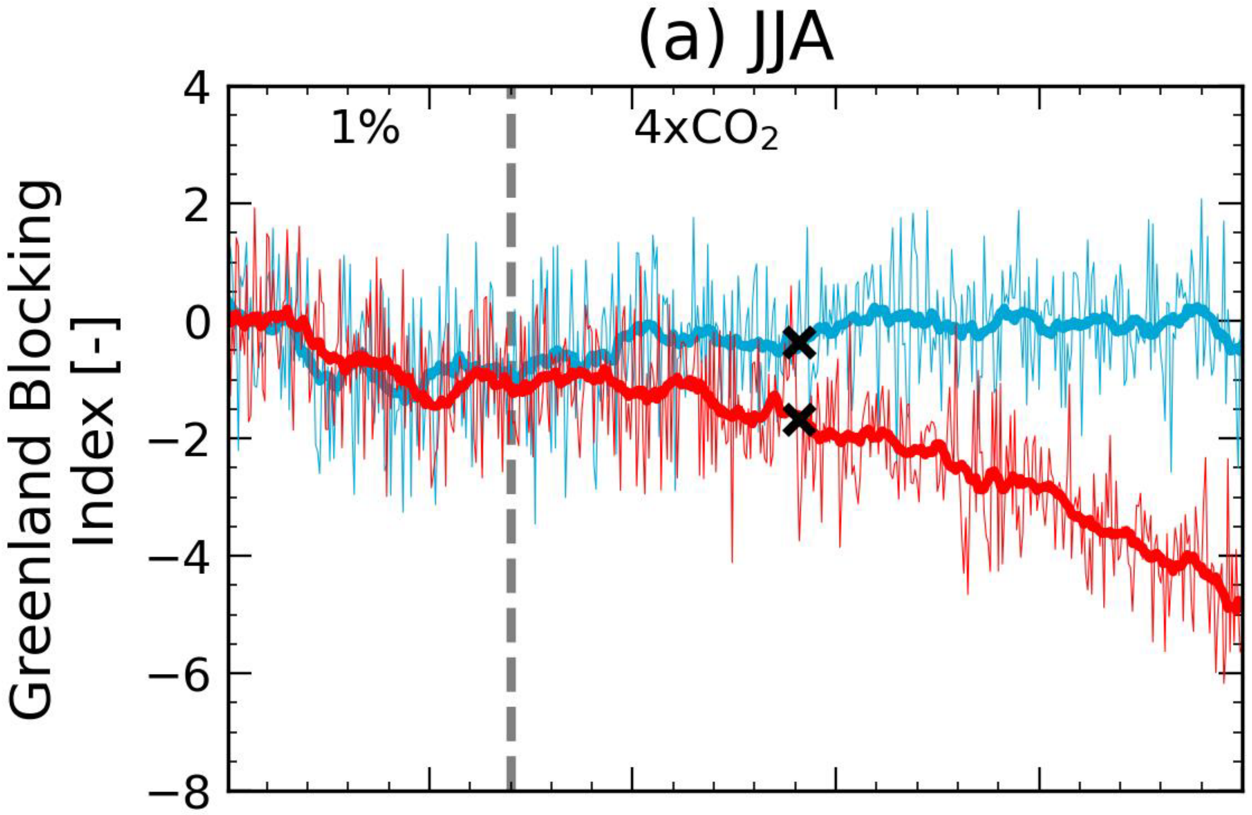




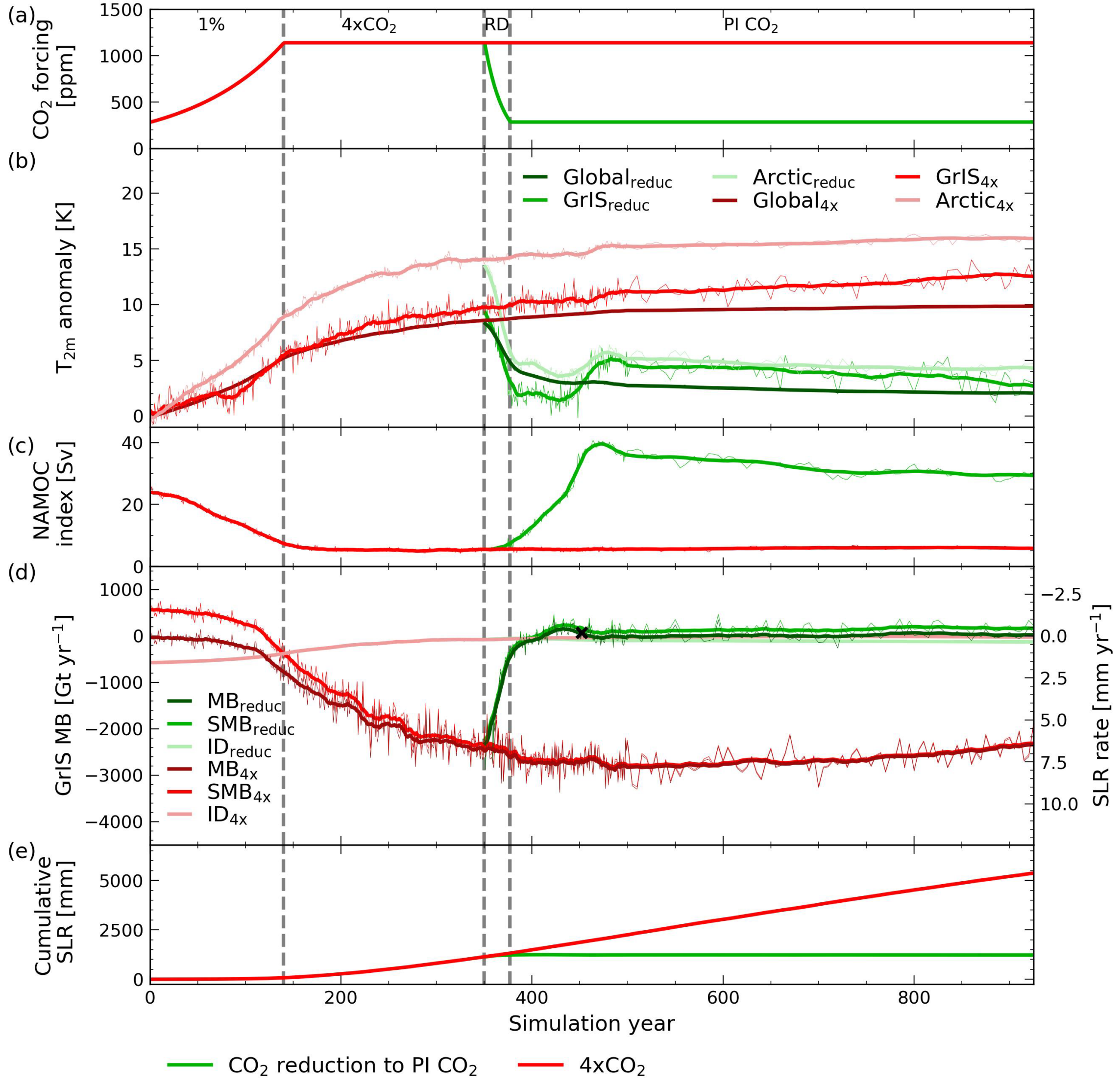
Effect of elevation on incoming longwave radiation



Effects of elevation change on blocking



Effect of abrupt mitigation

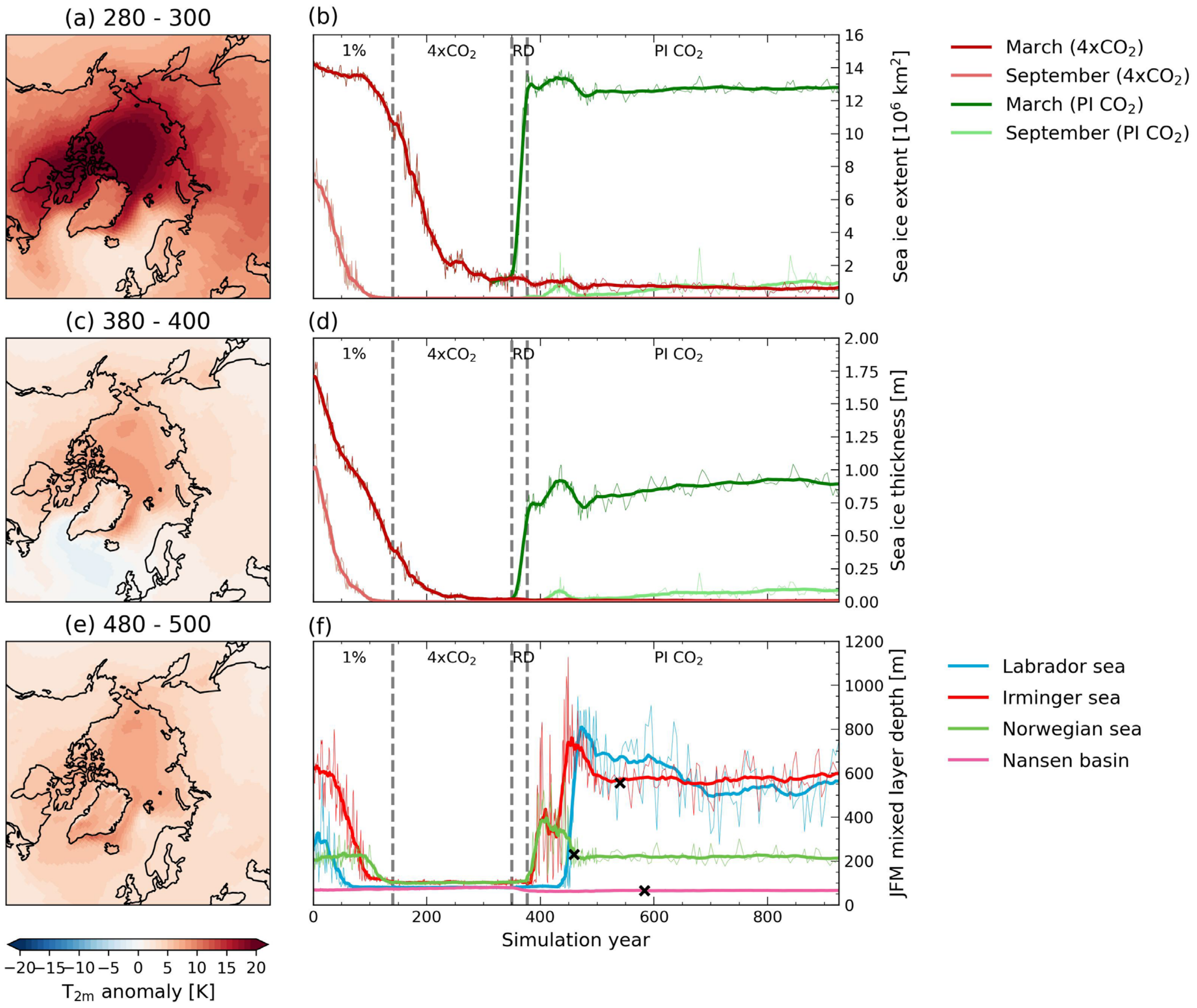


By year 350, most of GrIS margins are land terminating, due to large area contraction

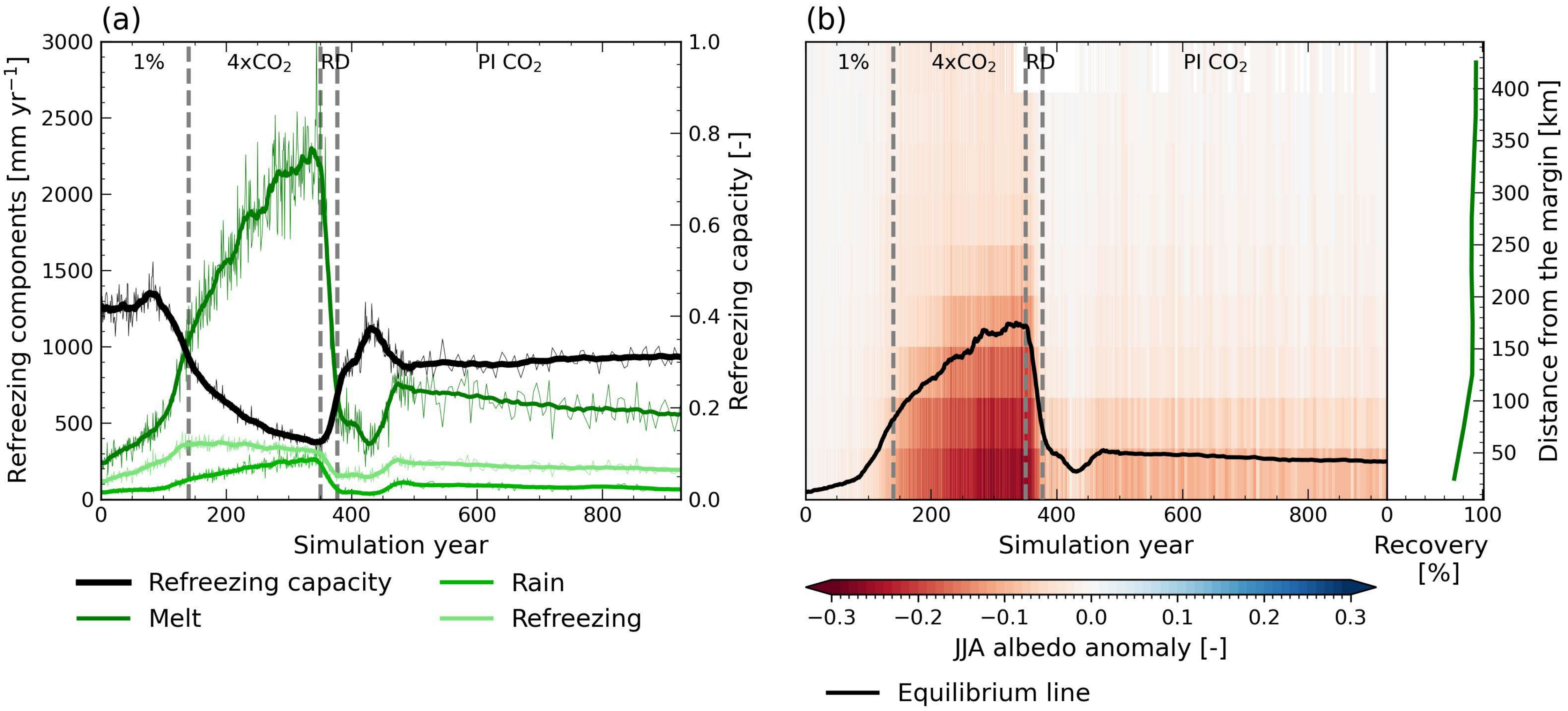
For this reason, GrIS mass loss halts if CO2 is reduced to preindustrial at year 350, regardless of **NAMOC overshoot**, residual 2 K global warming and non-recovered snow/firn conditions.

Feenstra et al, accepted for TC

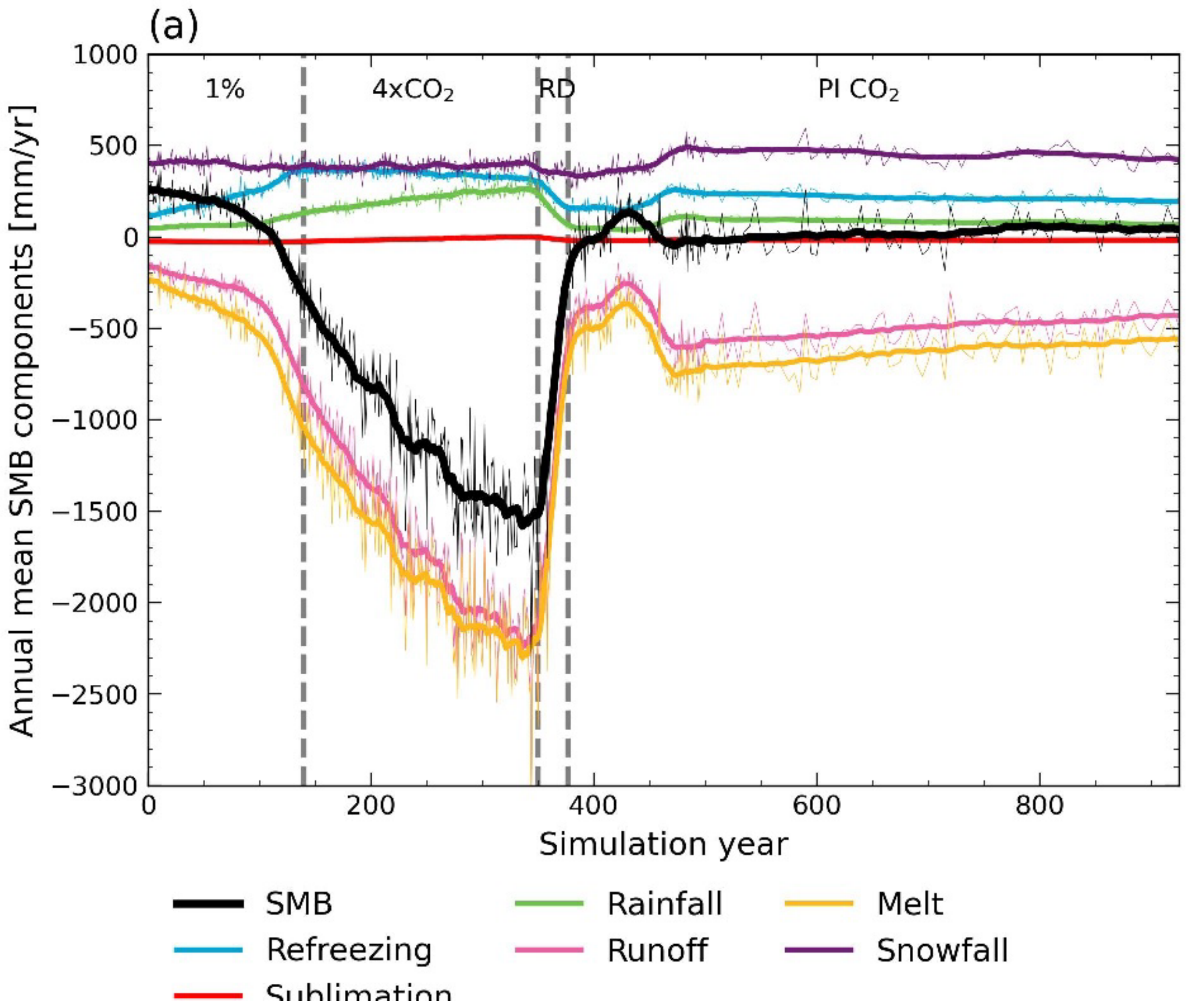
Effect of mitigation on polar climate



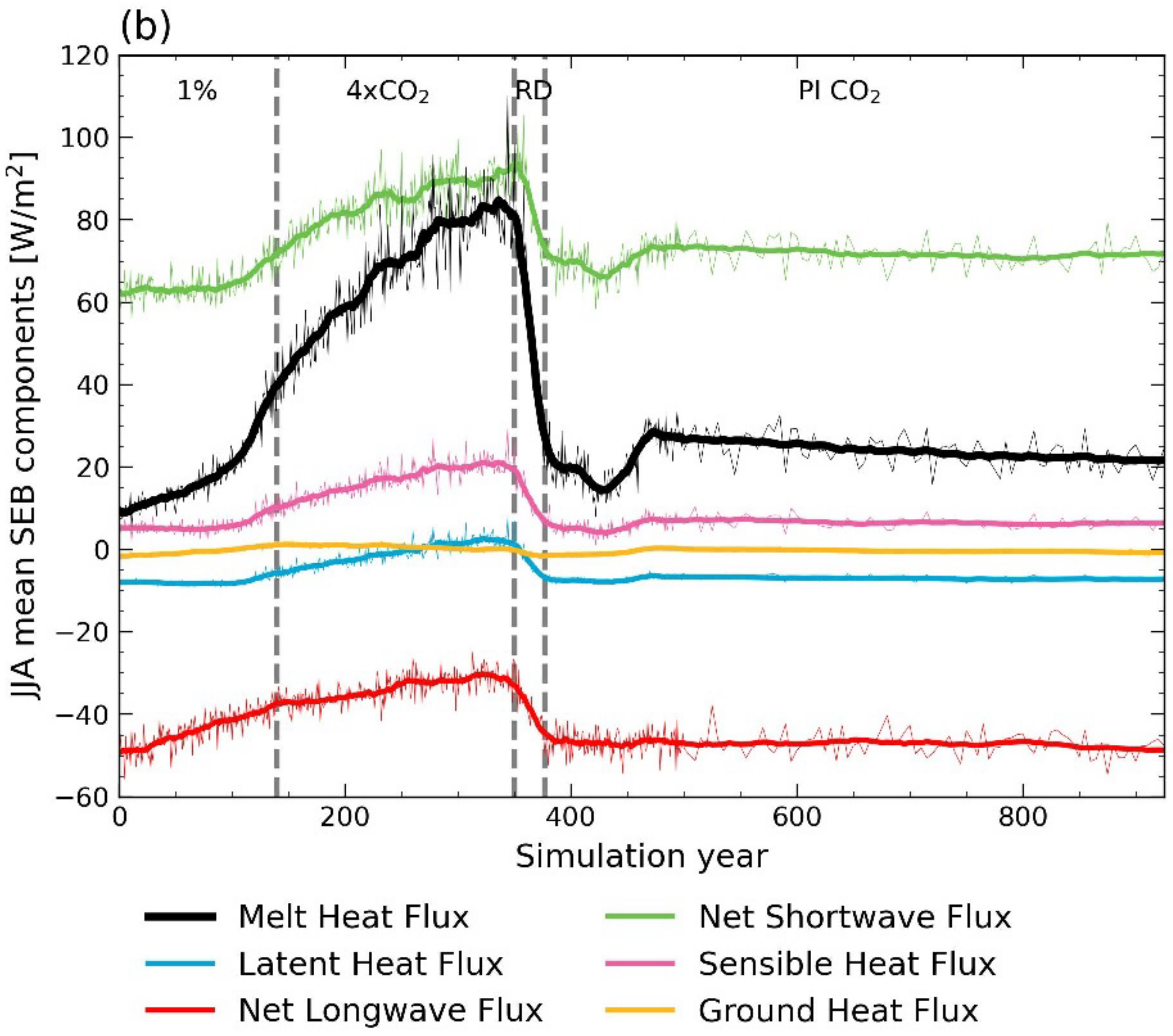
Effect of mitigation on firn conditions



Effect of mitigation on surface mass balance components



Effect of mitigation on melt energy components



Conclusions of 1% to 4xCO2 CESM2-CISM2

- **Elevation feedback** largely contributes to GrIS melt on a **multi-century scale** due to increases in temperature and incoming longwave radiation, only partially compensated by **reduced blocking** and incoming solar radiation
- Ice sheet mass loss remains similar in one-way and two-way simulations **until year 280**, due to similar AMOC strength and elevation corrections in the surface mass balance calculation
- Reduction of CO2 to pre-industrial levels from year 350 **halts mass loss**, regardless of residual 2 K global warming, in connection with zero ice discharge