On the role of feedbacks and climate mitigation on future Greenland ice sheet mass loss as simulated with CESM2-CISM2

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Motivation

- The Greenland ice sheet's contribution to sea level rise has been increasing and is expected to increase in a warmer climate
- A changing Greenland ice sheet can affect the local climate
  - In most of the sea level projections the effect of these ice sheet-climate interactions is not taken into account
  - Ice sheet-climate interactions might influence the response of the Greenland ice sheet to climate mitigation

Motivation

- The Greenland ice sheet's contribution to sea level rise has been increasing and is expected to increase in a warmer climate
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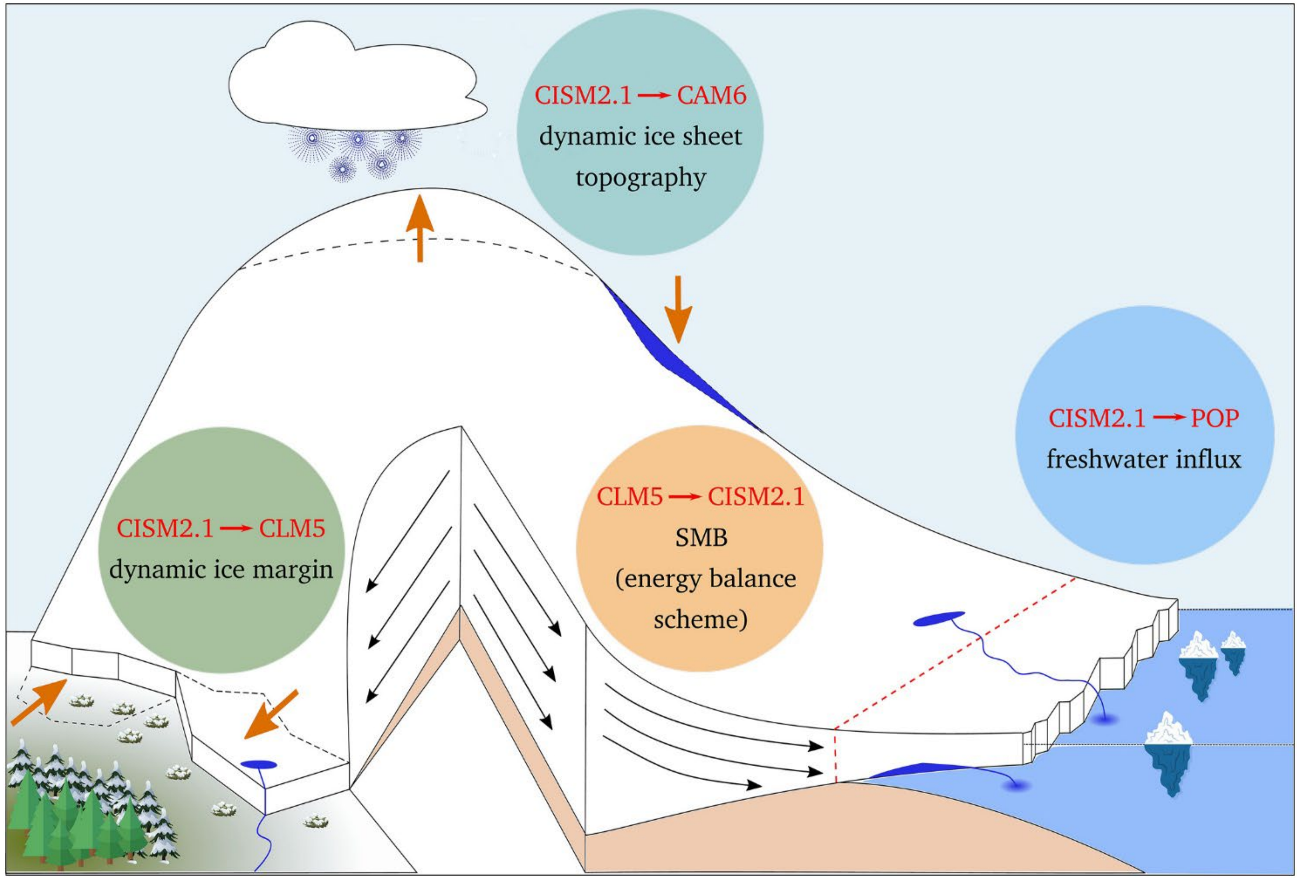
  - Ice sheet-climate interactions might influence the response of the Greenland ice sheet to climate mitigation

- What is the effect of accounting for ice sheet-climate interactions on the Greenland climate and the projected sea level rise?
- What is the role of ice sheet-climate interactions in a CO_2 reduction scenario?

Coupling in CESM2-CISM2

- 2-way coupling between CISM, CAM and CLM
- 1-way coupling between CISM and POP
- SMB is computed by CLM
  - Downscaling to CISM by using elevation classes

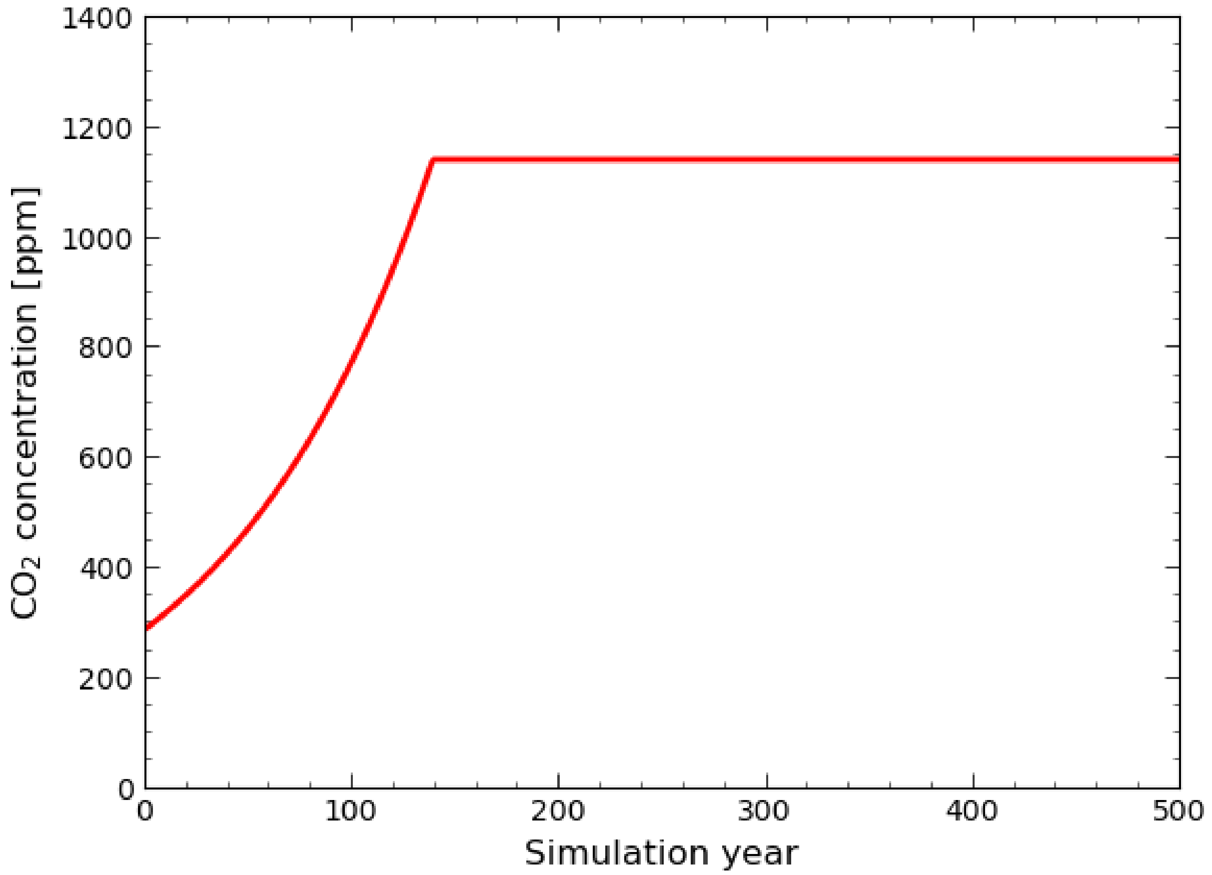
- 1-way coupled simulation
  - Fixed topography in CAM and CLM
  - Fixed freshwater fluxes
  - Lapse rate of -6 K/km for downscaling to CISM grid



Muntjewerf et al., 2021

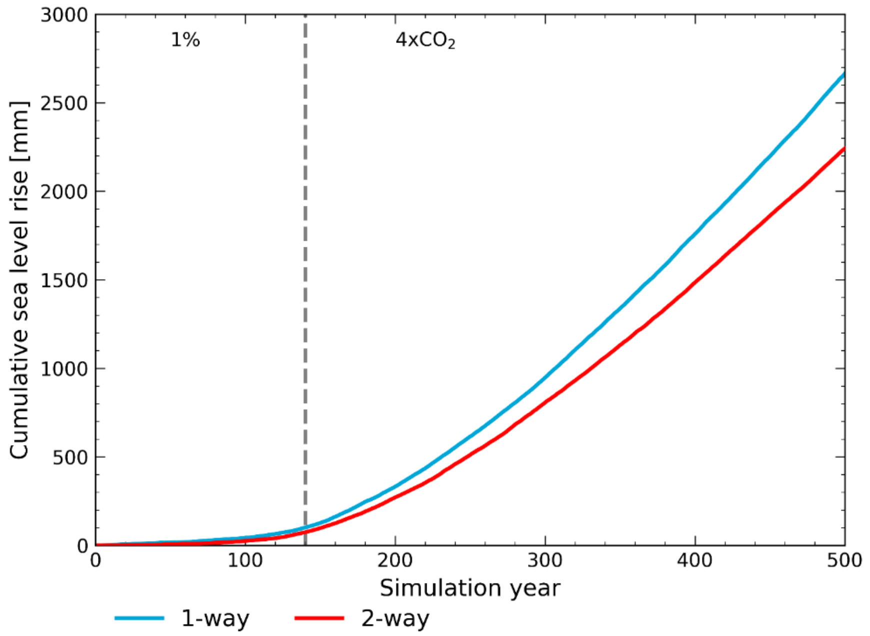
Comparing 1-way and 2-way coupling: $4xCO_2$ scenario

- 1% CO_2 increase from 1xPI to 4xPI concentrations (year 1-140)
- Comparison between 1-way and 2-way coupled simulation
- Investigate the effect of interactions and feedbacks between the GrIS and the climate on GrIS mass loss



Mass balance evolution

- 17% larger SLR in 1-way coupled simulation



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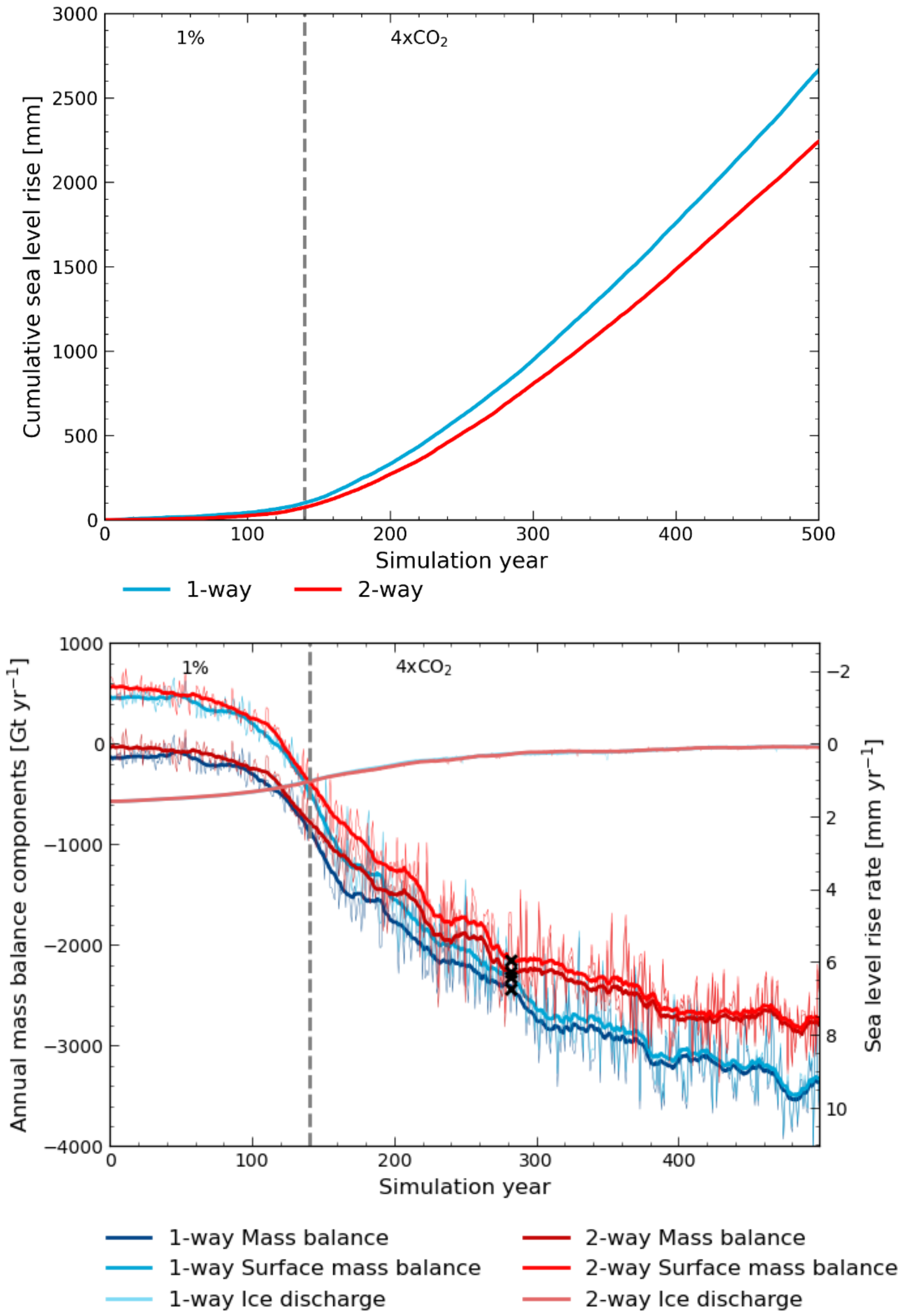
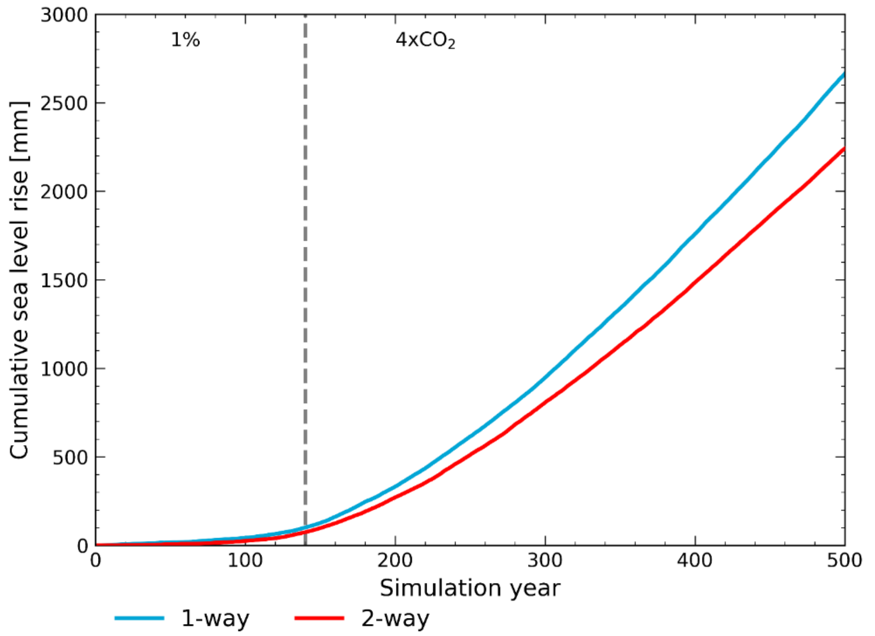
Mass balance evolution

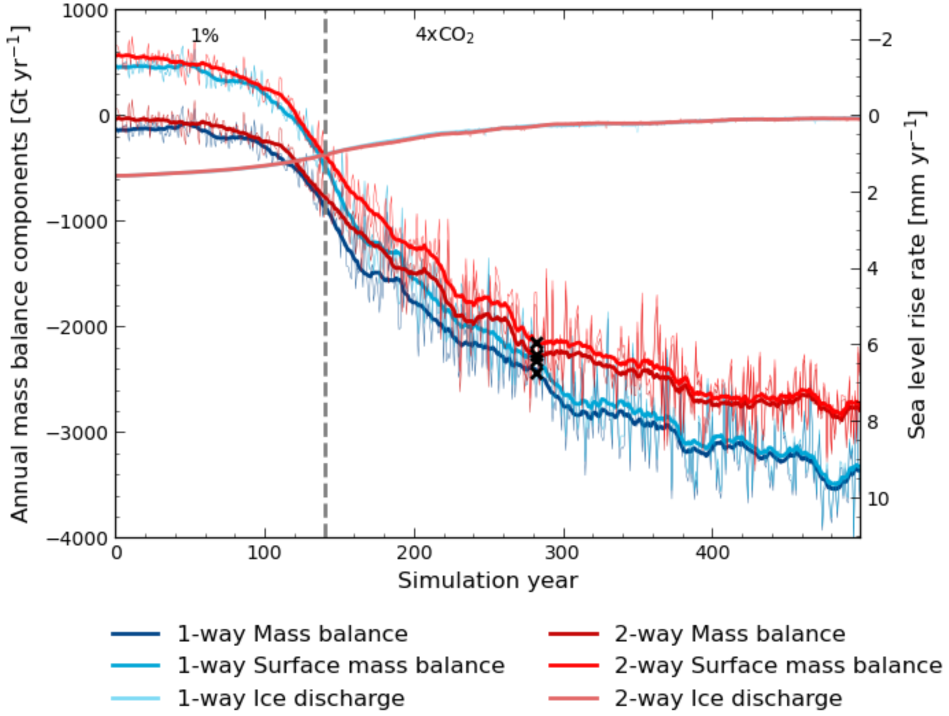
- 17% larger SLR in 1-way coupled simulation
  - Caused by difference in surface mass balance



Mass balance evolution

- 17% larger SLR in 1-way coupled simulation
  - Caused by difference in surface mass balance
- Why?
  - Representation of melt-elevation feedback
  - Some feedbacks are not represented in 1-way coupled simulations





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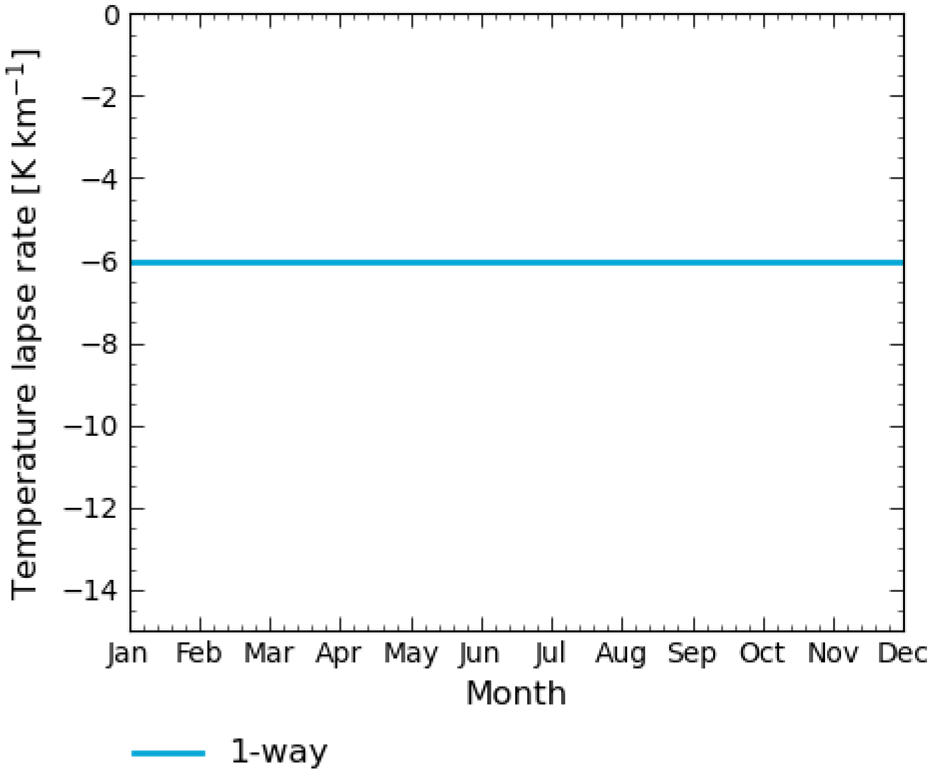
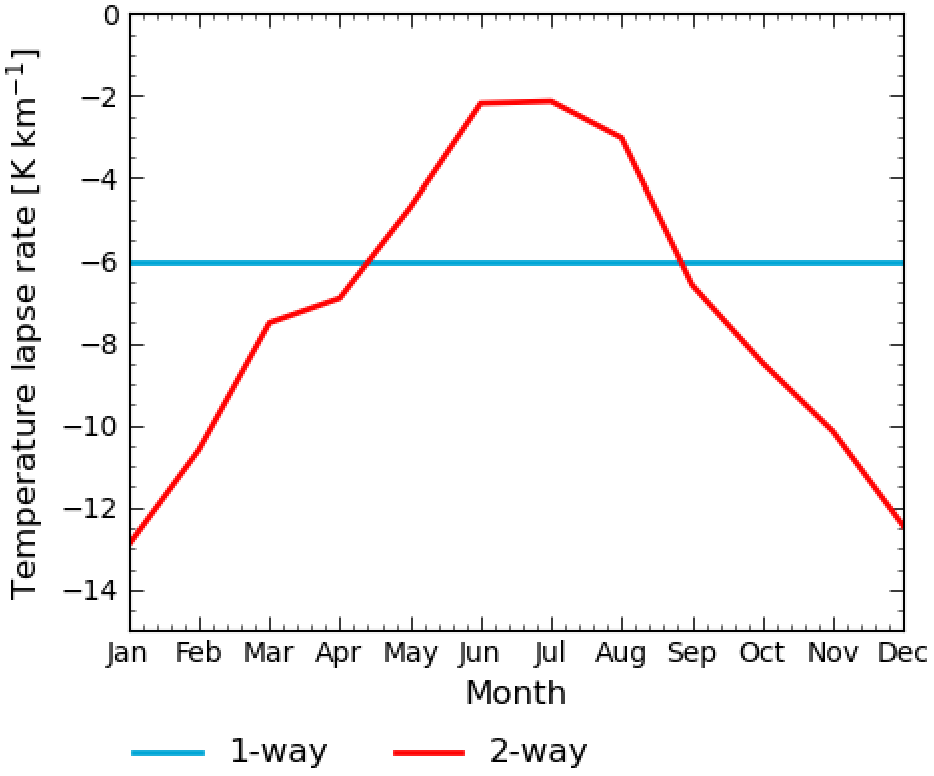
Representation of the melt-elevation feedback: temperature lapse rates

- 1-way coupled: -6 K/km



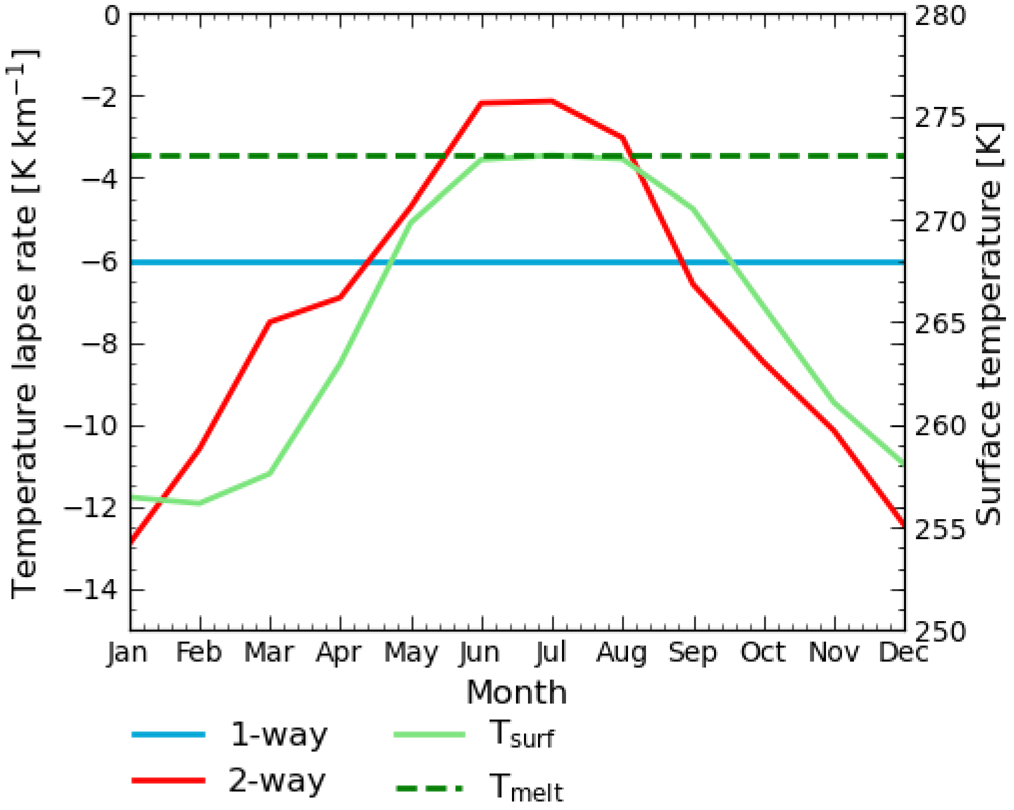
Representation of the melt-elevation feedback: temperature lapse rates

- 1-way coupled: -6 K/km
- 2-way coupled: seasonality



Representation of the melt-elevation feedback: temperature lapse rates

- 1-way coupled: -6 K/km
- 2-way coupled: seasonality
  - Melting surface



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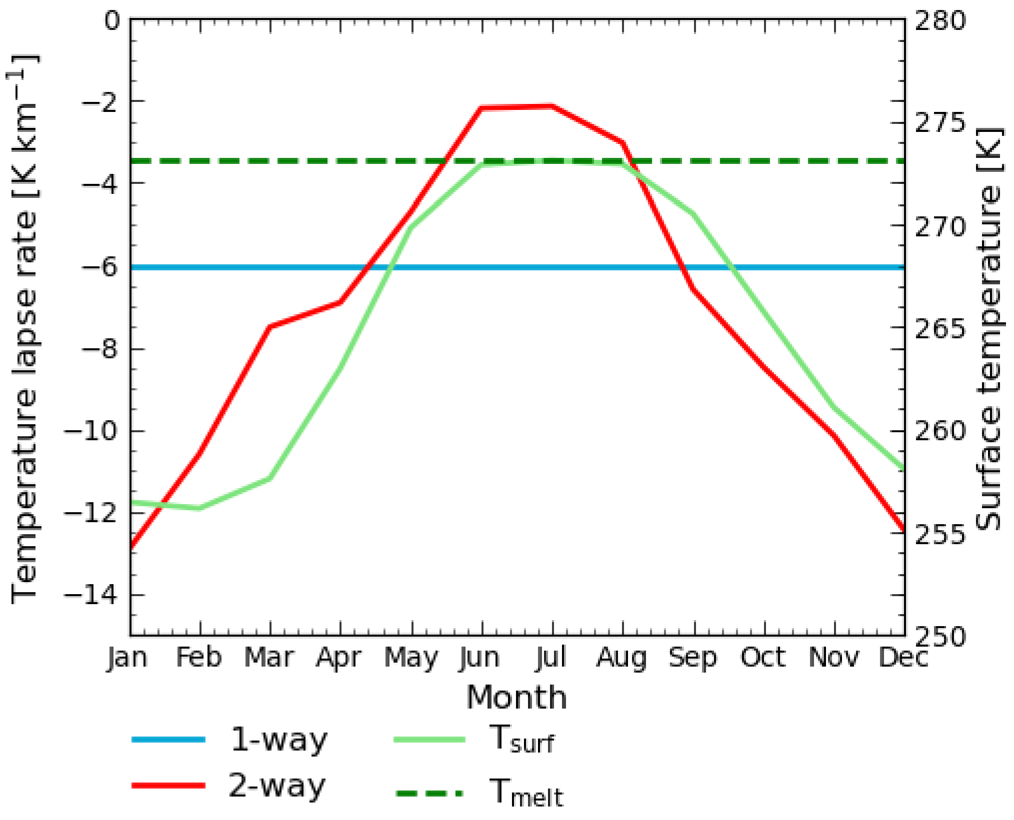
Representation of the melt-elevation feedback: temperature lapse rates

- 1-way coupled: -6 K/km
- 2-way coupled: seasonality
  - Melting surface

- Overestimation of melt-elevation feedback in 1-way coupled simulation



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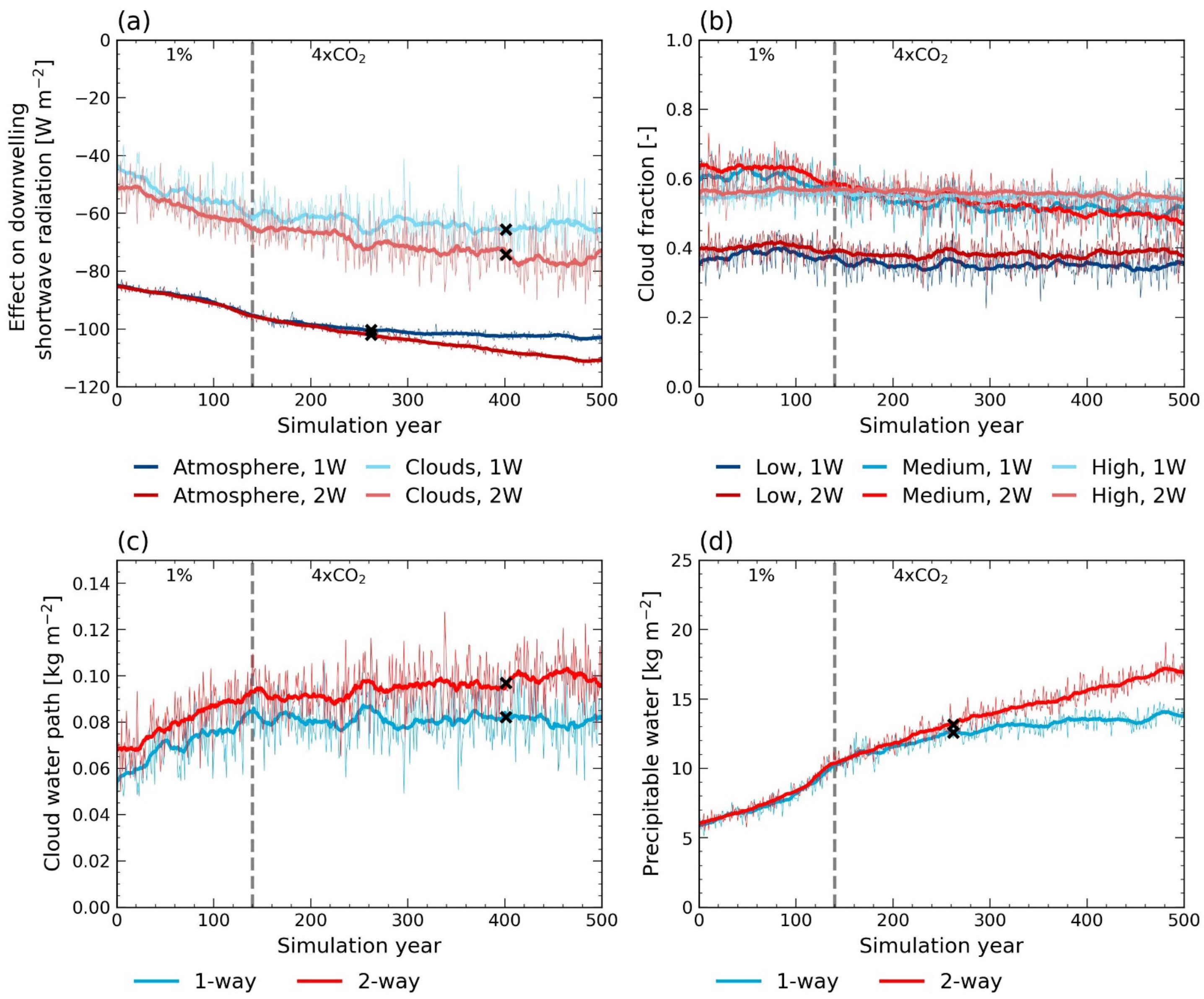
Shortwave radiation

- Increased shortwave reflection in the atmosphere
  - Larger amount of water vapor in the atmospheric column
  - Thicker clouds
  - Negative feedback on melt



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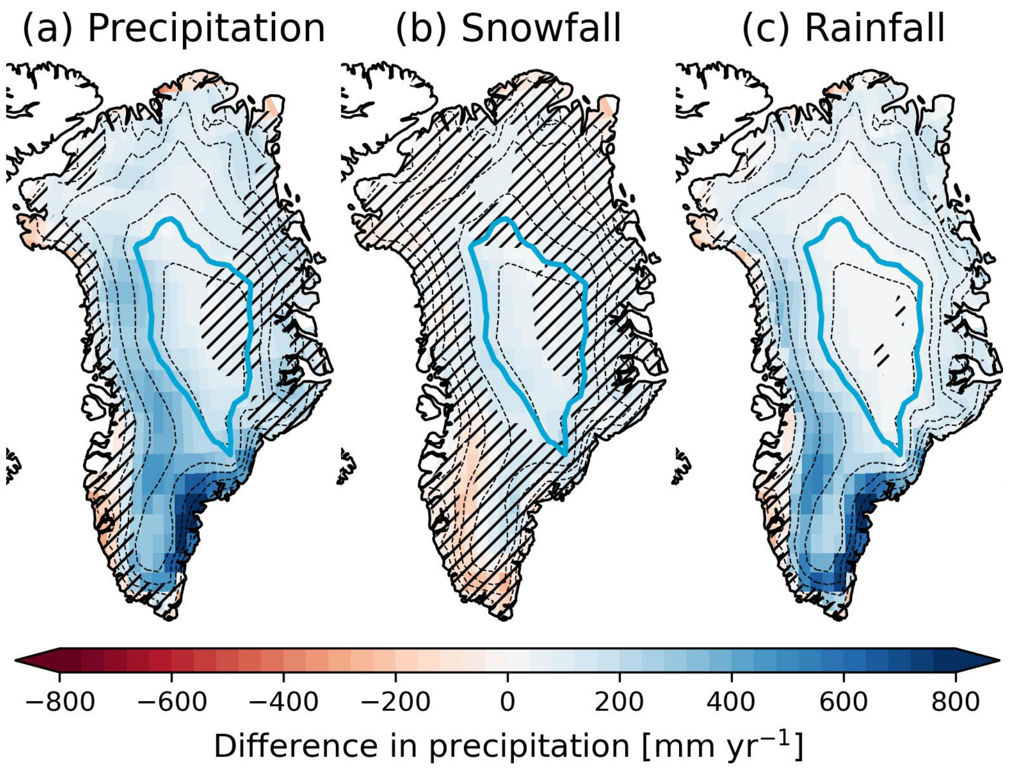
Precipitation

- Comparison in year 500 (2-way minus 1-way)

- Increased snowfall in accumulation area (negative feedback)

- Increase in relative amount of rainfall (positive feedback)



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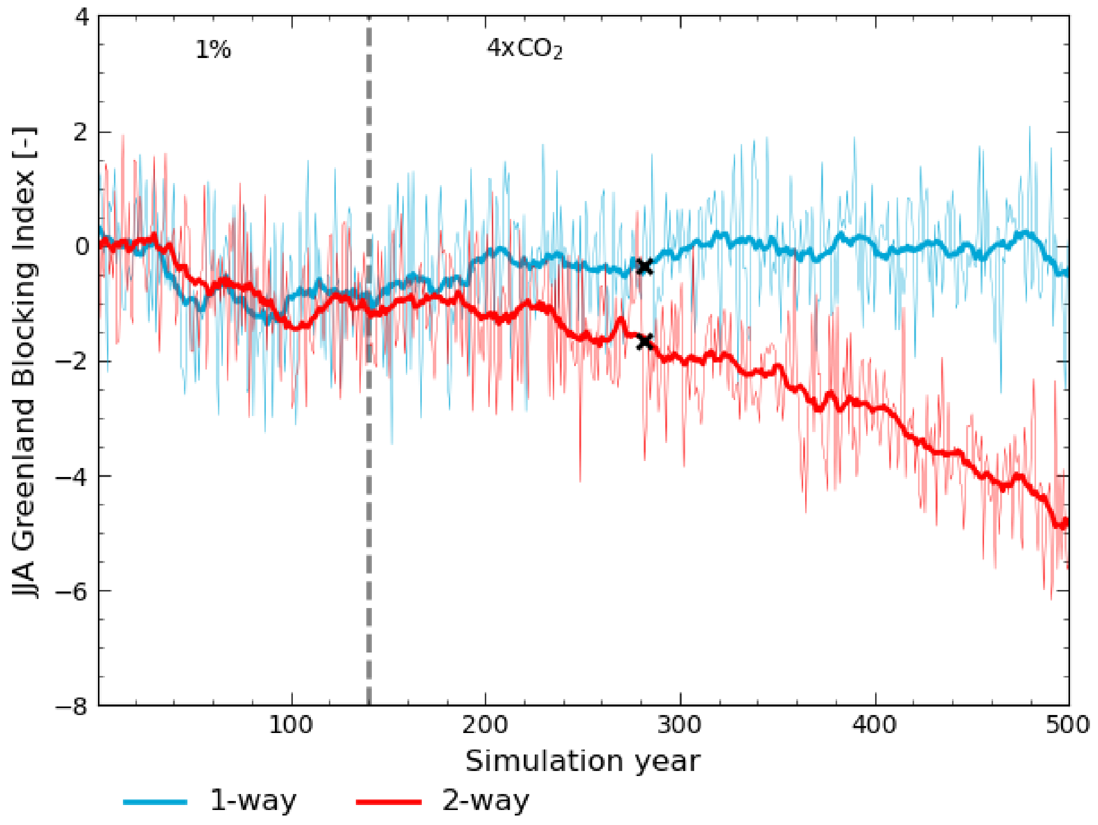
Atmospheric blocking

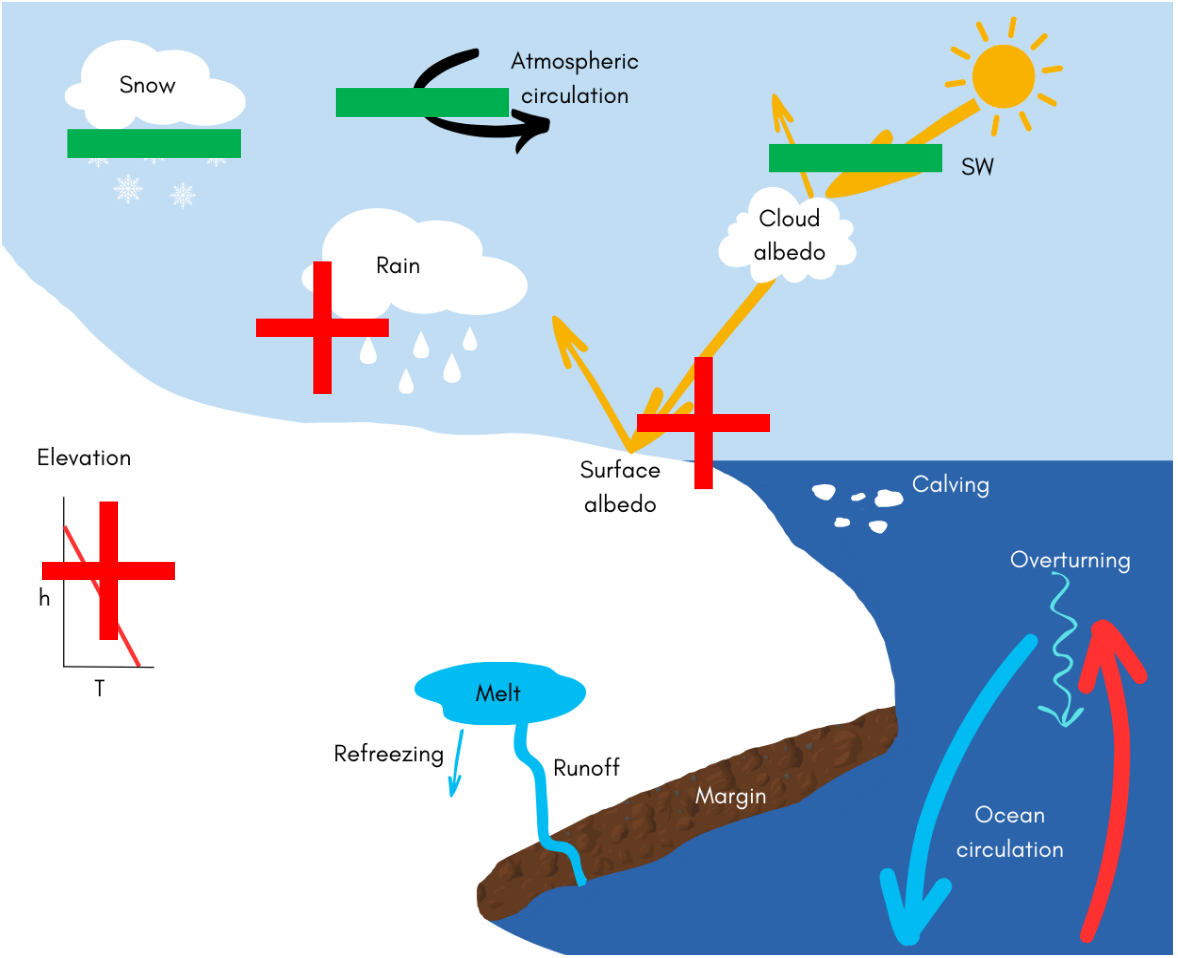
- Recent increases in summer blocking linked to increased melt

- Strong decrease in blocking as a result of topographic changes
  - Linked to 49% of SMB differences
  - Negative feedback on melt



Conclusion: effect of using 2-way coupling

- Lapse rate of -6 K/km does not represent melt-elevation feedback well
- A changing GrIS topography results in:
  - More reflection of shortwave radiation
  - Precipitation increase
  - Summer atmospheric blocking decrease
- Not accounting for or parameterizing feedbacks leads to an overestimation of melt



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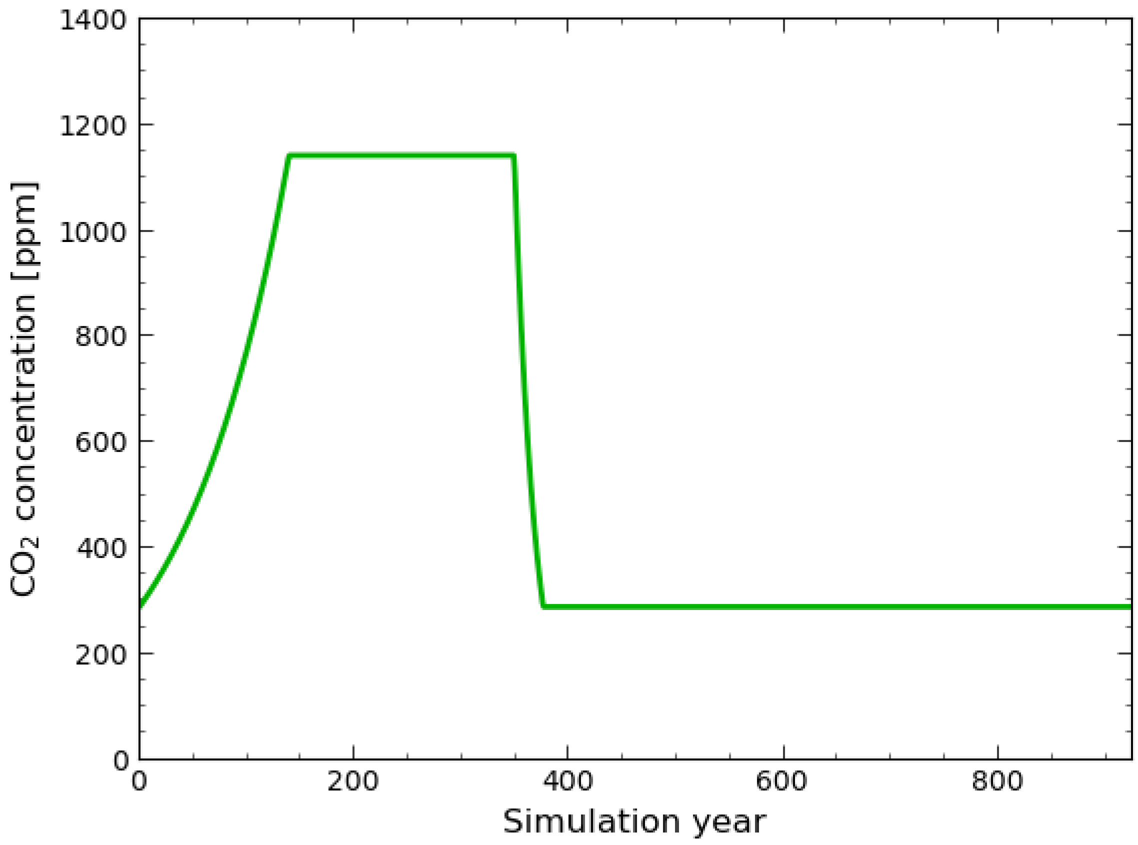
Greenland ice sheet response to CO_2 reduction

- First 350 years: $4xCO_2$ simulation
- Between 350 and 377: annual 5% decrease until pre-industrial CO_2 is reached



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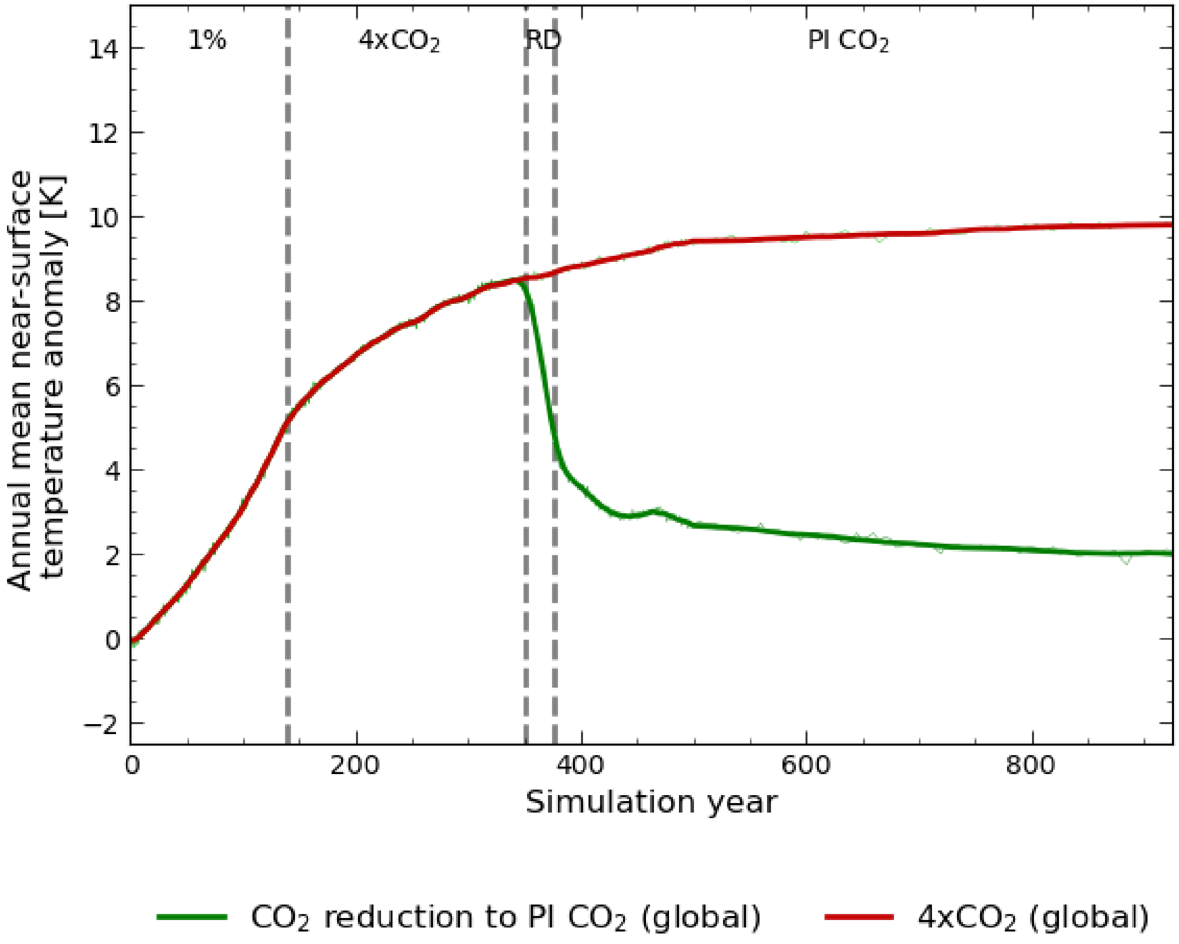
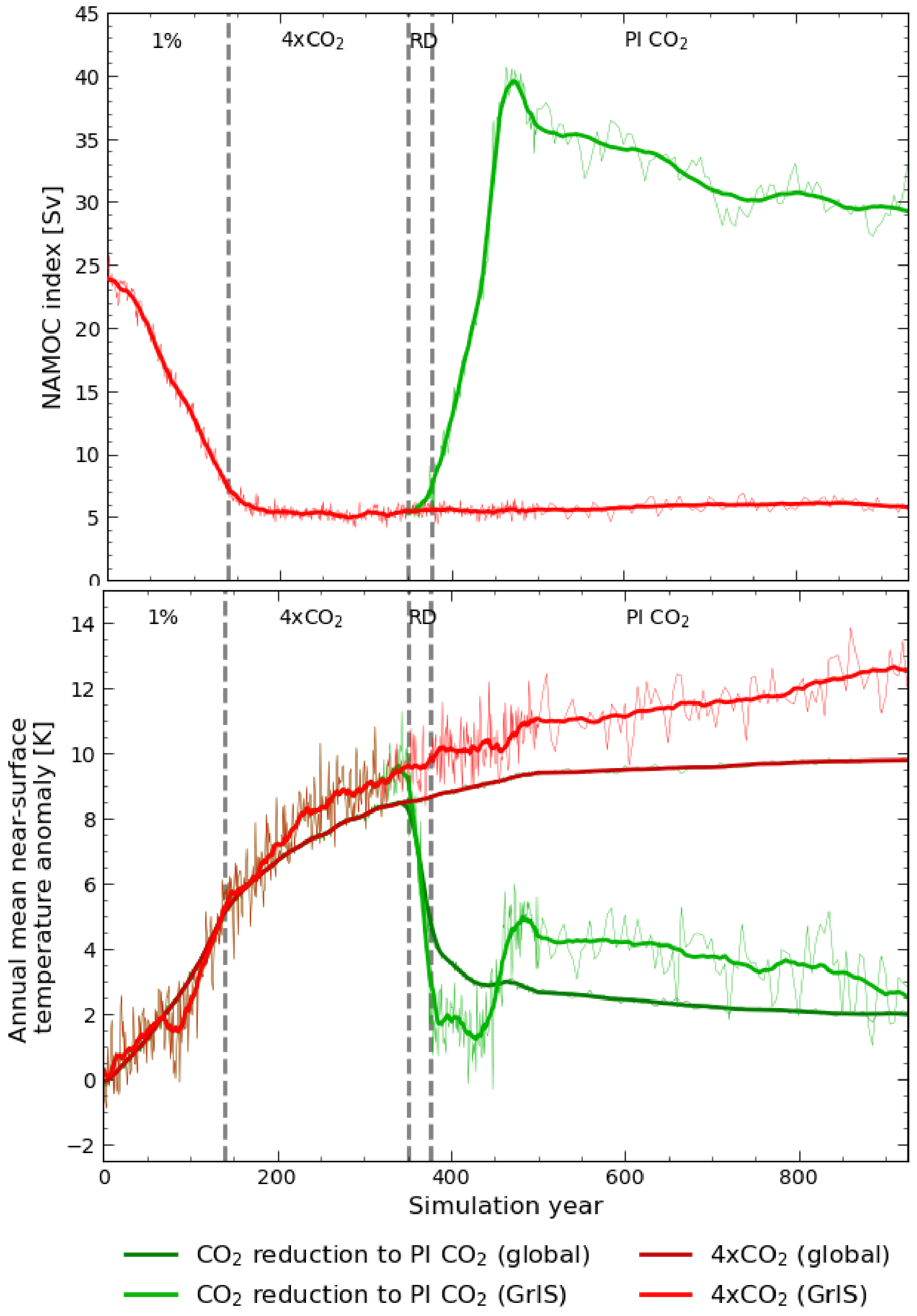
Temperature response

- Remaining 2 K global warming



Temperature response

- Remaining 2 K global warming
- GrIS experiences complex transitional phase
    - Delayed overshooting recovery of North Atlantic Meridional Overturning Circulation



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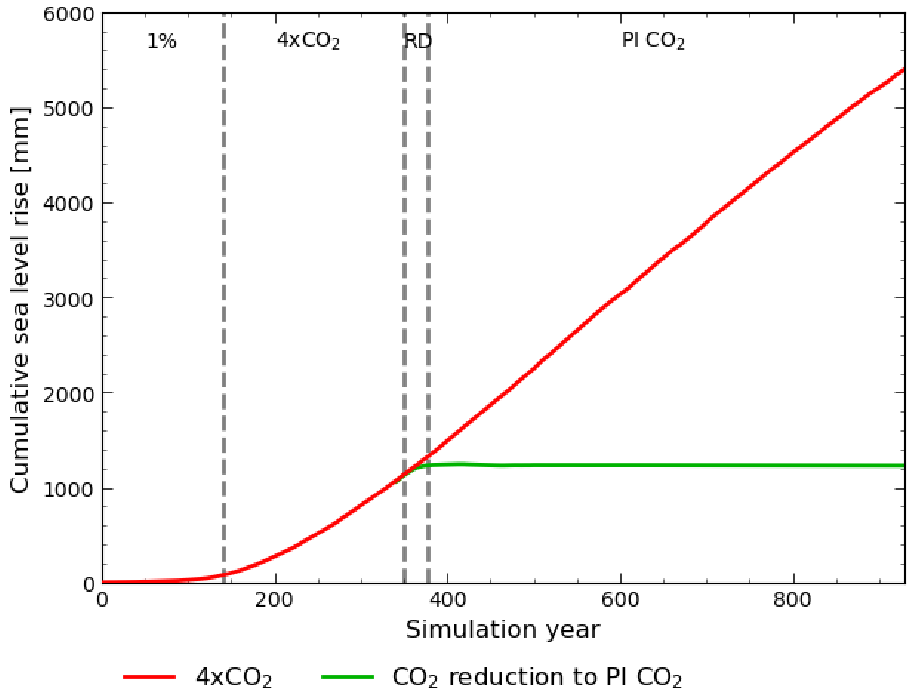
GrIS mass loss response

- Mass loss is halted despite 2 K remaining warming

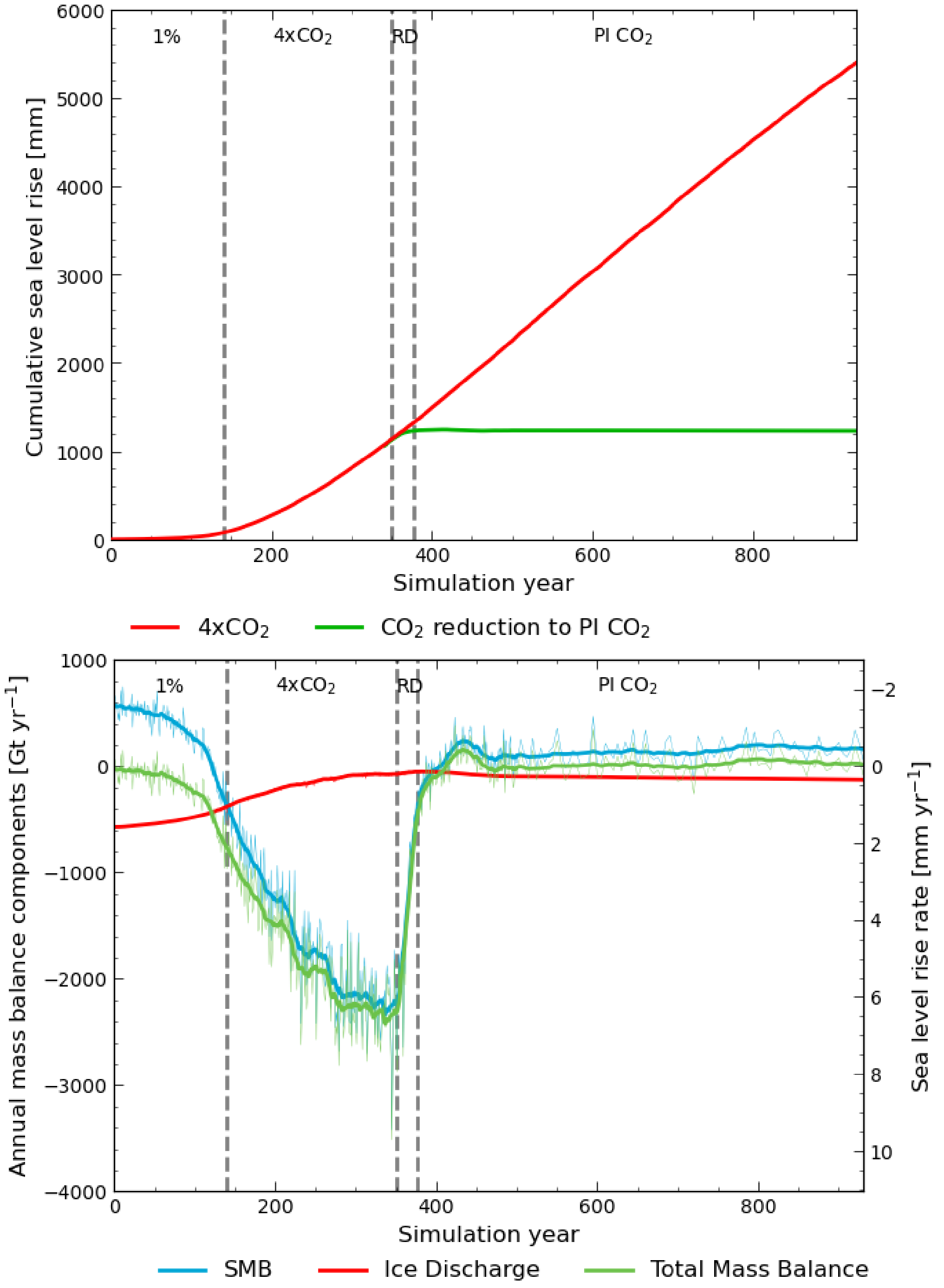
- Why?



GrIS mass loss response

- Mass loss is halted despite 2 K remaining warming

- Why?
  - SMB does not recover
  - GrIS has lost 1.2 m SLE
  - Therefore: small ice discharge due to retreated margins



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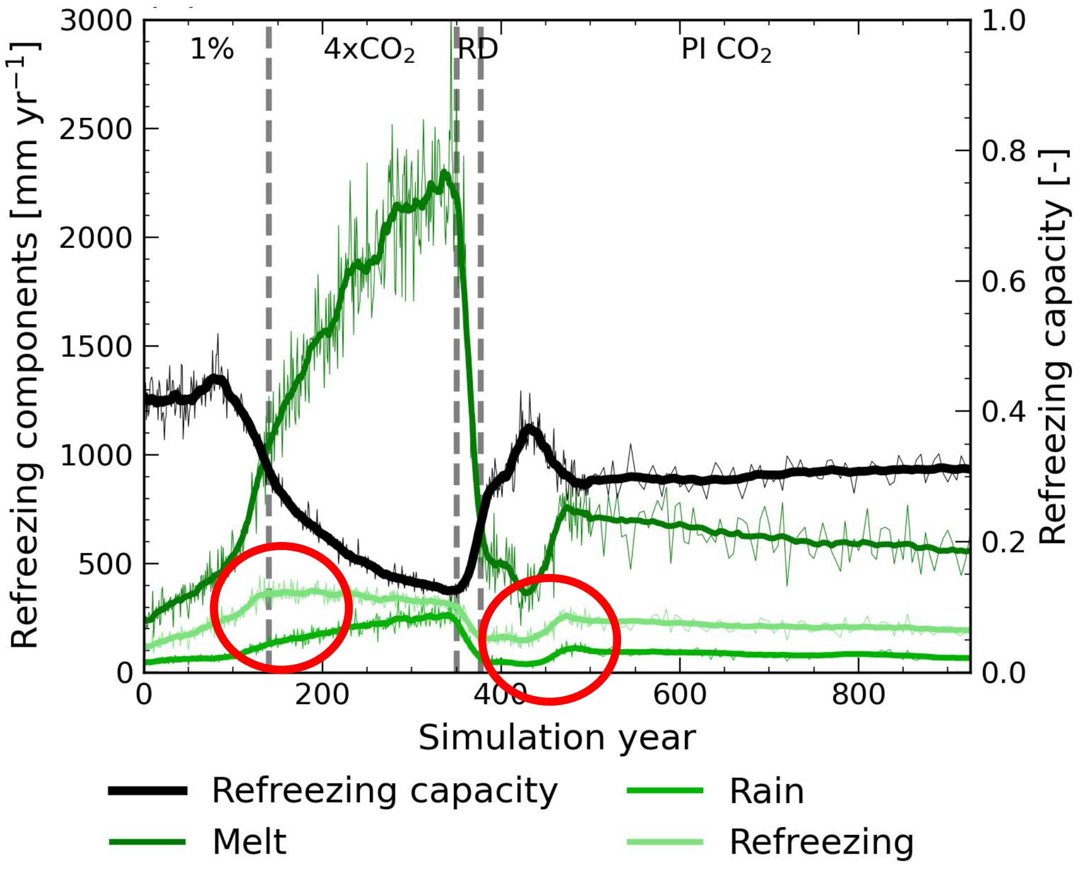
The surface mass balance does not recover

- Refreezing peaks at lower level after CO_2 reduction
  - Thinner snowpack
  - Higher snow temperatures



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The surface mass balance does not recover

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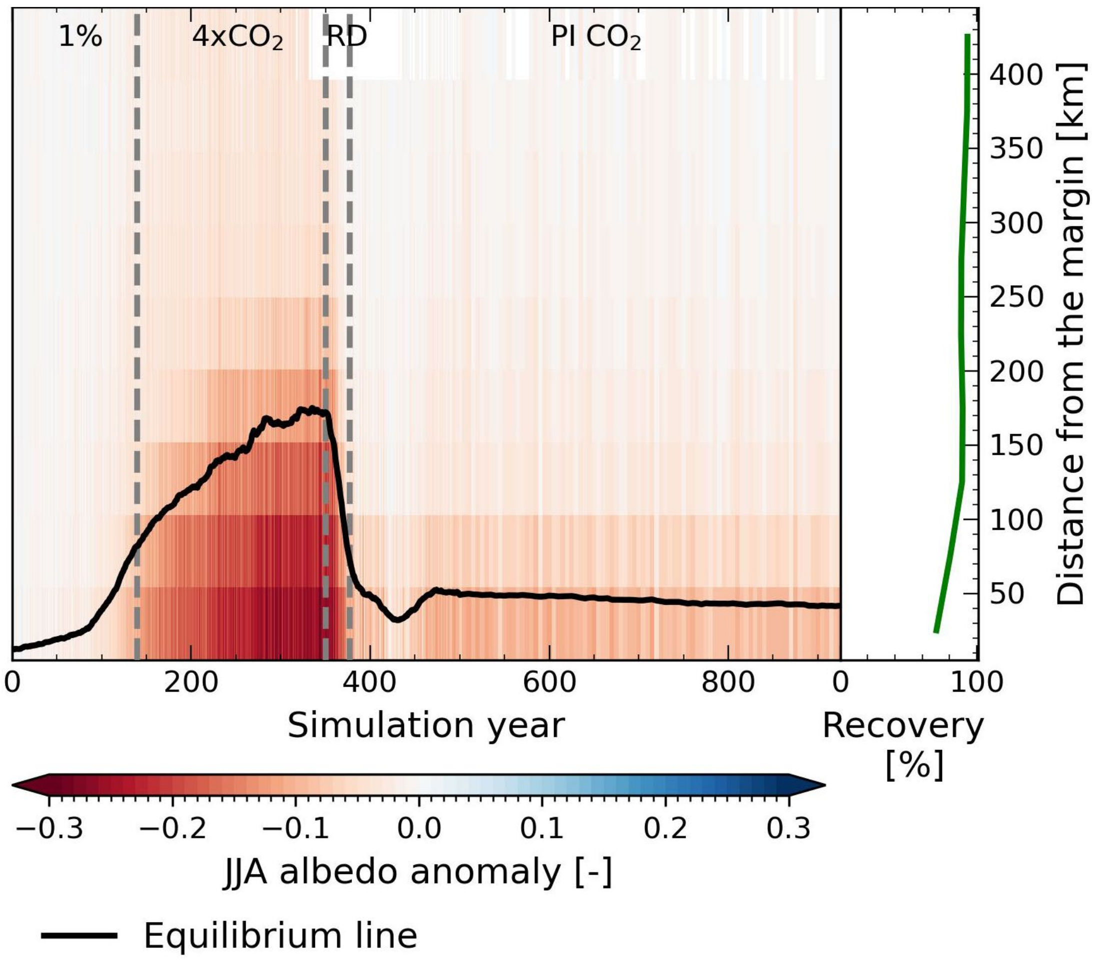
  - Thinner snowpack
  - Higher snow temperatures

- Albedo in the ablation area does not recover under remaining 2 K warming



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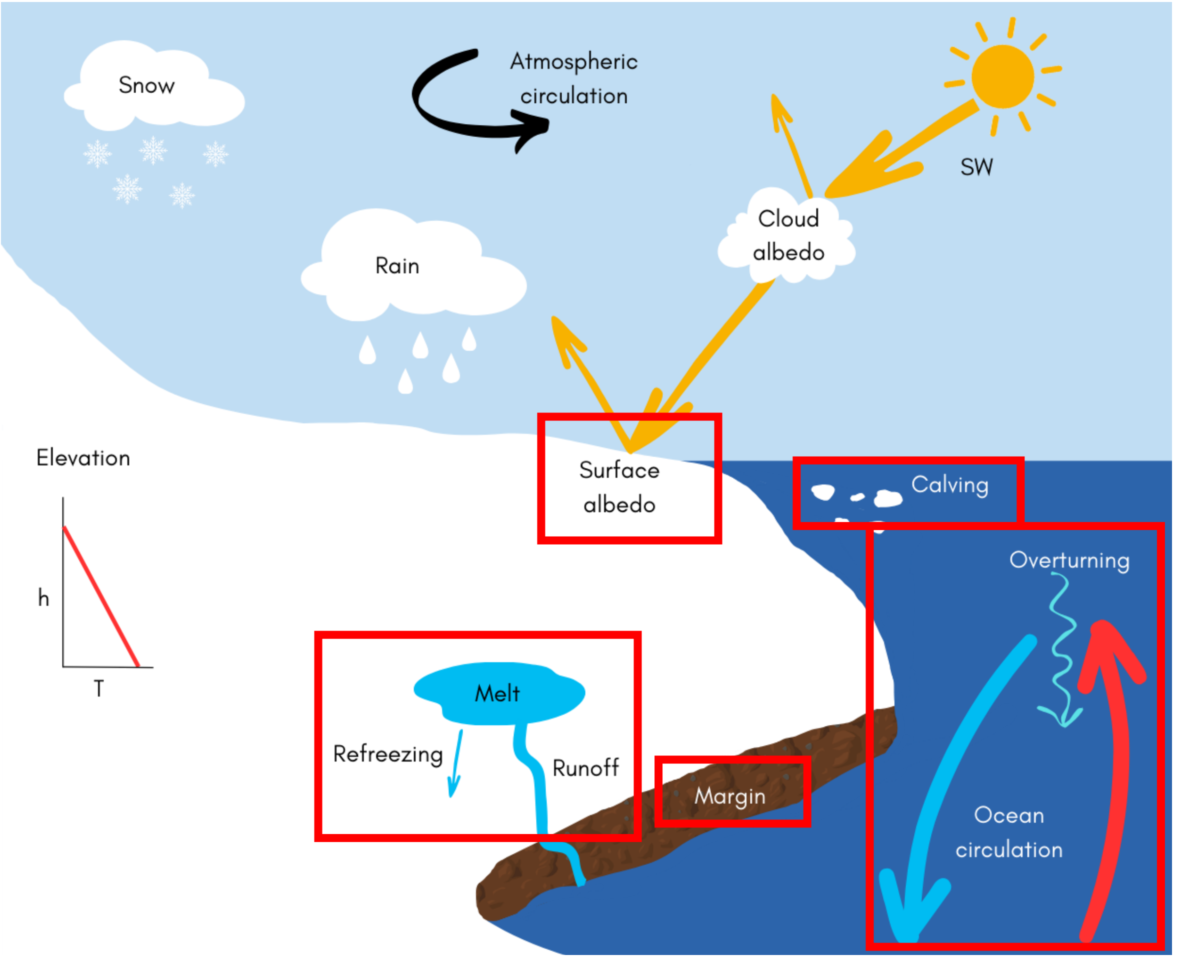
Conclusion: GrIS response to CO_2 reduction

- Ocean interactions play an important role during the transition phase

- Surface mass balance does not recover
- Reduced discharge due to retreated ice sheet

- Sea level rise can be halted despite 2 K remaining warming



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