Greenland ice sheet surface mass balance response to high CO2 forcing: threshold and mechanisms for accelerated surface mass loss

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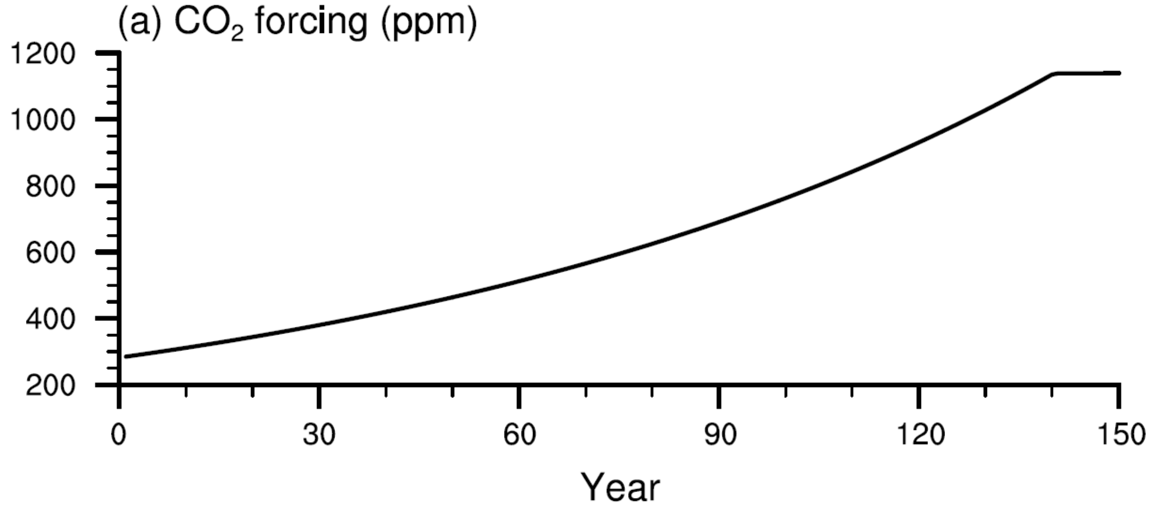
Motivation

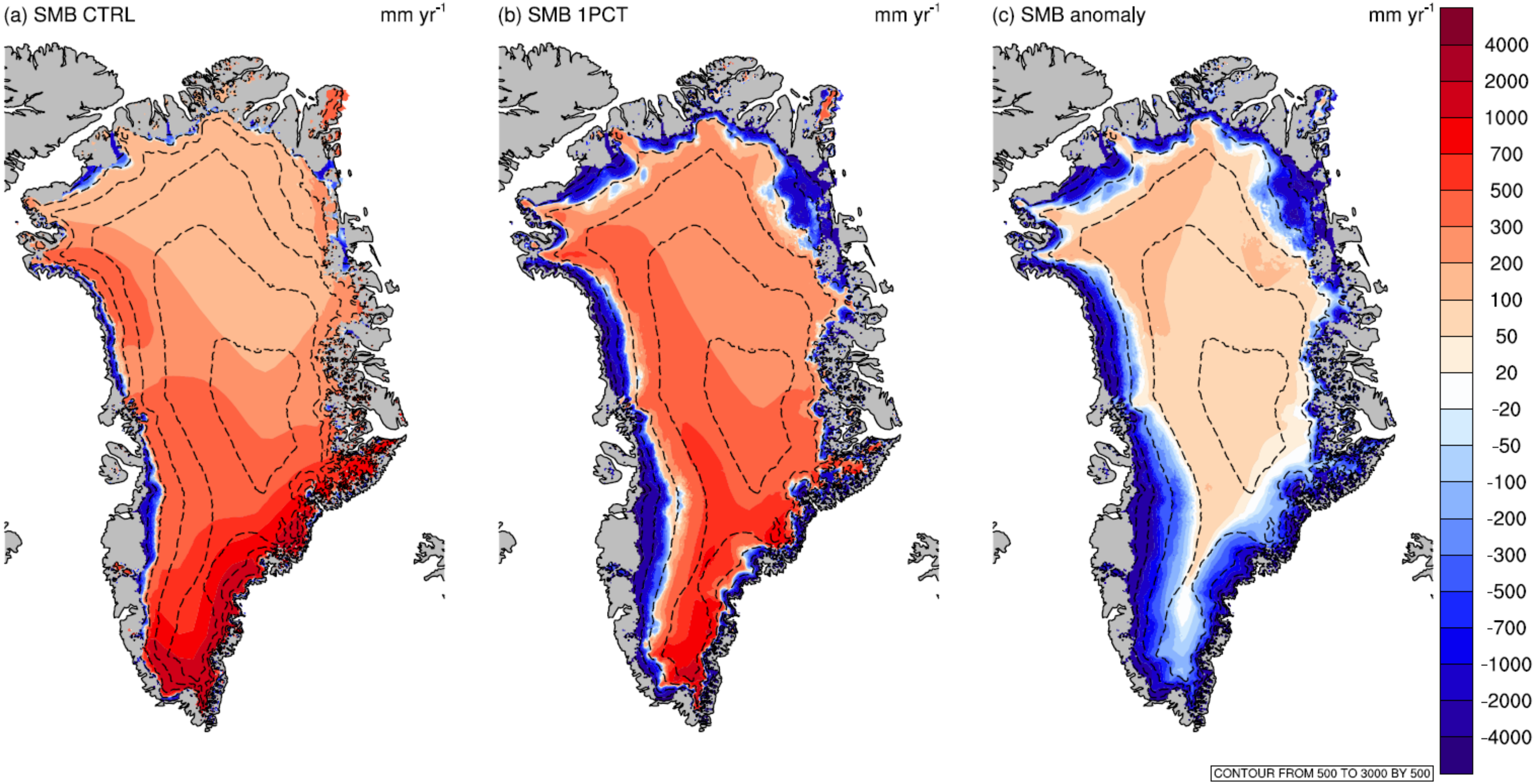
- Greenland ice sheet losing mass with increasing warming, contributing to global mean sea-level rise
- Understanding threshold and mechanisms for acceleration of surface mass loss important
- **Q:**
  - What is the modeled SMB evolution in response to increased CO_2?
  - What are the mechanisms involved in surface mass change?
  - What is the impact of future atmospheric circulation changes on the SMB?

Simulations

- CESM2.1 CMIP6 DECK experiments
- Fully coupled simulations at 1°
  - Non-evolving ice sheet
- Control simulation (CTRL): Pre-indsurtial 150 years
- 1% yr^{-1} CO_2 concentration (1PCT)
- CESM2.1 includes
  - Advanced firn modeling (van Kampenhout et al. 2017)
  - Explicit calculation of surface energy balance and surface mass balance using elevation classes (Sellevold et al. 2019)

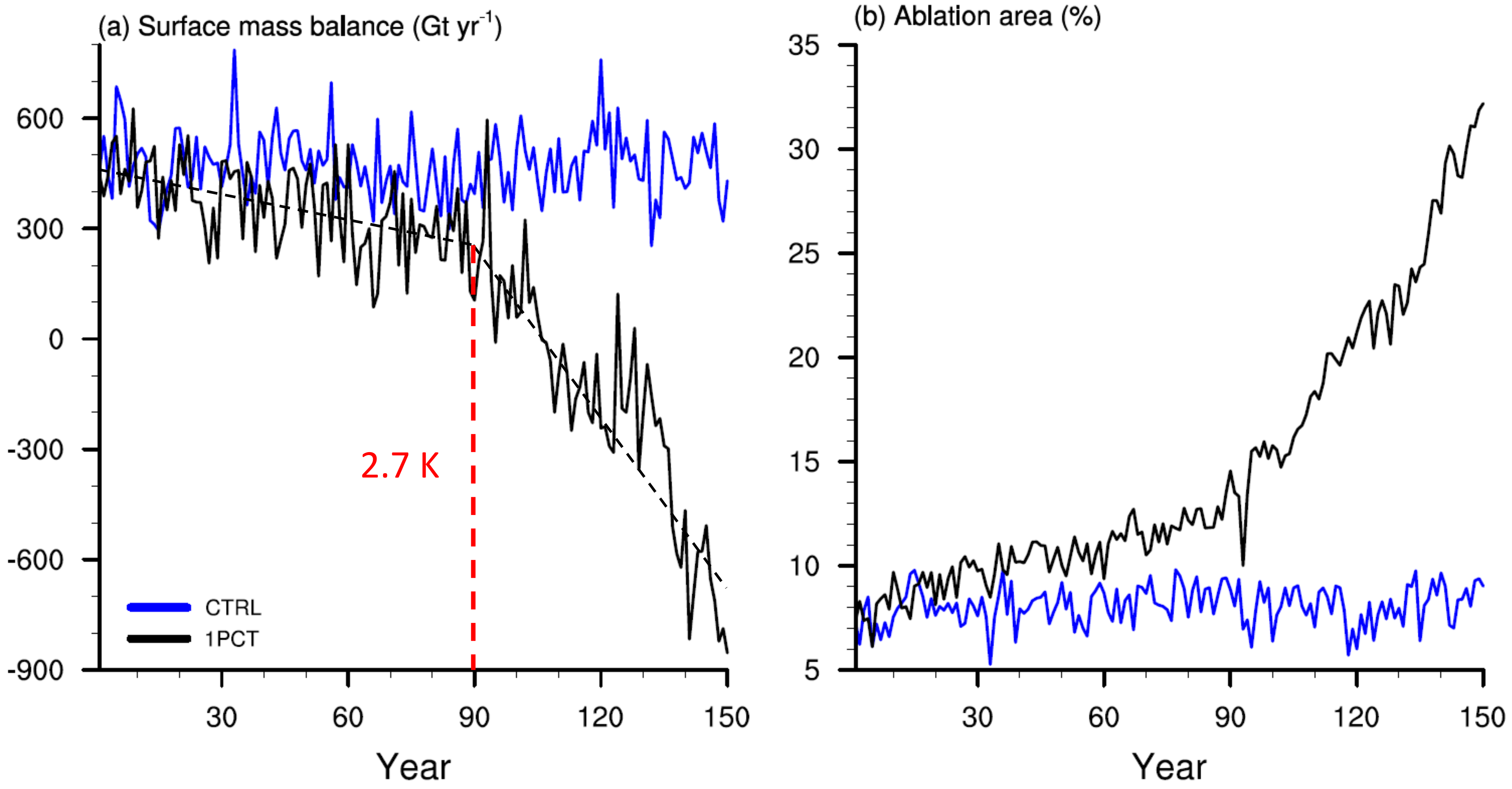


Greenland ice sheet surface mass loss



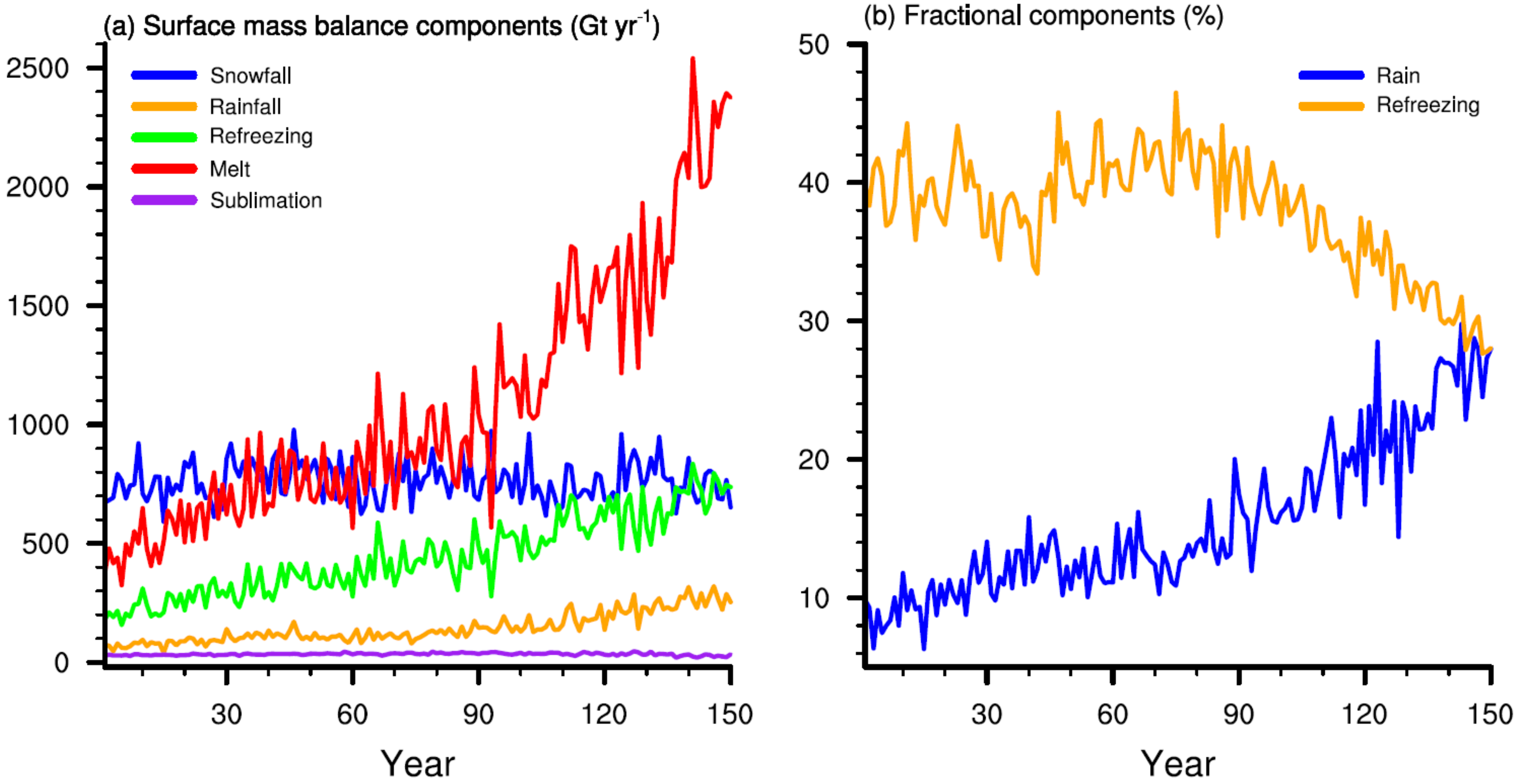
- Large expansion of ablation areas

SMB decrease acceleration at 2.7 K global warming



- Surface mass loss accelerates at 2.7 K of global warming
- Ablation areas expanding more rapidly at 2.7 K of global warming

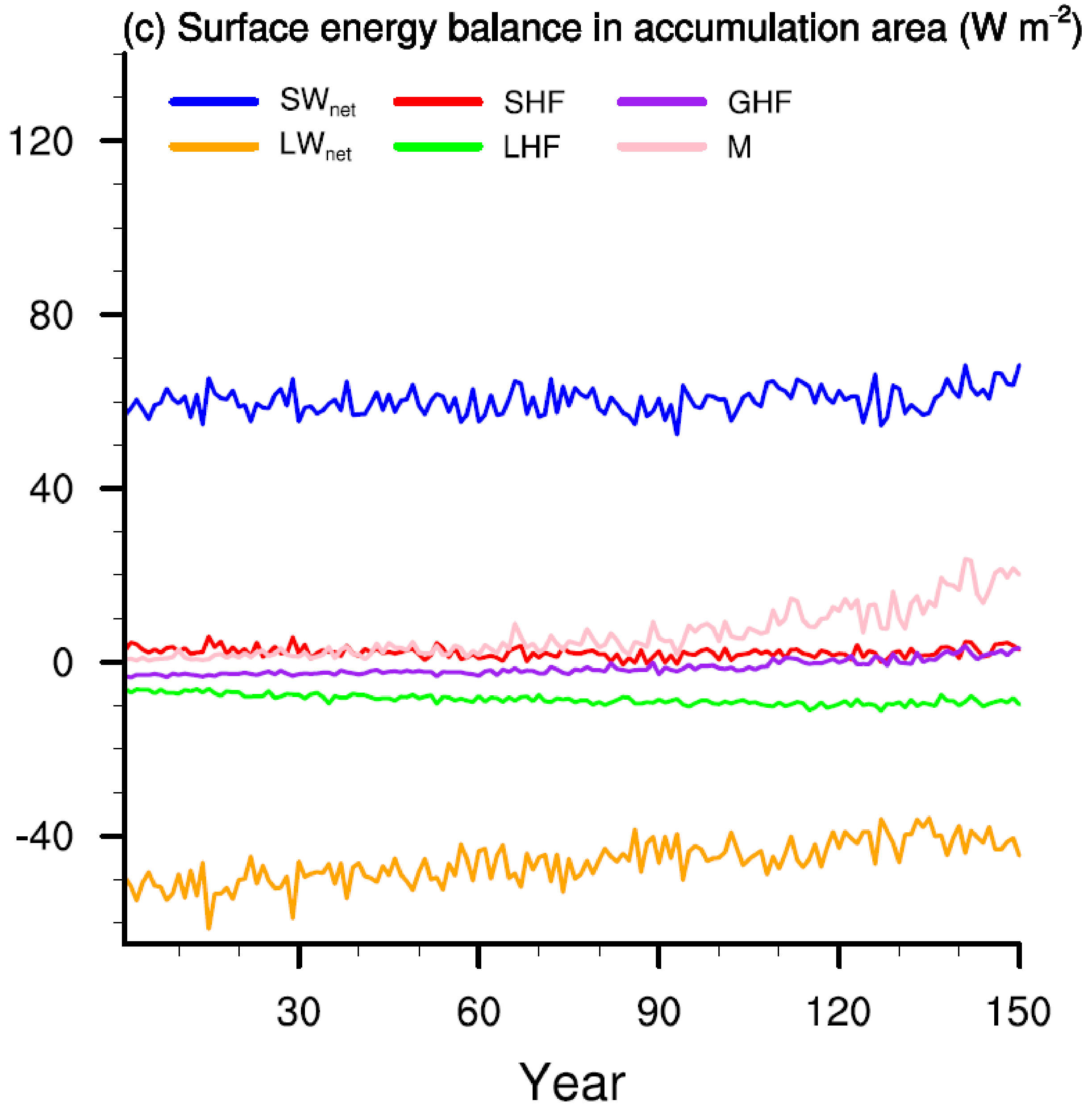
Surface mass balance



SMB = Snowfall + Refreezing – Melt - Sublimation

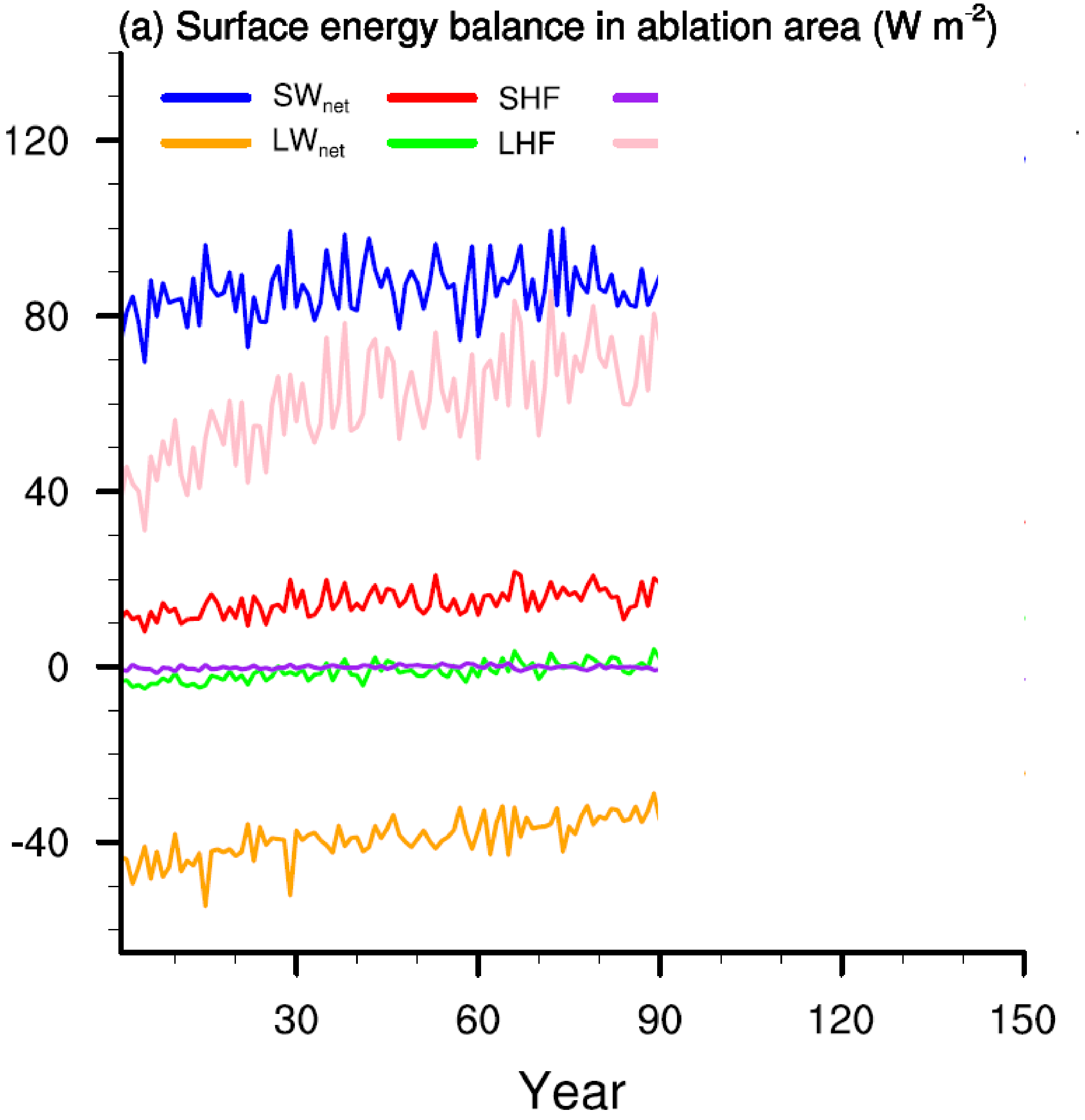
- Increased surface melt main contributor to surface mass loss
  - When melt > snowfall => rapid loss of refreezing capacity

Summer surface energy balance



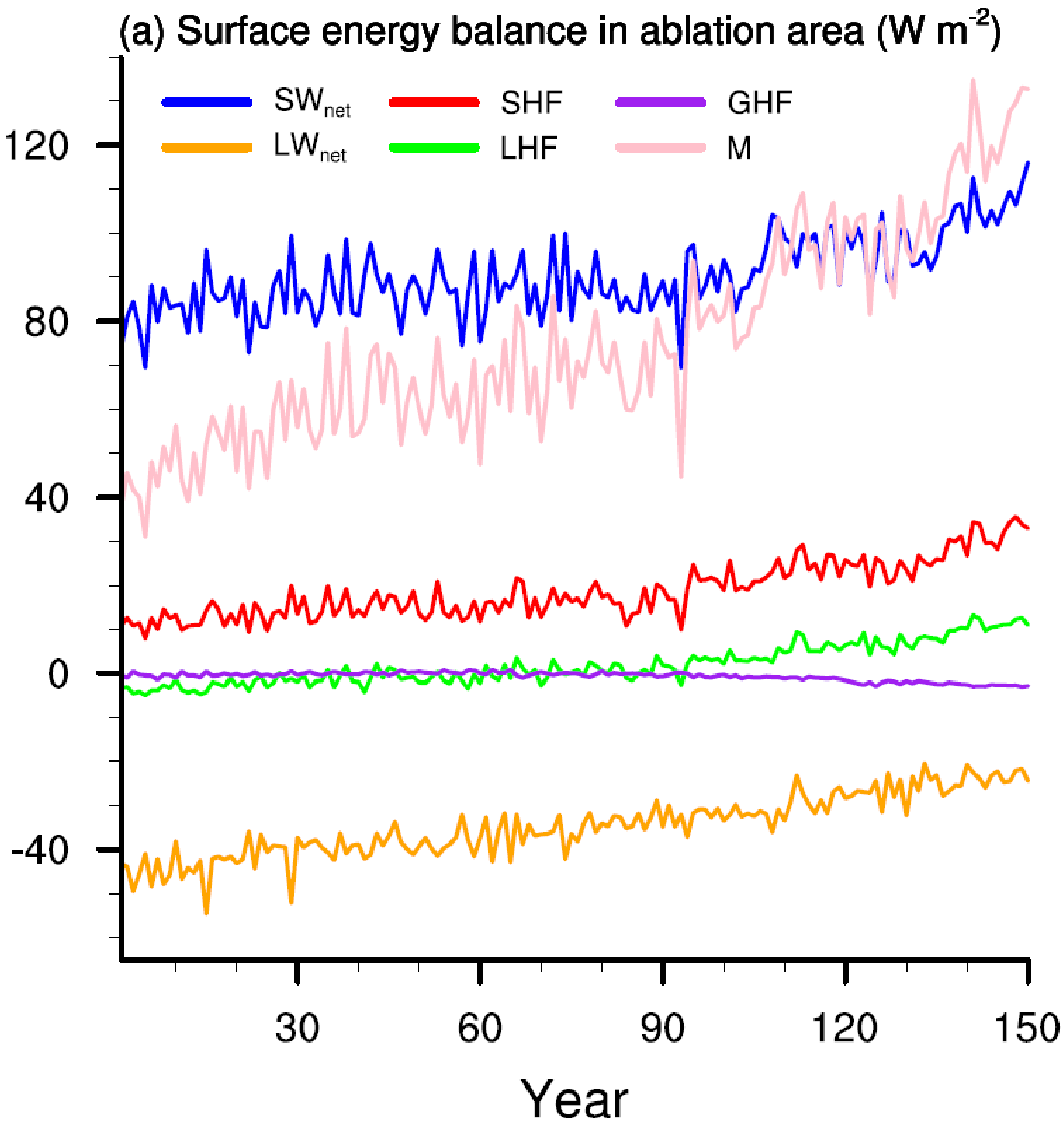
- In the accumulation area, longwave radiation is the main contributor to melt energy increase

Summer surface energy balance



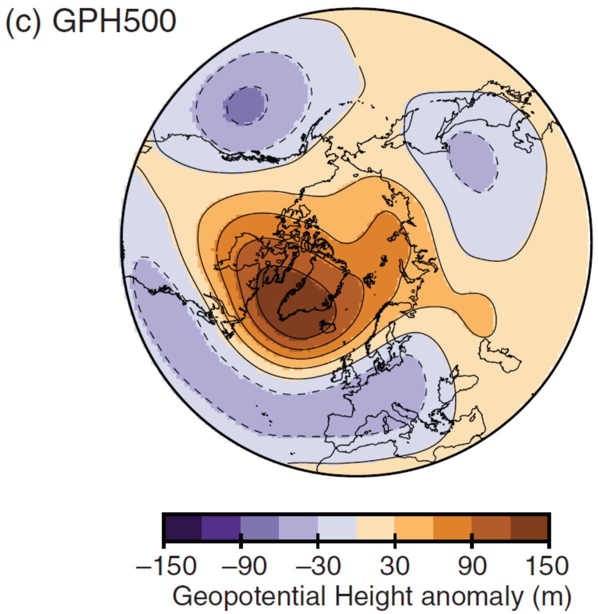
- Also, in the ablation area, longwave radiation is the main contributor to increased melt energy
- Sw_{net} does not increase despite lower albedo, as thicker clouds reduces incoming SW

Summer surface energy balance

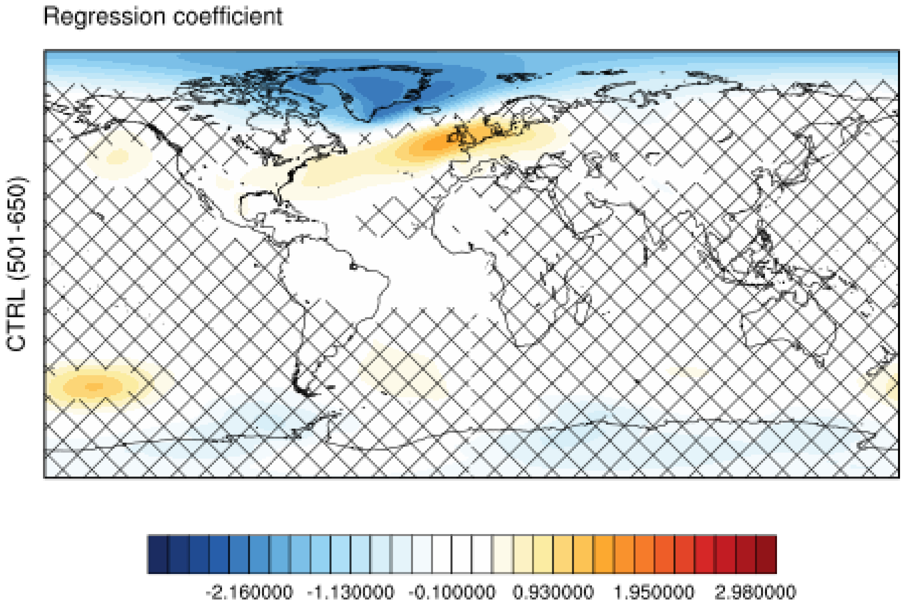


- At 2.7 K of global warming:
  - Albedo feedback: bare ice exposed for a longer time, no further reduction in incomg SW
  - SHF: as ice sheet surface is at melting point, increased atmospheric temperatures increases SHF
  - LHF: longer bare ice exposure, more moist atmosphere

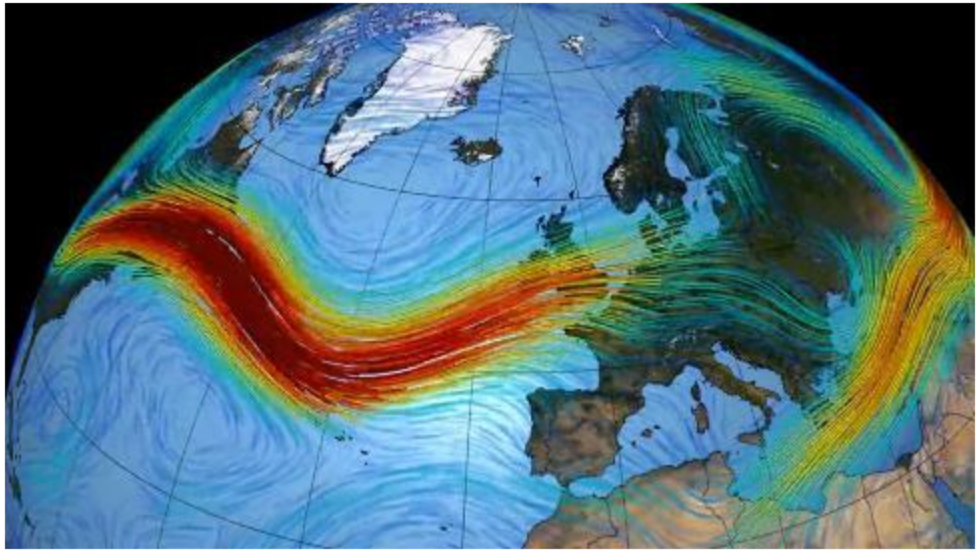
Summer circulation changes



Greenland blocking index (GBI)
Hanna et al. (2016)

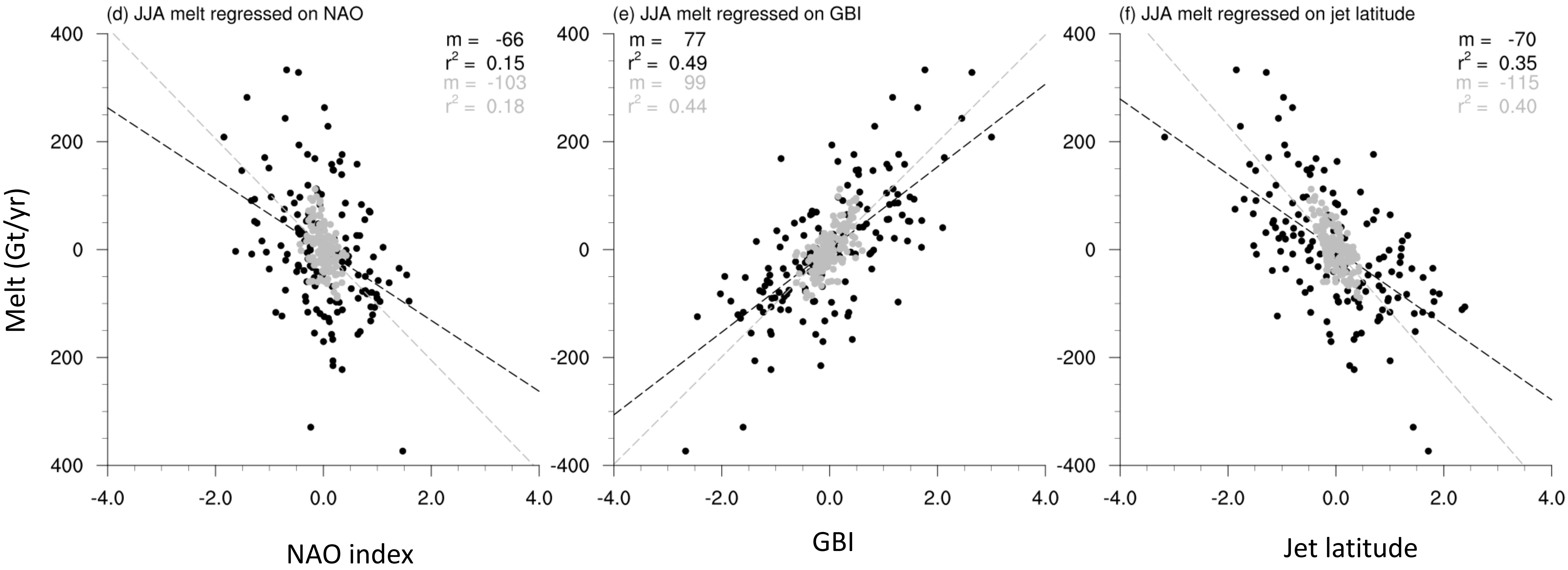


North Atlantic Oscillation (NAO)



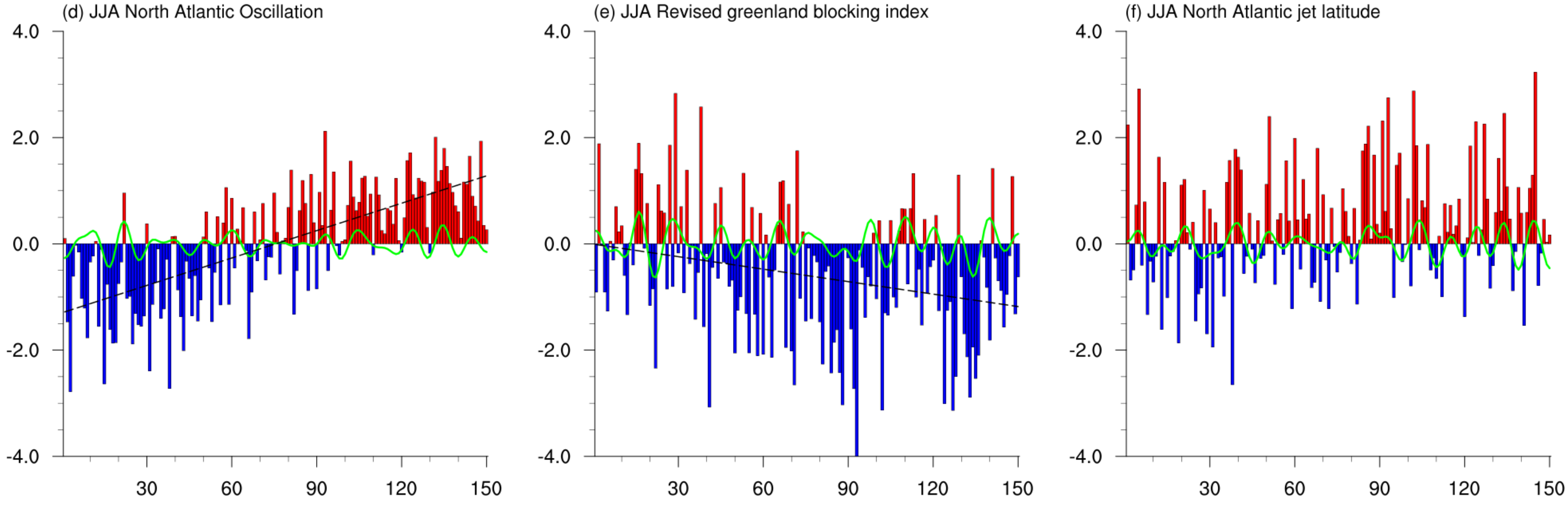
Polar jet latitude

Summer circulation changes



- More positive NAO index => less surface melt
- More positive GBI => more surface melt
- Jet latitude towards north => less surface melt

Circulation changes



- NAO trends towards more positive => reduces surface melt
- GBI trends towards more negative => reduces surface melt
- No trend in position of jet

Conclusions

- Accelerated GrIS surface mass loss for a global warming of 2.7 K through increased surface melt and loss of refreezing capacity
- Longwave radiation is the main contributor to melt increase before acceleration; albedo feedback and turbulent heat fluxes add major contributions after
- Anthropogenic-forced atmospheric circulation changes (NAO and GBI) partially reduces melt