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-industrial 150 years
- 1% yr⁻¹ CO₂ 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
• 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

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

\[ \text{SMB} = \text{Snowfall} + \text{Refreezing} - \text{Melt} - \text{Sublimation} \]
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
• $S_{\text{net}}$ 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 incoming 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
- 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