Greenland surface mass balance response to increased CO2

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Motivation

- Greenland is losing mass, contributing to global sea level rise
- Understanding processes contributing to surface mass loss essential for constraining response time to climate change and its possible influence on regional and global climate
- New development of CESM2 inquires study of its response to CO2 forcing
Model and experiment

• Model version: CESM2.1

• All components active (including WACCM), non-evolving ice sheet

• CESM2 include changes in snow scheme and ice sheet downscaling
  - allowing for firn development
  - temperature dependent snow grain size
  - downscaling of downwelling longwave radiation and rain/snow repartitioning

• Runs ran as part of the CMIP6

• Simulations analyzed
  - Pre-industrial (piControl) as control run
  - 1% increase in CO2 until 4xCO2 stabilization (1PCT)
Global temperature change

- **Winter (DJF)**
  - piControl (20 years)
  - 1PCT response (131-150)

- **Summer (JJA)**
  - piControl (20 years)
  - 1PCT response (131-150)

- **Temperature (°C)**
  - Winter (DJF)
  - Summer (JJA)

- **Temperature anomaly (°C)**
  - Winter (DJF)
  - Summer (JJA)

- **ΔT**
  - piControl (20 years): 5.2 K
  - 1PCT response (131-150): 5.0 K

- **AA factor**
  - piControl (20 years): 2.2
  - 1PCT response (131-150): 1.1
North Atlantic

EOF1: 40.9 %  
DJF

EOF1: 26.4 %  
JJA
Arctic summer evolution

- Arctic: 60°N - 90°N
- Ocean is close to ice-free
- Temperature rising quickly (2.2x global)
- Precipitation increases
- Cloud cover decreases
Greenland surface mass balance

- Surface mass balance decreases with 988 Gt/yr
- SMB is significantly different from year 58 (99% confidence)
- First time below zero in year 97 -> accelerated surface mass loss
- Stays below zero from year 120

- Ablation areas expand from 8.0% to 27.2%
- Ablation areas different in year 46 (99% confidence), a decade before the SMB signal is detected
Greenland surface mass balance

Surface mass balance (mm/yr), last 20 years of simulation

- Expansion of ablation areas
- Equilibrium line altitude increases with ~500 m
Surface mass balance trend

Surface mass balance trend (mm/yr / decade)

- Linear trend for last 20 years of 1PCT
- Interior is trending towards positive -> increased precipitation
Increased runoff causes surface mass loss

**Surface mass balance components (Gt/yr)**

- Precipitation
- Runoff
- Subl./Evap.

- Only for 1PCT run
- Precipitation increases with 217 Gt/yr
- Runoff increases with 1371 Gt/yr
- Increase in runoff greatly exceeds increase in precipitation
- Acceleration of runoff around year 100

\[ \text{SMB} = \text{PRECIPITATION} - \text{RUNOFF} - \text{SUBLIMATION} \]
Loss of refreezing capacity

- Only for 1PCT run
- 5-year running averages
- Melt and rain increase, while refreezing fraction decrease
- Year 80: refreezing fraction decrease faster and rain shows clear increase
- Year 100: acceleration of melt increase

RUNOFF = REFREEZING - RAIN - MELT
Surface energy budget

Surface energy balance components (W/m²)

- JJA averages
- Net radiation increase (monotonically)
- Increased cloud cover
  - less incoming solar
  - albedo effect
  - more longwave incoming
- Turbulent heat flux increase
  - Surface temperature can’t exceed 0K
• Surface mass balance sensitivity to increased CO2 is detected after ~60 years, with ablation areas showing expansion a decade earlier, due to increased runoff

• Interior of ice sheet is gaining mass by increase in precipitation

• Loss of refreezing capacity accelerates surface mass loss

• As ice sheet gets warmer, turbulent heat transfer to the ice sheet increases rapidly