Greenland surface mass balance response to increased CO2

Raymond Sellevold, Miren Vizcaino

Nederlandse Organisatie voor Wetenschappelijk Onderzoek

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Motivation

- Greenland is losing mass, contributing to global sea level rise

- Understdaning 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 CO_2 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 CO_2 until 4xCO_2 stabilization (1PCT)

Global temperature change

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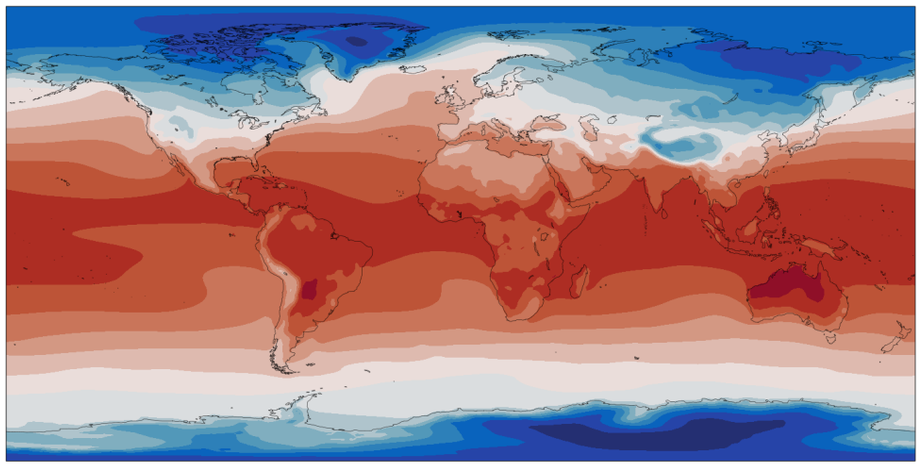
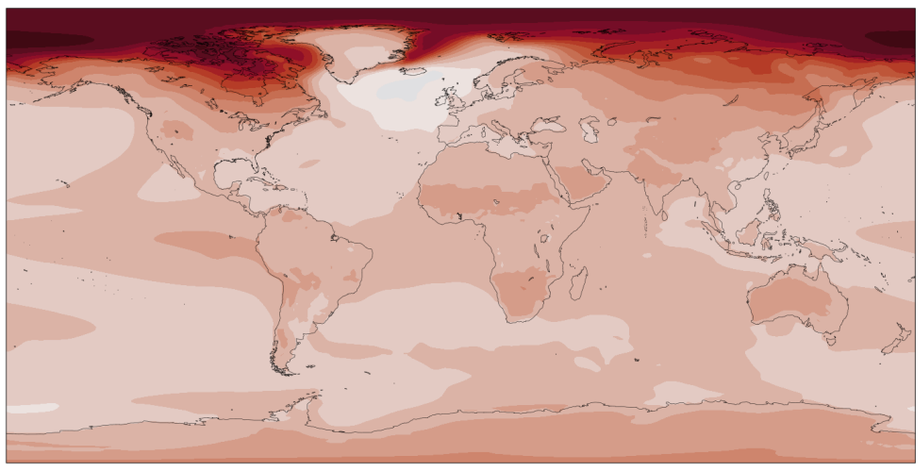
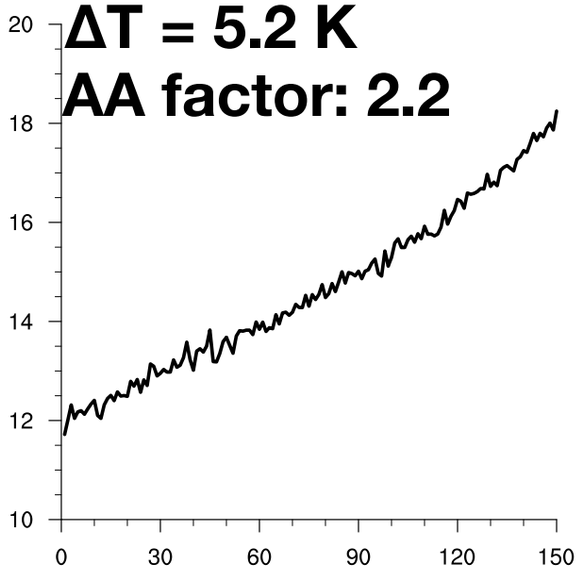
piControl (20 years)

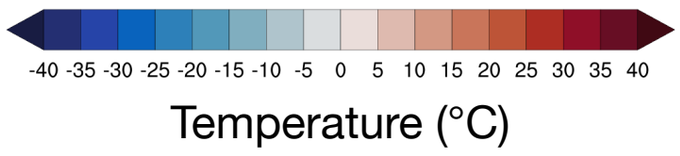
1PCT response (131-150)

Winter (DJF)

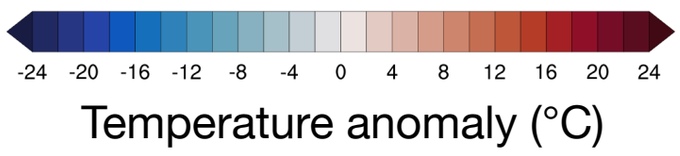






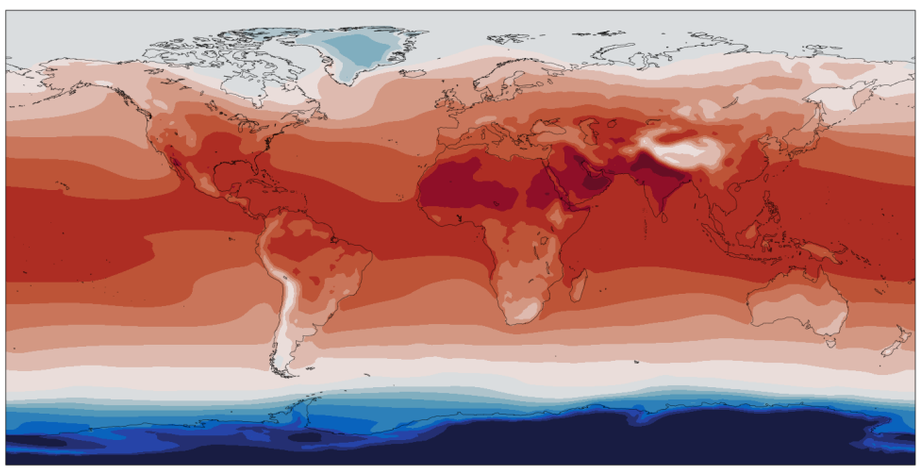


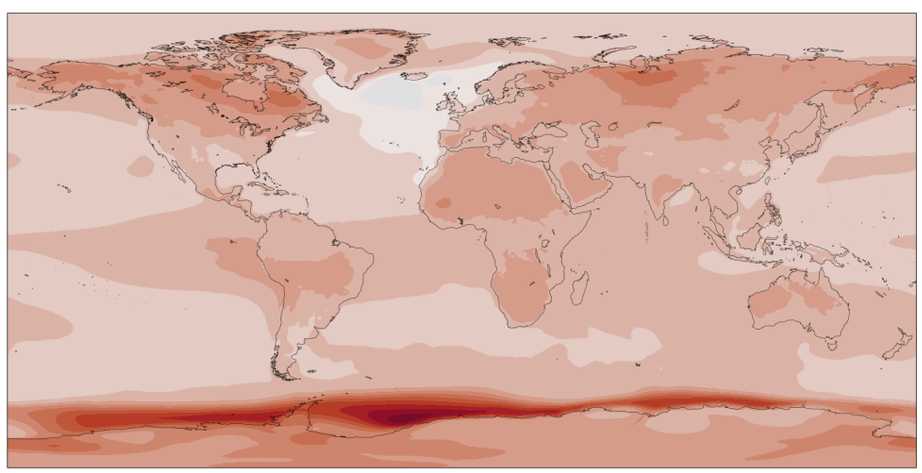
Temperature (°C)

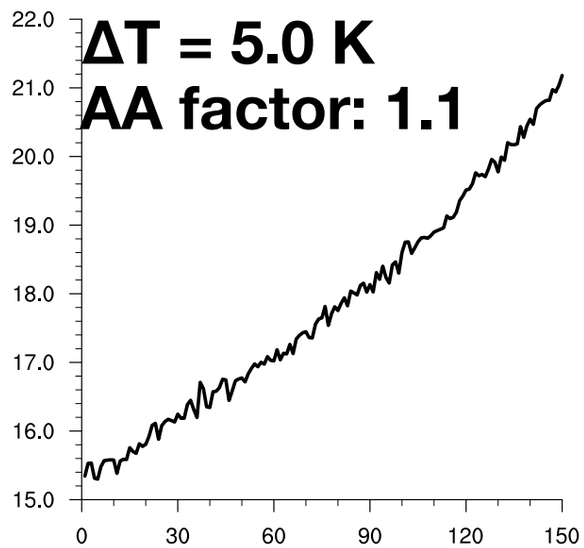


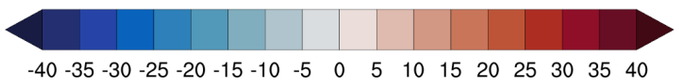
Temperature anomaly (°C)

Summer (JJA)









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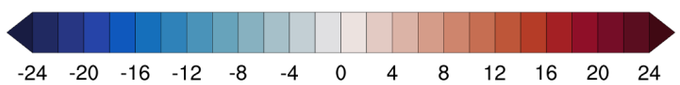

Temperature anomaly (°C)

North Atlantic

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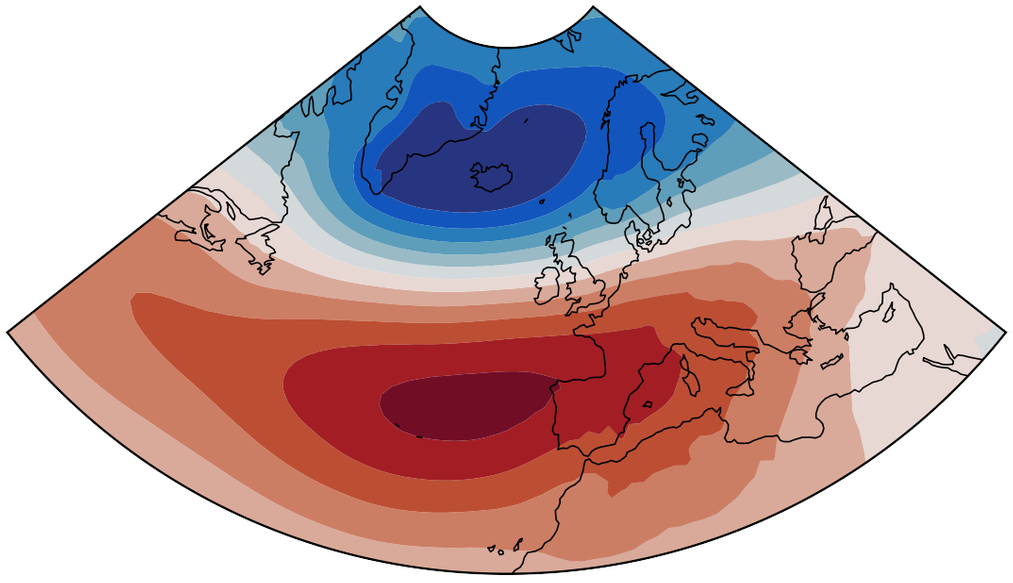
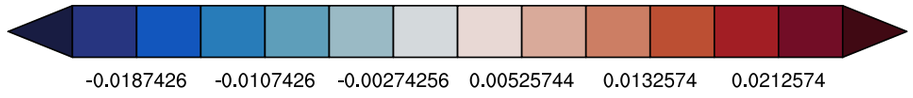
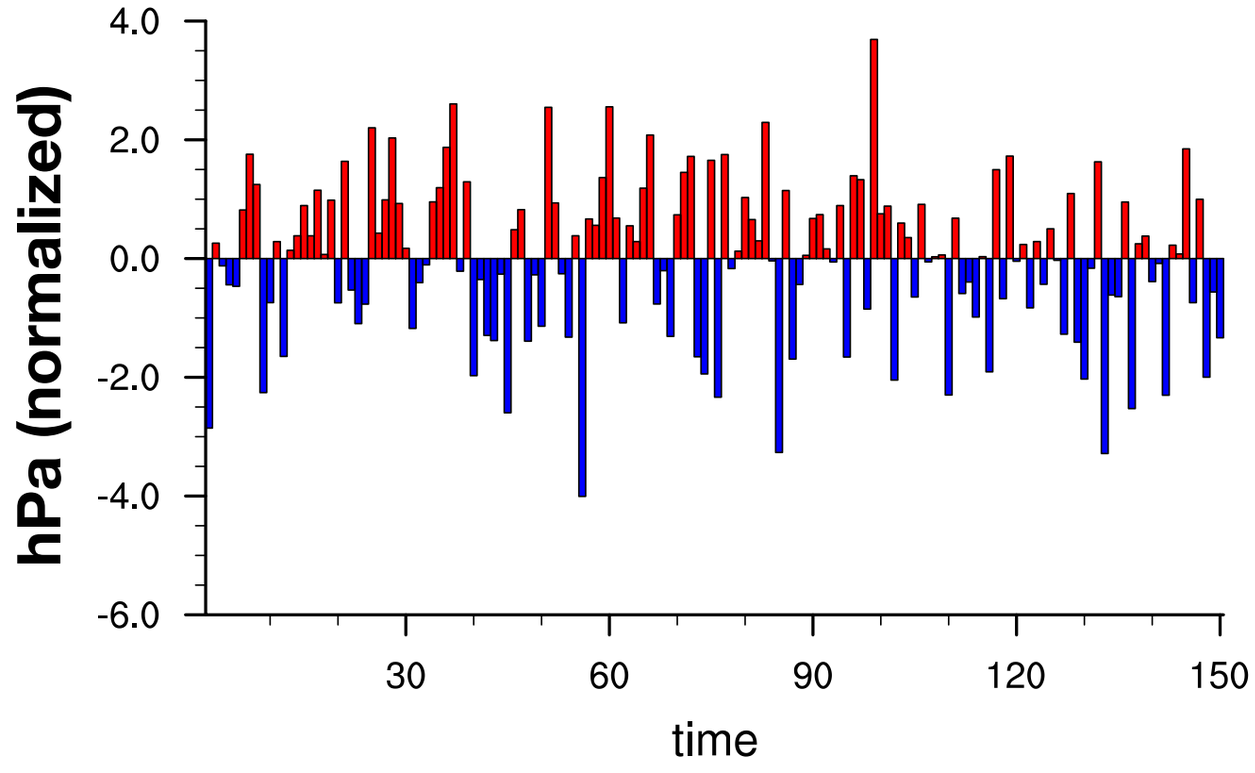
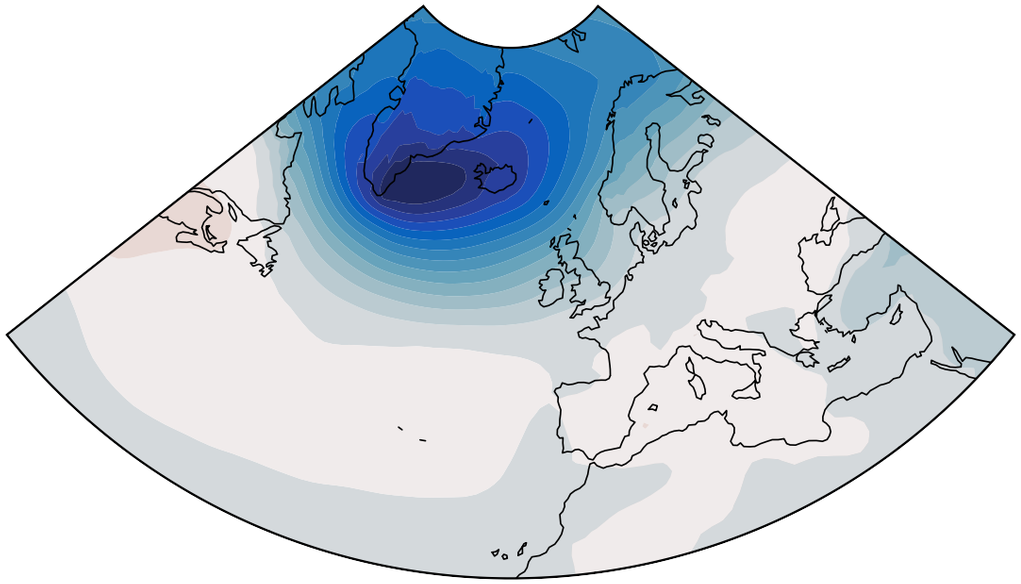
EOF1: 40.9 % **DJF**

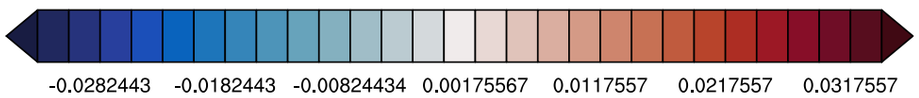


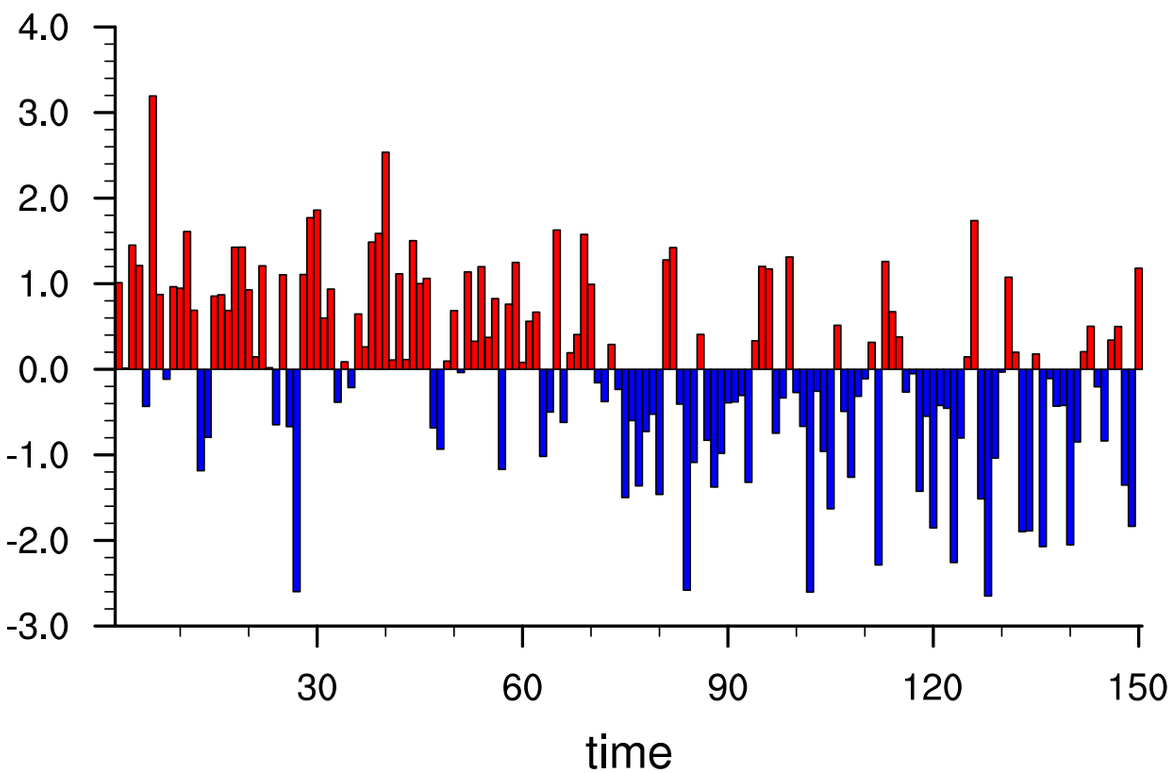




EOF1: 26.4 % **JJA**







Arctic summer evolution

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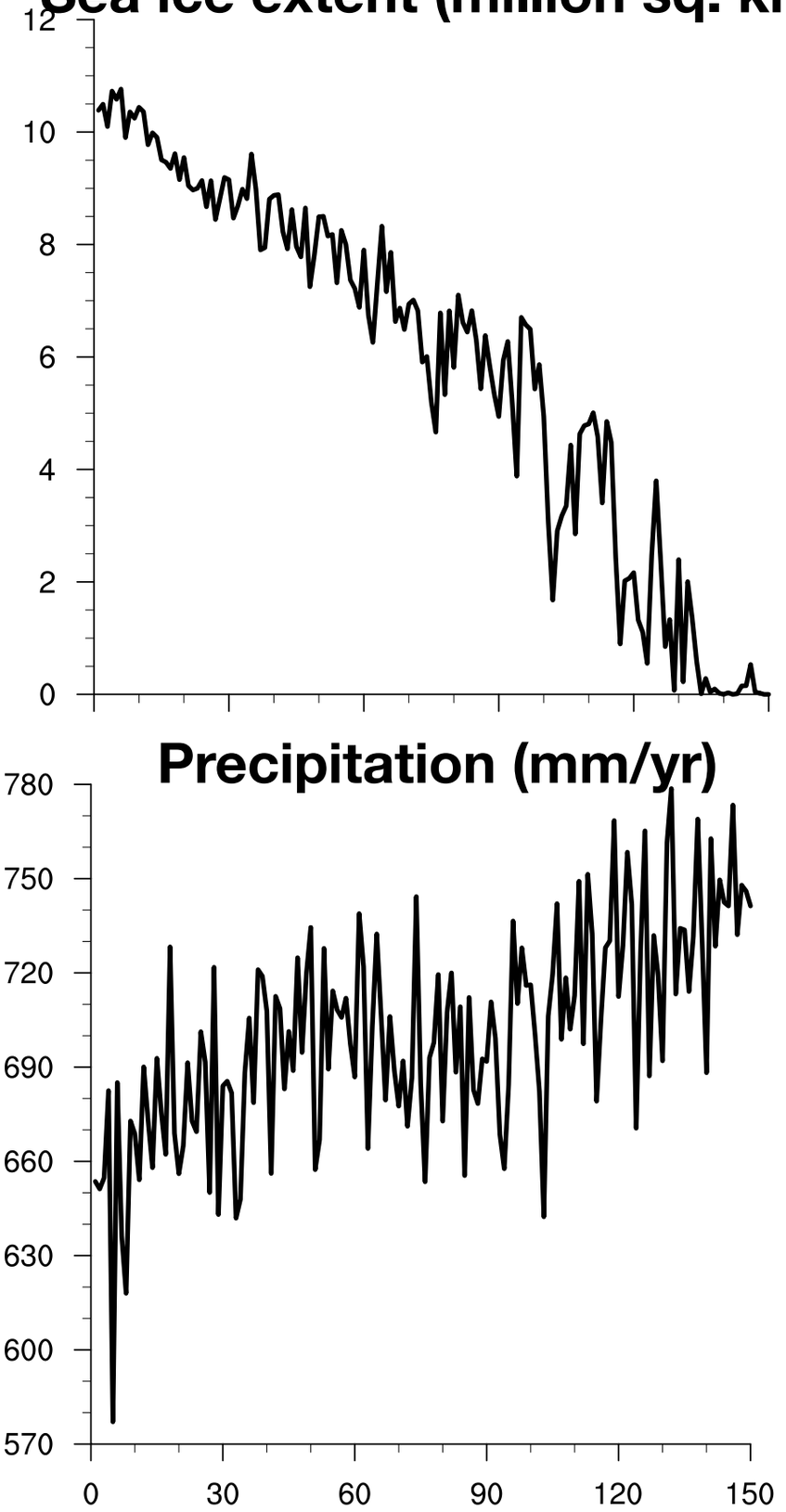
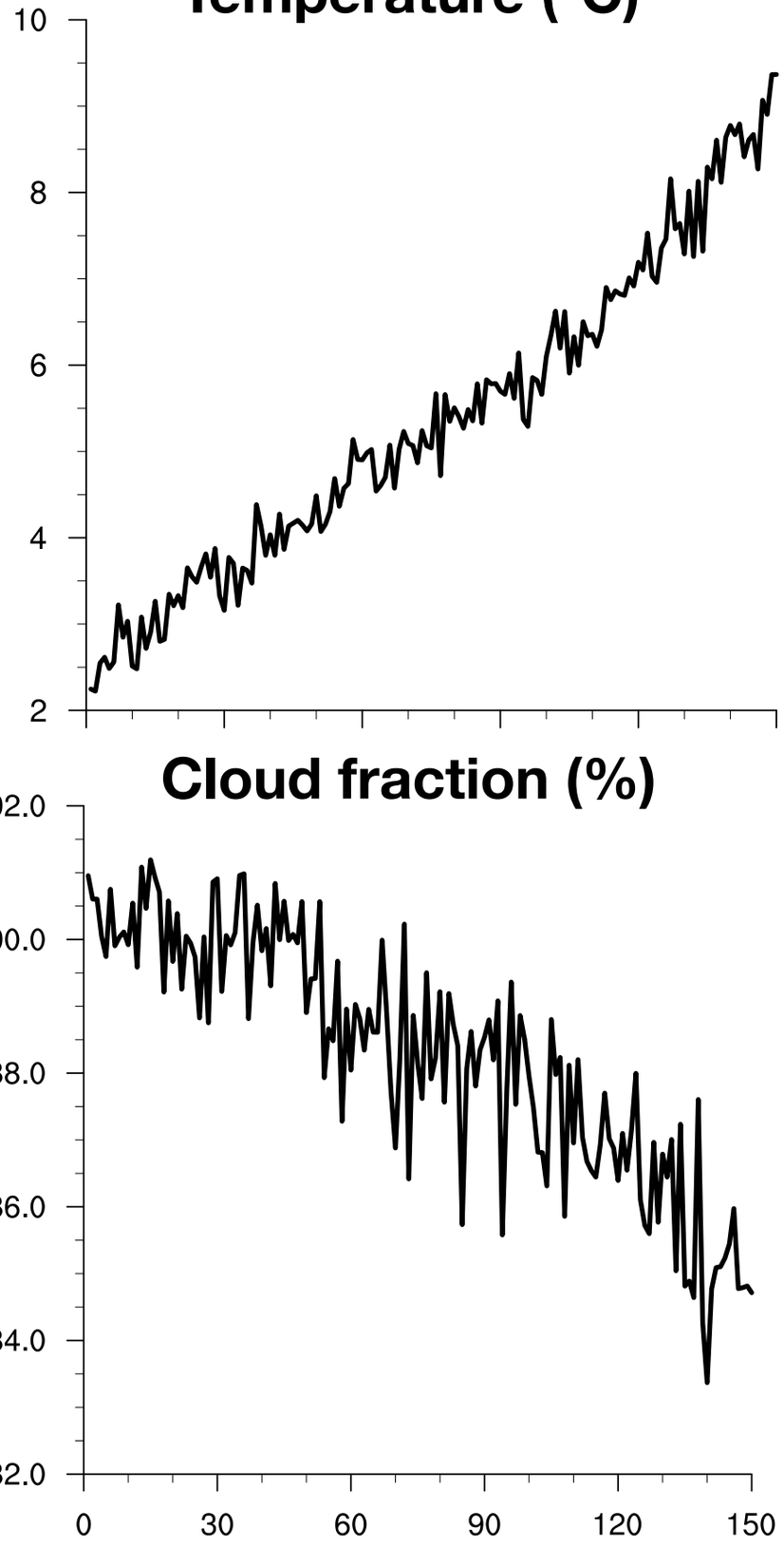
Sea ice extent (million sq. km)



Temperature (°C)



Precipitation (mm/yr)

Cloud fraction (%)

- 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

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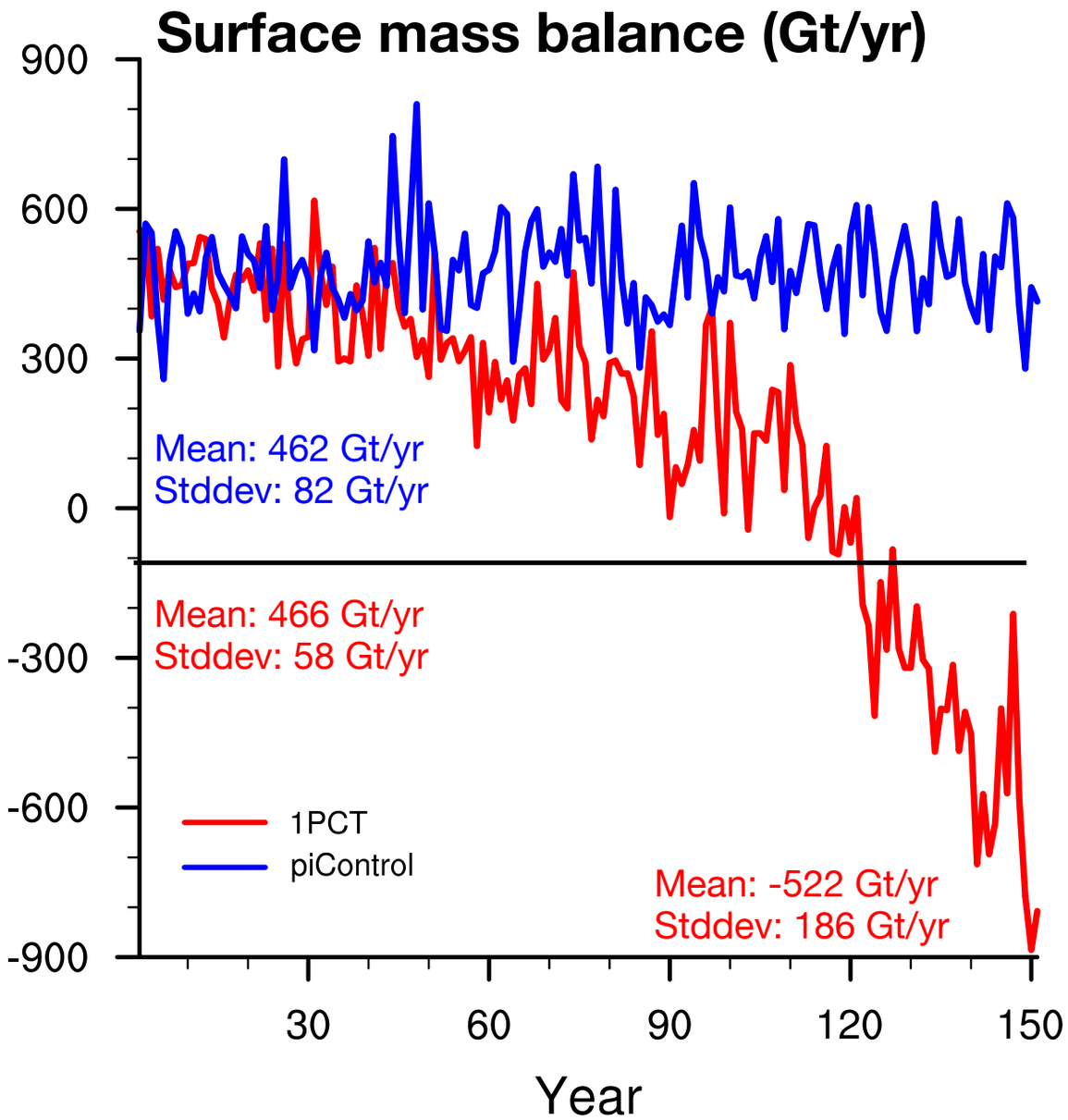
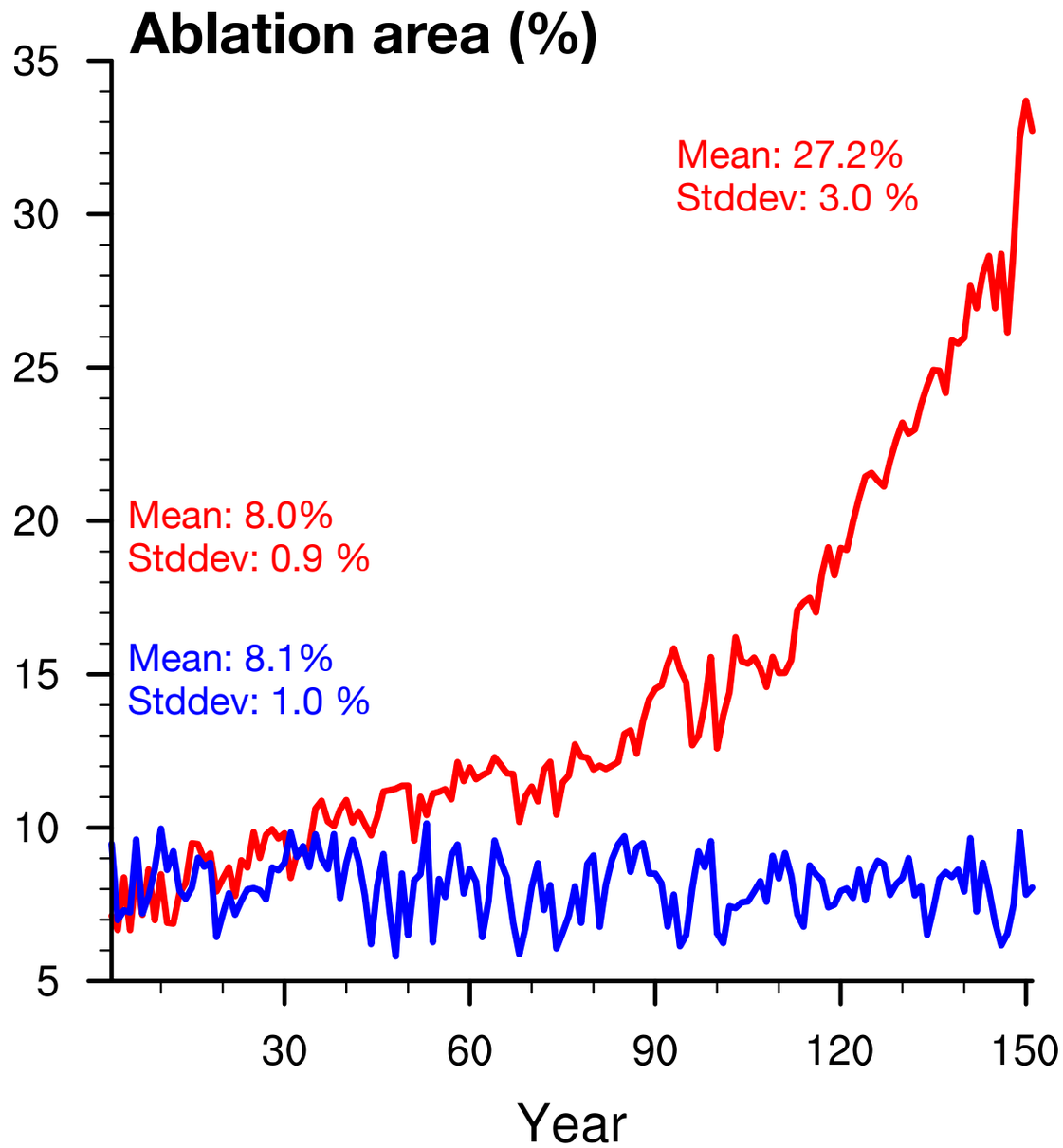


- **Surface mass balance decreases with 988 Gt/yr**
- **SMB is significantly different from year 58 (99% confidence)**
- **First time below zero in year 97 -> accelerated surface mass loss**
- **Stays below zero from year 120**



- **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

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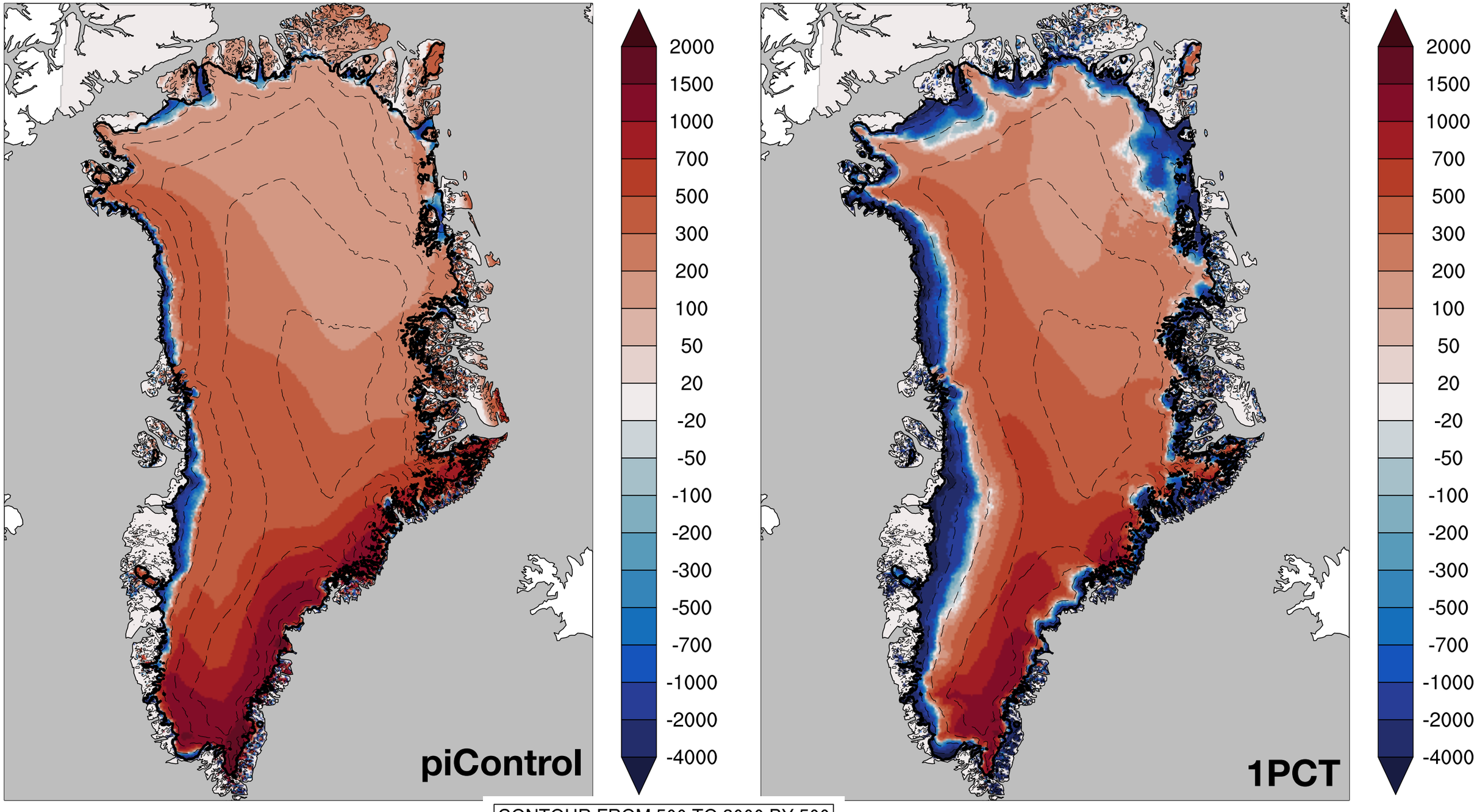
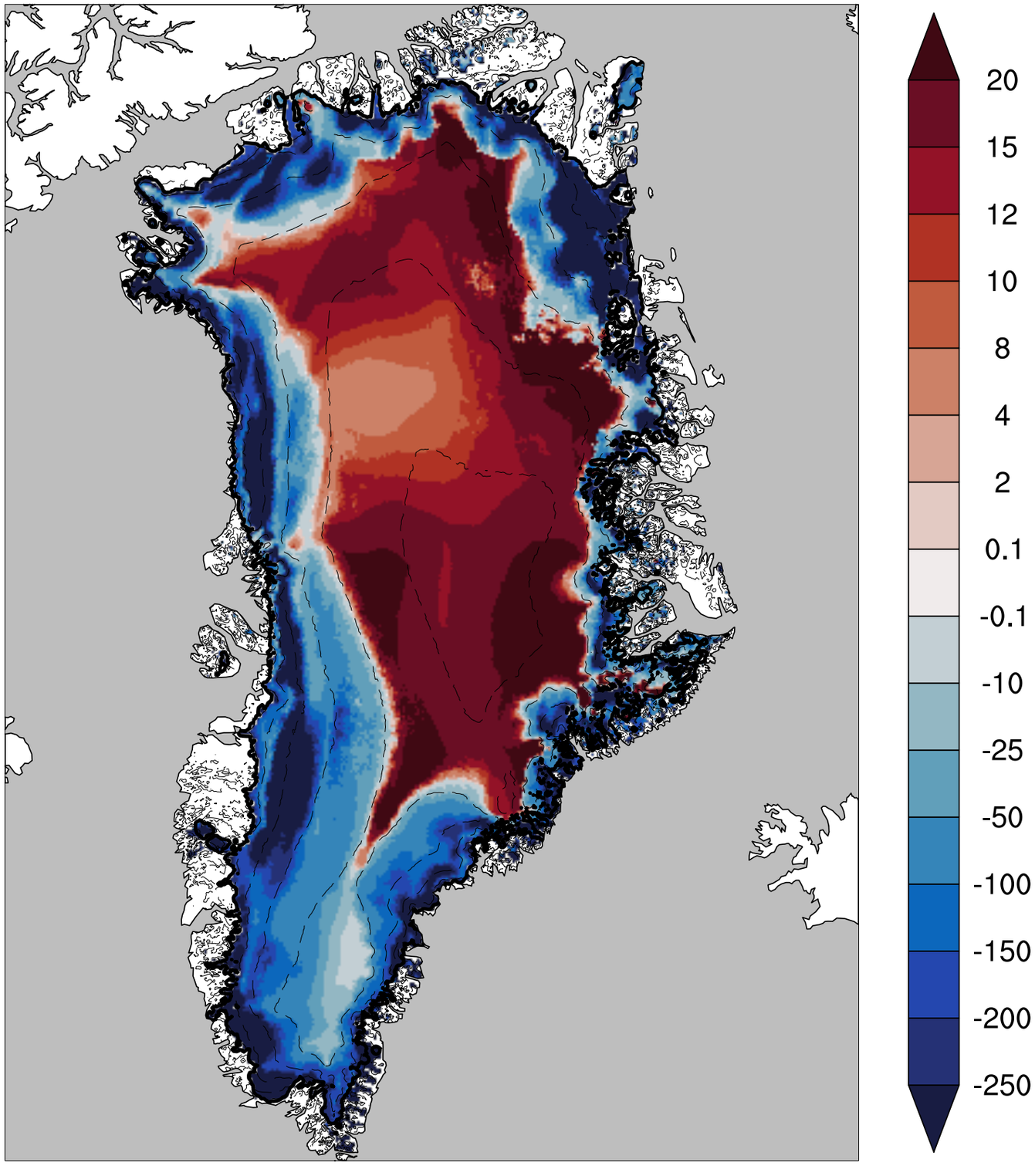
Surface mass balance (mm/yr), last 20 years of simulation



- **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

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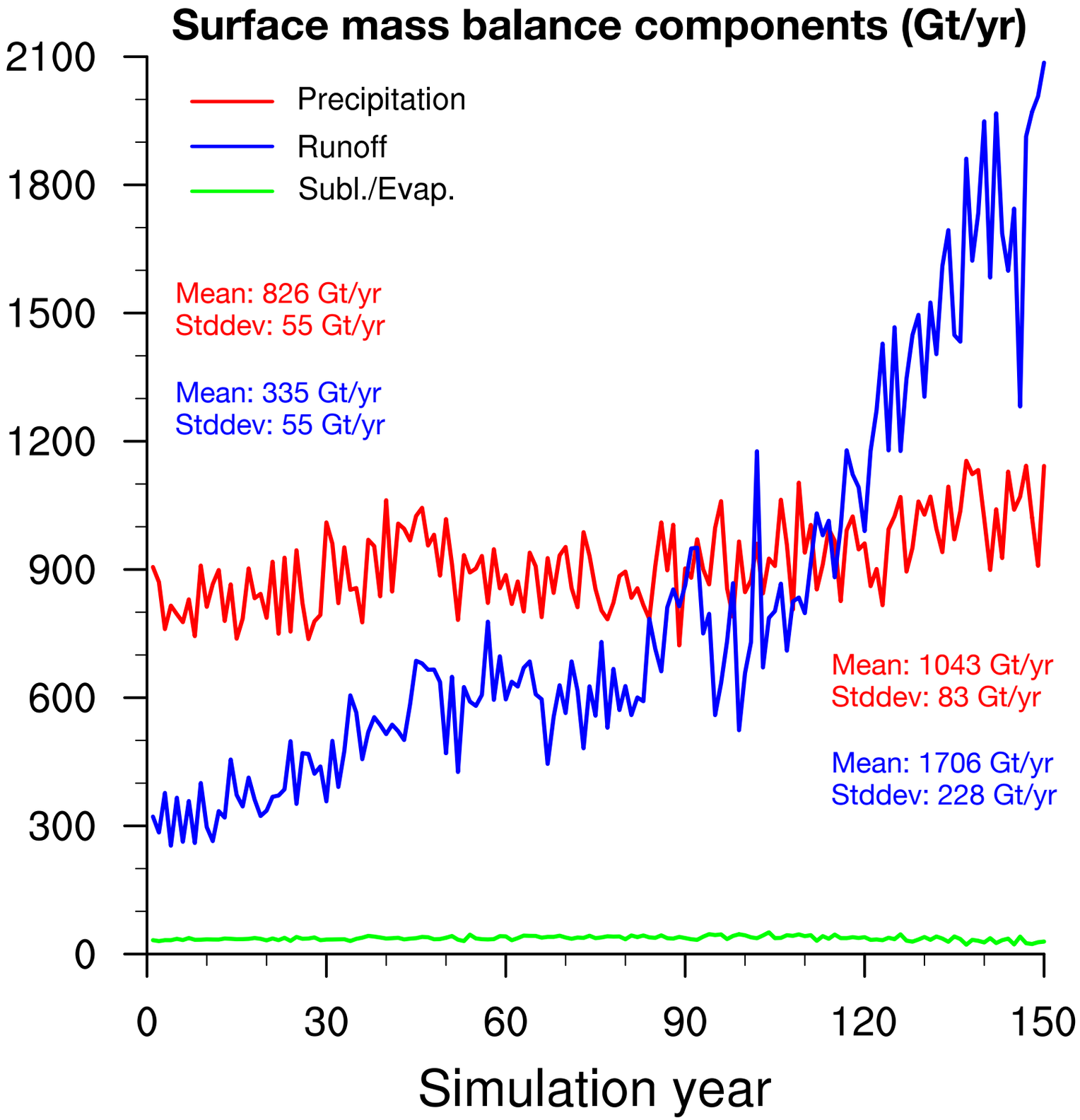
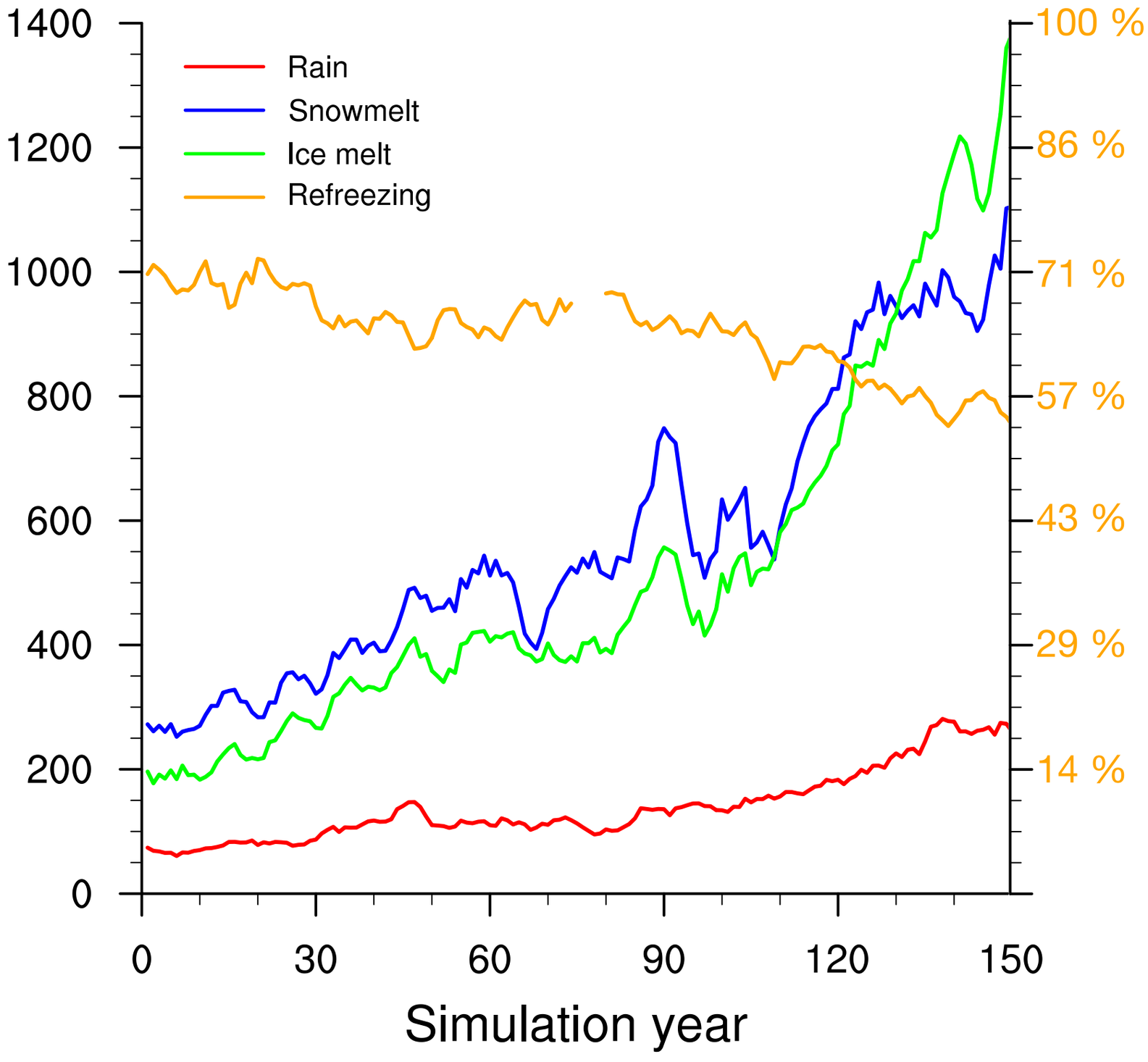


- **Only for 1PCT run**
- **Precipitation increases with 217 Gt/yr**
- **Runoff increases with 1371 Gt/yr**
- **Increase in runoff greatly exceeds increase in precipitation**
- **Acceleration of runoff around year 100**

SMB = PRECIPITATION - RUNOFF - SUBLIMATION

Loss of refreezing capacity



RUNOFF = REFREEZING - RAIN - MELT

- **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**

Surface energy budget

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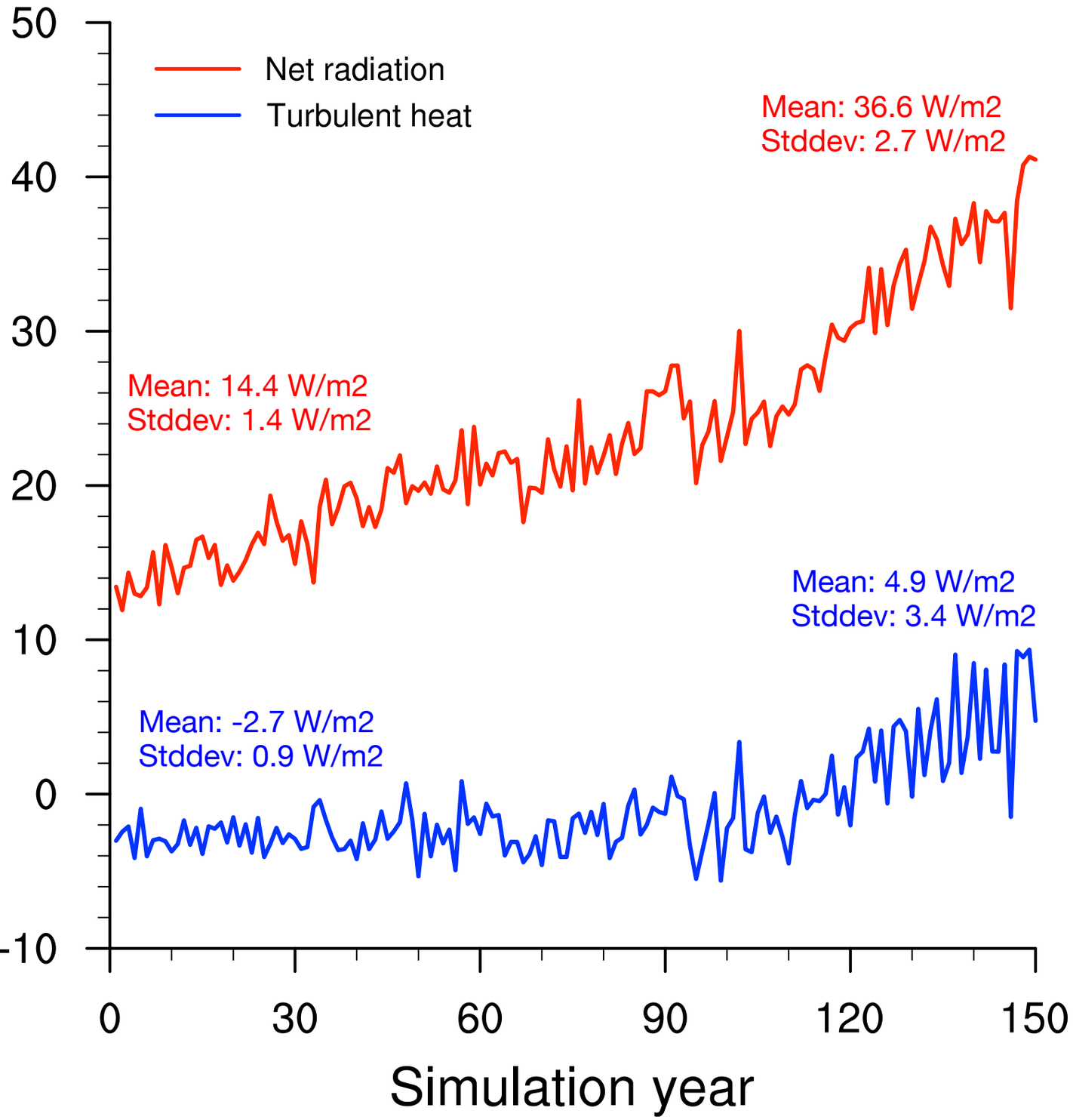
Surface energy balance components (W/m2)



- **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

Summary

- 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