Future complete deglaciation of the GrIS in CESM-CISM2 under high greenhouse gas forcing

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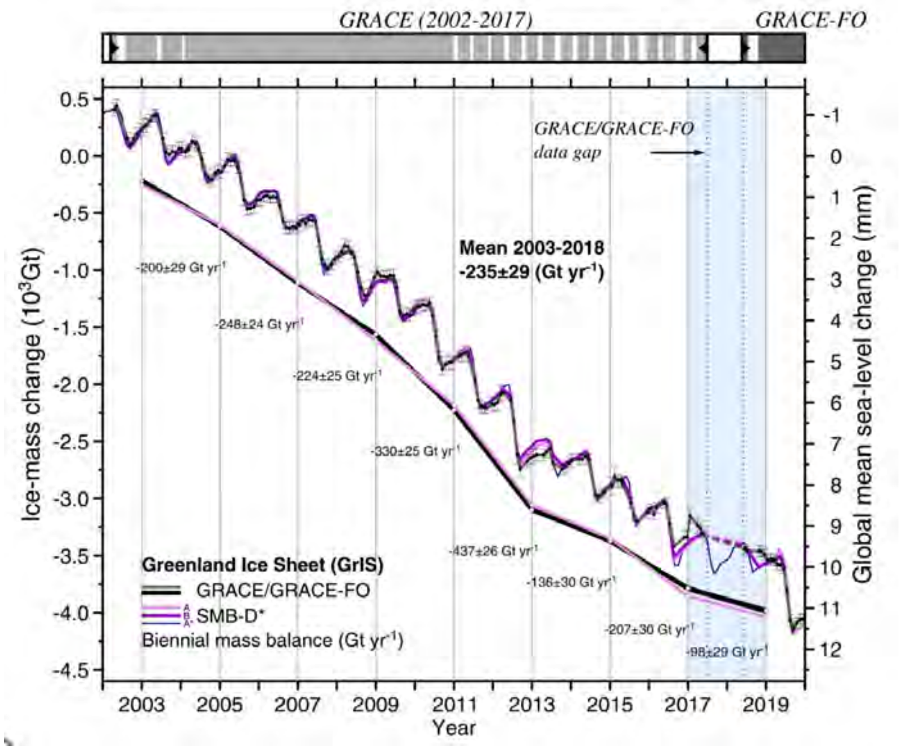
NWO
Netherlands Organisation for Scientific Research

erc
European Research Council
Established by the European Commission

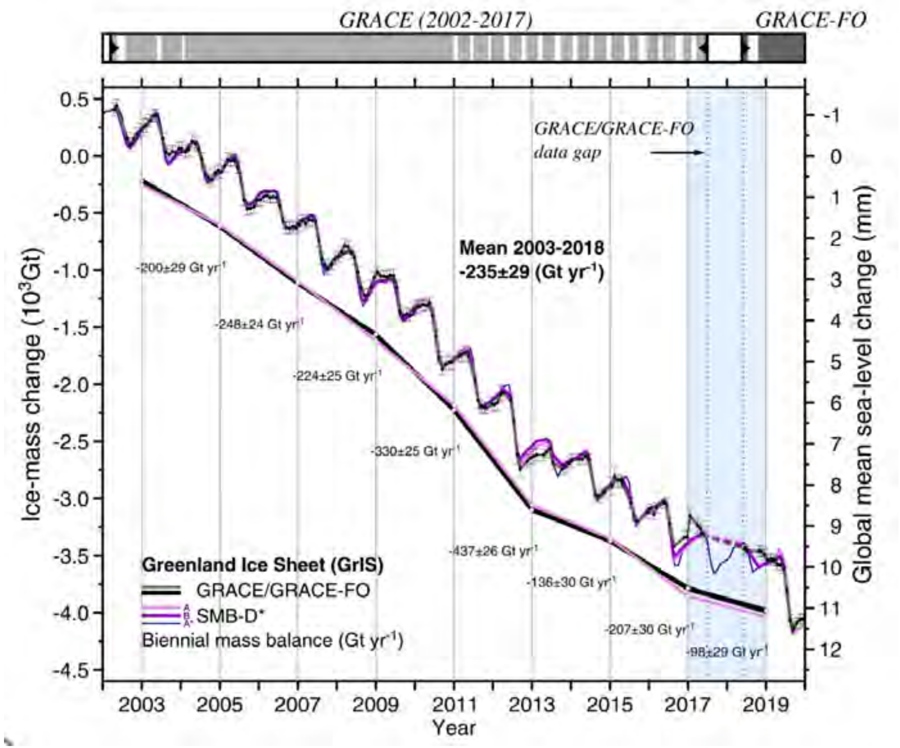
TU Delft

Imge from The Economist



- The GrIS has been losing mass since the early 90s, current contributing to sea level rise with 0.7 mm/yr
- Record mass loss in 2019

Sasgen, Wouters et al., Communications Earth & Environment (2020)

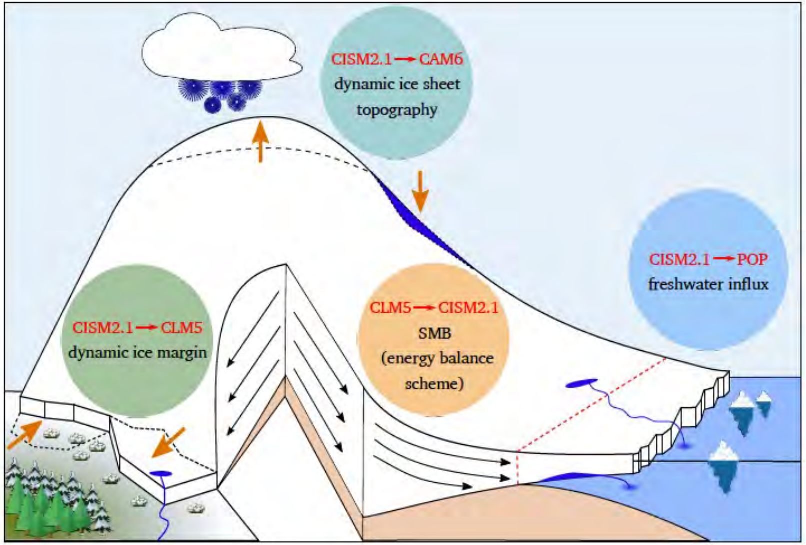


- The GrIS has been losing mass since the early 90s, current contributing to sea level rise with 0.7 mm/yr
- Record mass loss in 2019
- **How (fast) will the ice sheet melt under scenarios of high greenhouse gas forcing?**

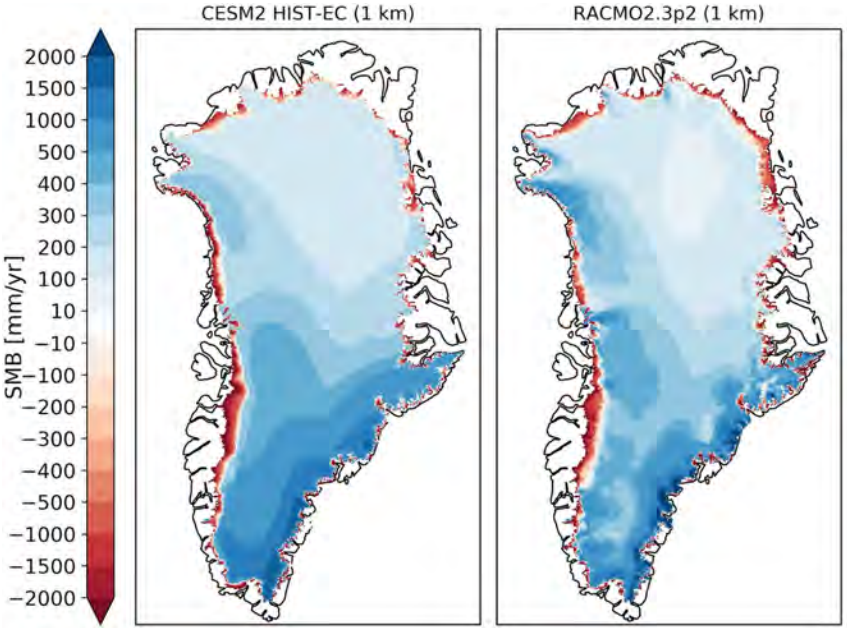
Sasgen, Wouters et al., Communications Earth & Environment (2020)

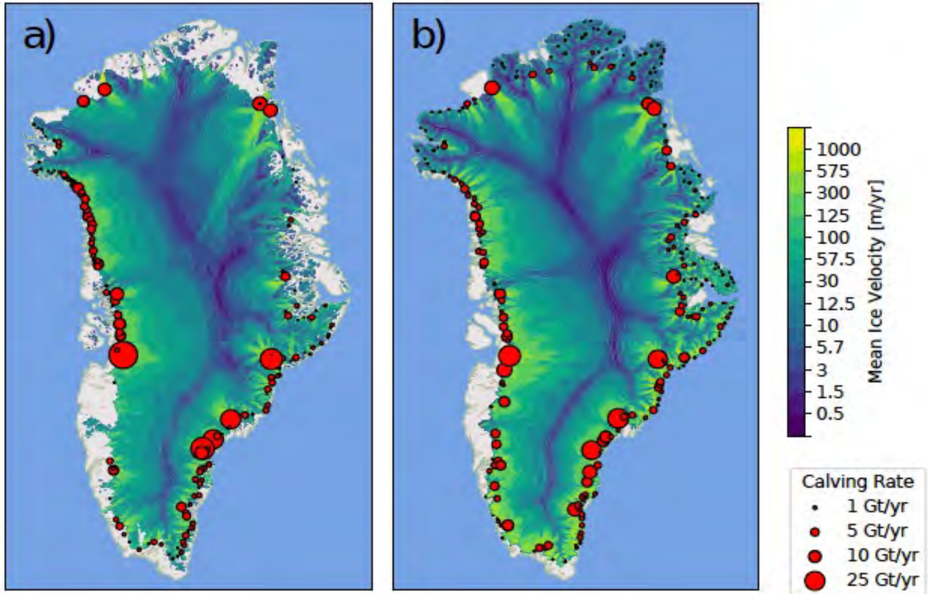
CESM2-CISM2:

- **Coupling** of ice dynamics, SMB & climate
- **Advanced, interactive SMB** simulation: in the land component of CESM2 with explicit albedo & refreezing calculation
- Relatively **advanced ice flow** (HO approx.) simulation for a coupled simulation
- **High resolution** (4km/**1 deg**) for a coupled ice/climate simulation



Muntjewerf et al, JAMES, 2021

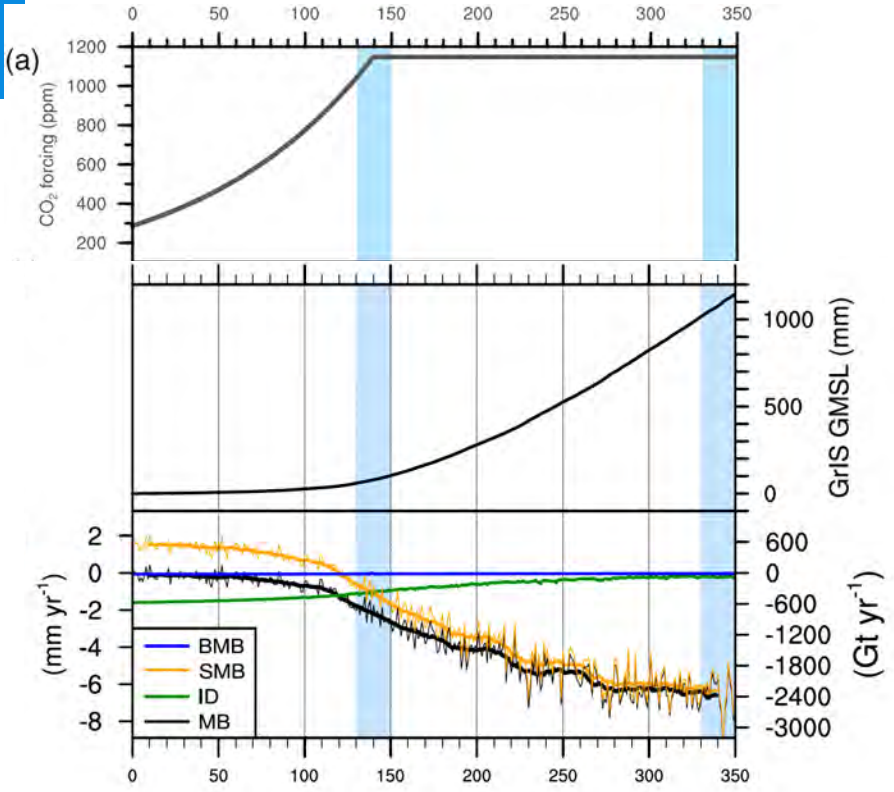




Observations (Joughin et al.; Enderlin et al, 2014)

CESM2-CISM2

Extending 1pct to 4xCO2 simulation *(Muntjewerf et al, JAMES, 2021)*

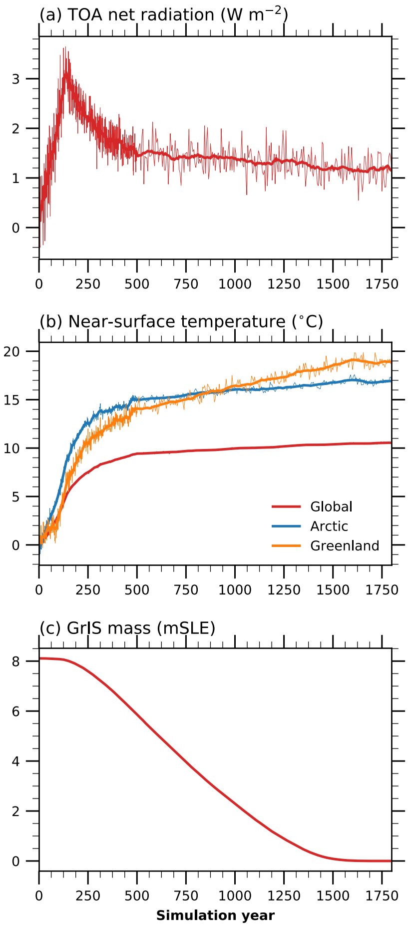


- Cumulative SLR contribution of **107 mm** (131-150)* & **1140 mm** (331-350)
- 20% area reduction

*similar to 2080-2100 under SSP5-8.5 (*Muntjewerf et al, GRL, 2021*

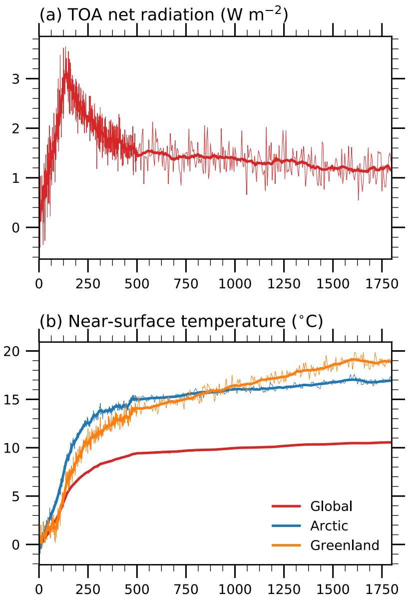
Results

- Climate
- Mass loss rates & pattern
- Precipitation evolution
- Runoff evolution



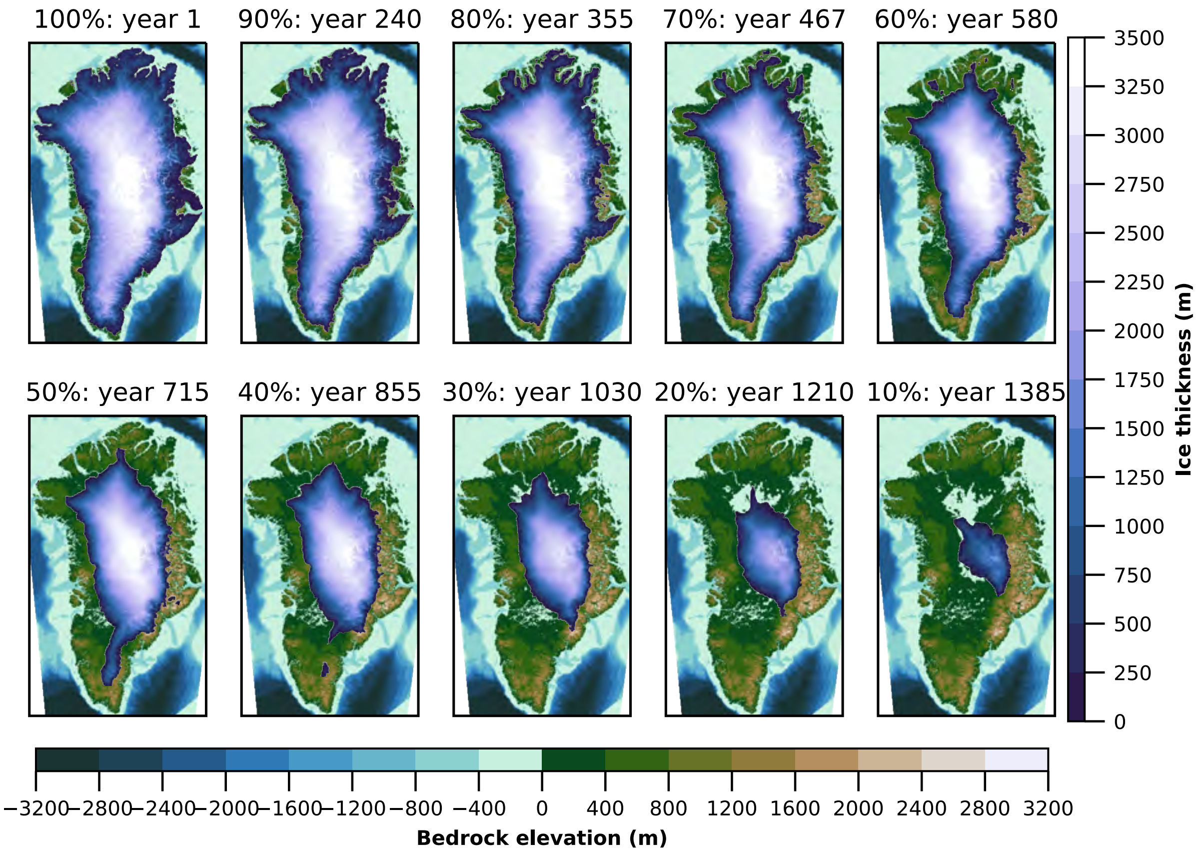
- 1:5 years acceleration of ice sheet model from year 500
- High warming by end of simulation (>10 K), TOA net radiation > 1 W/m2
- GrIS warming < Artic warming until year 800, when GrIS is substantially smaller

Climate & deglaciation timescale



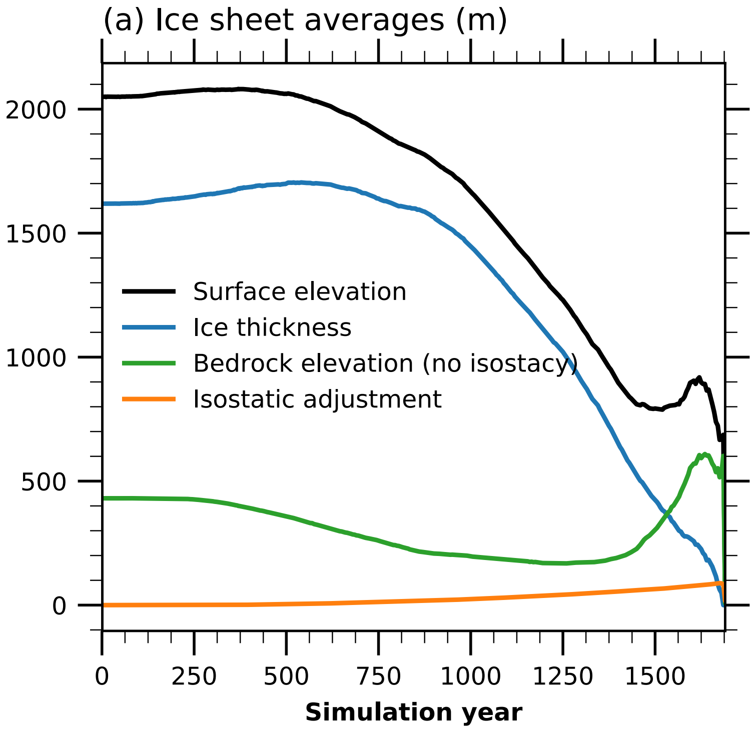
- 1:5 years acceleration of ice sheet model from year 500
- High warming by end of simulation (>10 K), TOA net radiation > 1 W/m2
- GrIS warming < Artic warming until year 800, when GrIS is substantially smaller
- Fast deglaciation in <1,700 years

Global Climate | Mass loss | Precipitation | Melt & runoff



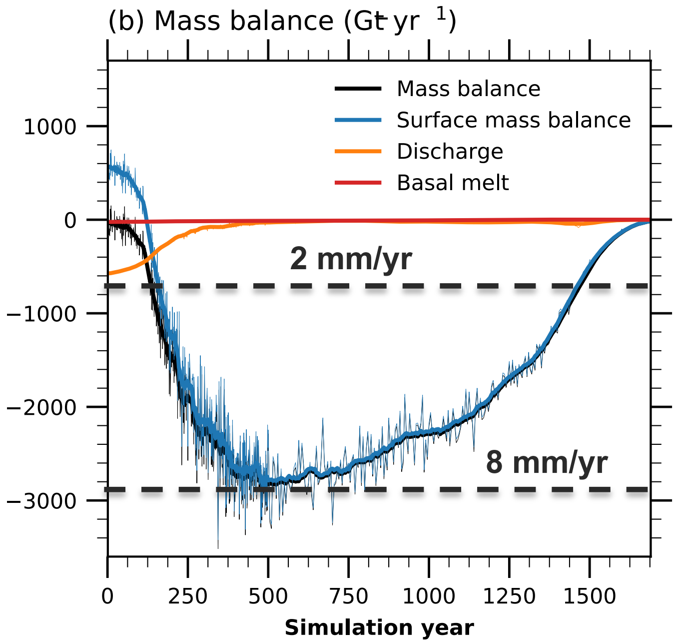
- 50% area reduction by year 715
- Southern Part deglaciates first

elevation change & contributors



- Mean thickness slightly **increases 250-600 as relatively thin margin retreats**, then **decreases**
- Ice sheet retreats from some relatively high bedrock at the margins first, and to high bedrock **in the Mid-East in the last centuries**
- **Small contribution from isostasy** (+100 m)

Mass balance = SMB – Discharge – Basal Melt



360 Gt y^{-1} = 1 mm SLR

- SMB decreases from ˜600 Gt/yr to 0 within the first 110 years
- Ice discharge decreases (negative contribution to sea level rise) in response to marginal thinning and retreat from increased melt
- By 140, sea level contribution is 2 mm/yr
- This increases rapidly in the following two centuries, reaching a maximum contribution of 8 mm/yr

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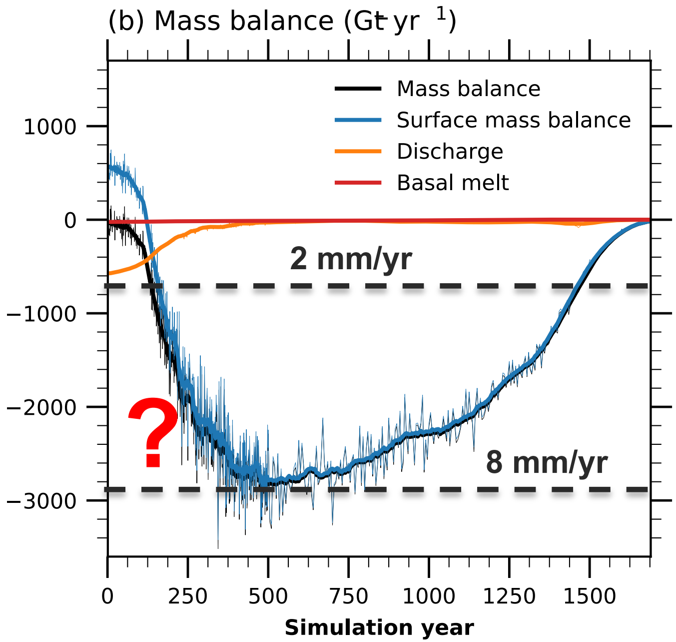

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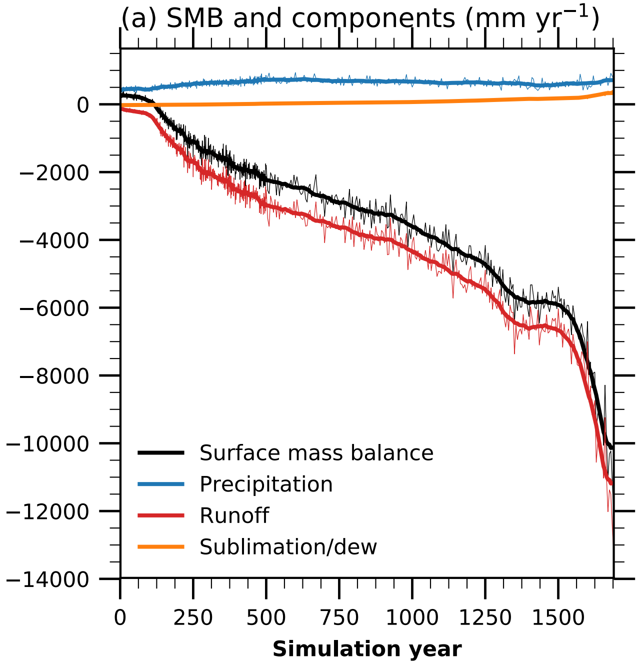
What causes this strong acceleration?

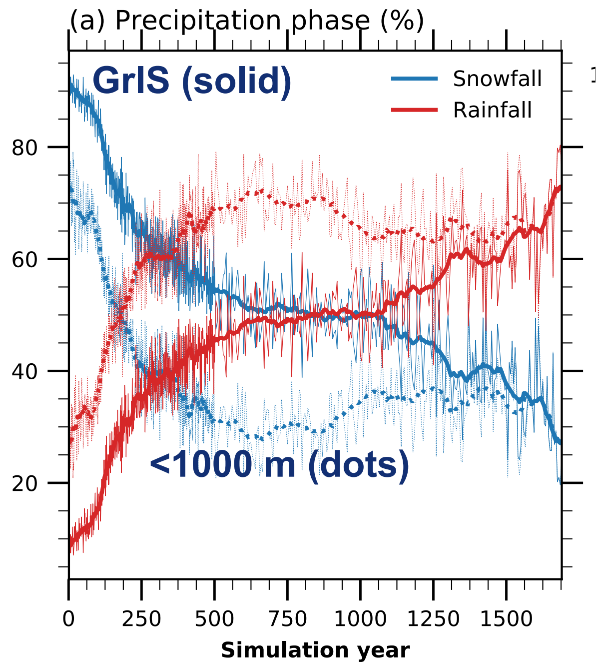
SMB = Precipitation - Runoff - Sublimation



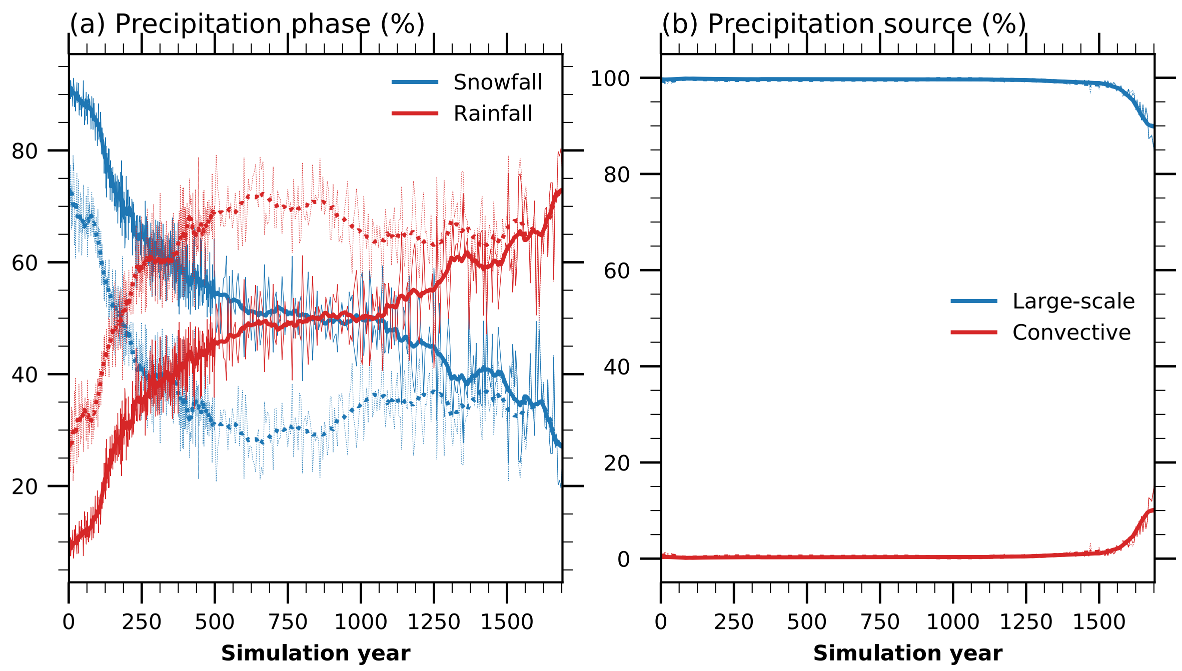
Evolving GrIS mean values

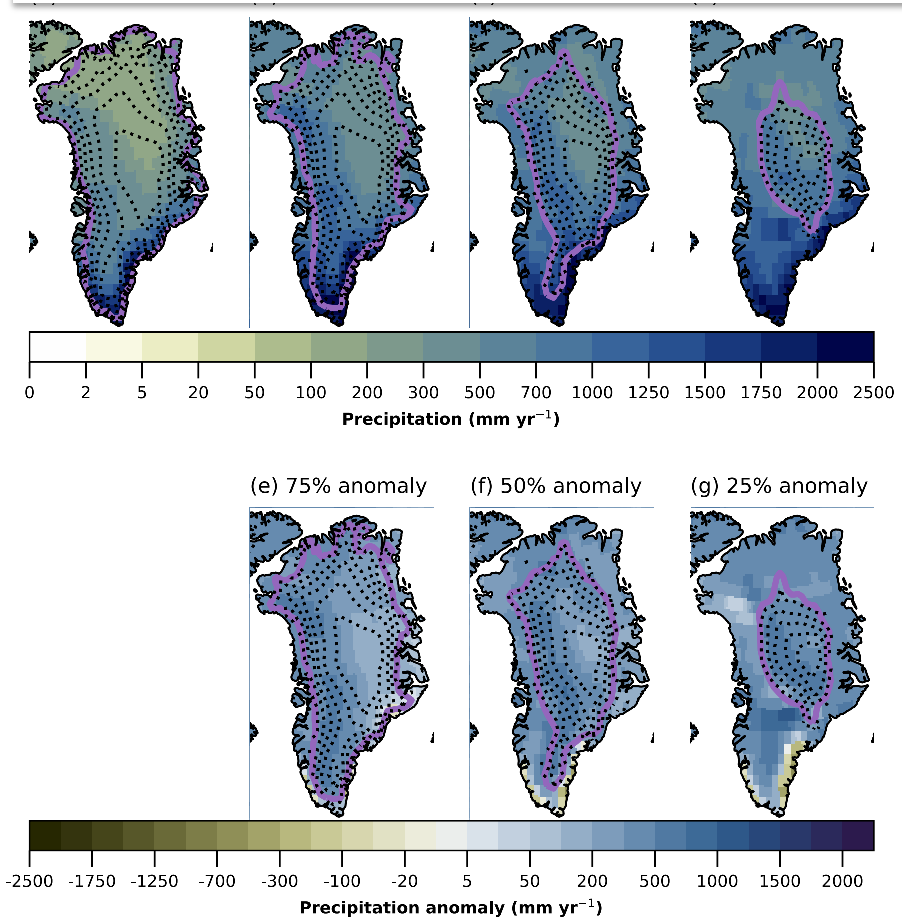
- We normalize by area (kg m^{-2} yr^{-1})
- SMB becomes negative by year 110
- Runoff dominates SMB evolution, with larger increases 120-500 and at end of simulation
- A period without increase 1300-1500

Component	Pre-industrial	Years 131–150		Years 331–350	
		Absolute	Anomaly	Absolute	Anomaly
SMB [4 km]	585 [85]	-367 [166]	-952	-2259 [357]	-2844
SMB [1°]	544 [103]	-521 [217]	-1065	-2589 [442]	-3133
Precipitation	846 [83]	986 [97]	140	1122 [97]	276
Snowfall	780 [80]	750 [74]	-30*	683 [71]	-97
Rain	72 [12]	235 [38]	163	439 [59]	367
Refreezing	223 [54]	693 [73]	470	534 [43]	311
Melt	415 [92]	1,914 [251]	1499	3,804 [443]	3389
Sublimation	45 [4]	50 [6]	5	3 [11]	-42

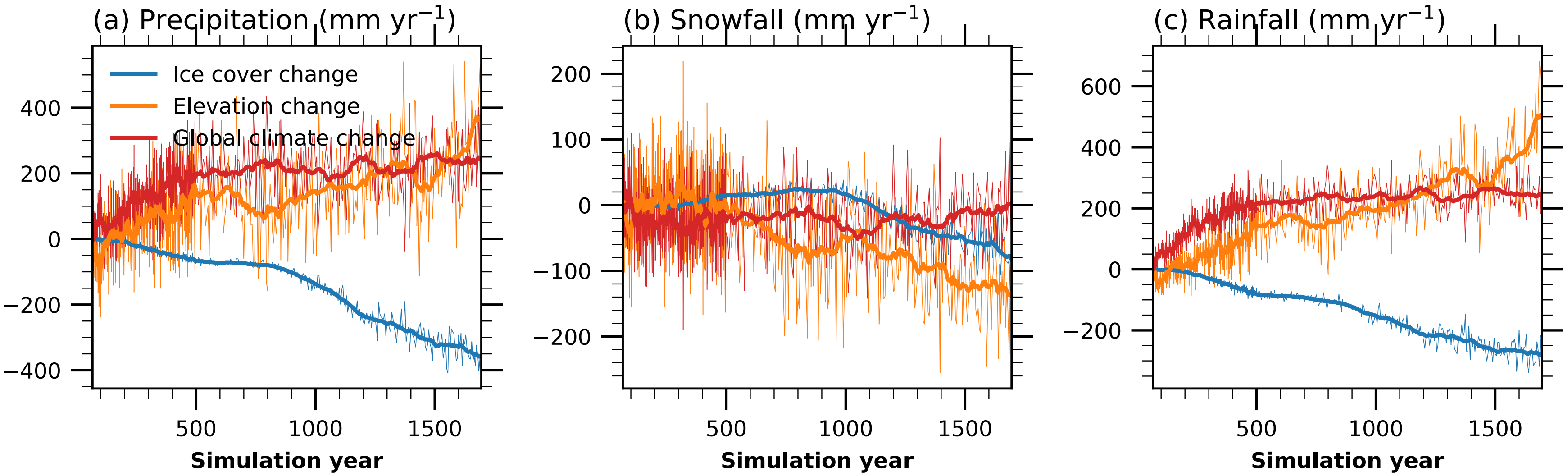


- **From 90% snowfall to 30%** by end of simulation
  - 50% by 850

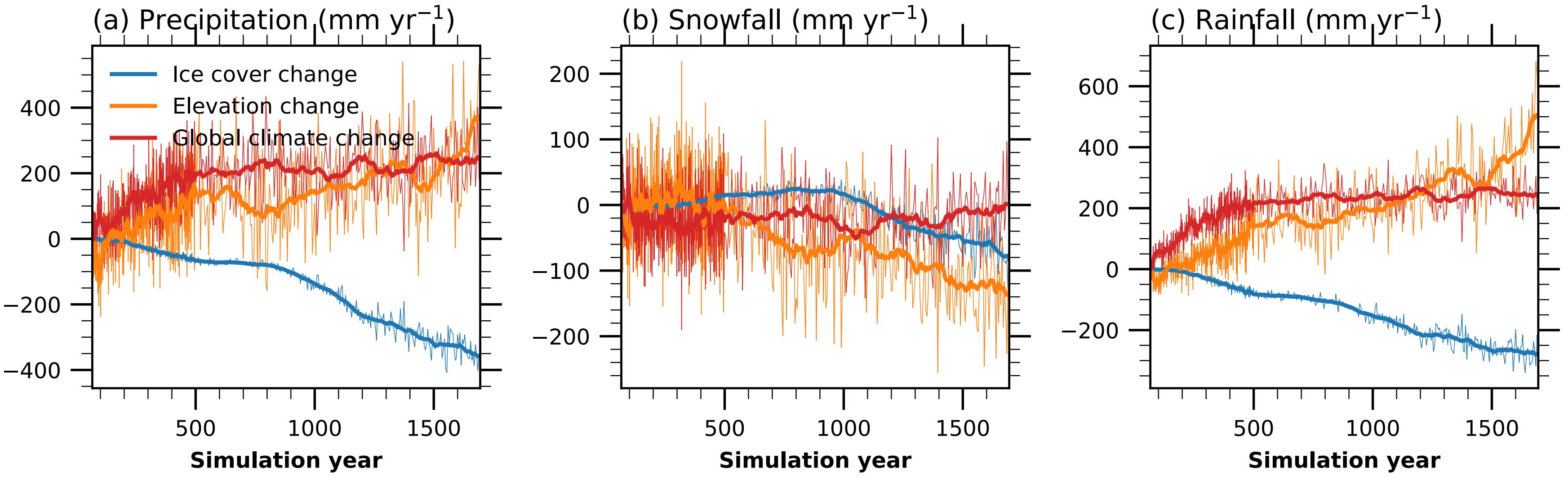

(a) Precipitation phase (%)
Snowfall
Rainfall
80
60
40
20
0
250
500
750
1000
1250
1500
Simulation year
(b) Precipitation source (%)
100
80
60
40
20
0
Large-scale
Convective
0
250
500
750
1000
1250
1500
Simulation year



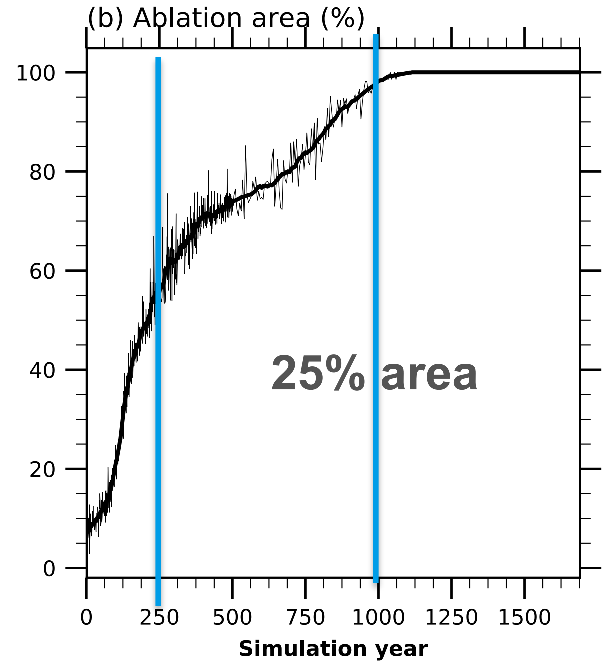
- Precipitation increases in response to climate change
- Precipitation maxima follows Western margin
- Precipitation reductions over deglaciated areas in the SE



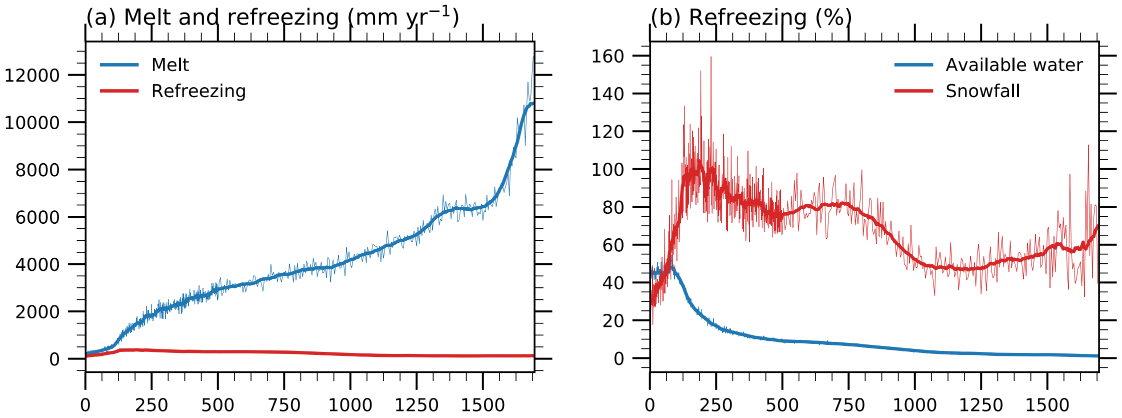
+ climate change	= climate change	+ climate change
+ elevation change	- elevation change	+ elevation change
- ice cover change	+/- ice cover change	- ice cover change



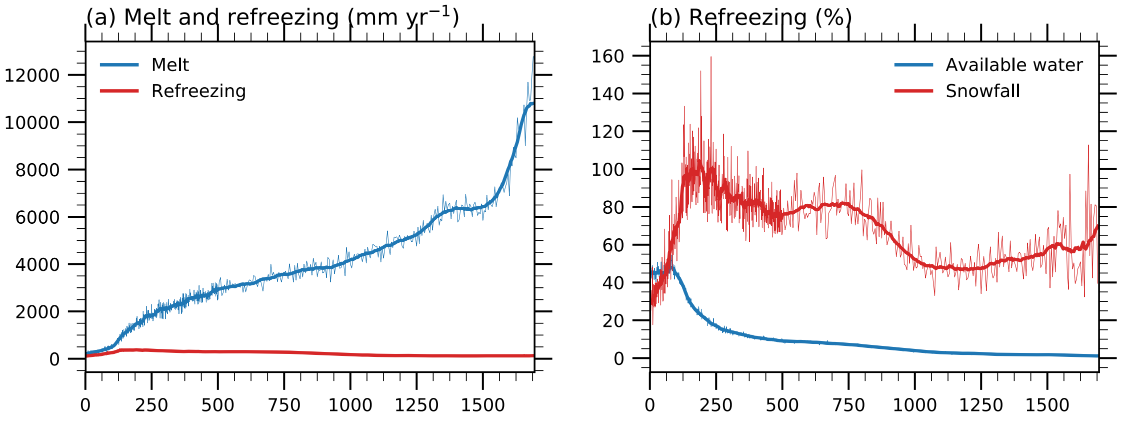
- Snowfall does not increase, and decreases by end of simulation
- Rainfall increases both due to climate and elevation change
- Precipitation partially decreases as the GrIS retreats from North Atlantic area

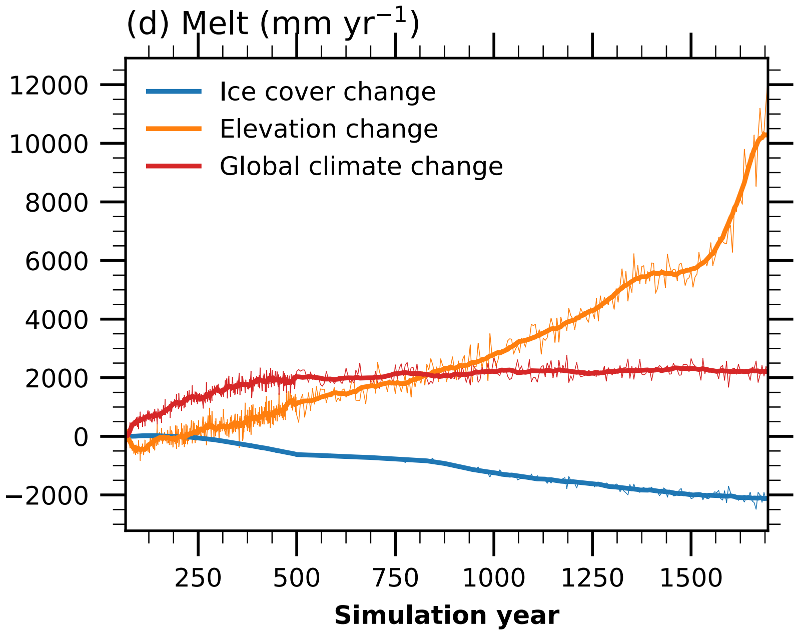

(b) Ablation area (%)
100
80
60
40
20
0
0
250
500
750
1000
1250
1500
Simulation year
25% area

Runoff=Melt+Rain-Refreezing

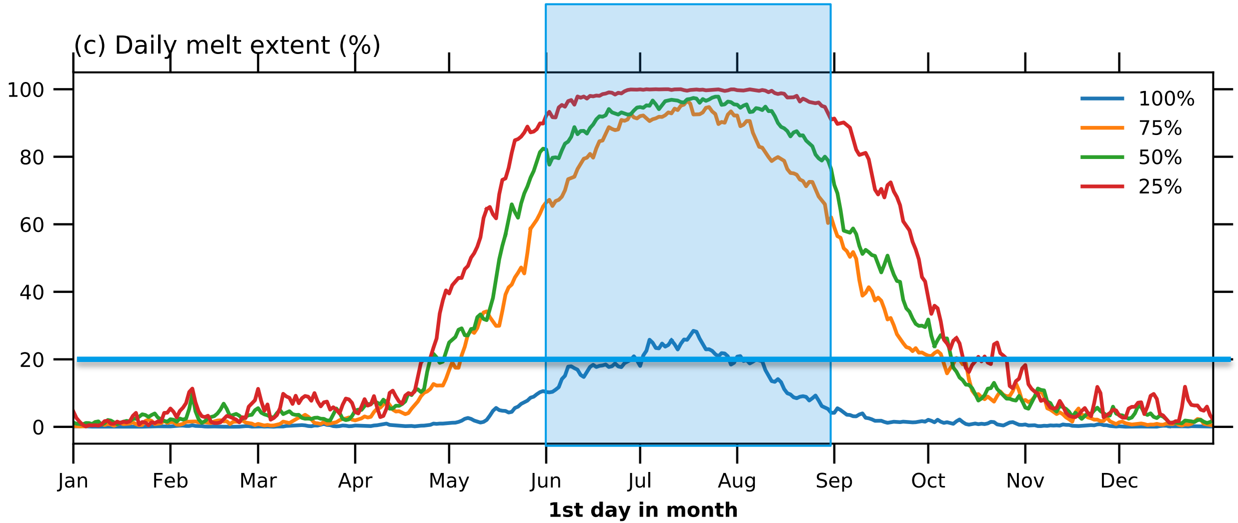


Runoff=Melt+Rain-Refreezing

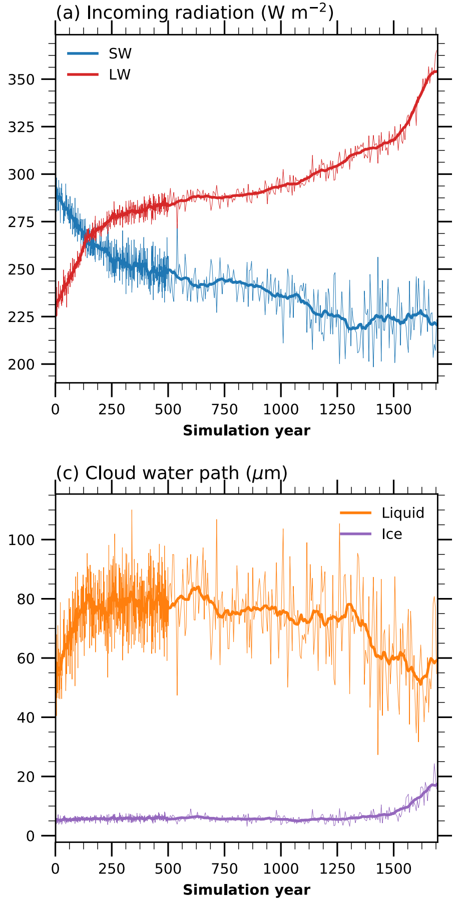




- Elevation contribution equals climate contribution at mid simulation

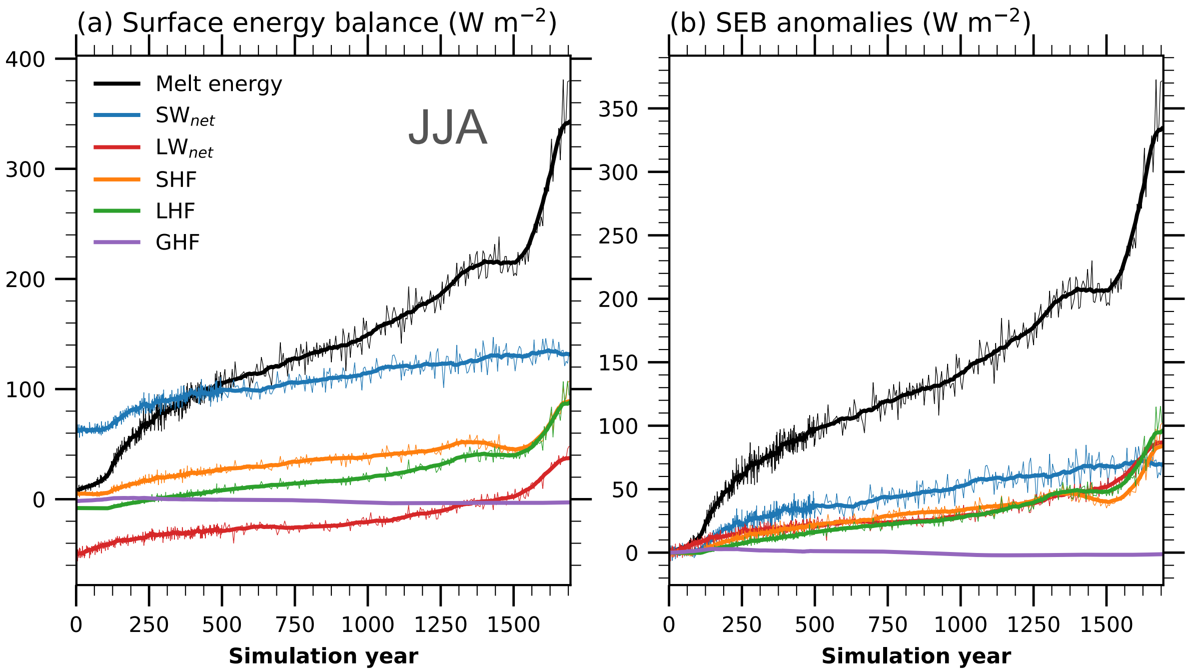


- By 400 most of ice sheet melts in July
- By 1100 most of ice sheet melts in June-July-August
- Melt season extends towards the Fall as deglaciation progresses



- Incoming SW decreases due to clouds and surface albedo reduction
- LW increases similarly to near-surface temperature, due to climate and elevation change
- Cloud liquid water path increases with climate, but (likely) decreases with elevation and areal change (less maritime areas)
- Increase in ice water path in the last two centuries.

Melt=Swnet+Lwnet+SHF+LHF+GHF

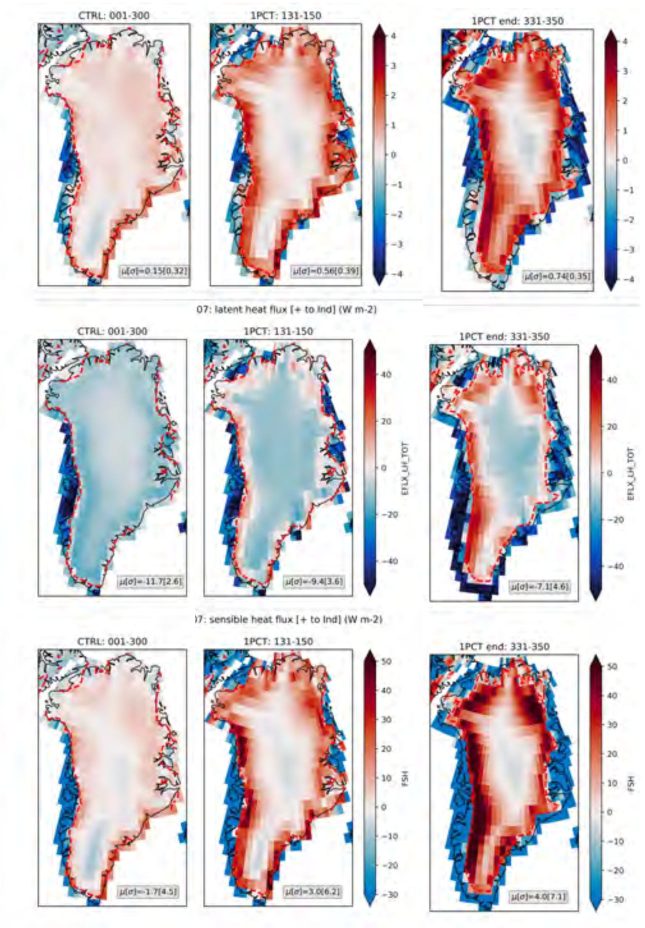


- LW$_{net}$ dominates until 120, then Swnet due to albedo feedback
- SHF & LHF largely increase from 120, and each contribute similarly to Lwnet between 500-1400
- Small decrease in SHF contribution around 1500
- Temperature-related fluxes dominate during the last century

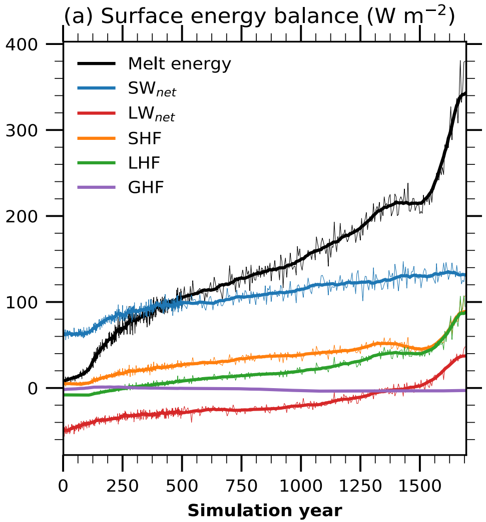
T2m-Tsurface (K)

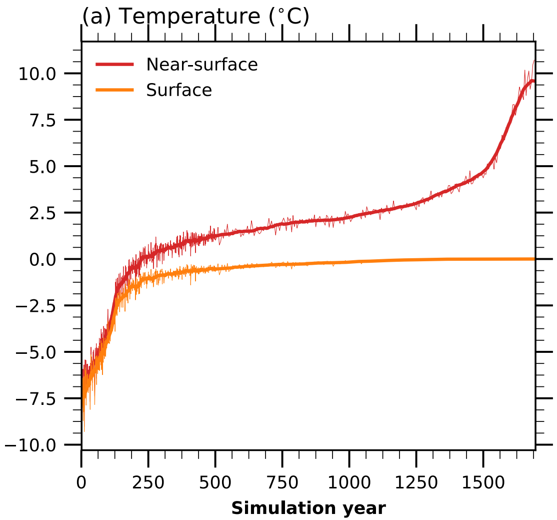
Latent heat flux (Wm^{-2})

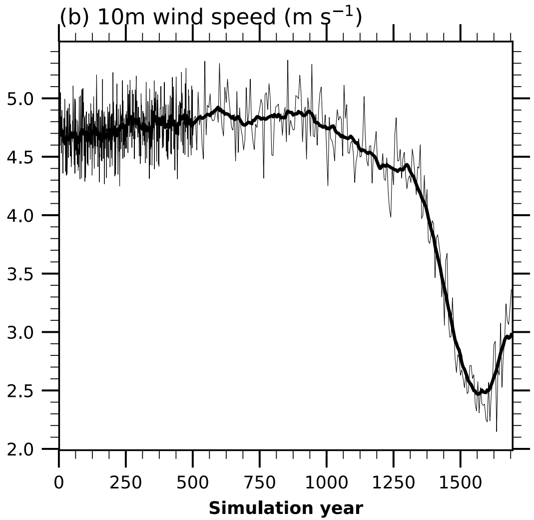
Sensible heat flux (Wm^{-2})



- Strong surface temperature inversion as ablation areas expand
- Results in much increased latent and sensible heat flux

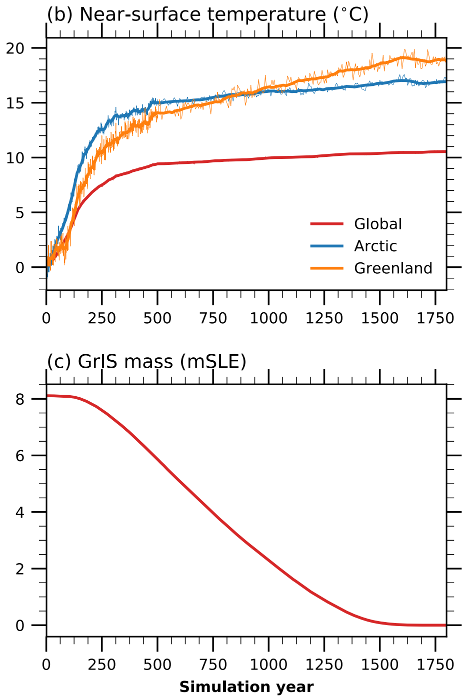


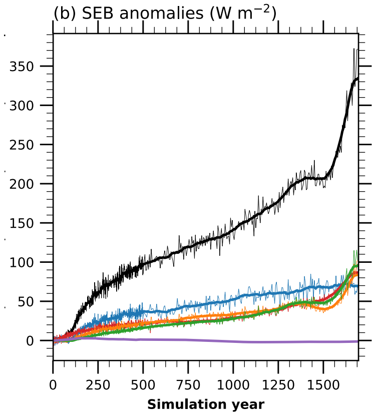




- Large increase in SHF & LHF around 120 relates to large areas reaching melt conditions and associated increasing near-surface temperature inversion
- Decrease in SHF around 1500 related to decreased wind speed

Summary



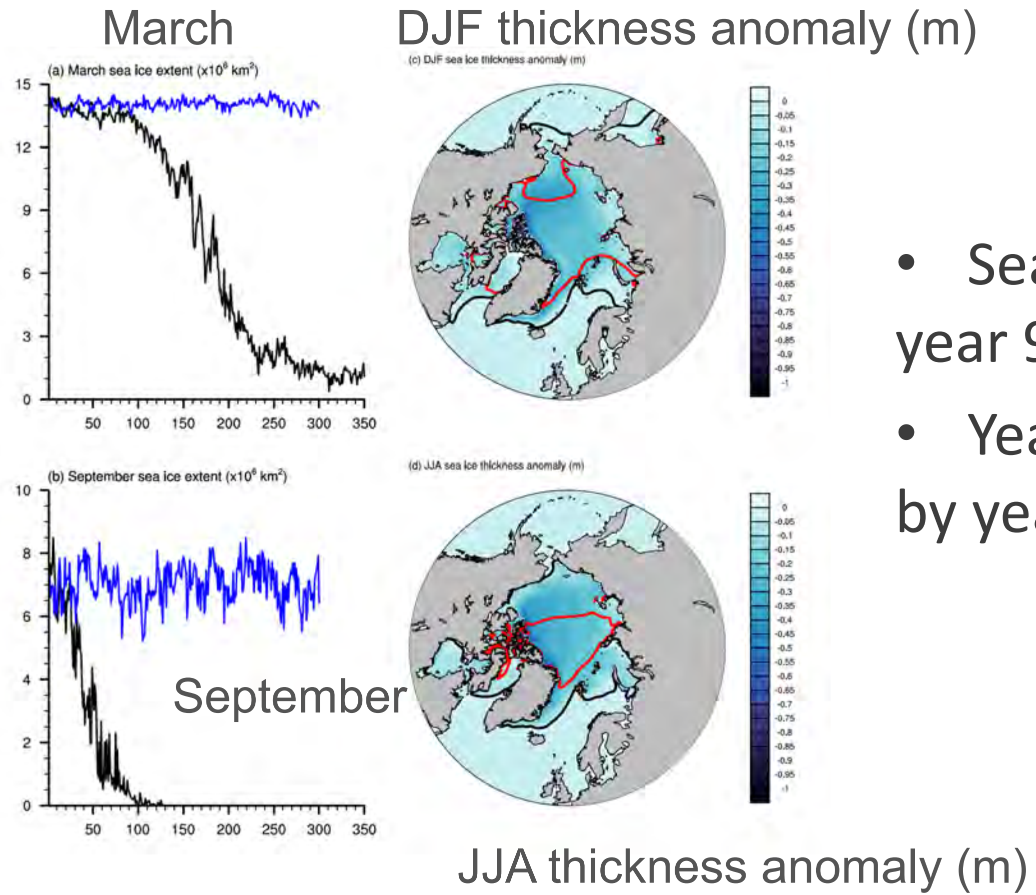


Vizcaino et al, in preparation
Sellevold et al, in preparation

- 5 K (140), 8 K (350), 10 K (1750)
- Fast deglaciation: <1,700 yrs
- Fastest margin retreat from SW, then North
- Snowfall rates are similar to pre-industrial during most of simulation
- Large melt acceleration from + albedo feedback and much increased turbulent heat fluxes
- Refreezing increases with initial melt increase, up to snowfall accumulation rate, then declines
- Large + elevation-melt feedback
- Small - melt-isostasy feedback

Additional slides

Arctic change

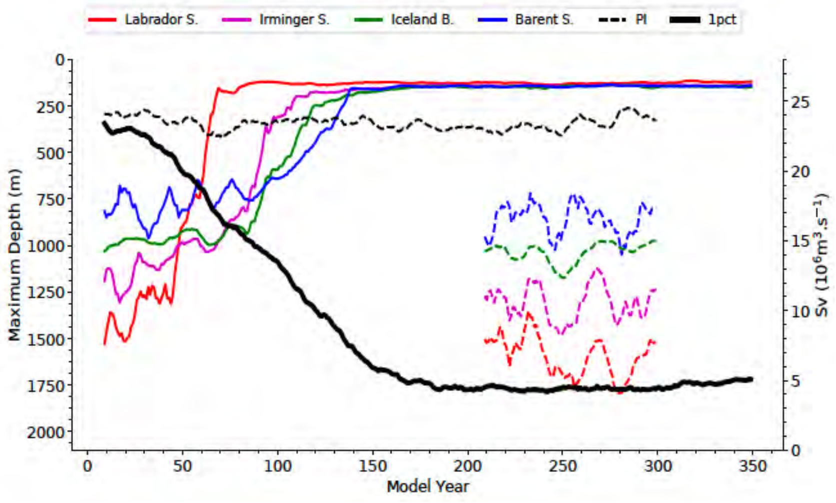


- Seasonally ice-free by year 90
- Year-around ice-free by year 300

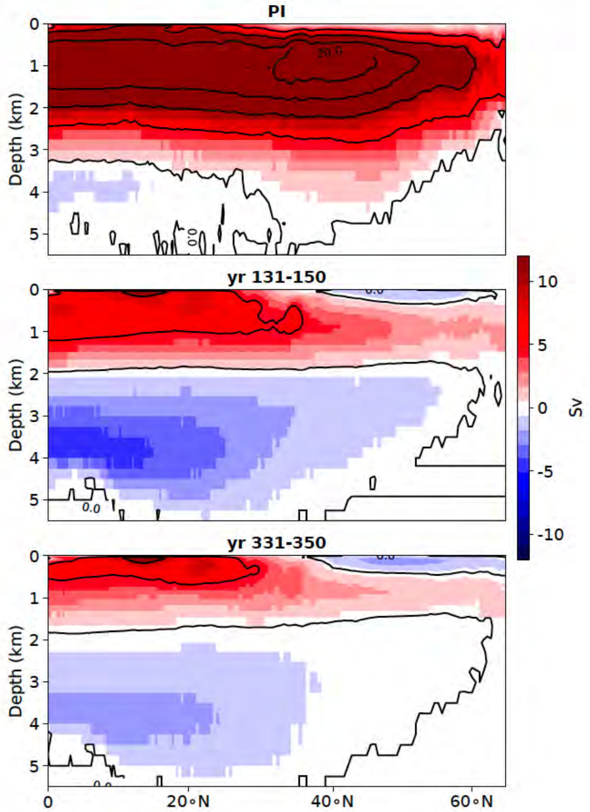
NAMOC weakens

Mixed layer depth declines in all basins

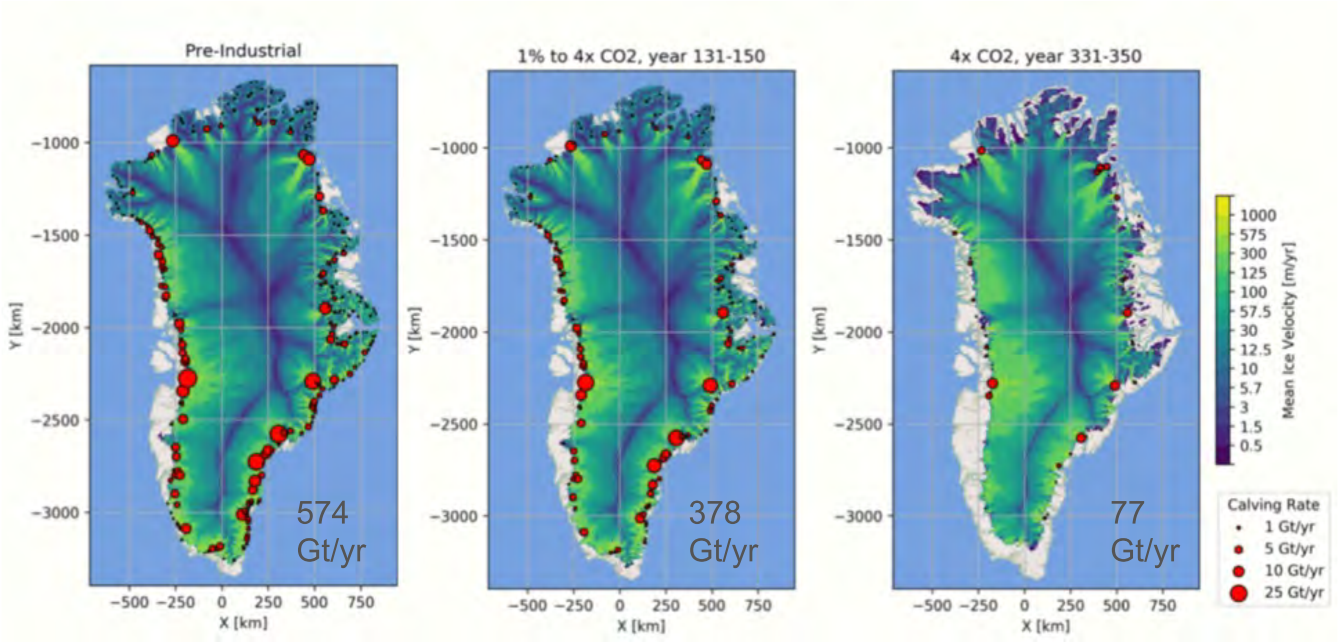
NAMOC index **strongly declines in the first 140 years**



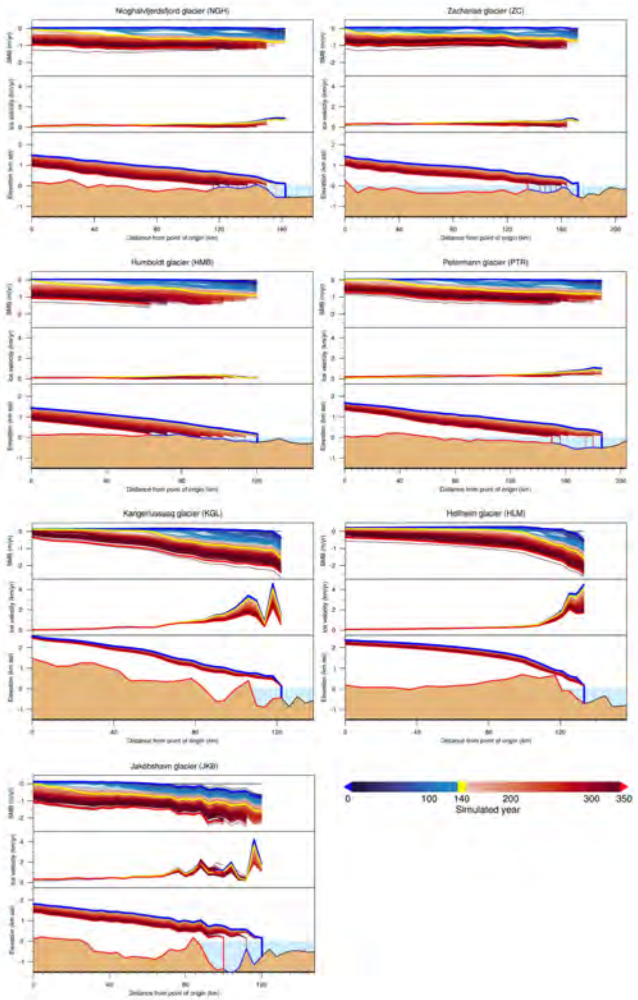
Mixed Layer Depth in individual basins (m), and NAMOC index (Sv, maximum of overturning stream function)

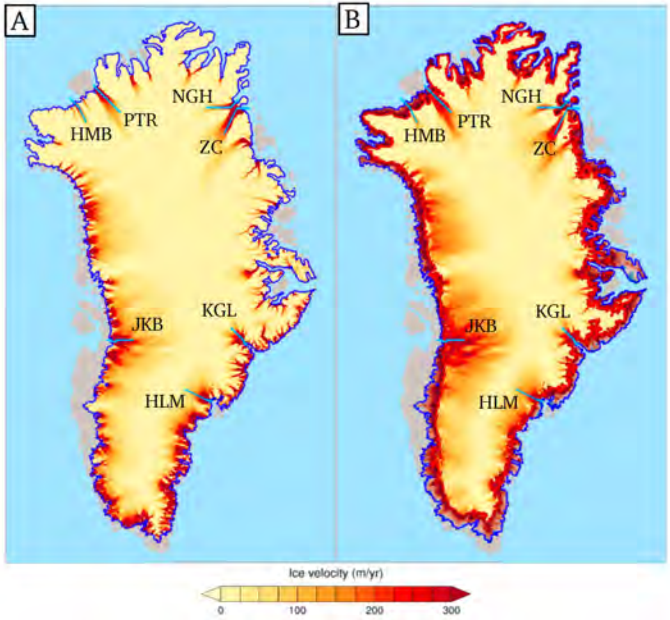


Atlantic Overturning Stream Function, Sv



Marginal thinning (-15% volume) & retreat (-20% area) result in an **almost land-terminating** ice sheet by years 331-350





Basin	Glacier	Terminus position. at year 350 (km)	Start retreat (year)	Transition to land margin (year)
NE	Nioghalvfjerdsfjord	-46	159	N/A
NE	Zachariae	-50	180	N/A
NO	Petermann	-36	246	N/A
NO	Humboldt	-60	184	311
SE	Kangerlussuaq	0	-	N/A
SE	Hellheim	0	-	N/A
CW	Jakobshavn	-20	271	N/A