EFFECT OF EMISSION REDUCTIONS ON FUTURE GRIS MELT
AS SIMULATED BY CESM2-CISM2

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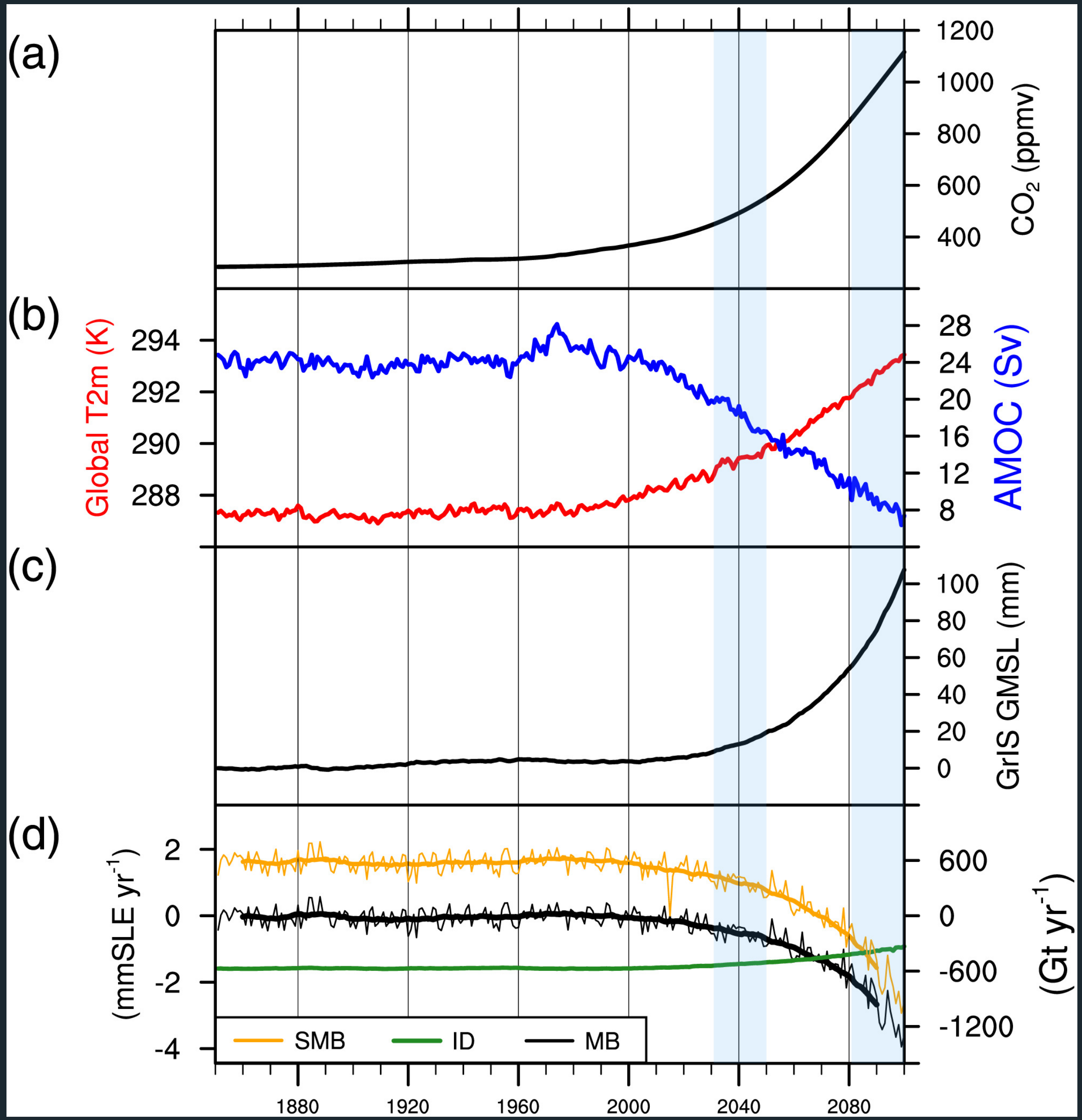
Content

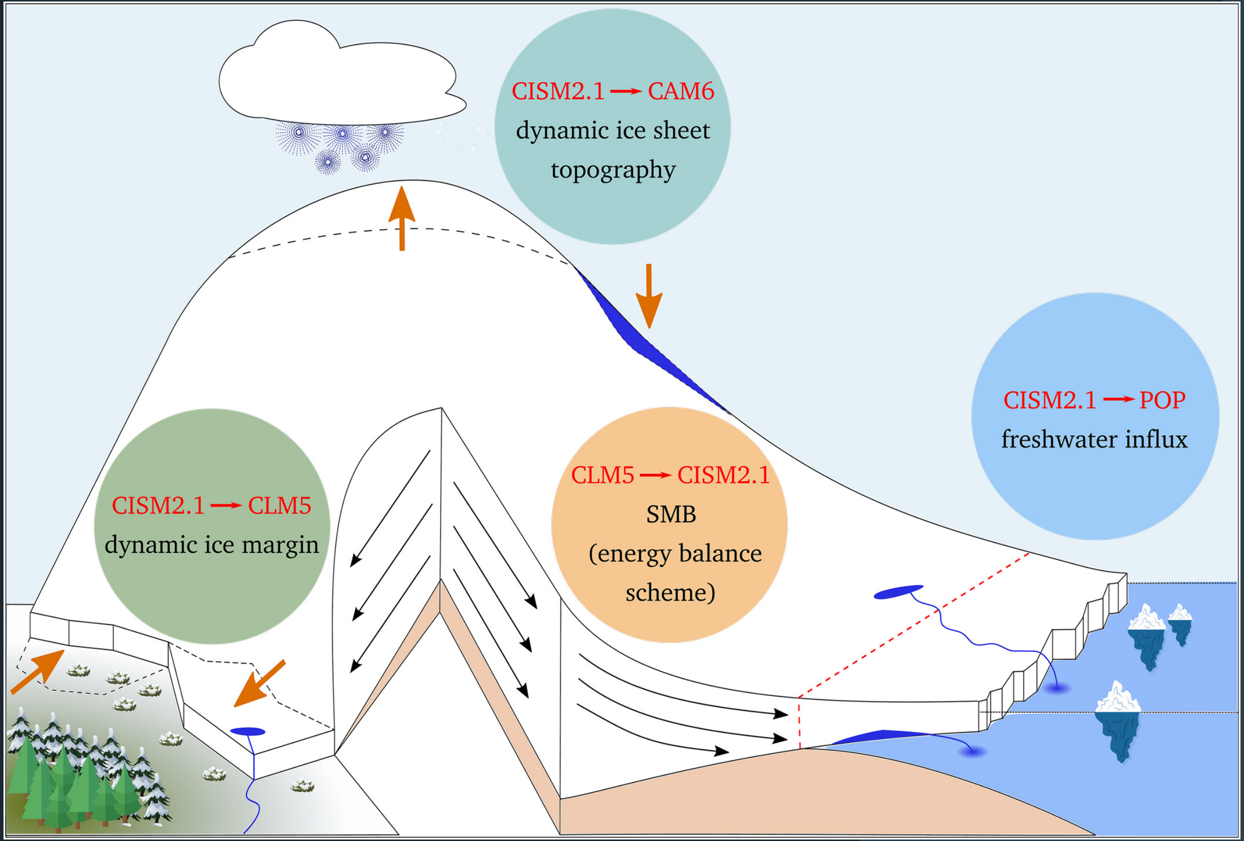
- Greenland melt under scenario 4xCO2
- Greenland melt under lower emission scenarios
- LGM simulation with CESM2
- Conclusions, follow-up and perspectives

Historical & high warming scenario 1850-2100 (Muntjewerf et al, GRL, 2020)

- 5.4 K warming and strong NAMOC weakening by 2100 in SSP5-8.5 w.r.t. preindustrial
- 23 mm GMSLR by 2050 and 109 mm by 2100
- Contribution of northern basins largely increases during the second half of the 21st century



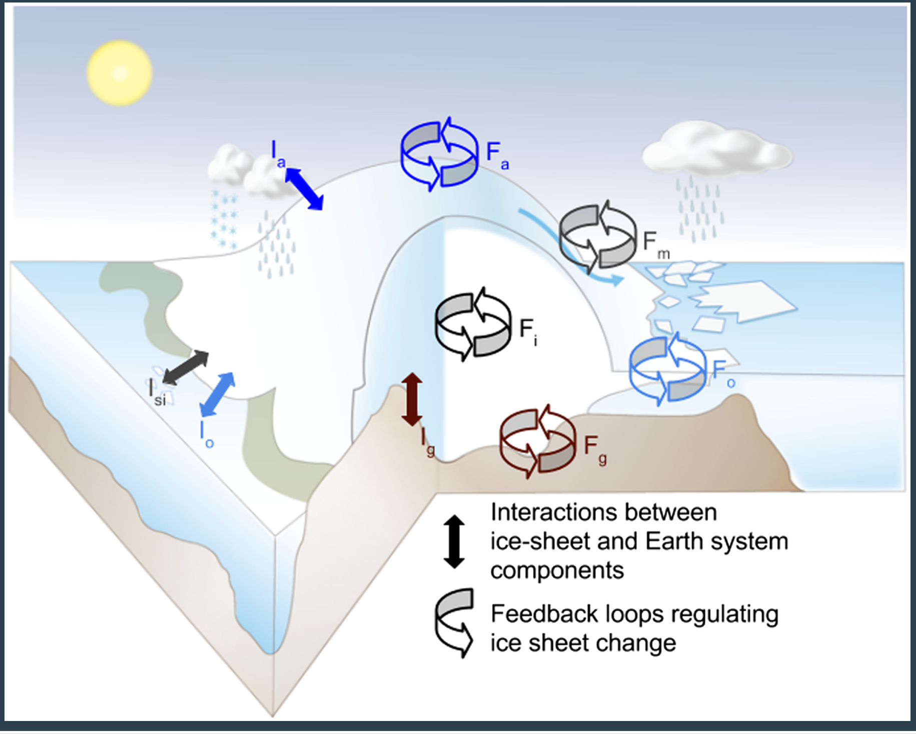
CESM2-CISM2 (Muntjewerf et al, model description, JAMES, 2021)

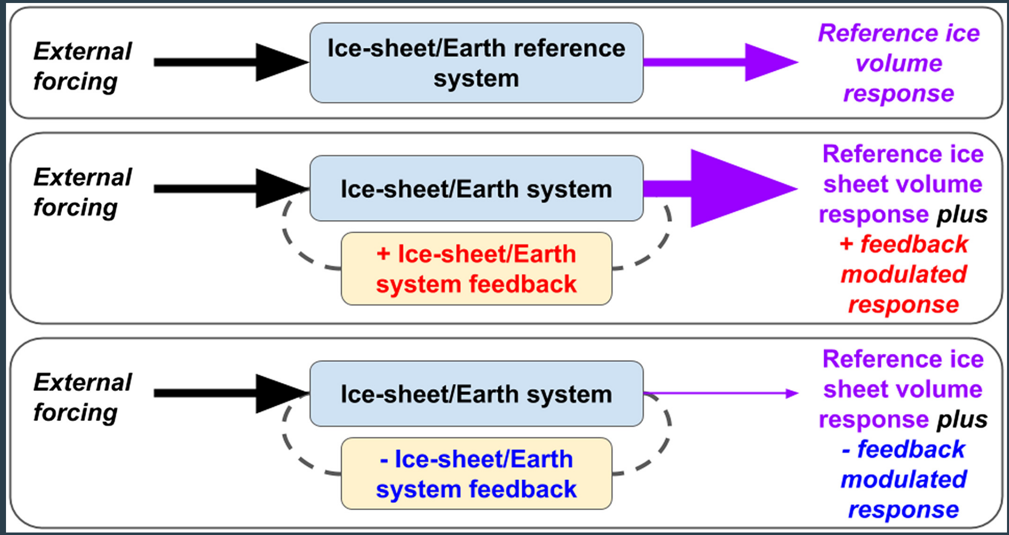


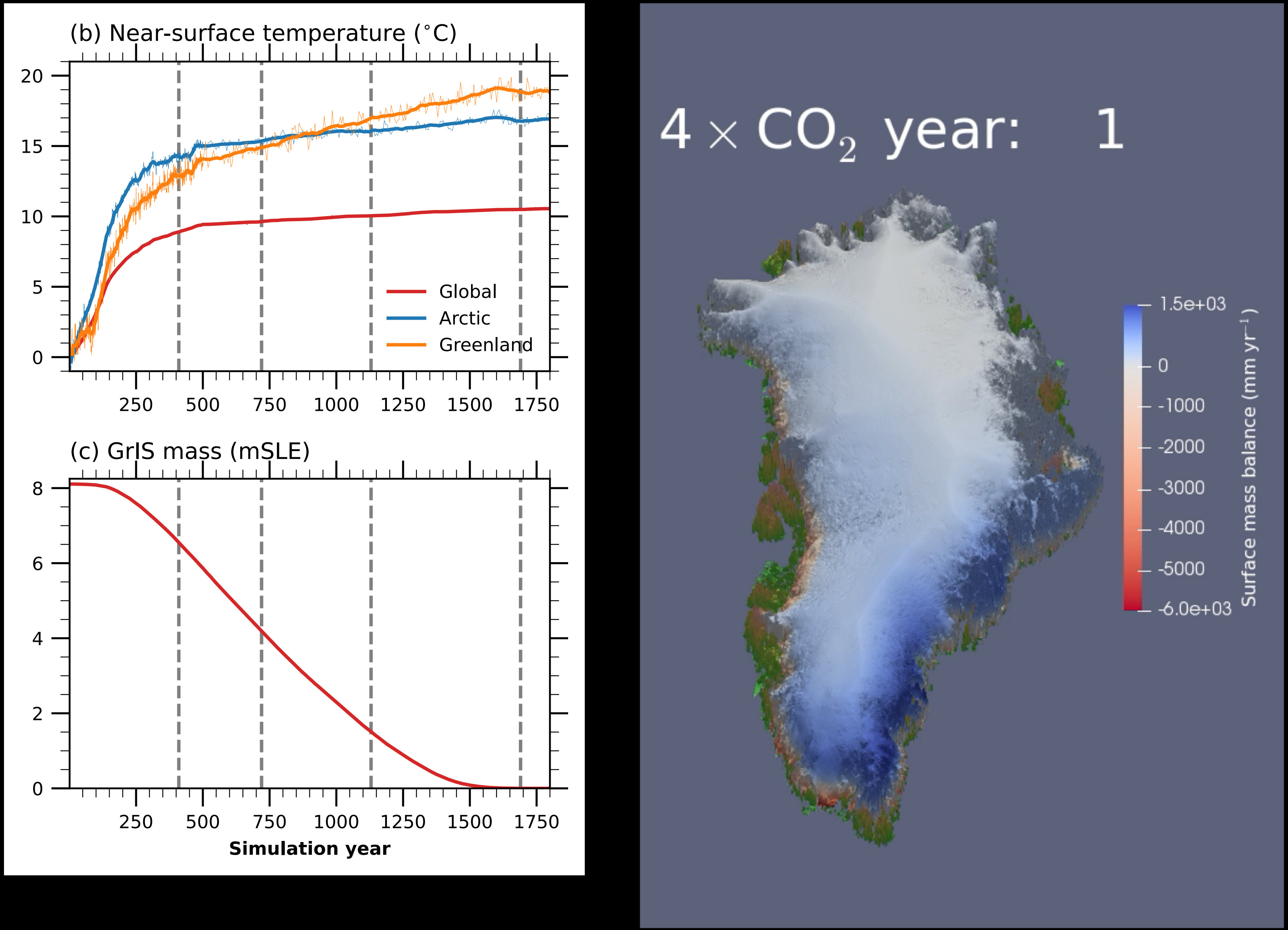
- We calculate melt from the sum of surface energy fluxes
- Interactive albedo calculation, depending on grain size (melt, rain, aging, etc)
- Modelling of snow/firn processes (up to 10 m w.e. snow/firn, up to 20 layers) such as compaction, refreezing
- In the land component of the model with a time-step of 3 hours
- Changes in **glacier area** communicated yearly
- Changes in **topo** communicated every 5-10 years
- **Freshwater fluxes** from surface melt (CLM) and ice discharge (CISM, yearly) are passed to ocean (POP)
- **Missing**: ocean forcing at the glacier fronts

Added value of coupled modelling

- Current projections with regional climate models and/or ice sheet models forced with output from climate models
- This prevents the representation of climate-ice interaction including feedbacks
- With coupled models, we would be able to connect anthropogenic emissions and global change with ice sheet change within the same platform

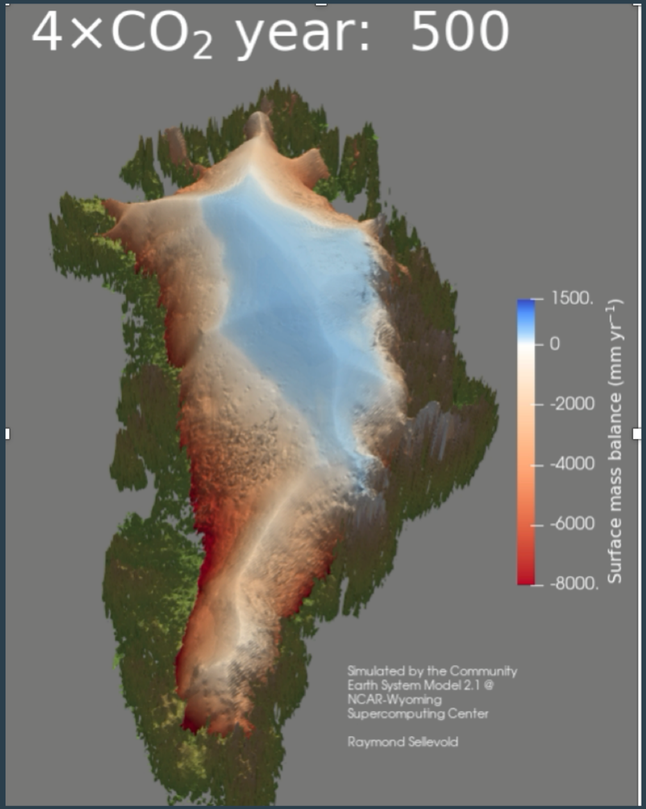


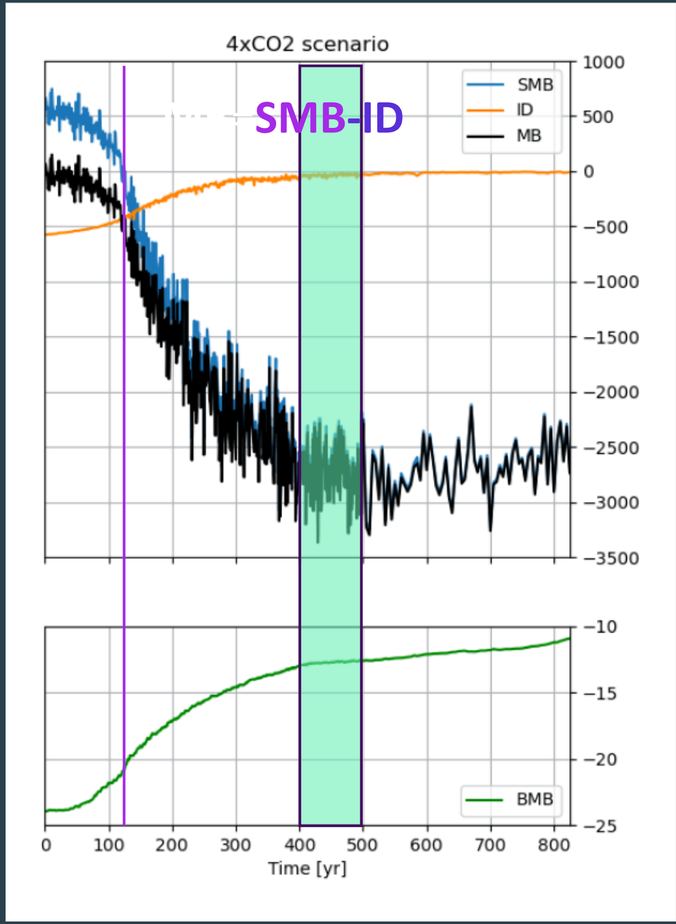



(b) Near-surface temperature (°C)
Global
Arctic
Greenland
(c) GrIS mass (mSLE)
Simulation year
4 × CO_2 year: 1
Surface mass balance (mm yr^{-1})
1.5e+03
0
-1000
-2000
-3000
-4000
-5000
-6.0e+03

Multi-century evolution under 1% 4xCO2

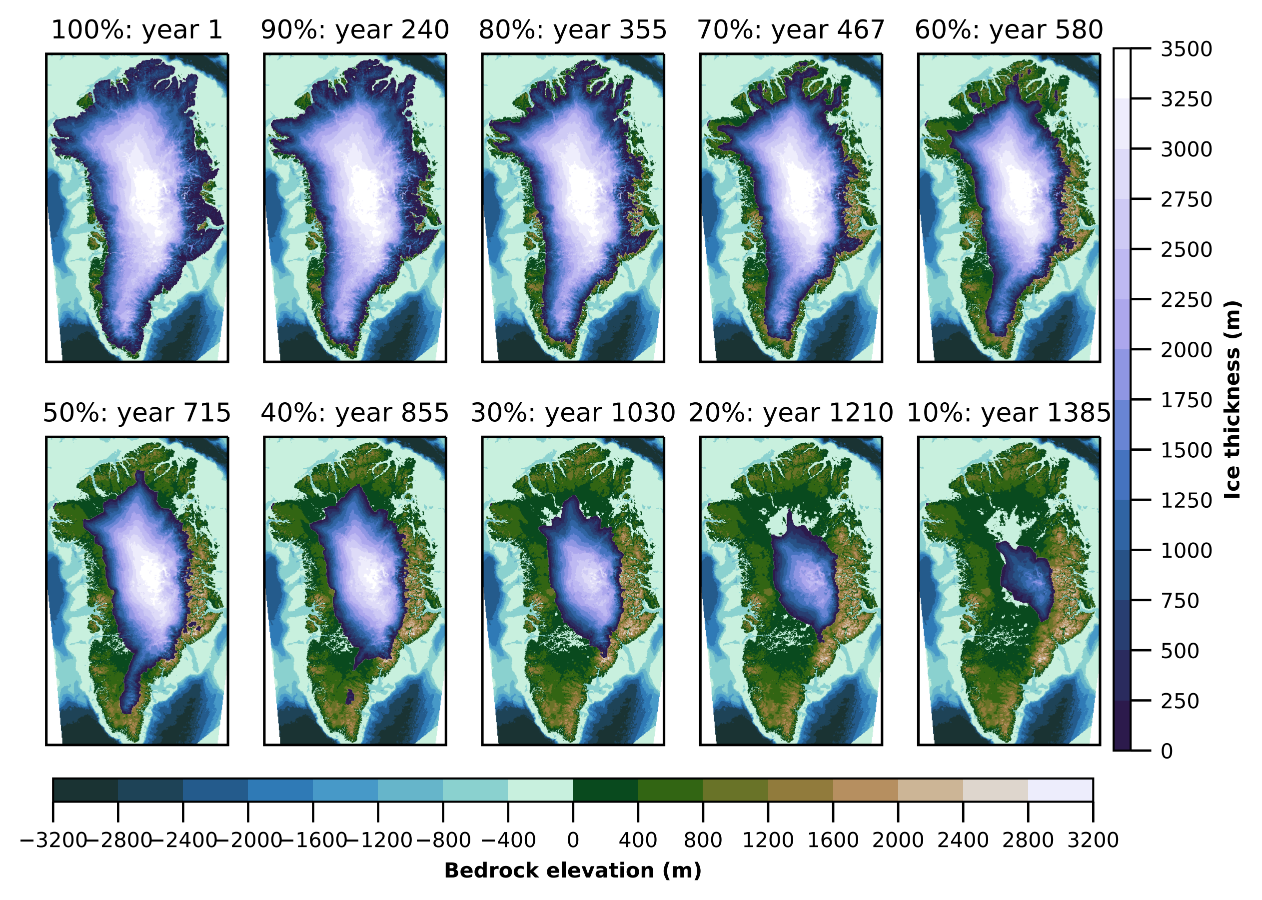
Mass loss in Gt/yr (360 Gt yr^{-1}= 1 mm SLR yr^{-1})

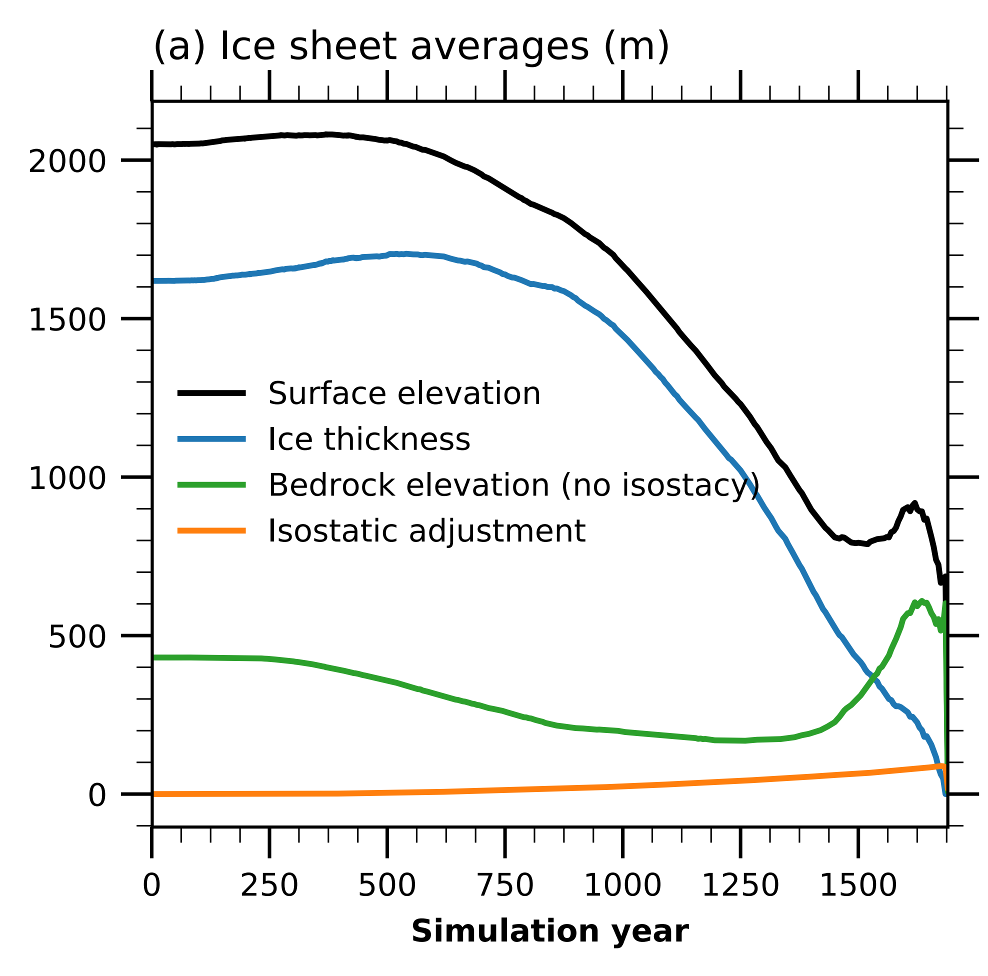




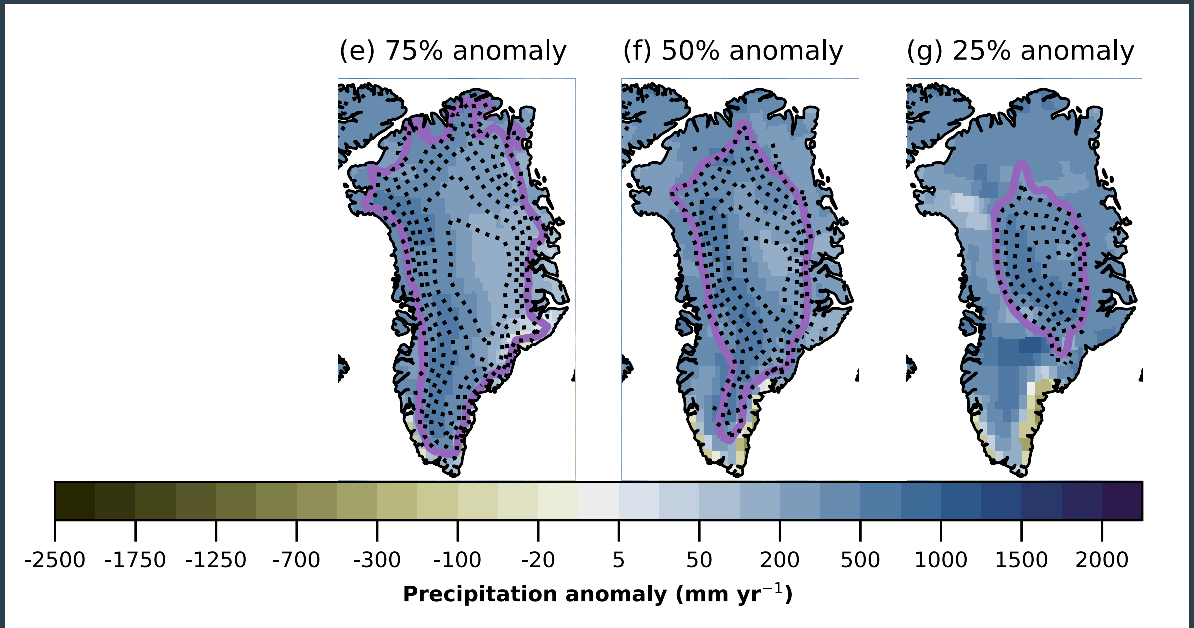
- In this scenario, 4xCO2 is reached at year 140
  - ➢ in SSP5-8.5, at year 2100
- **Large increase in mass loss rate & ablation area expansion ~year 120**
- Maximum mass loss rate at year 500 (8 mm SLR yr^{-1})
- GrIS is lost in 1,700 years

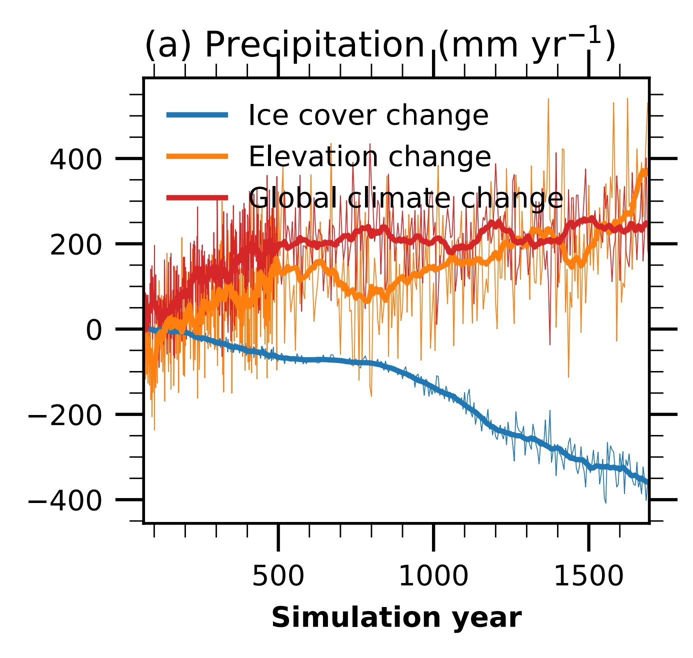
Elevation change



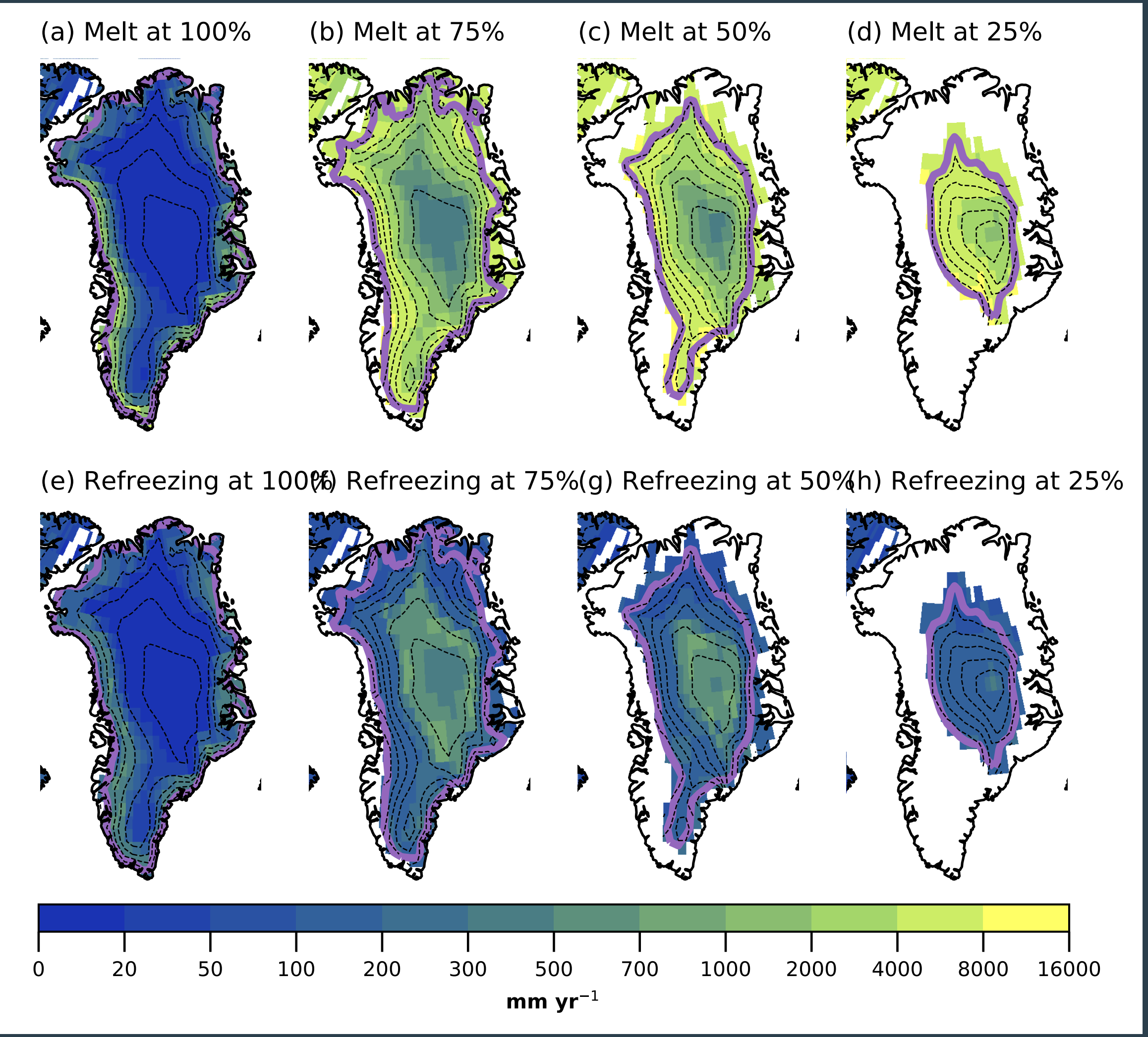


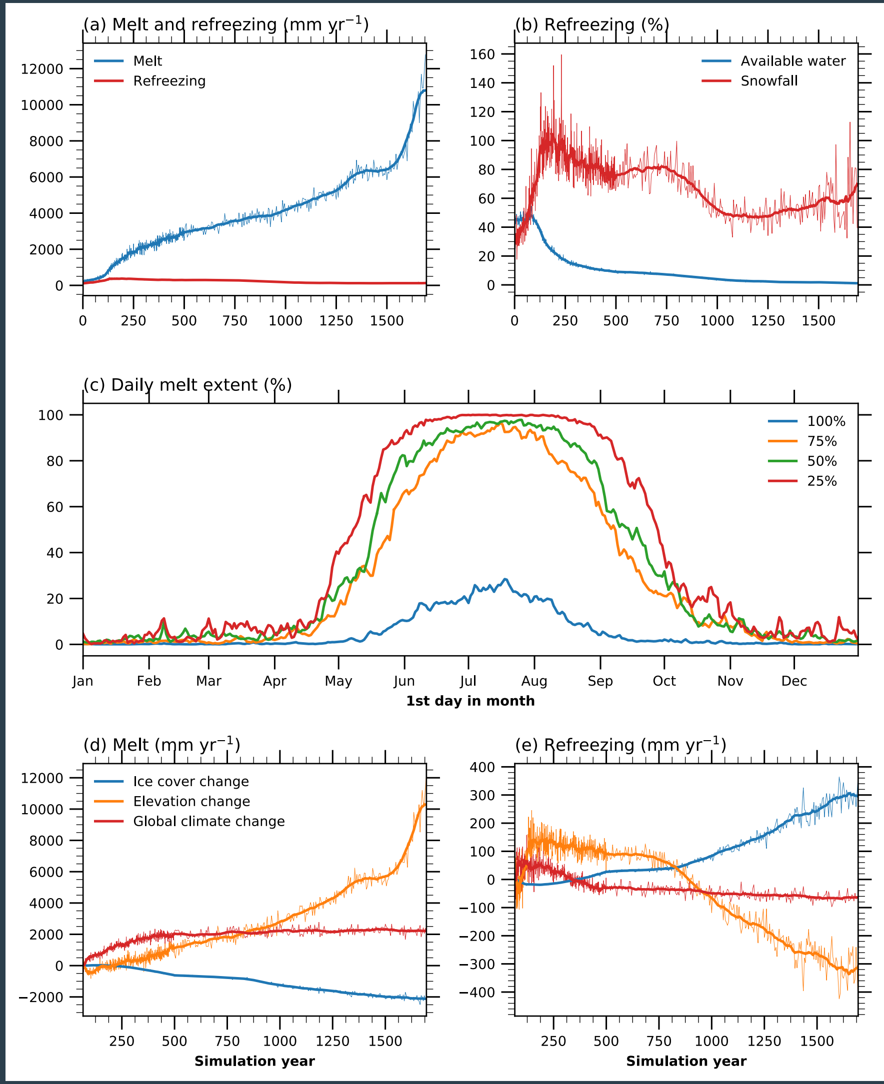
Precipitation



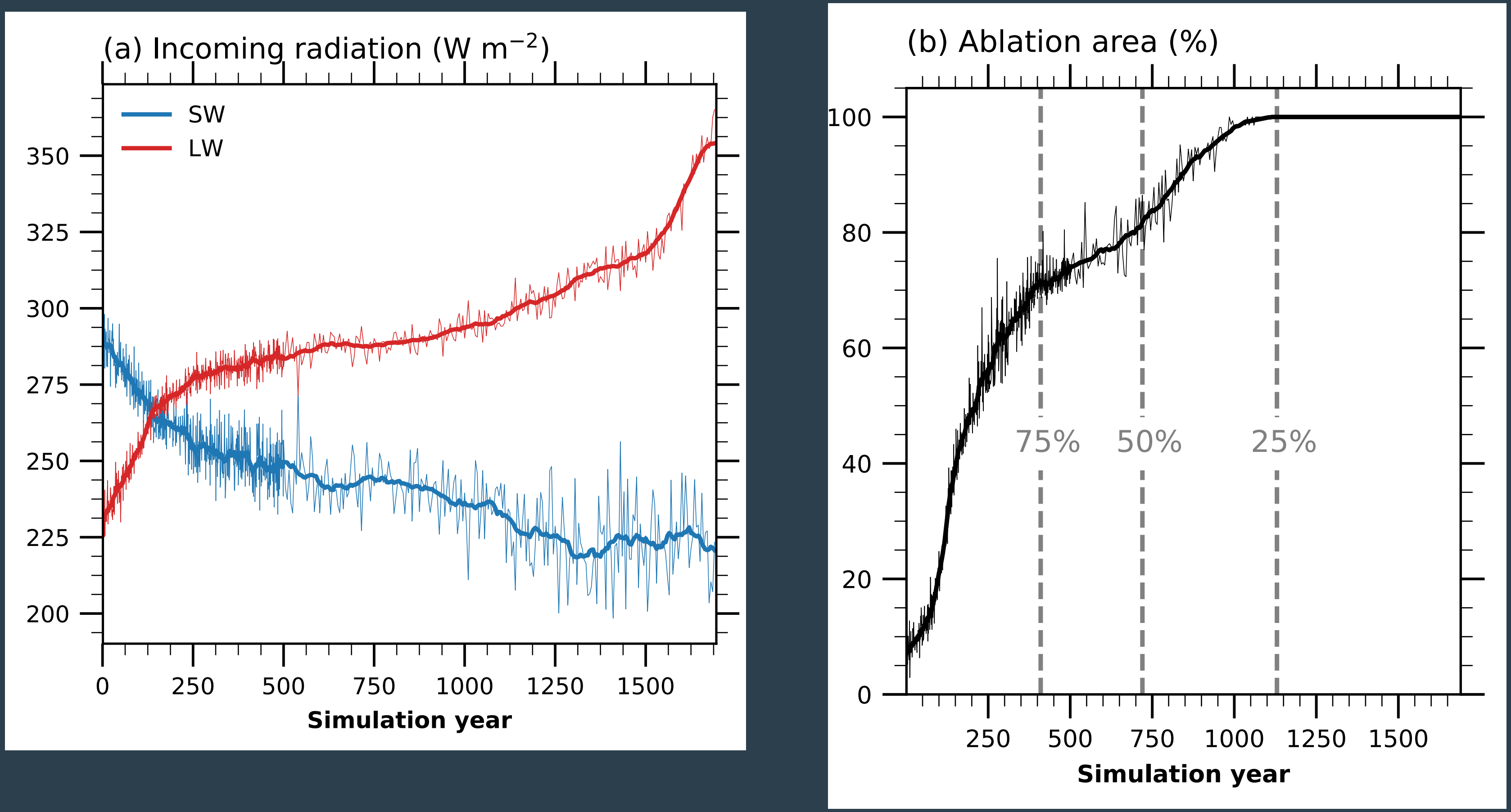


Melt and refreezing evolution

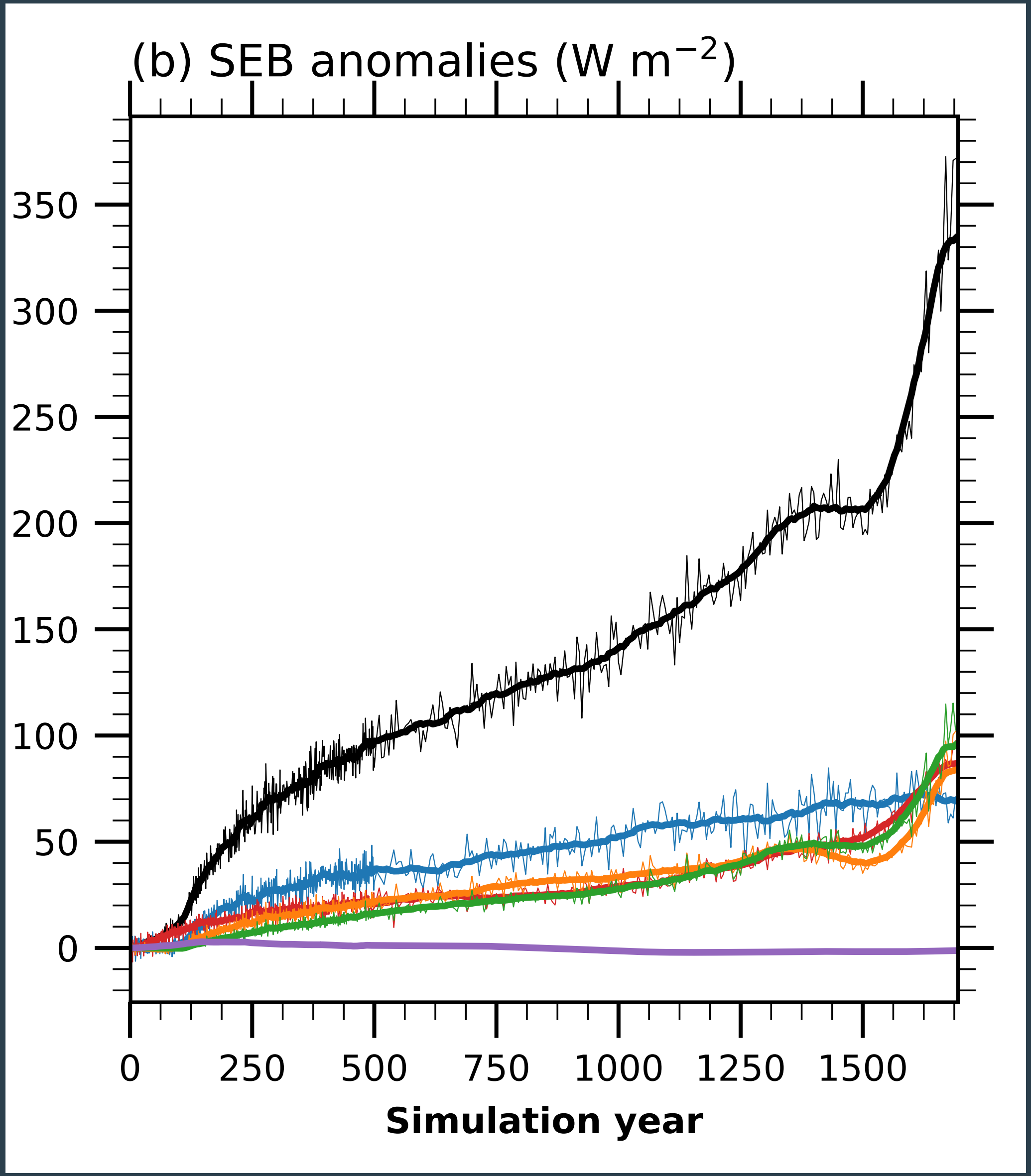




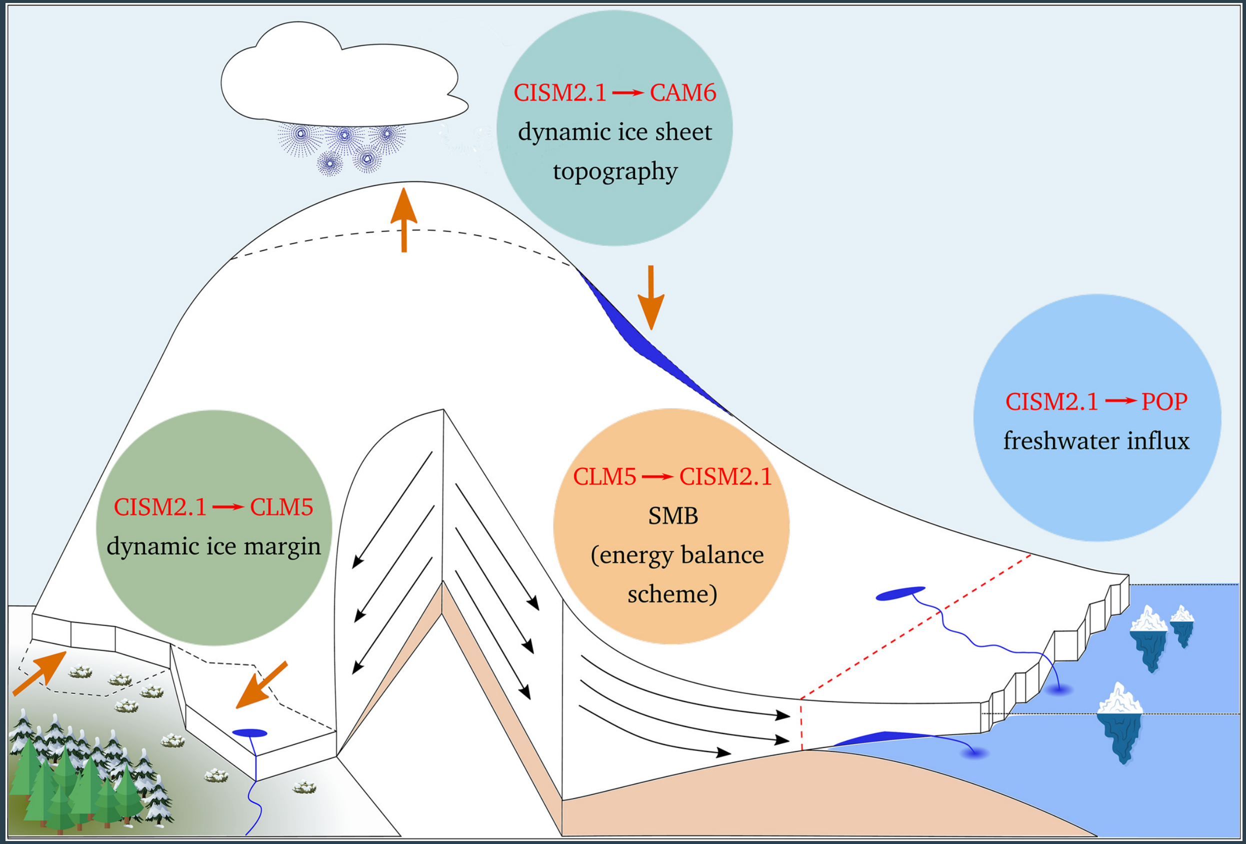
Albedo


(a) Incoming radiation (W m^{-2})
SW
LW
350
325
300
275
250
225
200
0
250
500
750
1000
1250
1500
Simulation year
(b) Ablation area (%)
100
80
60
40
20
0
75%
50%
25%
250
500
750
1000
1250
1500
Simulation year

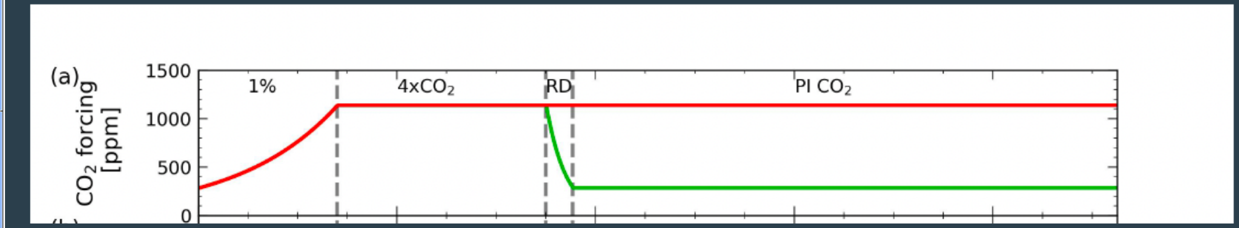
Melt


(b) SEB anomalies (W m^{-2})
350
300
250
200
150
100
50
0
0
250
500
750
1000
1250
1500
Simulation year

Feedbacks and reversibility (Thirsza Feenstra)



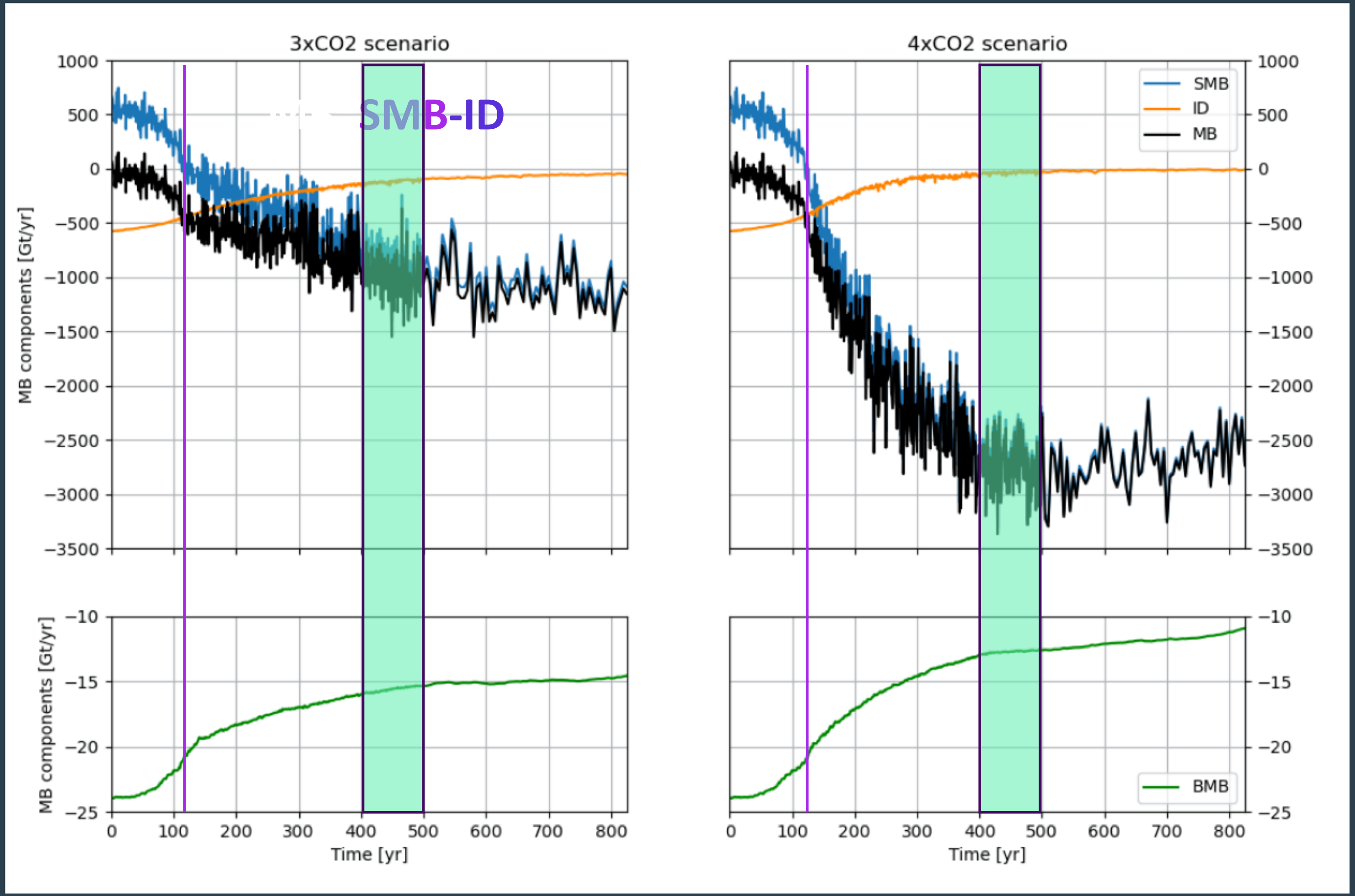
- Topographic change effect on GrIS climate and mass balance
- GrIS effect of -5% from 4xCO2 to 1xCO2



Mitigating Greenland melt

- What if we cap at $3xCO_2$ (year 111)?

Mass loss in Gt/yr (360 Gt yr^{-1}= 1 mm SLR yr^{-1})

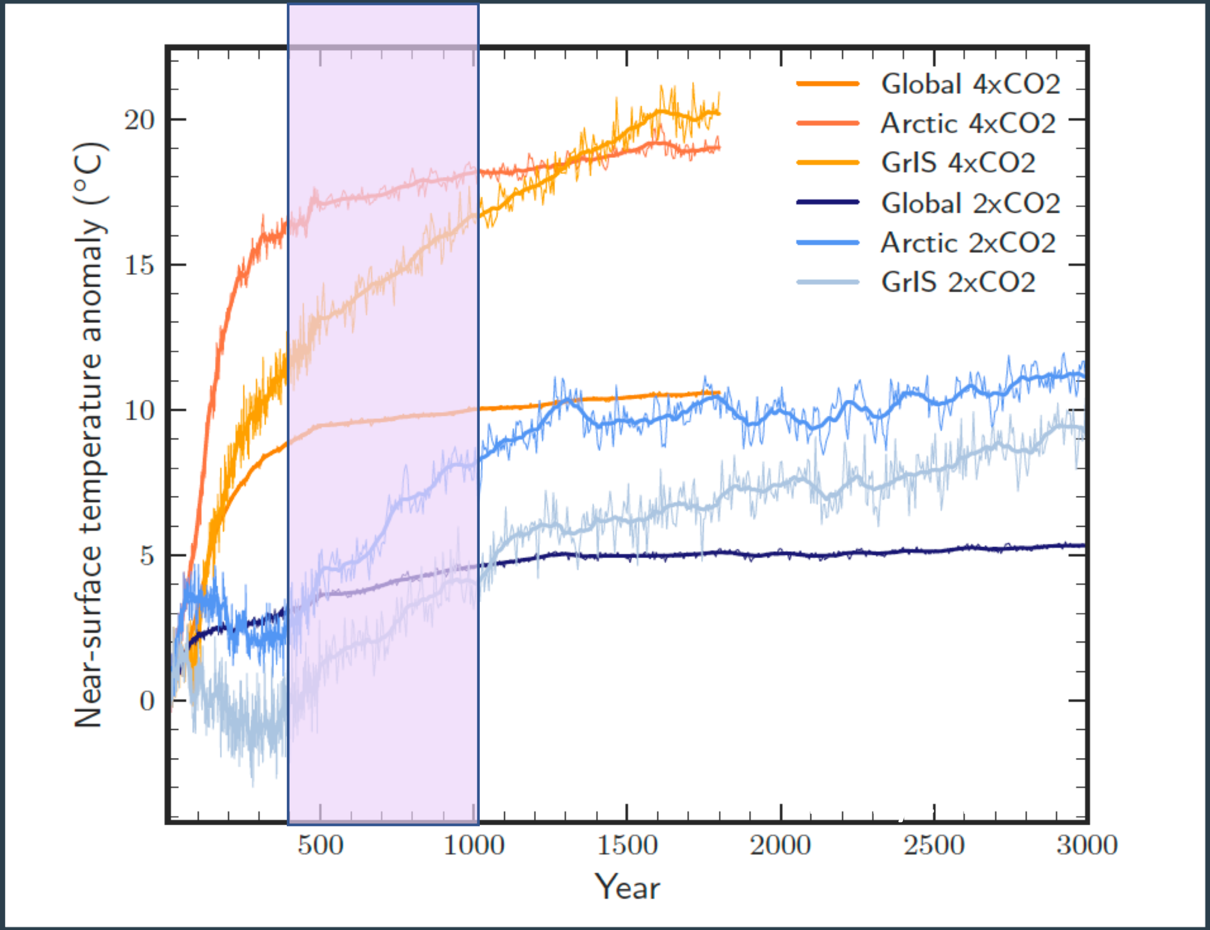


- **Mass loss acceleration around year 120 is avoided with capping at 3xCO2**
- Mass loss rates by year 500 are reduced by almost 2/3
  - ➢ Non-linear effect of emission reduction

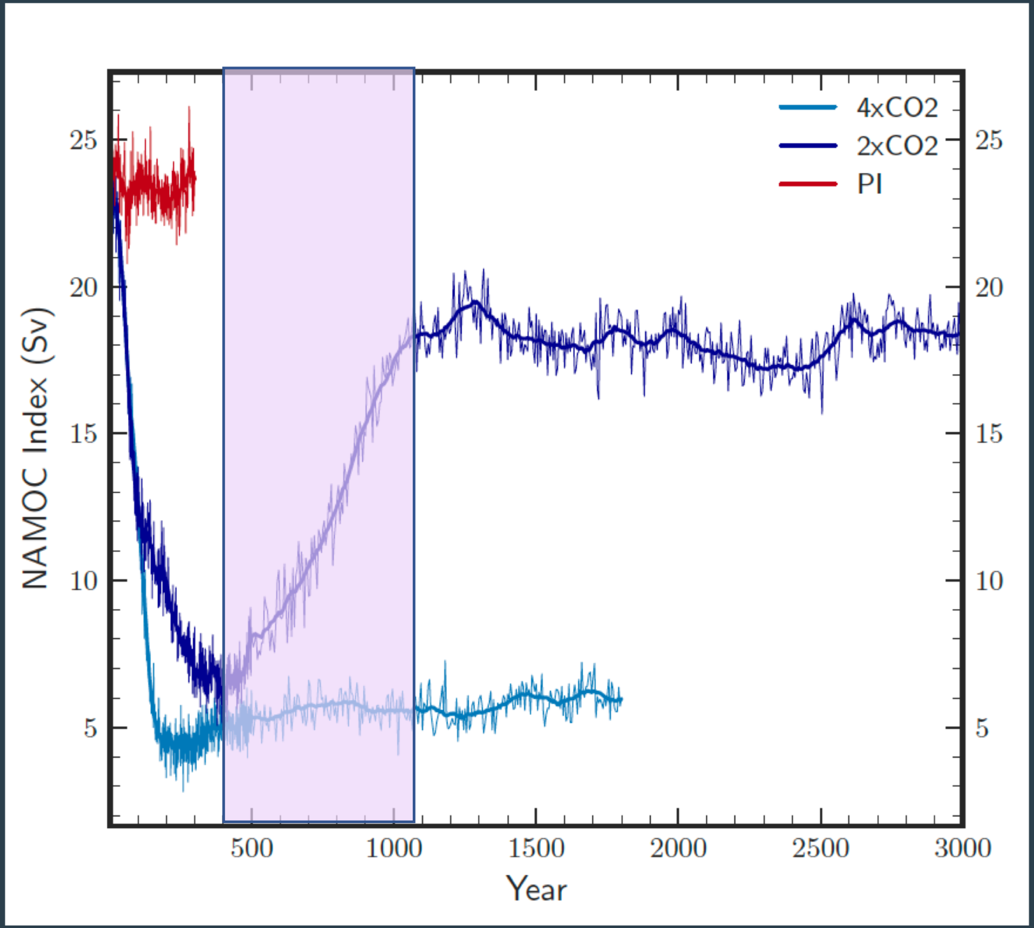
Mitigating Greenland melt

- What if we cap at $2xCO_2$ (year 70)?

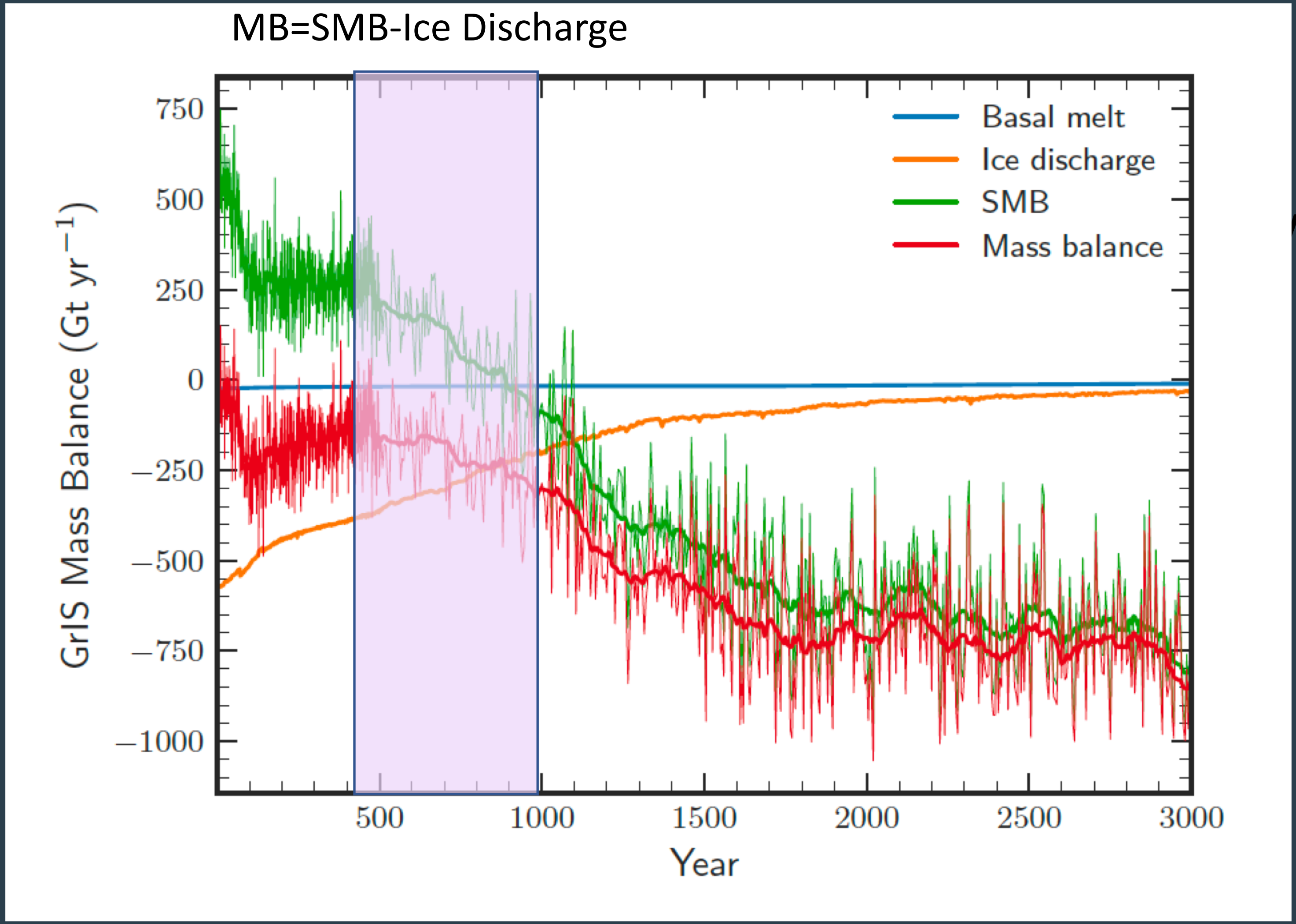
Global warming



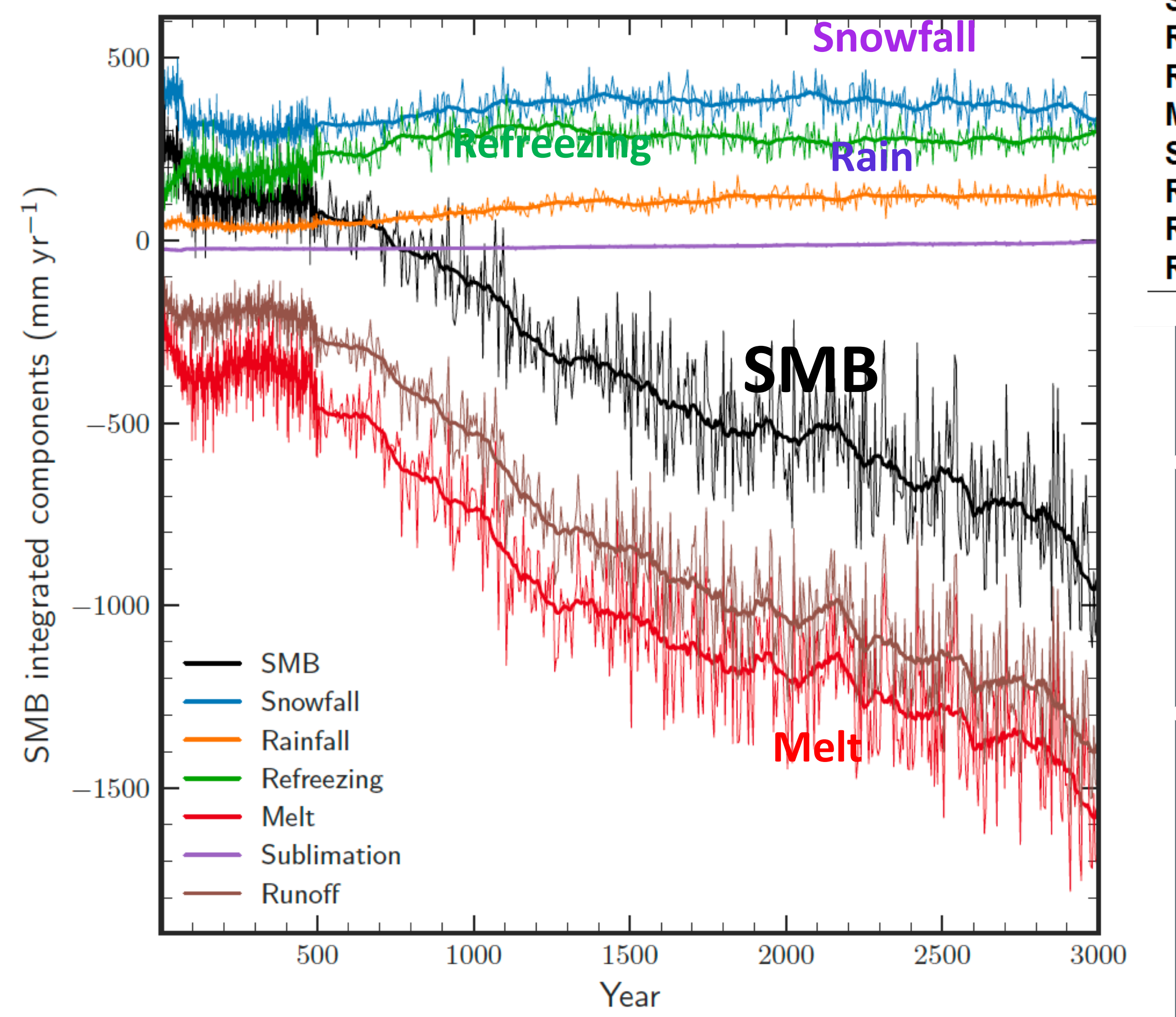
NAMOC



Mass loss increases with NAMOC recovery



very

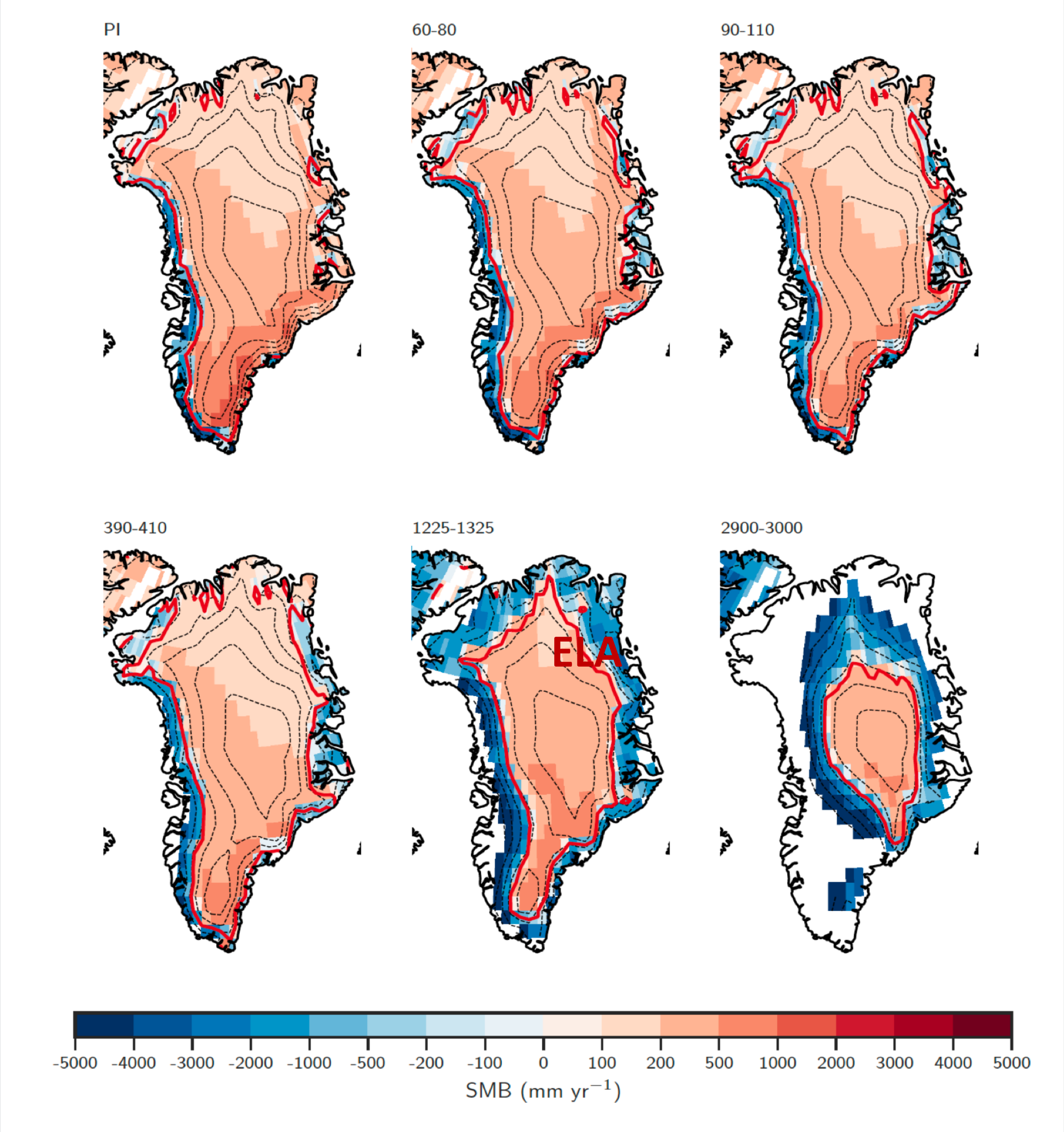


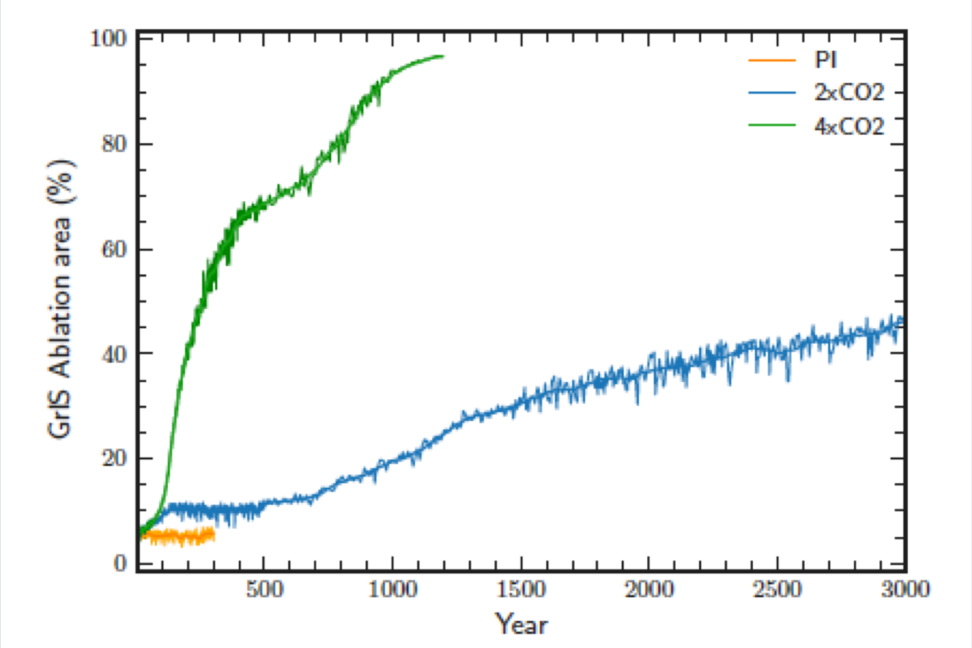
Gt per year

	PI 1-20	Years 60-80	Years 90-110	Years 390-410	Years 1225-1325
SMB	556 (87)	374 (94)	249 (106)	215 (91)	-574 (140)
Precipitation	863 (74)	846 (111)	699 (62)	657 (55)	844 76)
Snowfall	790 (68)	725 (98)	617 (59)	582 (44)	662 (65)
Rain	73 (11)	100 (20)	81 (14)	75 (16)	183 (28)
Refreezing	221 (53)	388 (47)	413 (82)	371 (75)	554 (46)
Melt	410 (89)	691 (89)	737 (152)	695 (139)	1757 (146)
Sublimation	45 (4)	49 (6)	44 (3)	42 (3)	31 (4)
Runoff	262 (48)	403 (64)	405 (79)	399 (74)	1386 (122)
Rain (%)	8.5	12	11.6	11.4	21.7
Refreezing (%)	45.8	49	50.5	48.2	28.6

- *Before NAMOC recovery:* SMB reduced to half of PI due to melt increase and snowfall decrease, refreezing increases
- *After NAMOC recovery*: large increase in melt, small increase in snowfall, decline in refreezing capacity (as % of melt+rain)

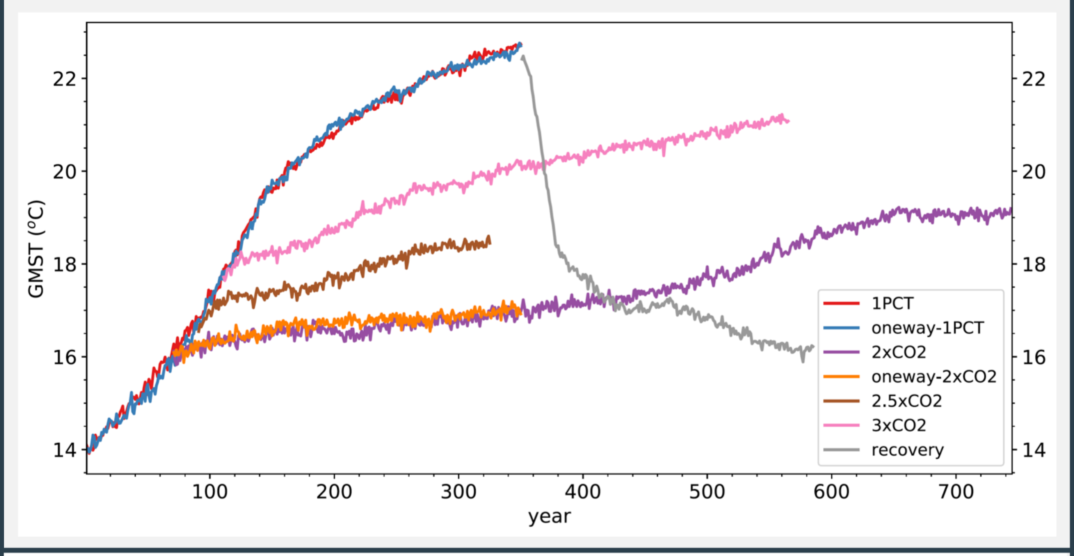
Surface mass balance

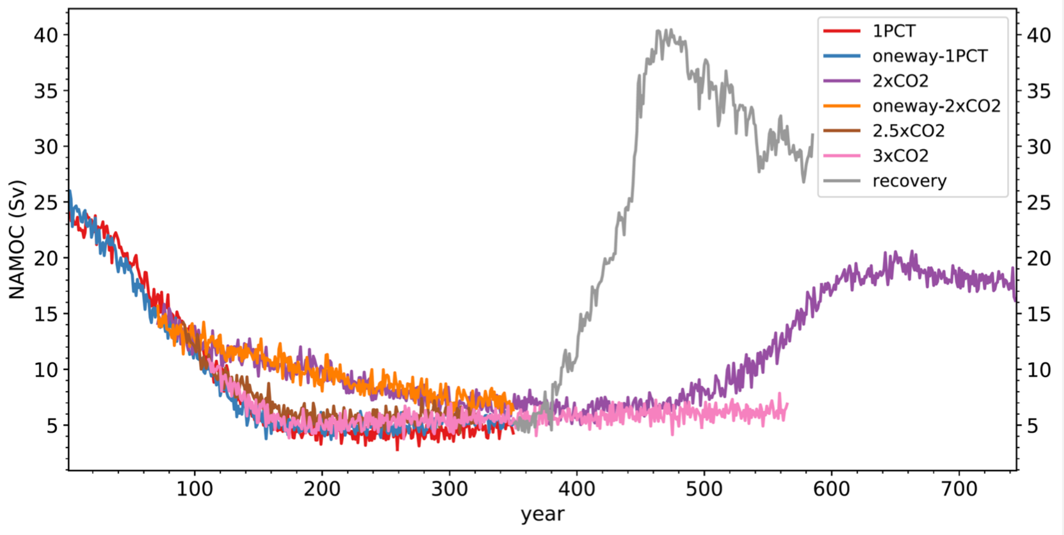


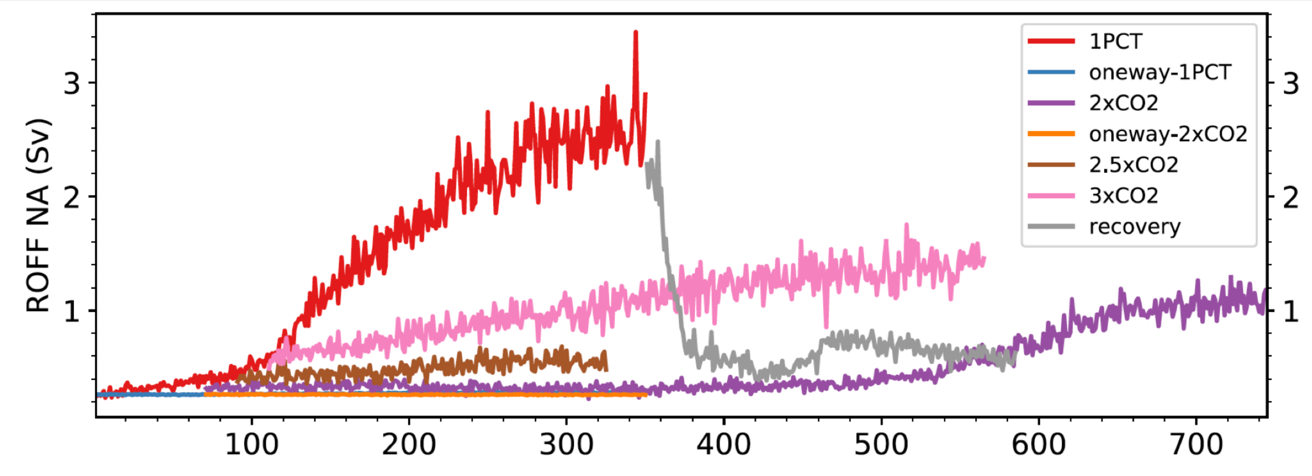


- Ablation area expands in the first 70 years and following NAMOC recovery

Conclusions



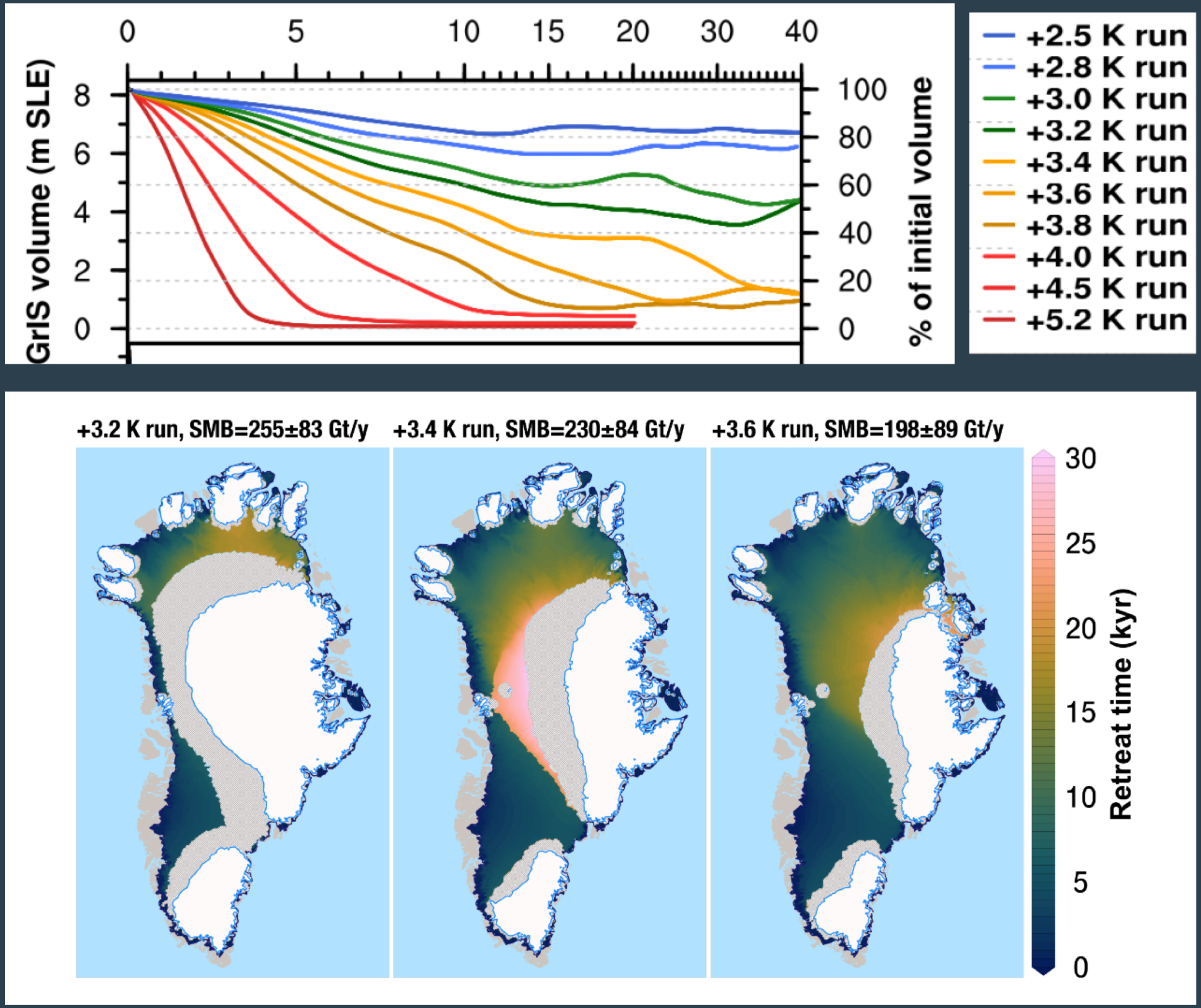




- NAMOC collapses is all scenarios
  - Bifurcation fast collapse for 2.5xCO_2
- Warming relatively linear with CO_2
- Melt is not linear with CO_2 (albedo and elevation feedbacks, and coupling with ocean change)

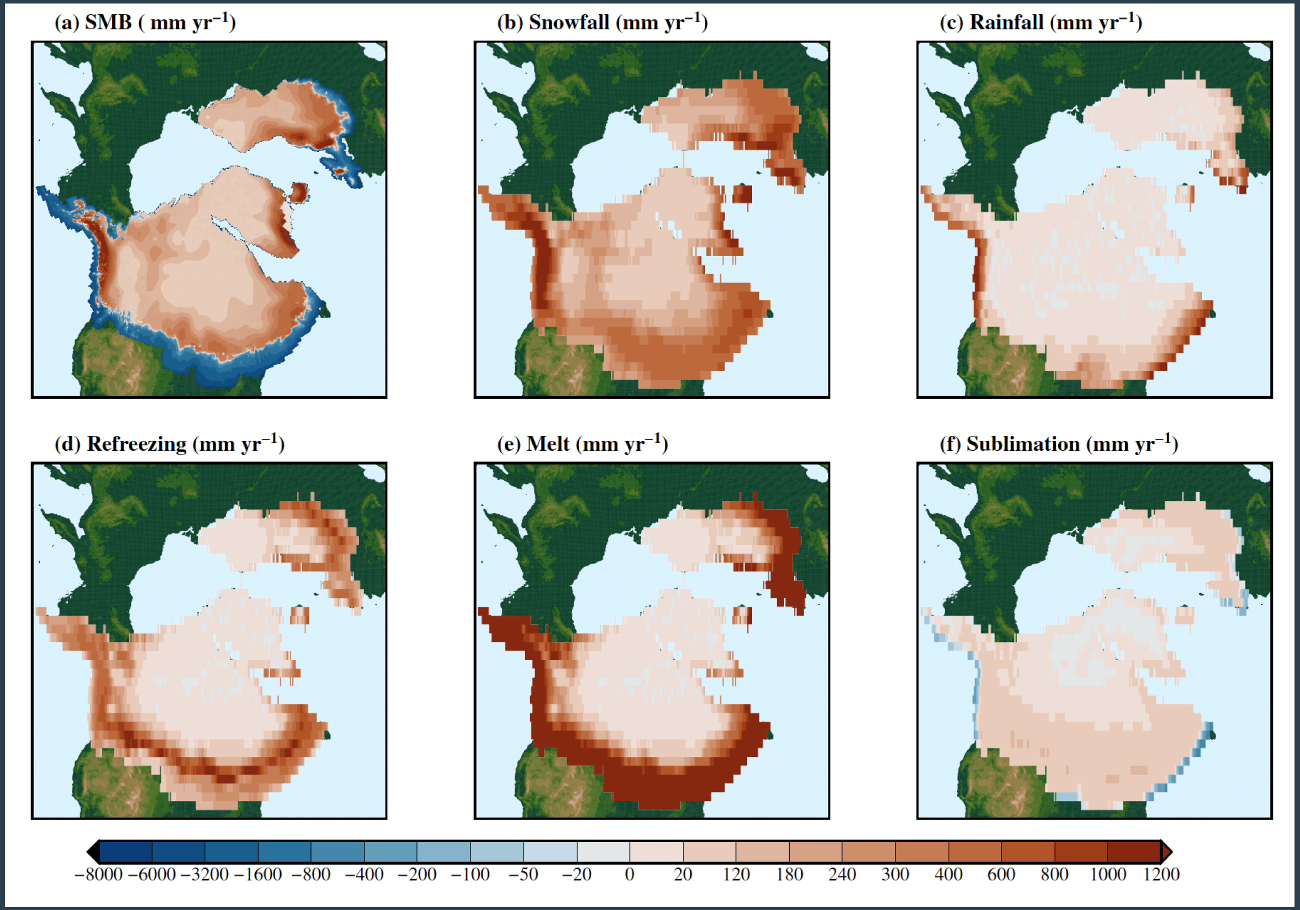
Tipping: follow-up

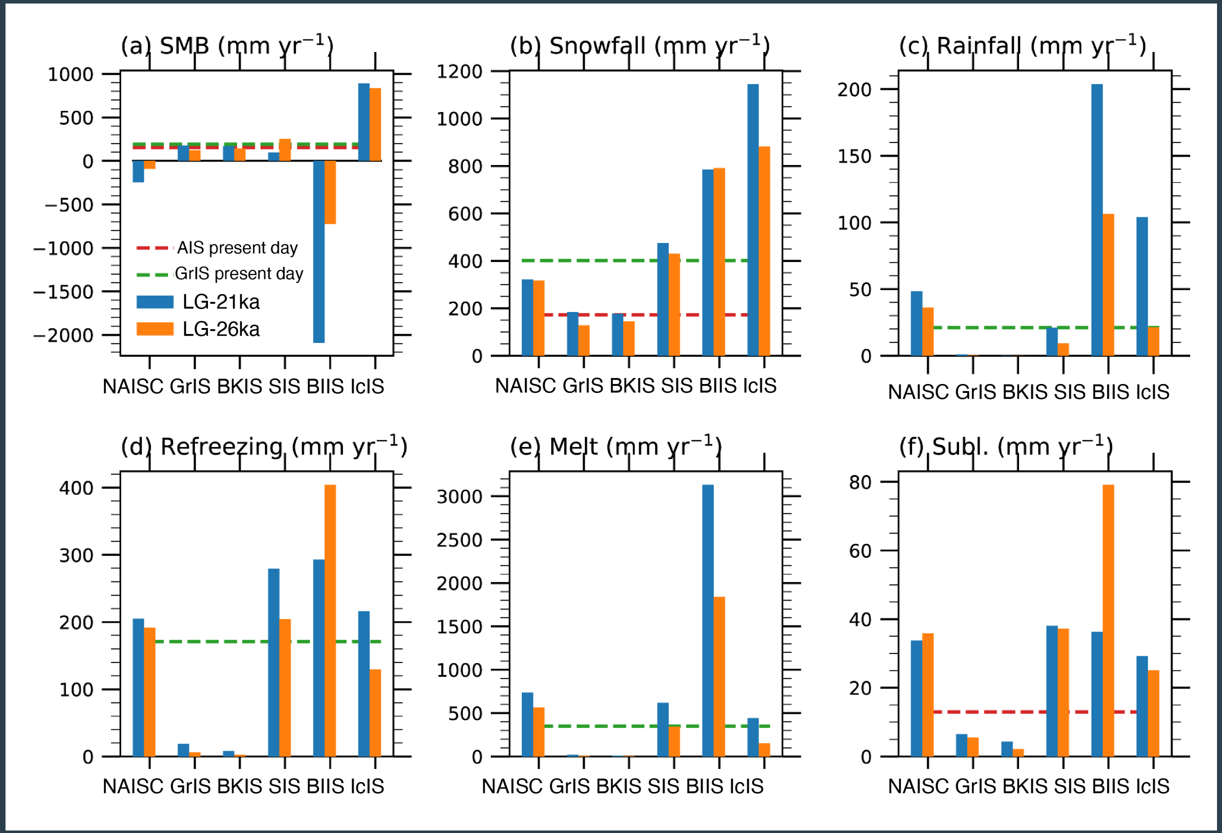
- We will revisit tipping with the suite of simulation shown here

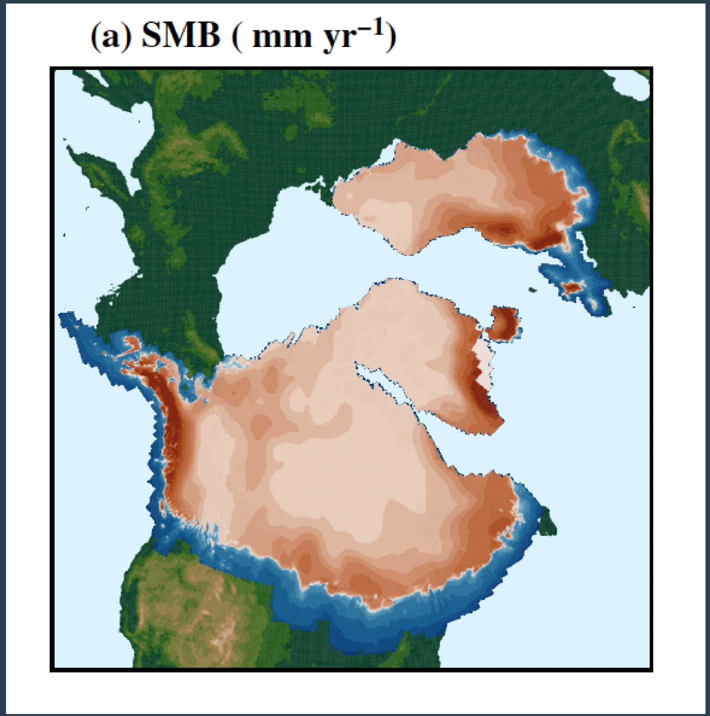


Simulation of Last Glacial Maximum (21-18 ka BP) climate of northern hemisphere ice sheets (Bradley et al, Clim Past, 2024)

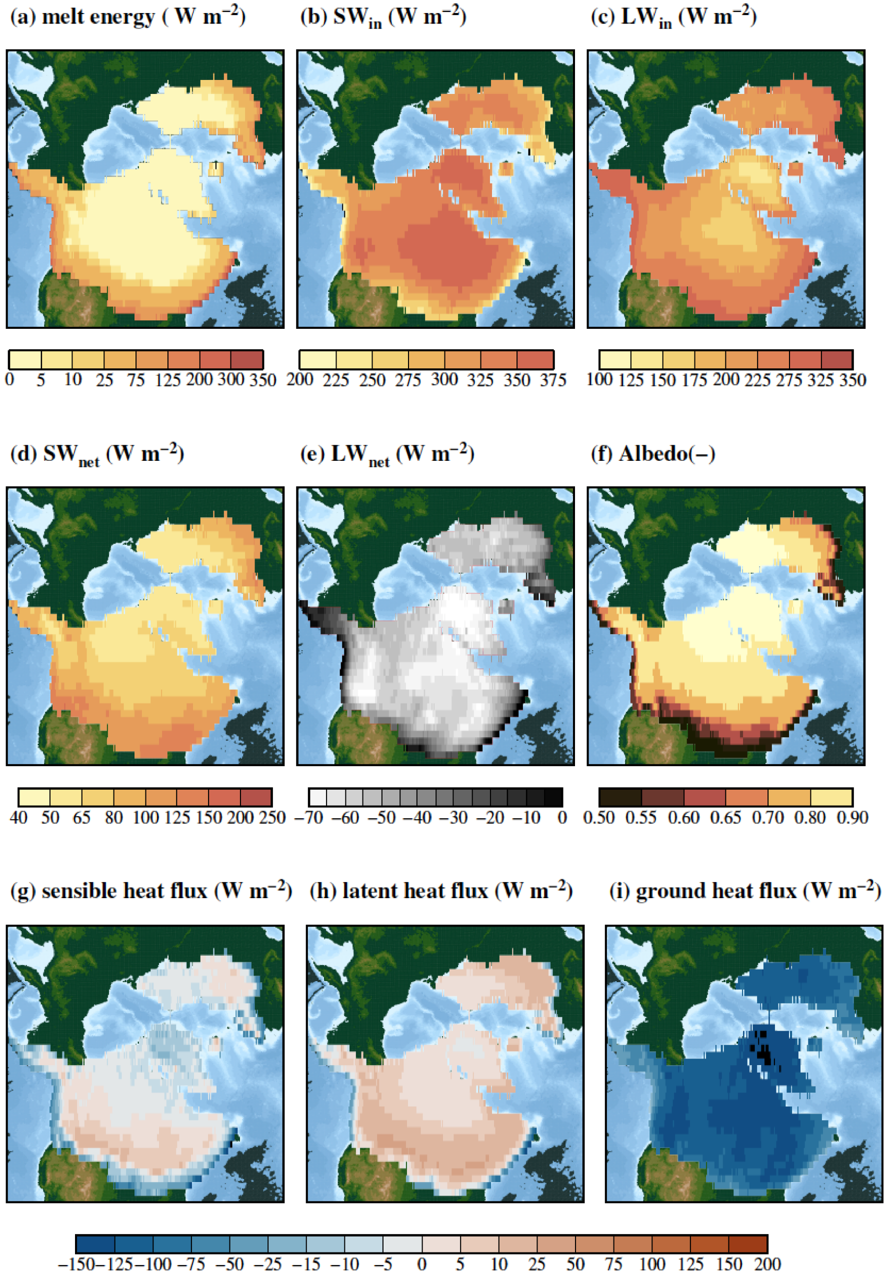
- We use CESM2-CAM5 at standard resolution of 1 degree in the climate components
- We apply some type of analysis as for present-day ice sheets SMB







- Greenland and Barents-Kara ice sheets are <u>driest and coldest</u>: snowfall and (zero) melt as present-day Antarctica
- Scandinavian has similar snowfall and melt to present-day Antarctica
- British ice sheet has very high melt
- North American ice sheet has **too high melt**


(a) melt energy (W m^{-2})
(b) SW_{in} (W m^{-2})
(c) LW_{in} (W m^{-2})
0 5 10 25 75 125 200 300 350
200 225 250 275 300 325 350 375
100 125 150 175 200 225 275 325 350
(d) SW_{net} (W m^{-2})
(e) LW_{net} (W m^{-2})
(f) Albedo(–)
40 50 65 80 100 125 150 200 250
−70 −60 −50 −40 −30 −20 −10 0
0.50 0.55 0.60 0.65 0.70 0.80 0.90
(g) sensible heat flux (W m^{-2})
(h) latent heat flux (W m^{-2})
(i) ground heat flux (W m^{-2})
−150 −125 −100 −75 −50 −25 −15 −10 −5 0 5 10 25 50 75 100 125 150 200