Minor contribution of ablation area expansion to future Greenland Ice Sheet mass loss

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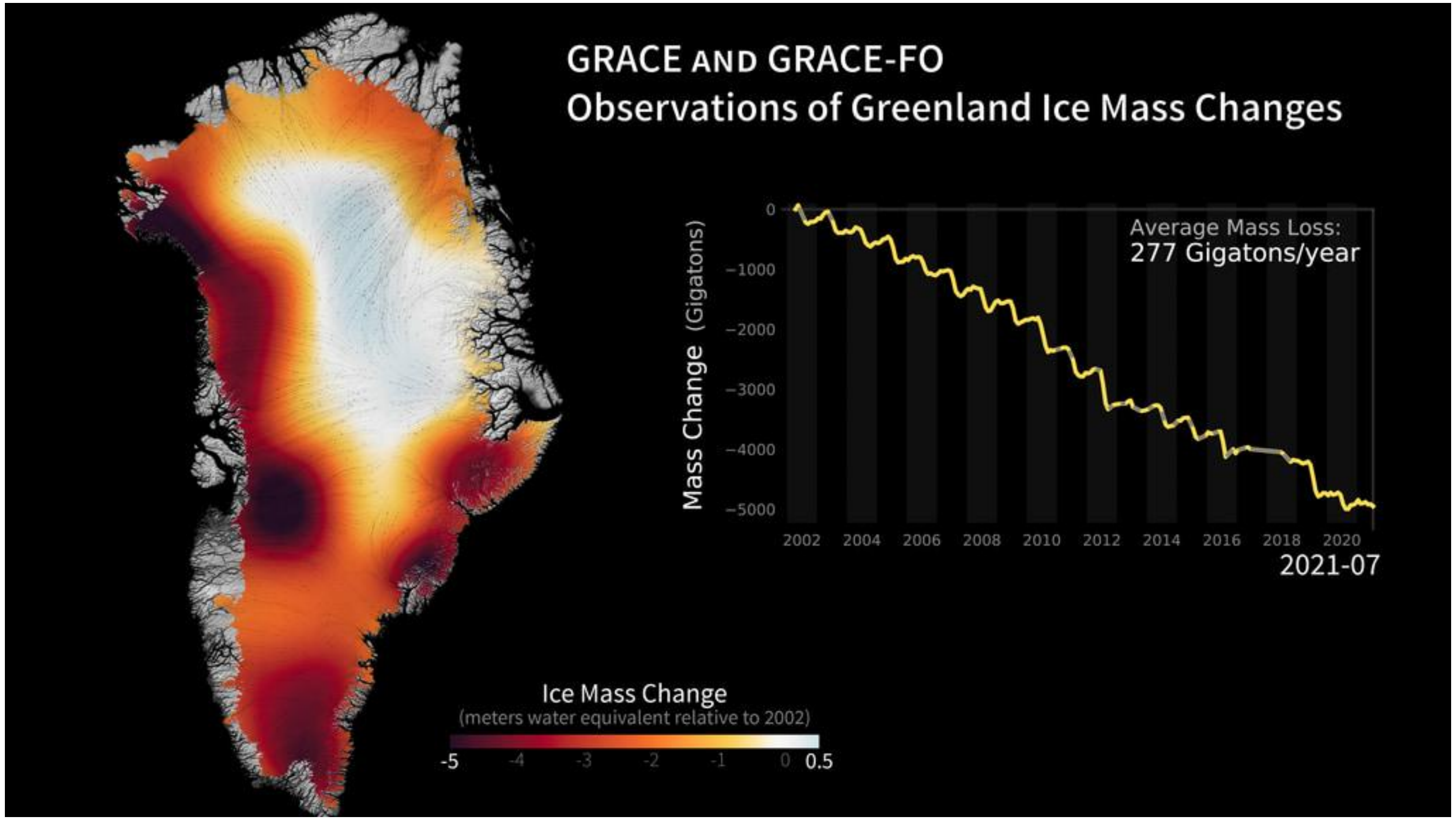
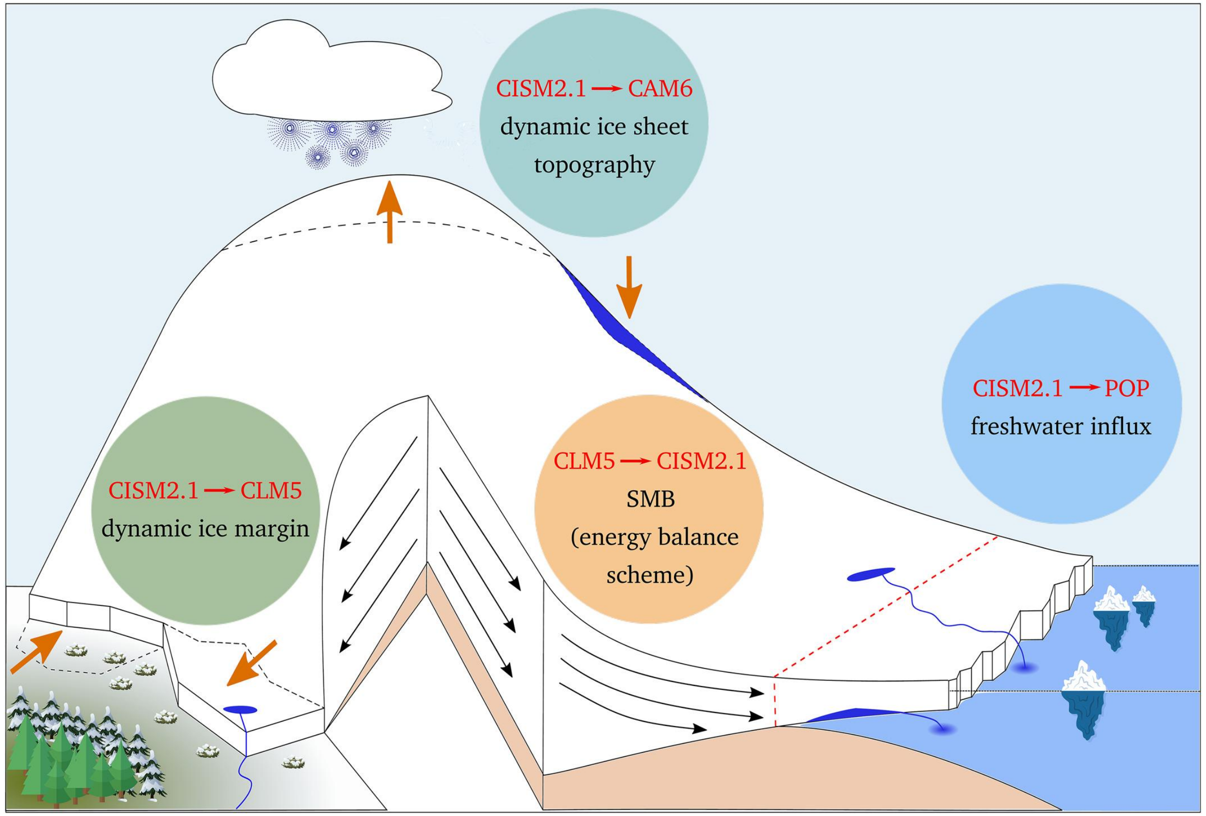
Greenland is losing mass: 0.7 mm SLR/yr



- Mass loss has accelerated due to accelerated runoff, primarily from SW
- Becoming a major contributor to GMSLR (3.7 mm/yr)
- Record melt in 2012 & 2019

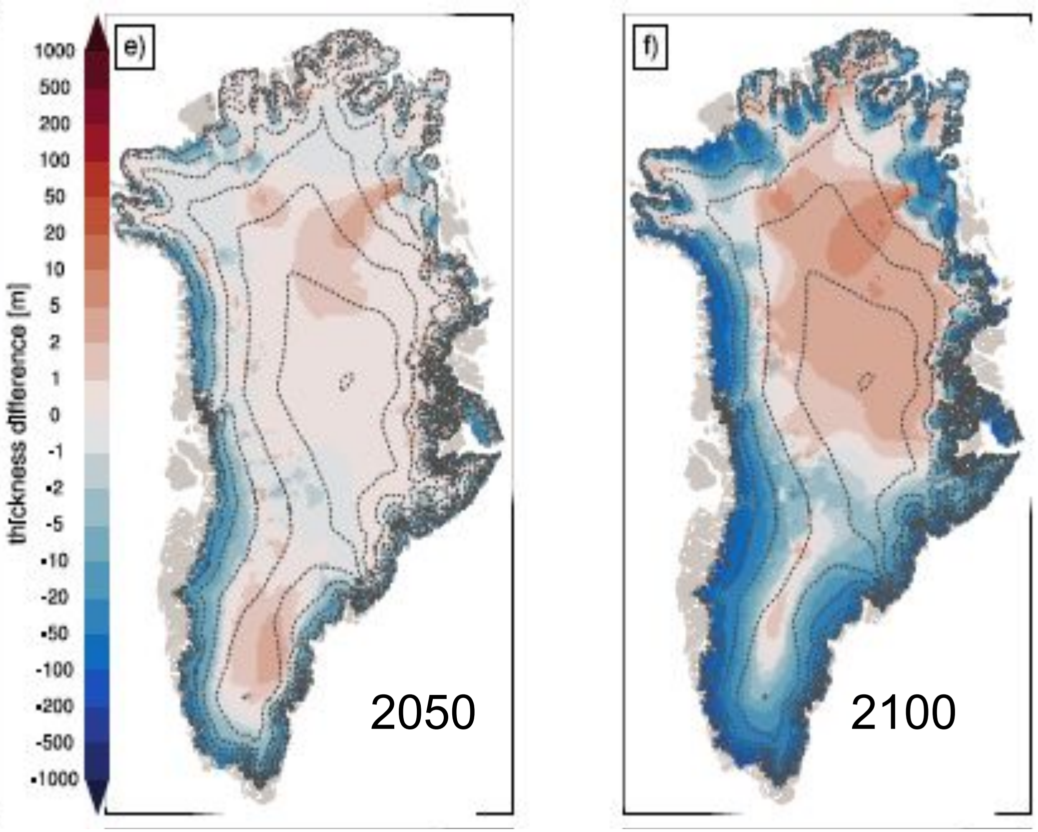
CESM2-CISM2 applied for SSP5-8.5 estimates

Projections
Muntjewerf et al, GRL, 2020



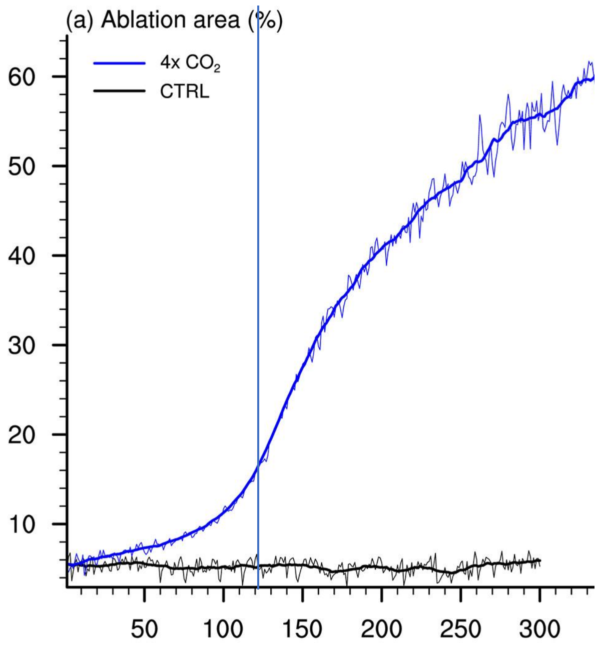
Model description
Muntjewerf et al, JAMES, 2021

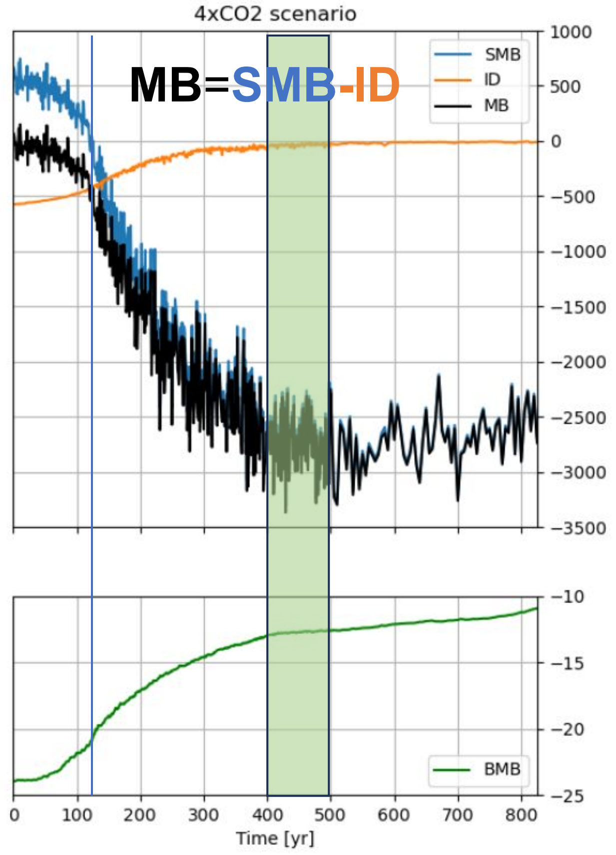
Thickness change (m), SSP5-8.5 (m)



Multi-century evolution under 1% 4xCO2

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

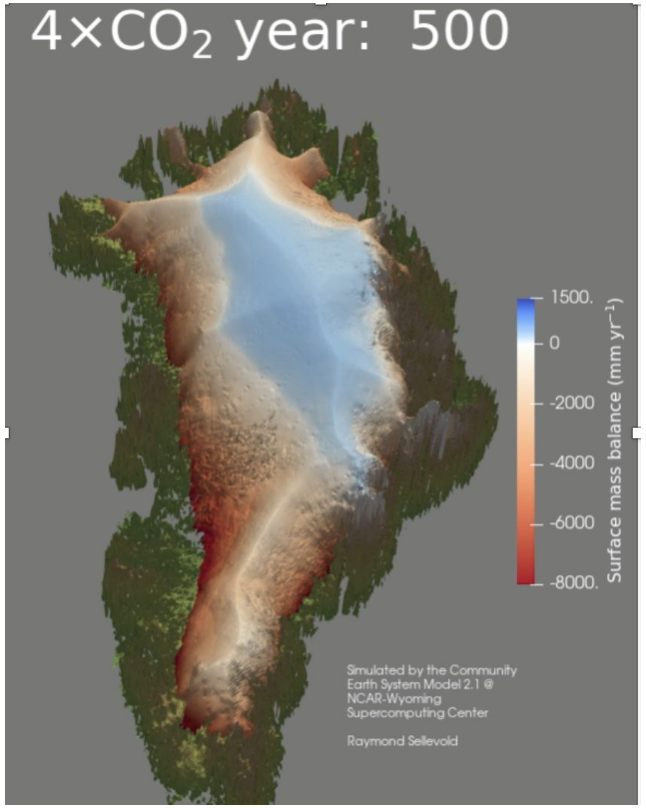


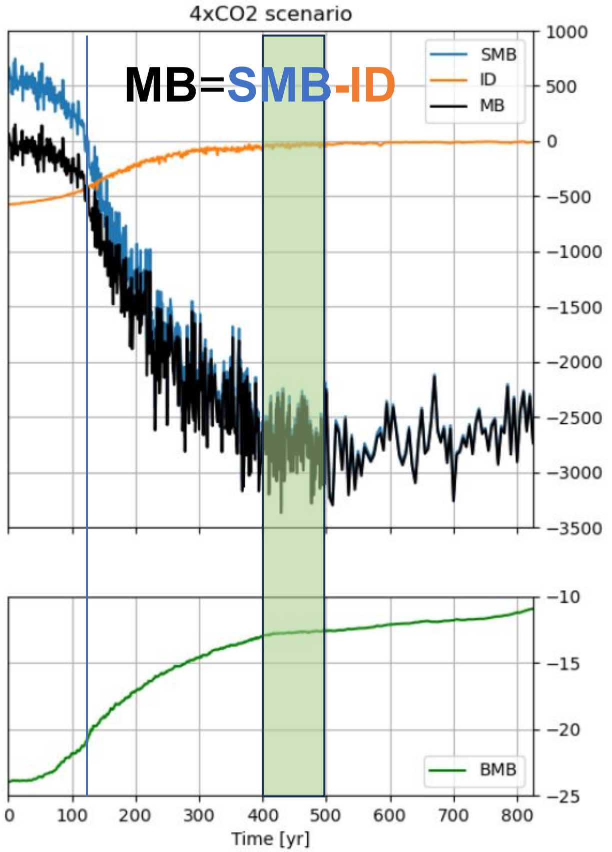


- In this scenario, 4xCO2 is reached at year 140
  - in SSP5-8.5, at year 2100
- **Large increase in mass loss rate & ablation area expansion ~year 120**

Multi-century evolution under 1% 4xCO2

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



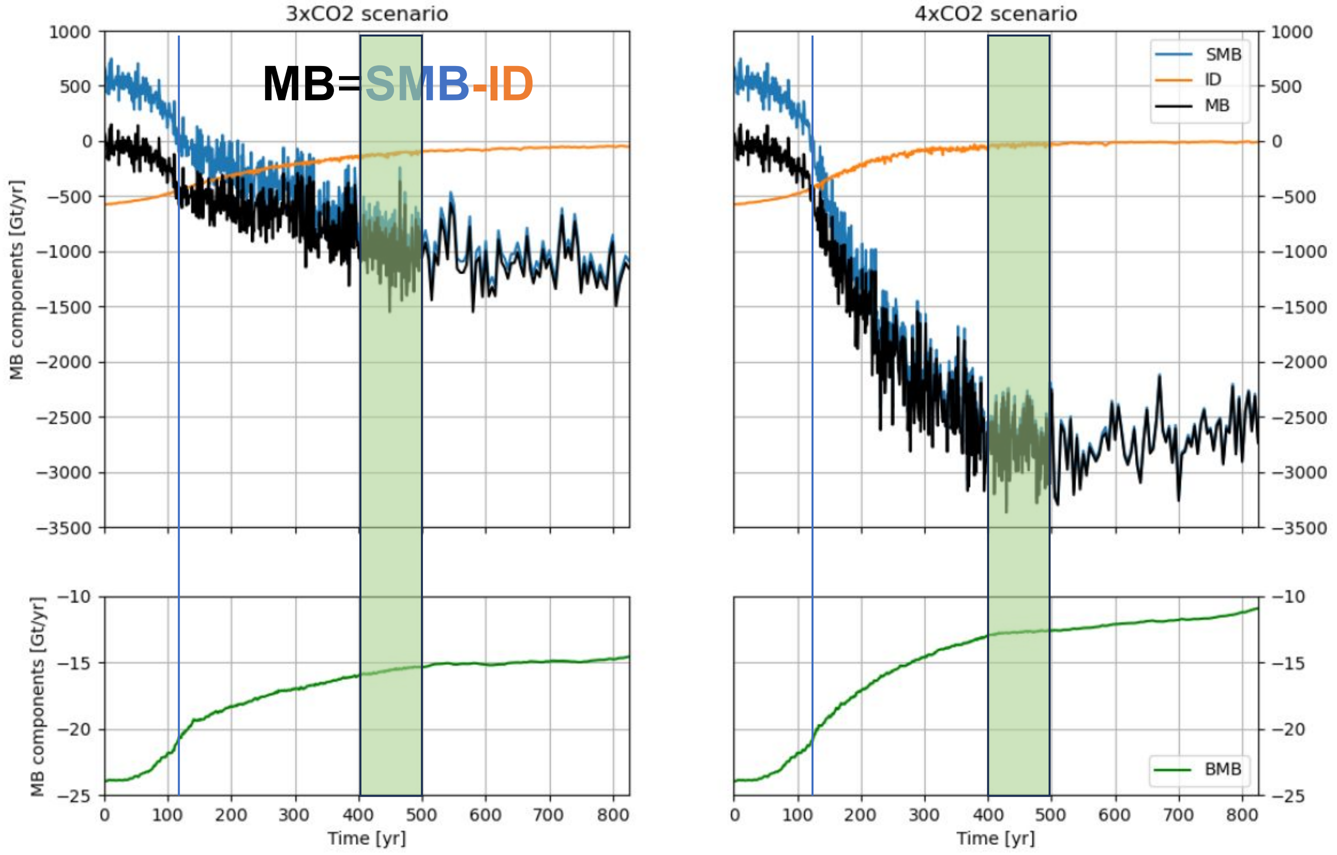


- In this scenario, 4xCO2 is reached at year 140
   - in SSP5-8.5, at year 2100
- **Large increase in mass loss rate & ablation area expansion ~year 120**
- Maximum mass loss rate at year 500 (8 mm SLR yr^{-1})
- GrIS is lost in 1,700 years

What if we cap CO2 before large acceleration?

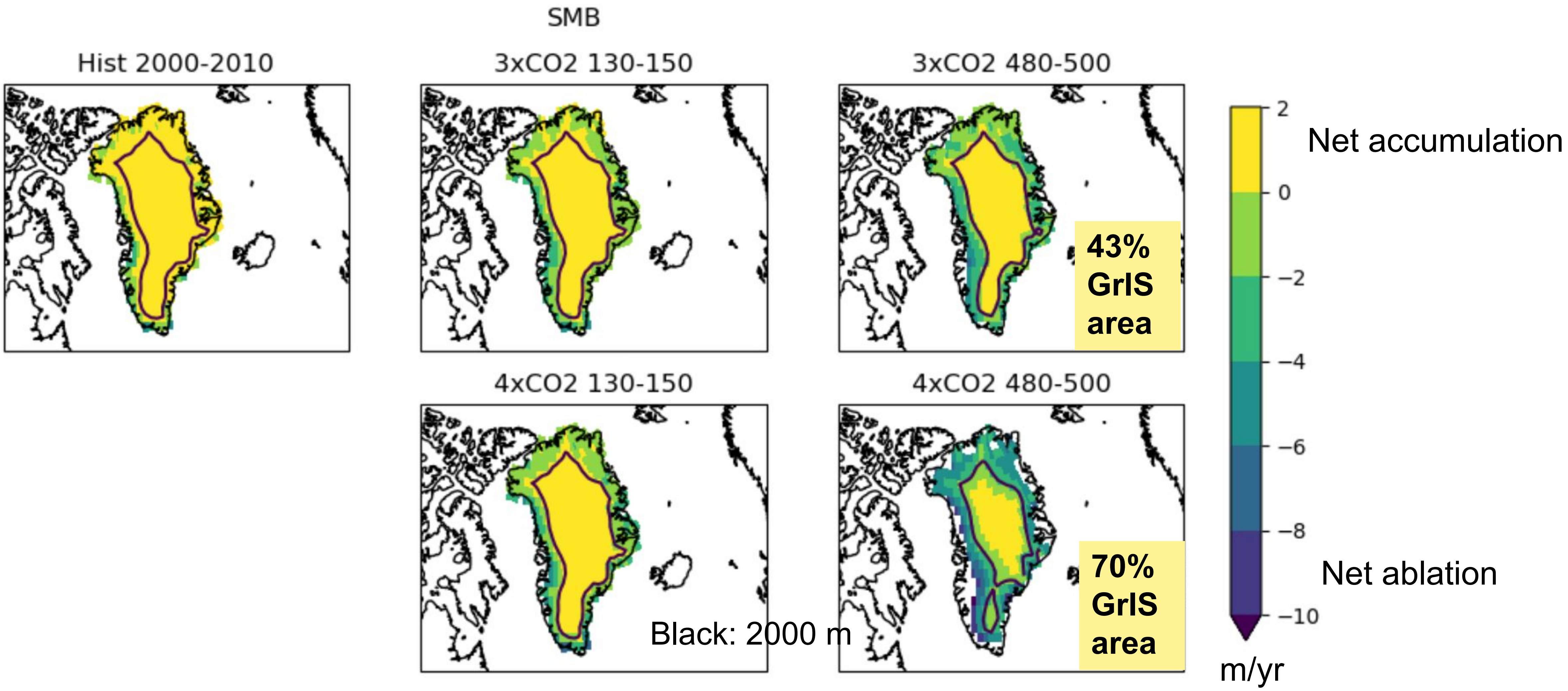
We branch a 3xCO2 simulation at year 111

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

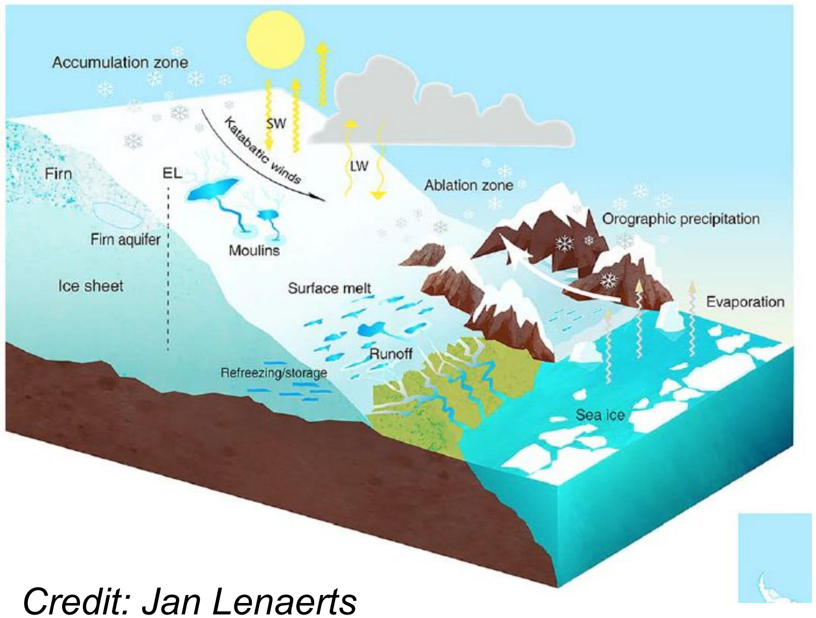
The ablation area expands much faster in 4xCO2



What explains the much reduced deglaciation rate?

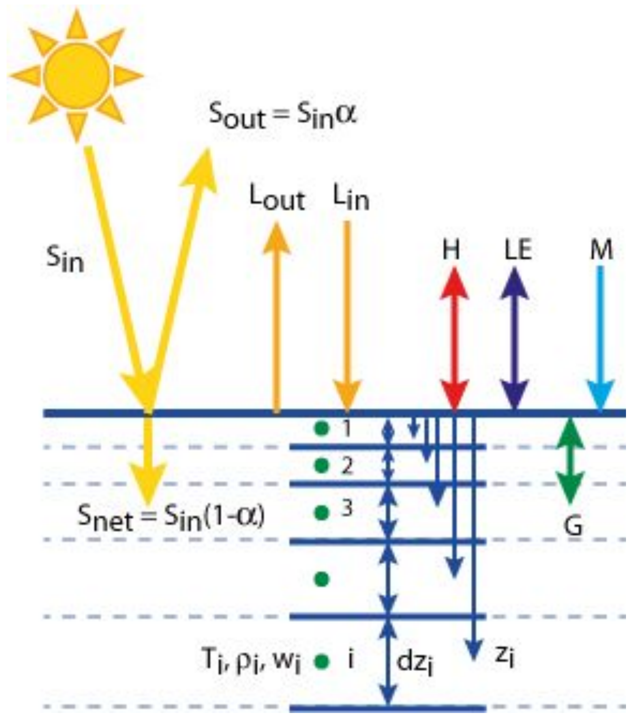
Approach: mass & energy fluxes & AA expansion

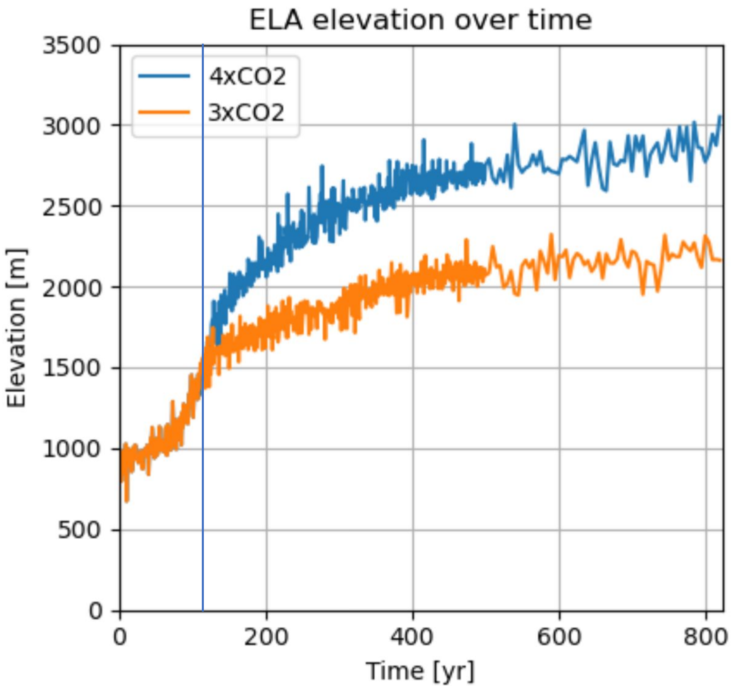
SMB=snowfall-melt+refreezing-sublimation



Credit: Jan Lenaerts

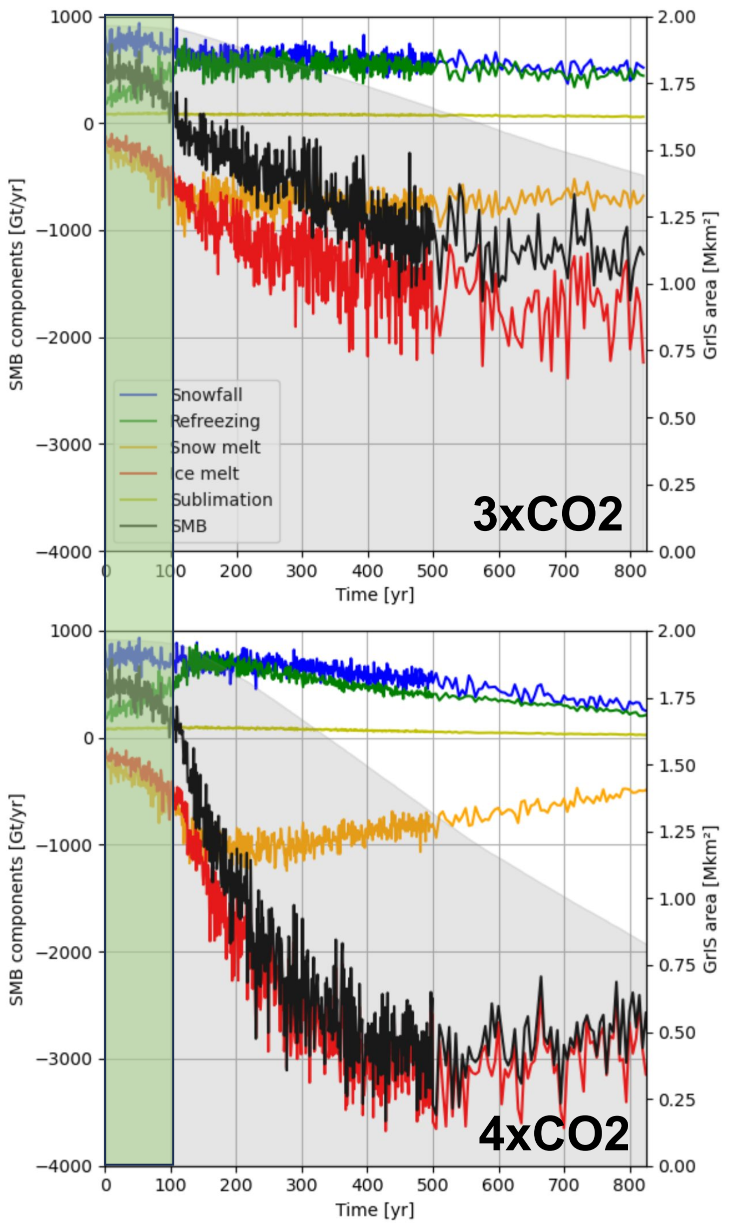
Credit: IMAU, UU

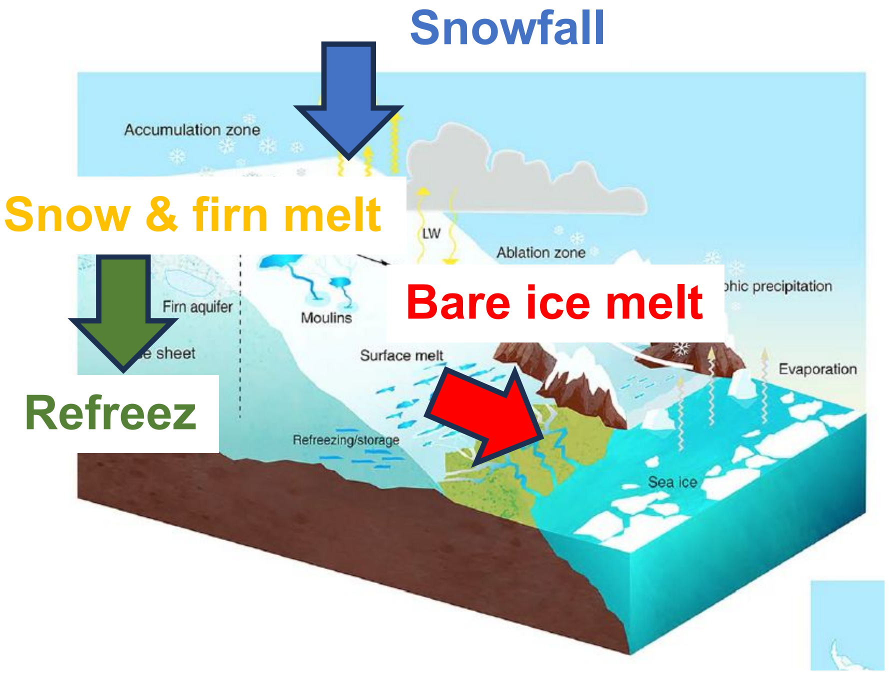




Ablation (z) ?

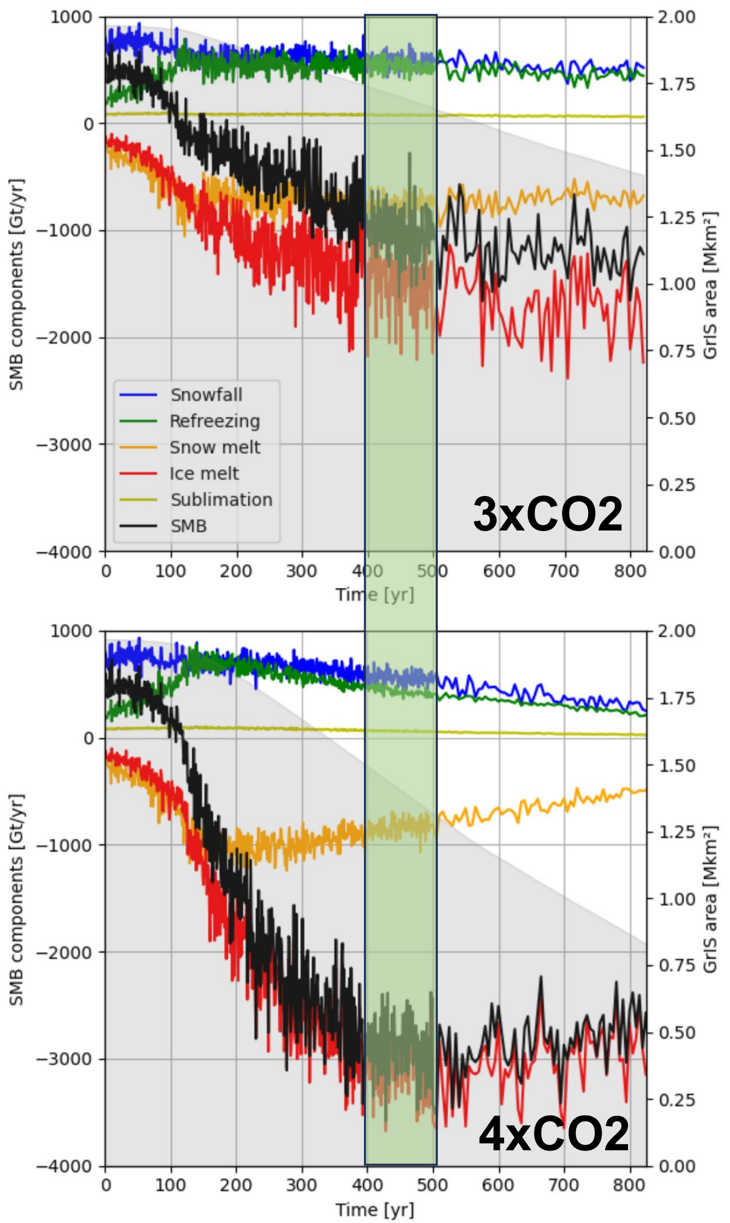
Evolution of SMB components

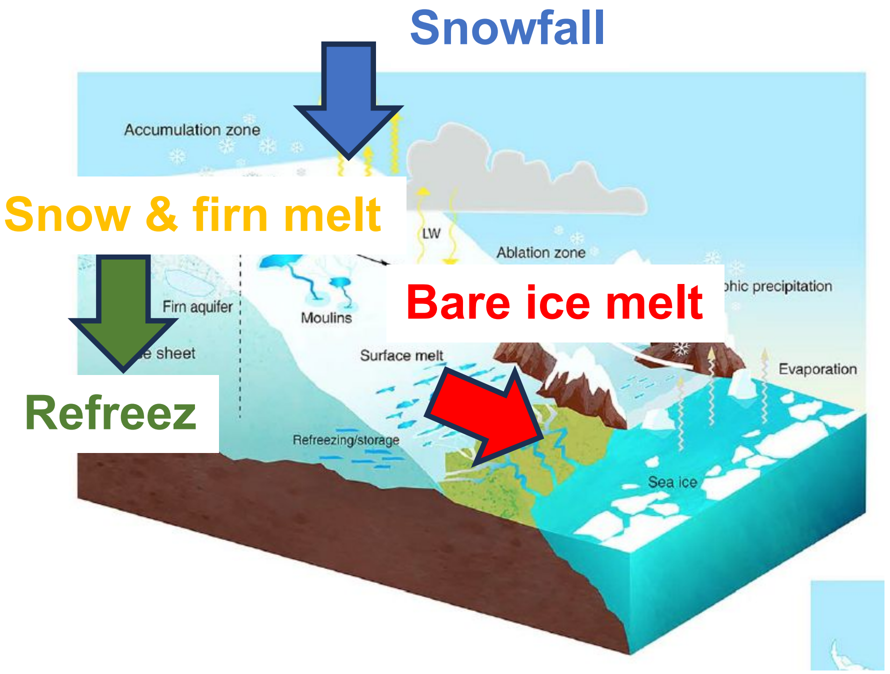




GgGt/yGt/yr	SMB	Snowfall	Snow melt	Ice melt	Refreezing	Sublim.
Both, 0-100	294	748	-405	-299	338	-88
3xCO2, 400-500						
4xCO2, 400-500						
Diff, 400-500						

Evolution of SMB components

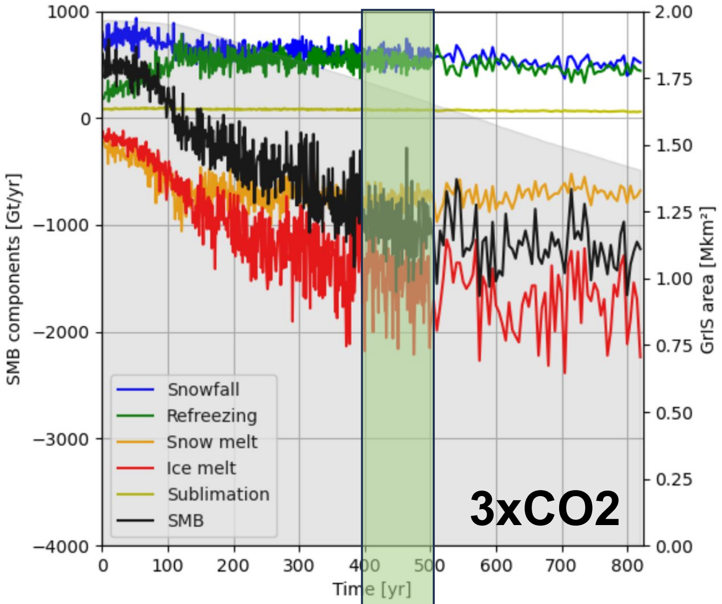


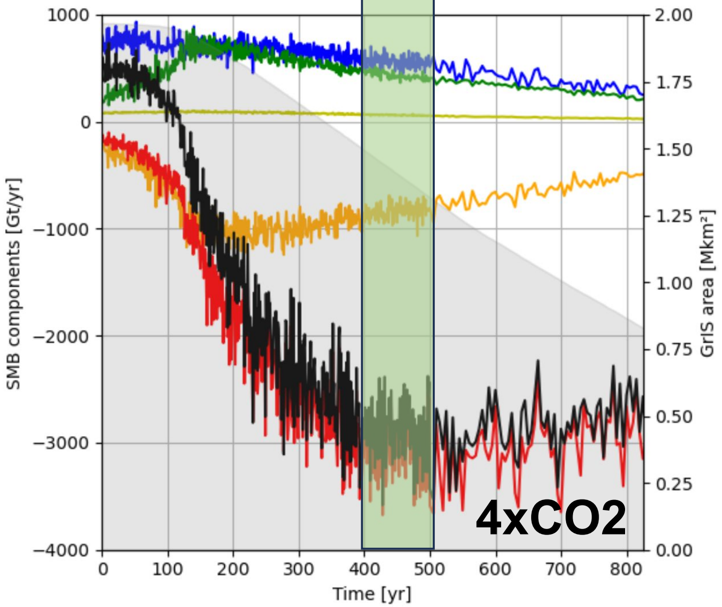


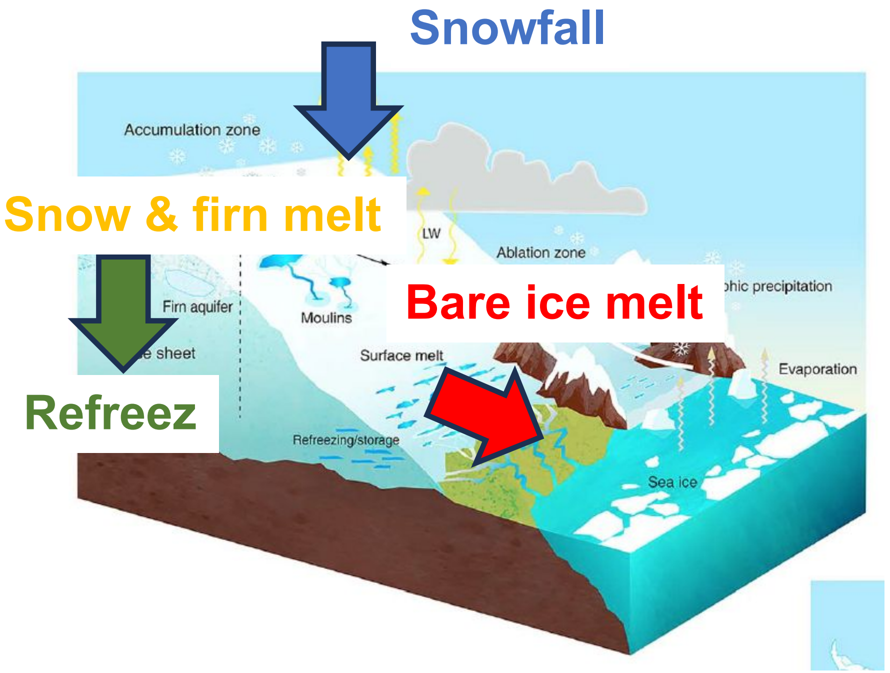
- Snowfall decreases with time
- Refreezing increases first, without exceding snowfall rate
- Relatively similar snow melt evolution

	SMB	Snowfall	Snow melt	Ice melt	Refreezing	Sublim.
Both, 0-100	405	748	-405	**-299**	338	-88
3xCO2, 400-500	-1020	581	-760	**-1523**	530	-75
4xCO2, 400-500	-2877	560	-837	**-3054**	432	-62

Evolution of SMB components



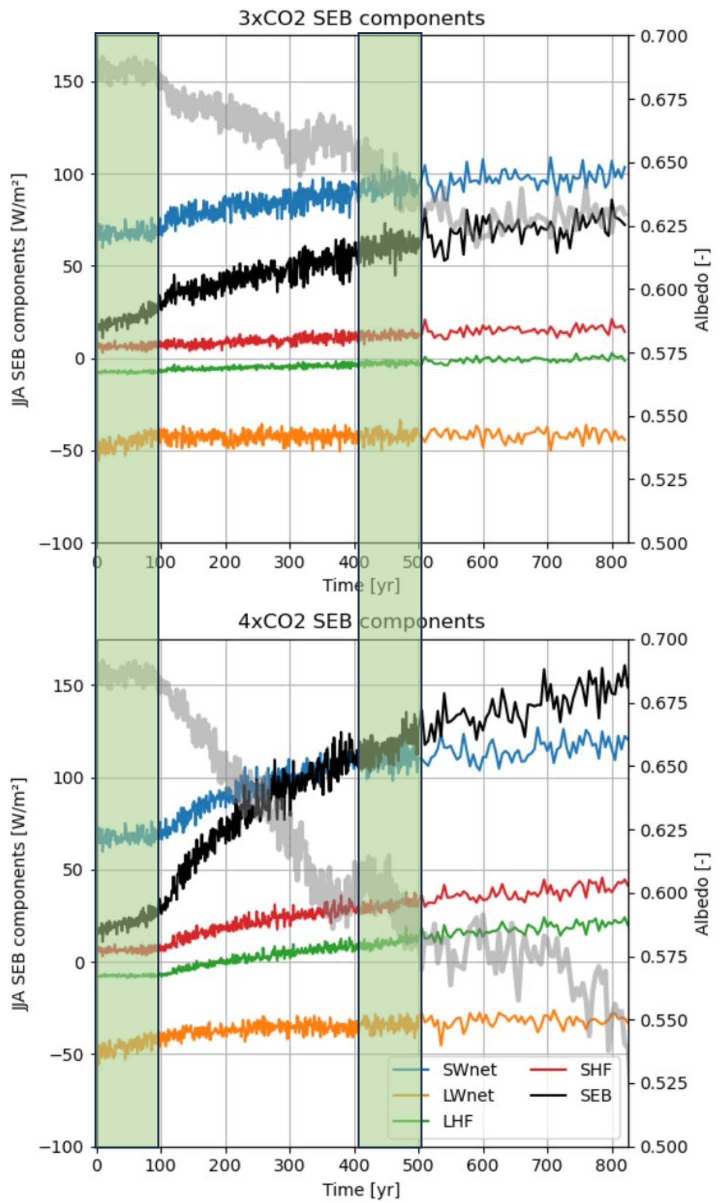




- Largest contributor to large mass loss is **bare ice melt**

	SMB	Snowfall	Snow melt	Ice melt	Refreezing	Sublim.
Both, 0-100	405	748	-405	-299	338	-88
3xCO2, 400-500	-1020	581	-760	-1523	530	-75
4xCO2, 400-500	-2877	560	-837	-3054	432	-62
Diff, 400-500	-1857	-21	-77	-1531	-102	-13

Evolution of melt energy contributors

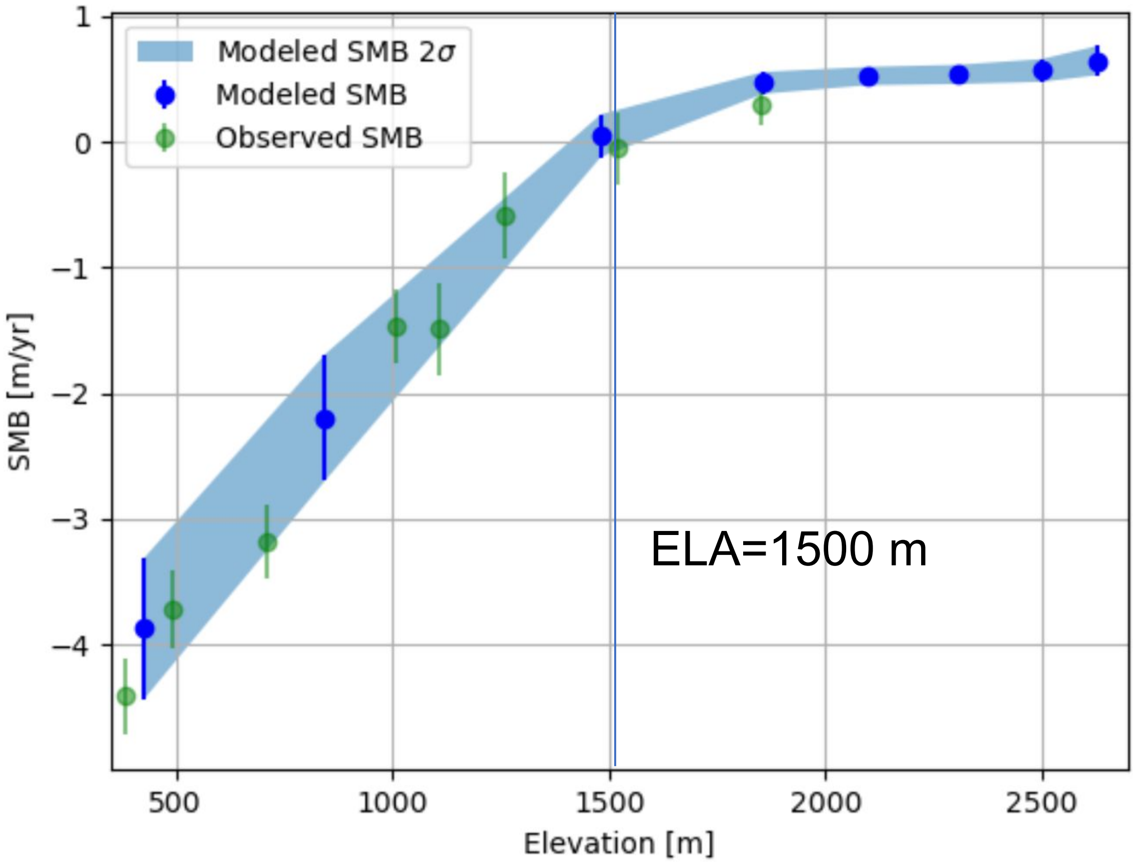


W/m^2	Melt	SWnet	LWnet	sensible	latent
Both, 0-100	22	68	-45	6	-7
3xCO2, 400-500	60	93	-42	12	-3
4xCO2, 400-500	116	109	-34	30	10
Diff, 400-500	**56**	16	8	**18**	13

- All fluxes increase in both simulations, with non-linear increases in solar, sensible and latent
- Largest contributor to additional melt energy in 4xCO2 is **sensible heat flux**
- Followed by **net solar** (albedo feedback on melt)

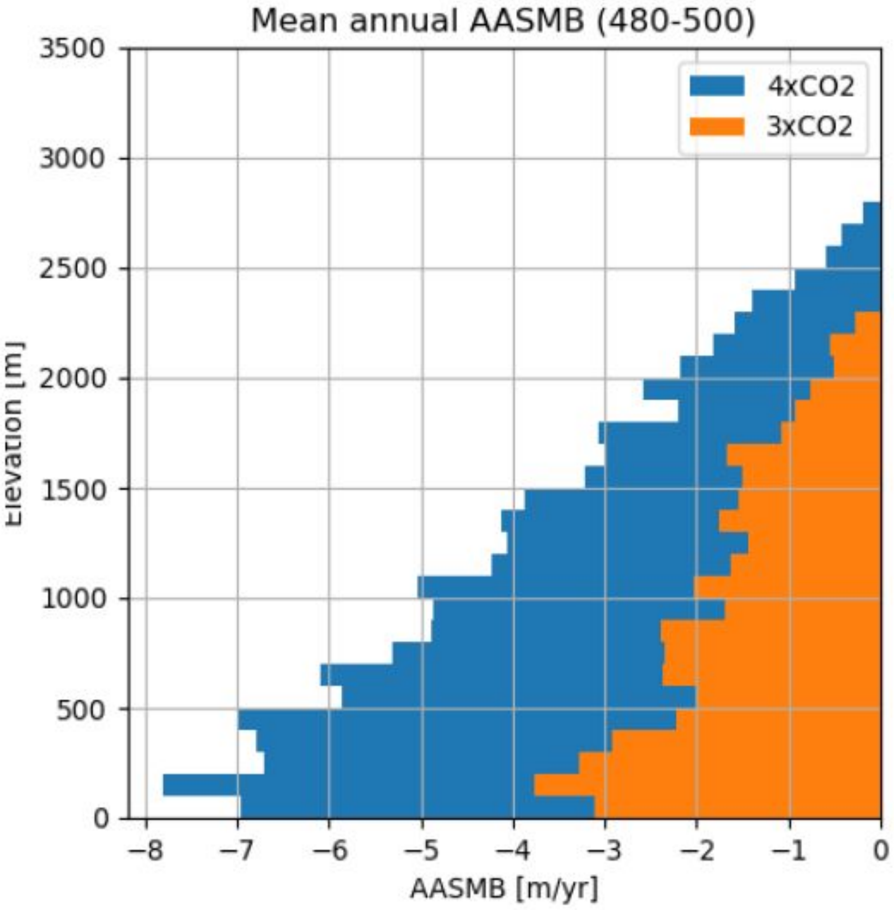
Let's examine ablation = f(z)

Comparison of historical CESM2-CISM2 ablation gradient with IMAU measurements along K-transect (2001-2013)



- CESM2-CISM2 reproduces observed SMB gradient over ablation area

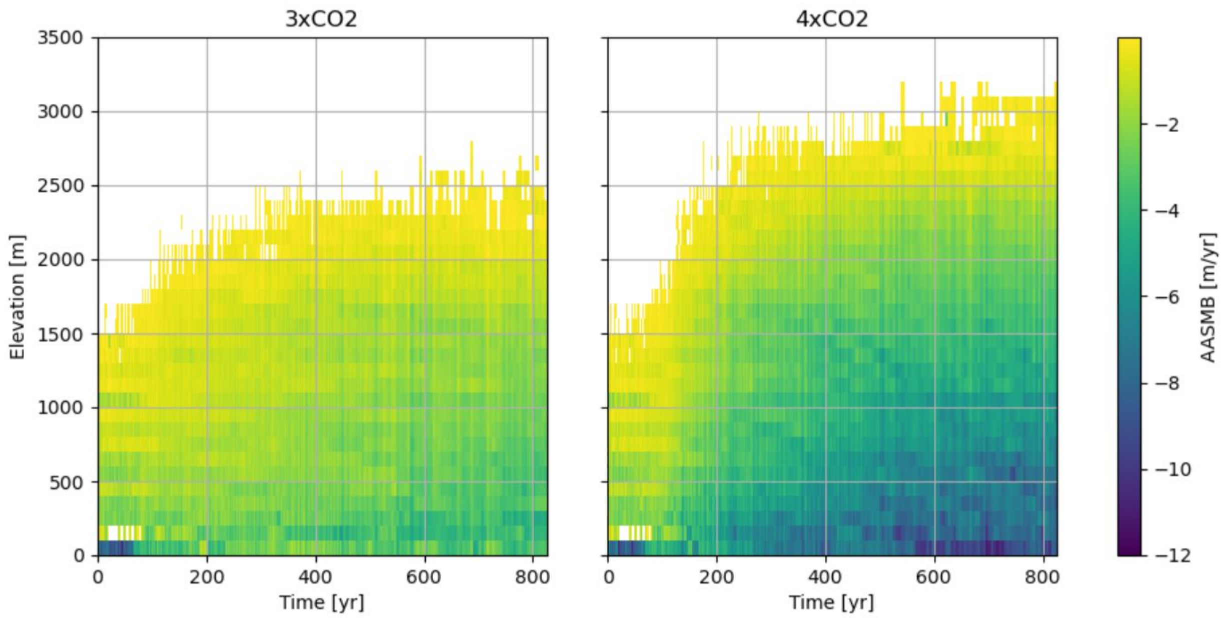
Mass loss per elevation 480-500, whole ice sheet

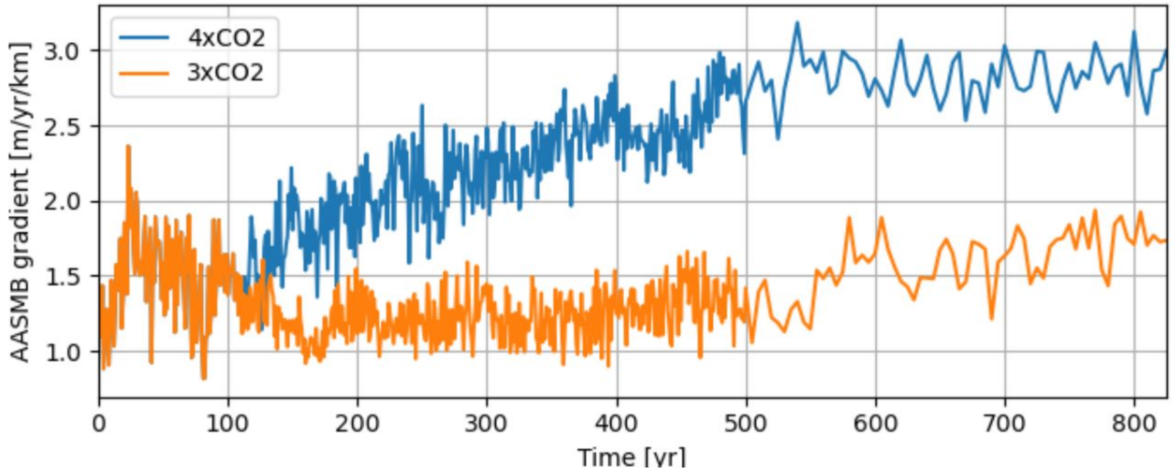


AASMB= ablation area SMB

- Linear relationship between ablation rate and elevation
- Larger gradient in 4xCO_2
    - Melt is much larger in all elevations in 4xCO_2 (larger ablation-elevation gradient), ***particularly at low elevations***

Time evolution of ablation gradient



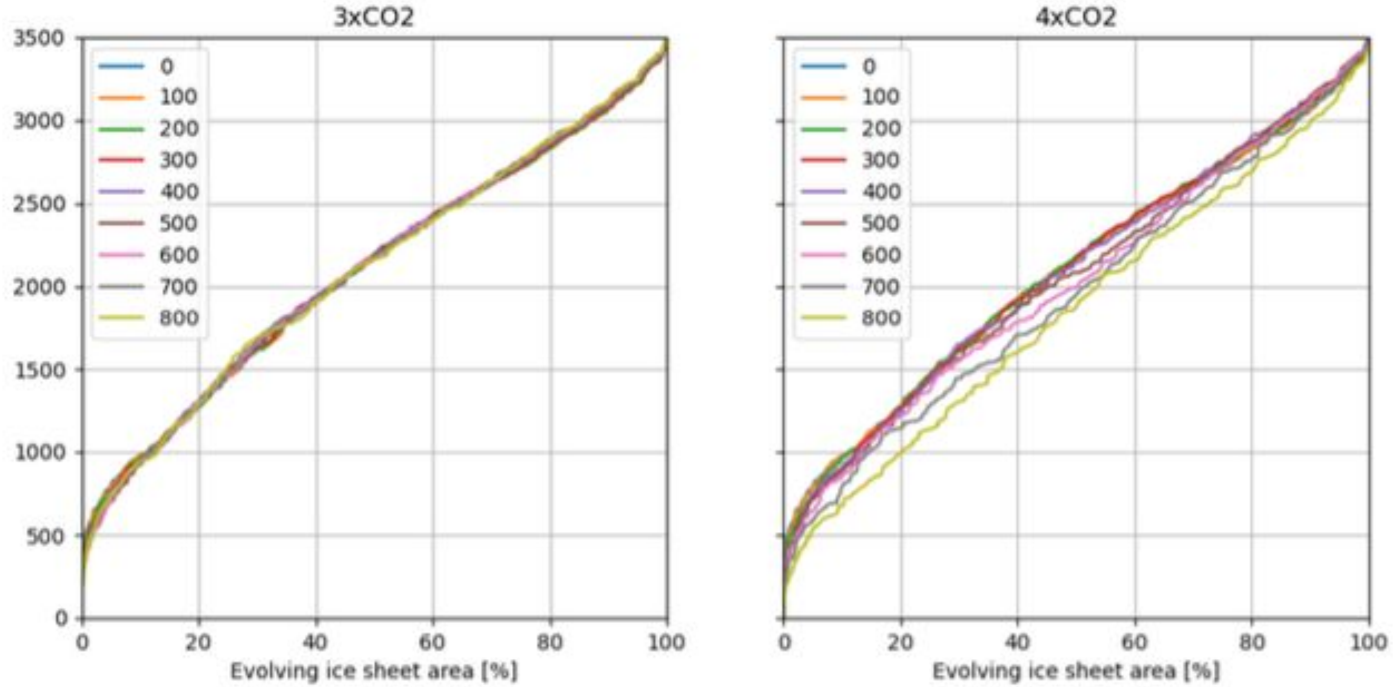


- In 4xCO2, ablation gradient **increases from year 120**
- In 4xCO2, it is close to 3 m yr^{-1} km^{-1} by year 500
- We need to weight these ablation rates with **area per elevation**

Cumulative GrIS area distribution per elevation

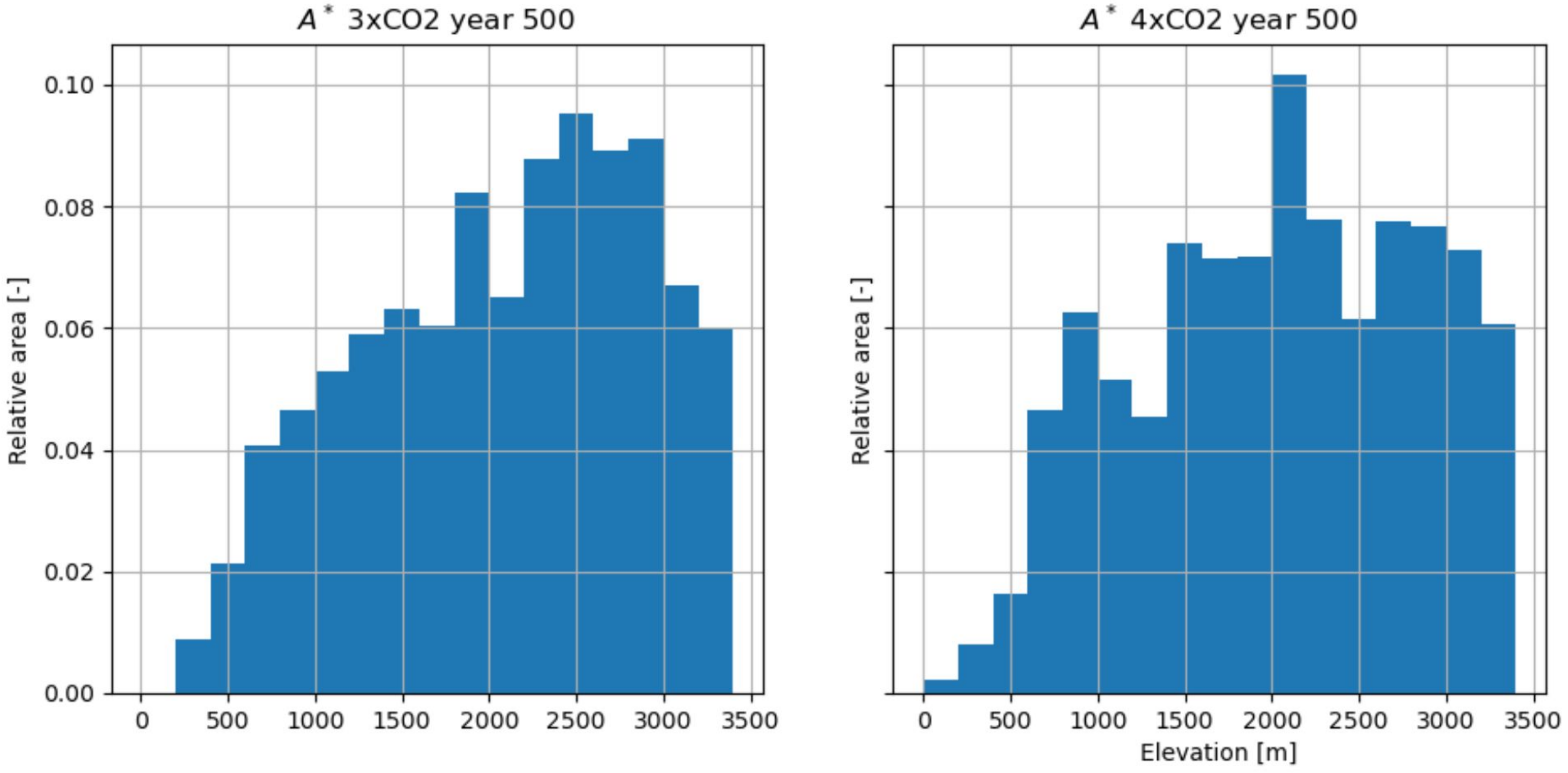
Greenland ice sheet hypsometry

Elevation (m)



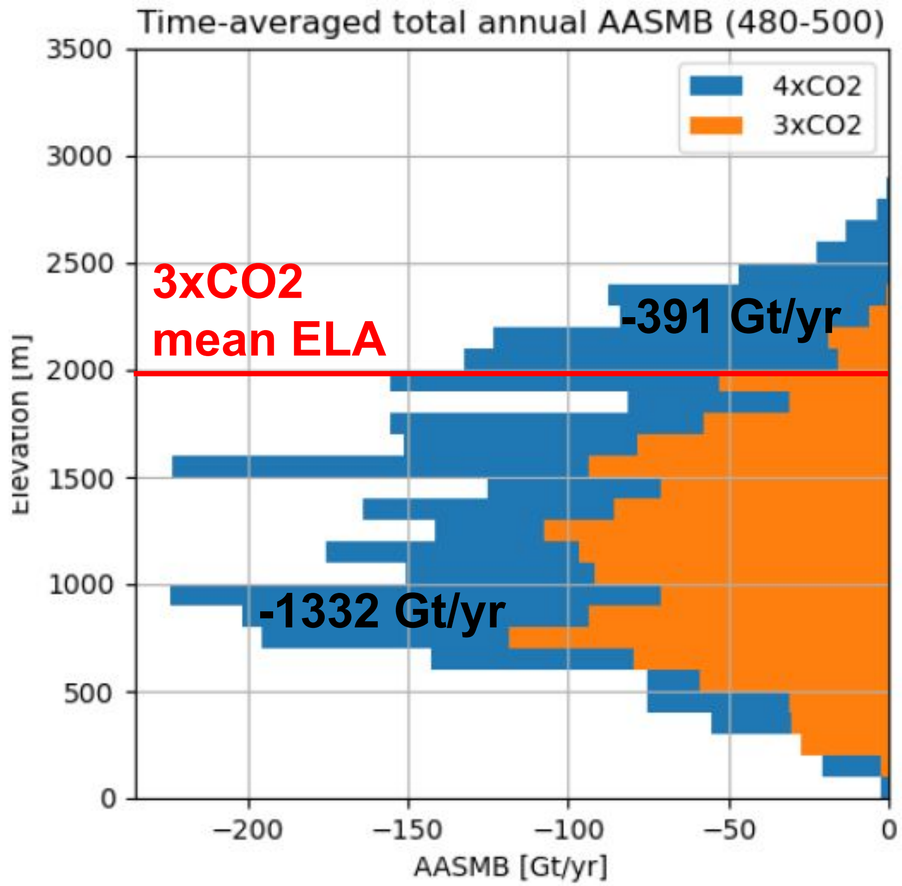
- For the whole 3xCO2, and 4xCO2 until 500, the **elevation-area distribution remains constant**
- Quasi-parabolic profile of an ice sheet: less area at low elevations

Area distribution per elevation



- Larger areal weight of elevations above 1500 m
- By year 500, ELA is above 1500 m in both simulations

Mass loss per elevation 480-500 [Gt/yr]

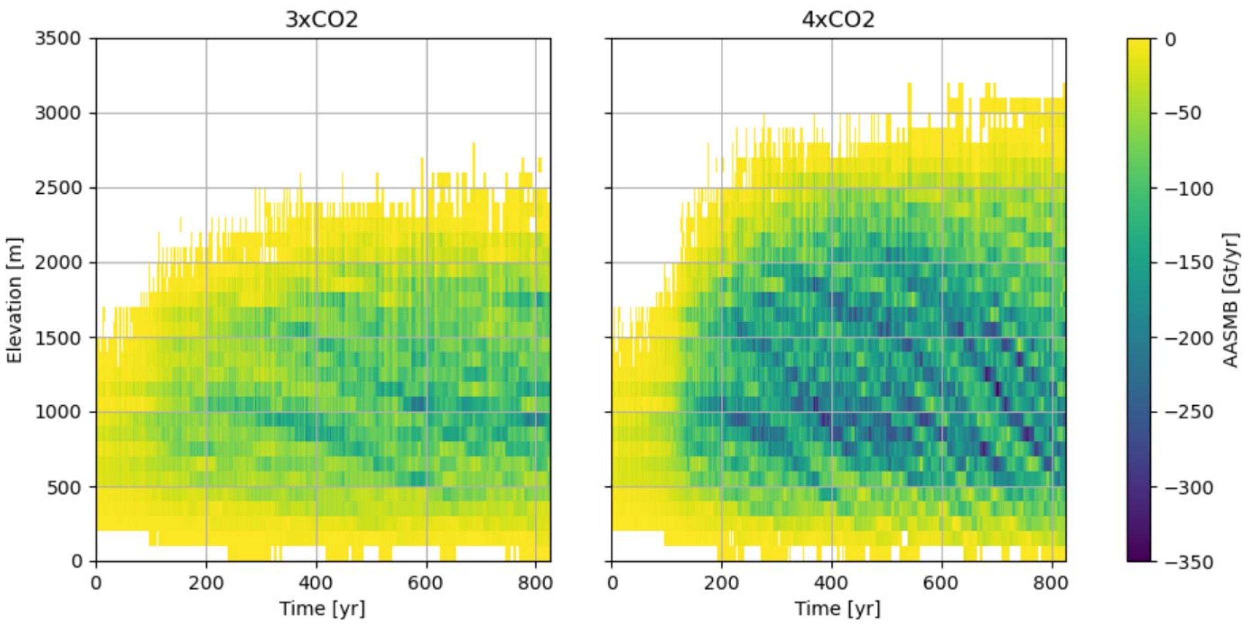


- Largest increases around 1000 m and 1500 m
   - Areas below 700 m do not contribute much to mass loss due to relative low area weight
   - Areas above 2000 m do not contribute much due to low melt rates
- **23%** of additional mass loss in $4xCO_2$ from elevations above the $3xCO_2$ ELA_{GrIS}

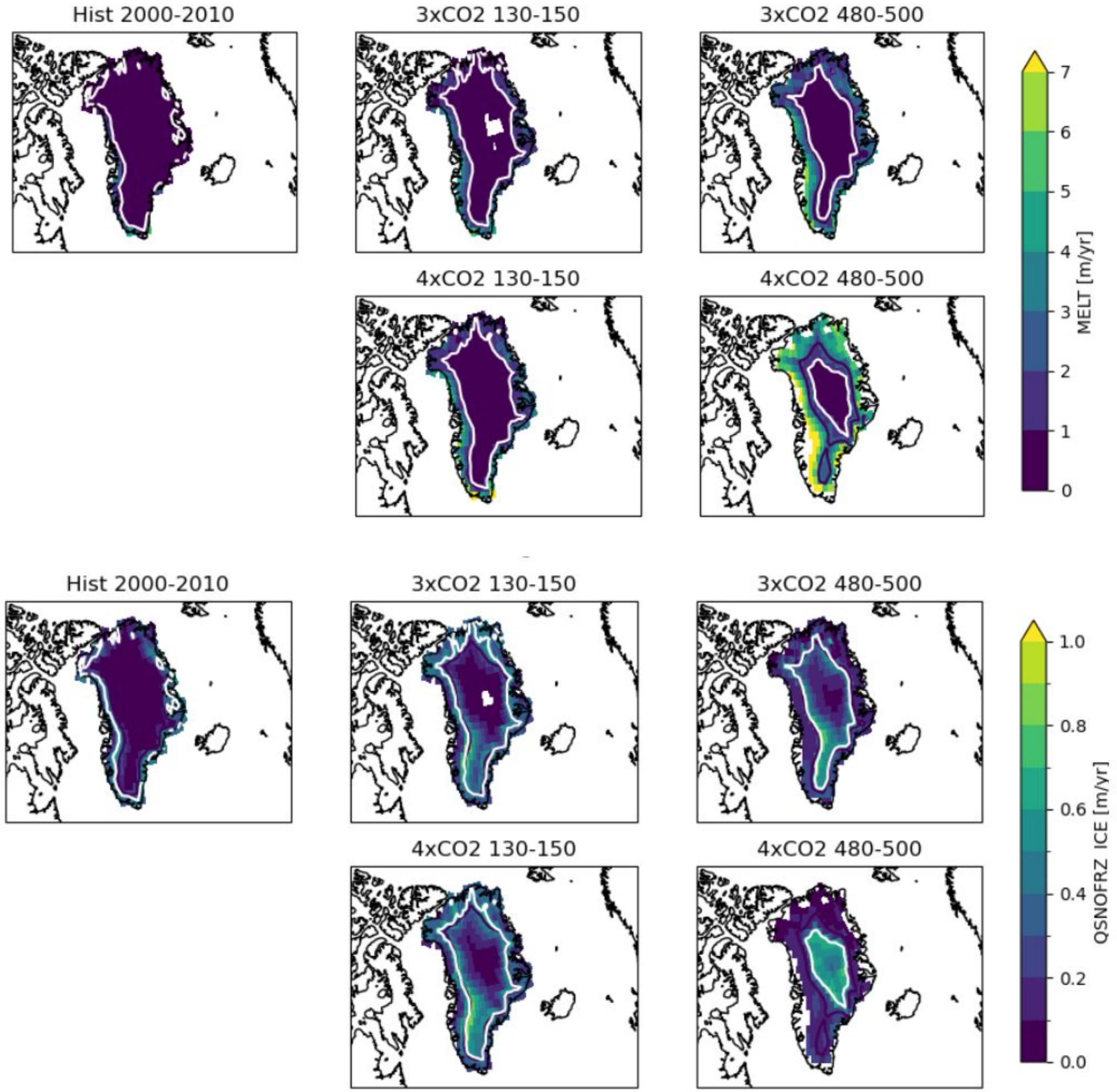
Conclusions

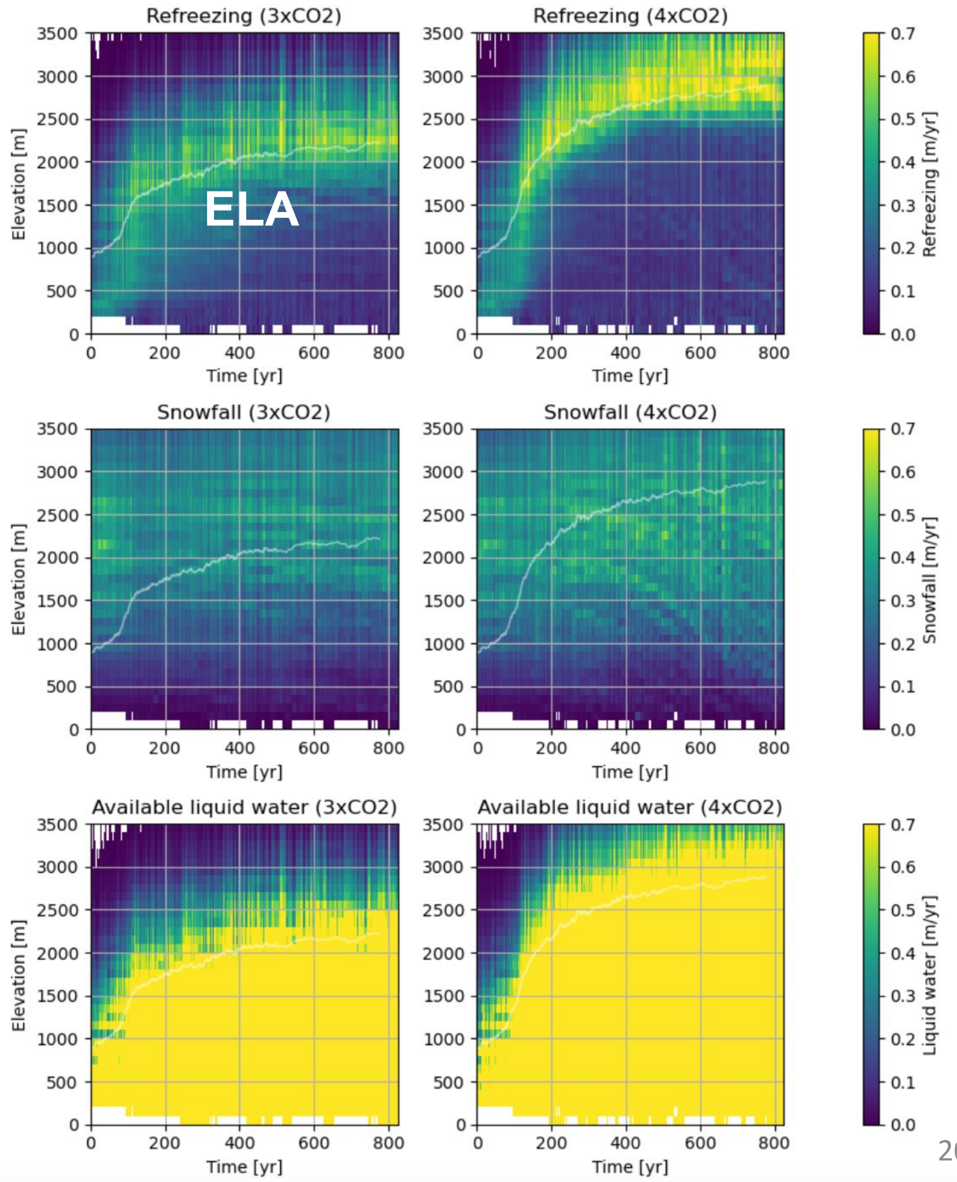
- ***ONE: Actionable science*: mass loss acceleration is avoided by capping at 3xCO2** (versus 4xCO_2): emission reduction is highly effective to avoid worst impacts
- ***TWO:*** Expansion of ablation area at higher elevations has a relatively minor effect on total mass loss
- **Largest contribution from enhanced ablation at ”baseline” ablation area**
- ***THREE:*** Developed framework to relate ice sheet mass loss and elevation

Evolution of mass loss per elevation bin [Gt/yr]



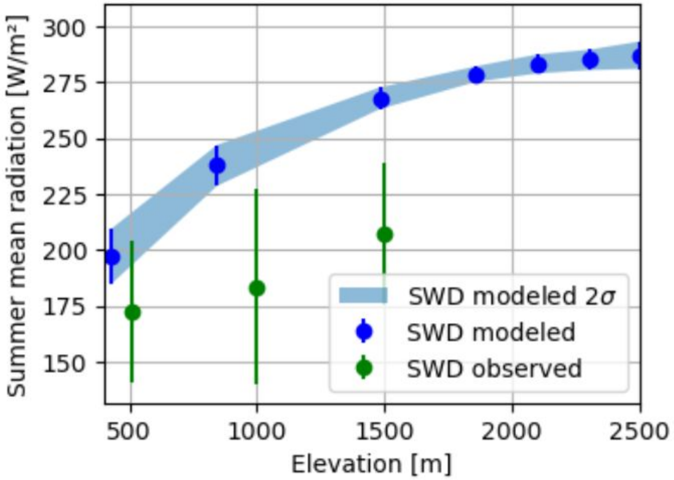
Application of framework to refreezing



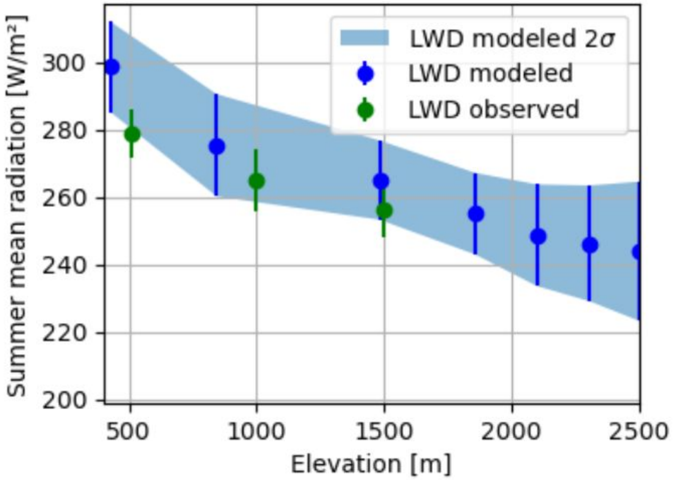


Additional slides

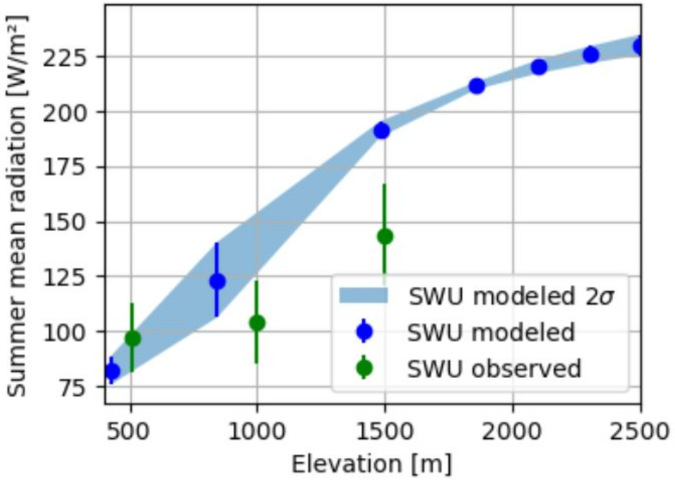
Evaluation of radiation fluxes along K-transect



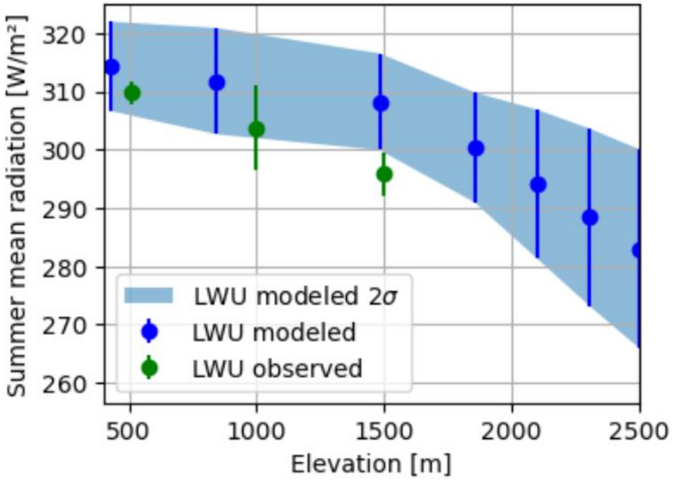
(a) Downward SWR flux



(b) Downward LW flux

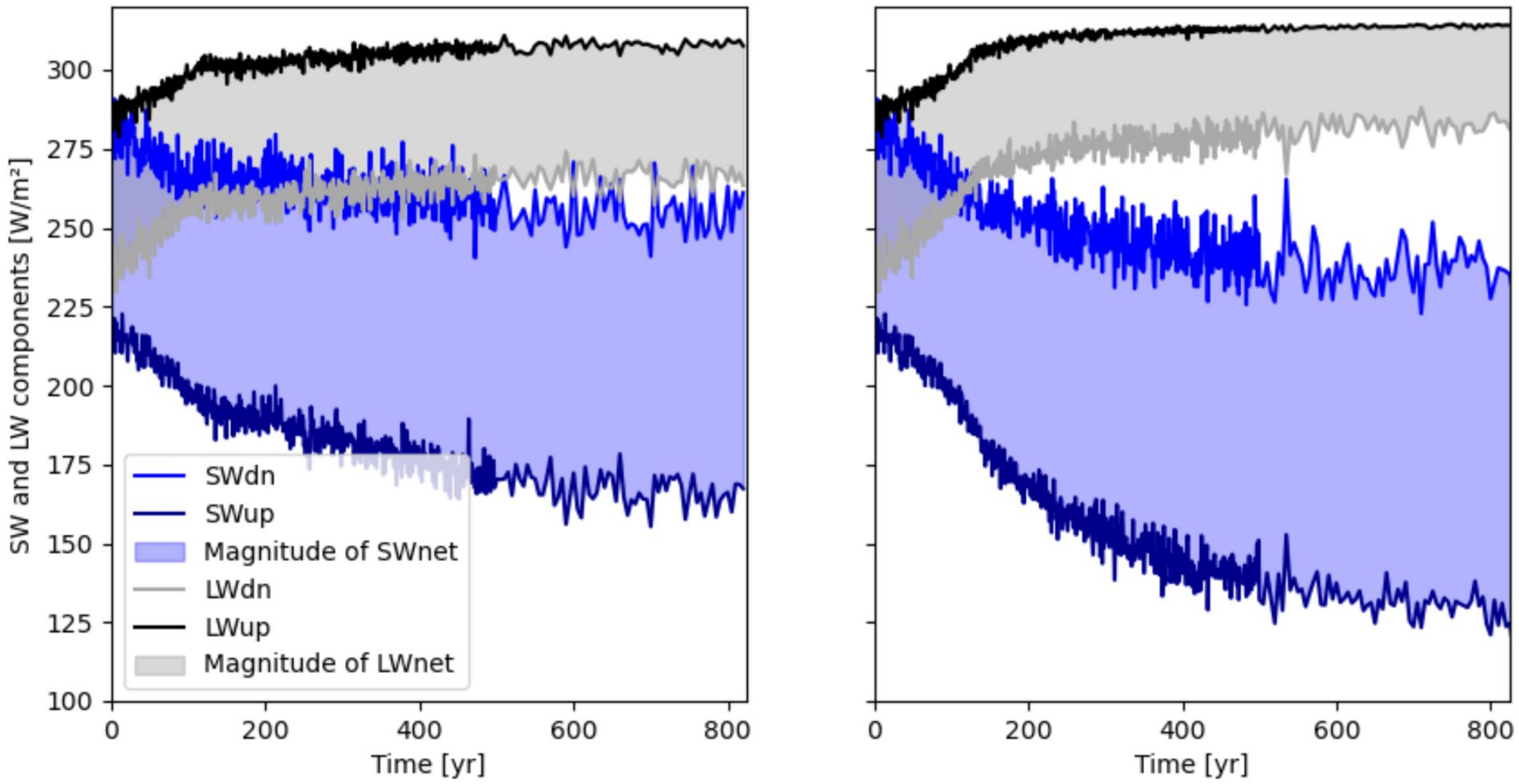


(c) Upward SWR flux



(d) Upward LW flux

Comparison of radiation fluxes



Albedo feedback on melt: maps of net SW