Overestimation of elevation-melt feedback in uncoupled projections of ice sheet mass loss

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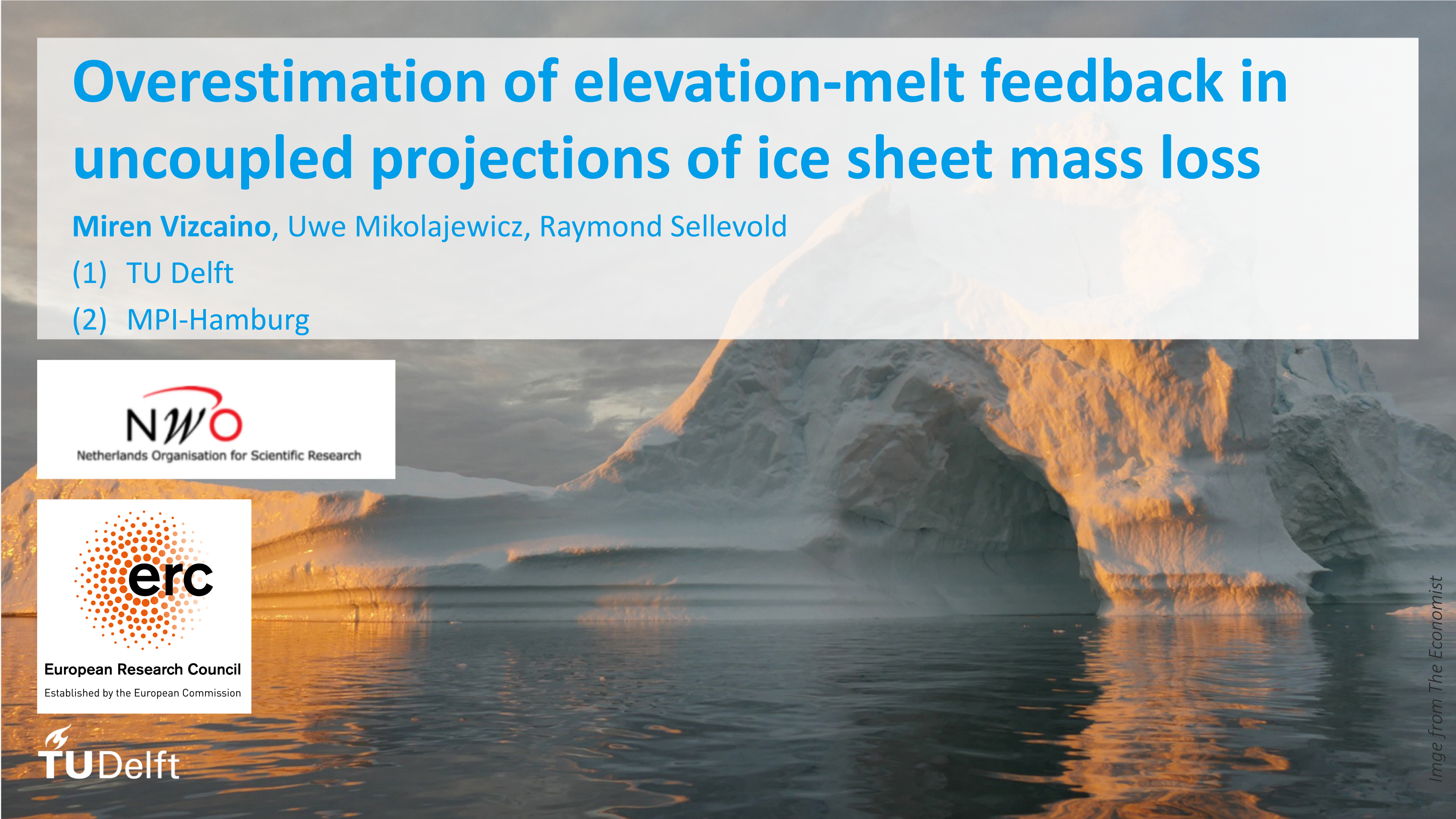
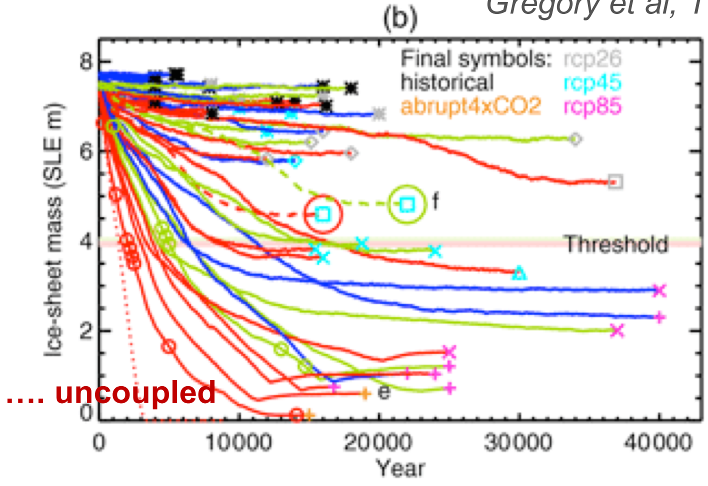
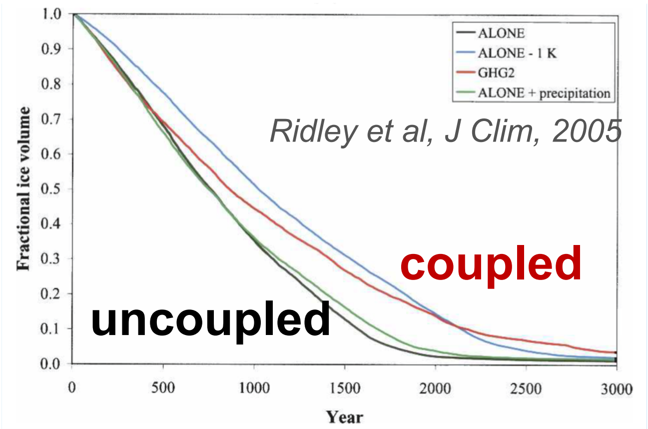


the elevation feedback on melt

- A key + feedback at multi-century scales: as surface lowers, temperatures increases, melt increases and surface lowers further
- Parameterized through the so-called "**lapse rate**" in ice-sheet-only simulations. Typically -6 K per km.
- Greenland **deglaciates faster in uncoupled ice sheet-climate simulations** compared to corresponding coupled simulations

Gregory et al, TC, 2020





Ridley et al, J Clim, 2005

- Is **-6 K km^{-1}** an **adequate** lapse rate?
- **Why** do **uncoupled simulations overestimate** deglaciation rates?

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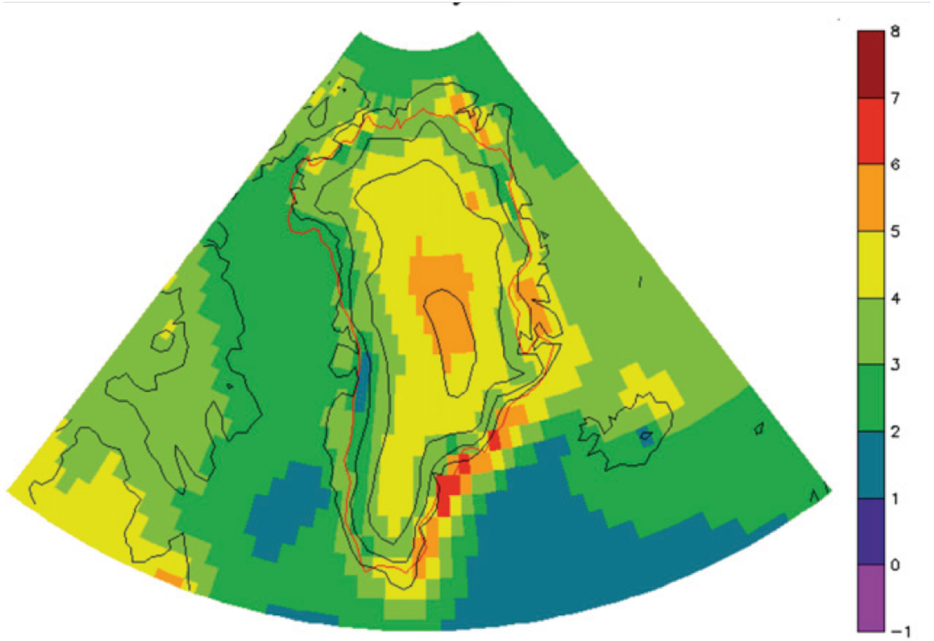
    - *Gregory et al. TC, 2020* proposed this is due to negative feedbacks (shortwave & precipitation)

Background Question Method Results Conclusions

- Is **-6 K km^{-1}** an **adequate** lapse rate?
- **Why** do **uncoupled simulations overestimate** deglaciation rates?
  - *Gregory et al. TC, 2020* proposed this is due to negative feedbacks (shortwave & precipitation)
  - Here, I hypothesize **it relates to overestimation of the lapse rate**

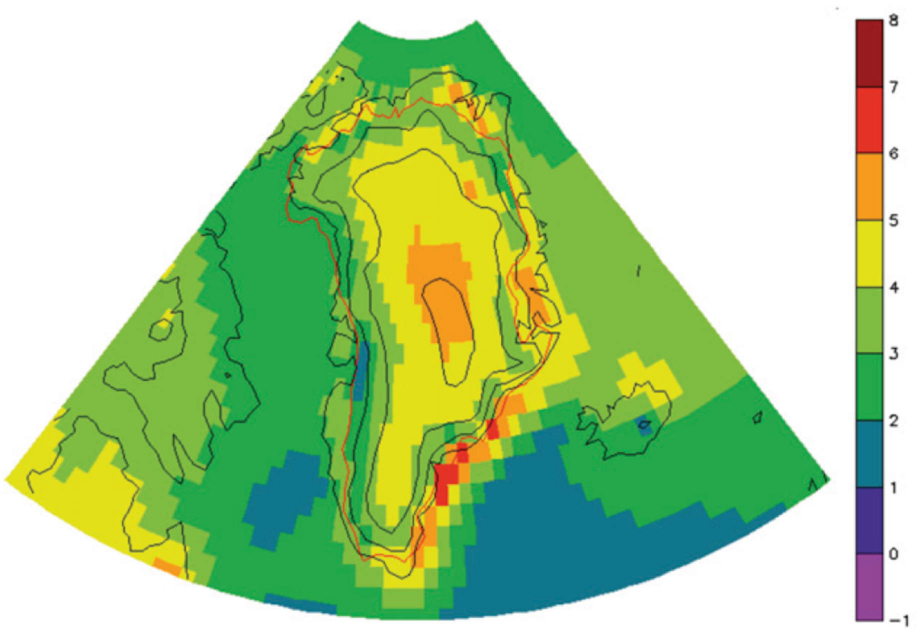
Hypothesis motivation



Change in summer T-2m by 2080-2100 under SSP8.5 (CESM1)

- End-of-century climate projections indicate **lower summer temperature increases over ablation areas than over GrIS interior**

Hypothesis motivation



Change in summer T-2m by 2080-2100 under SSP8.5 (CESM1)

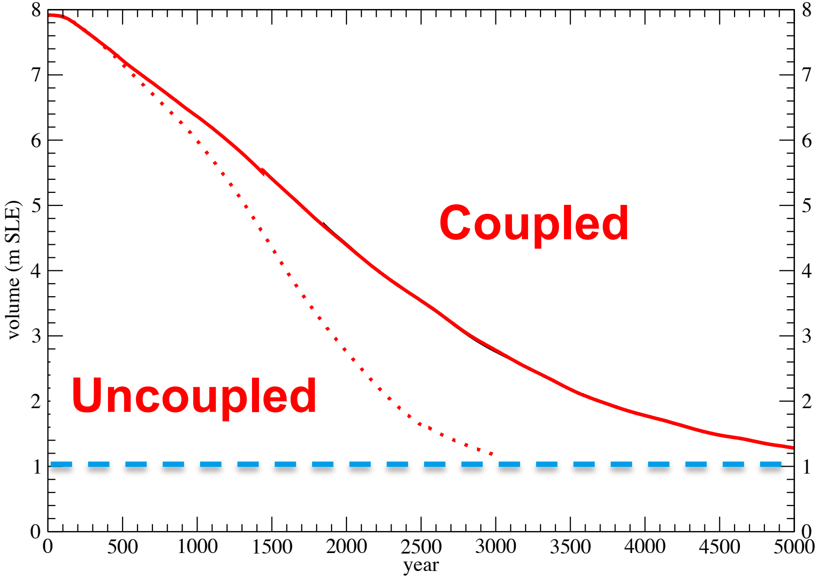
- End-of-century climate projections indicate **lower summer temperature increases over ablation areas than over GrIS interior**

- **<u>Are elevation-related temperature increases also reduced when the GrIS surface reaches melt point?</u>**

Comparison of two coupled & uncoupled ice sheet-climate simulations under 4xCO2 forcing

- Model 1: ECHAM5/MPIOM/LPJ/SICOPOLIS (T31/10 km)
- Model 2: CESM2-CISM2 (1 deg/4 km)

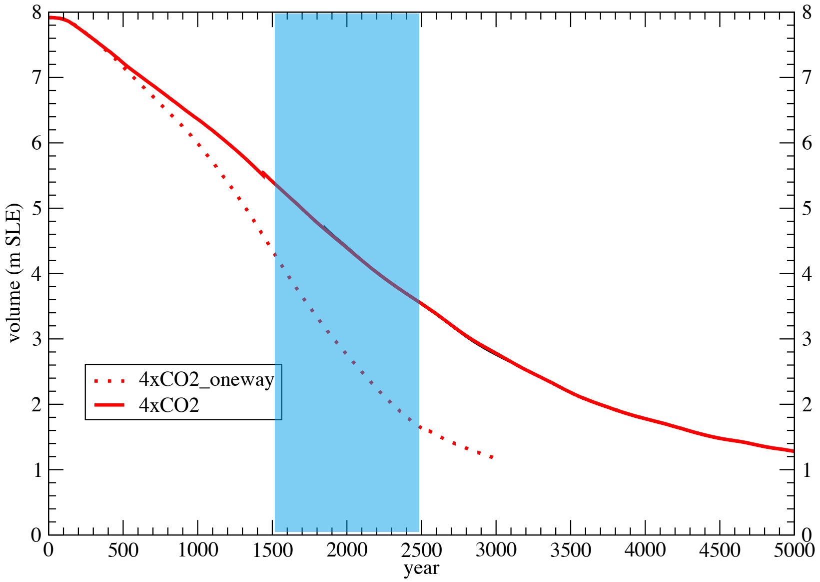
4xCO2 MPI-SICOPOLIS



Greenland ice sheet loses 85% volume after 5,000 years

Faster deglaciation in uncoupled simulation

4xCO2 MPI-SICOPOLIS

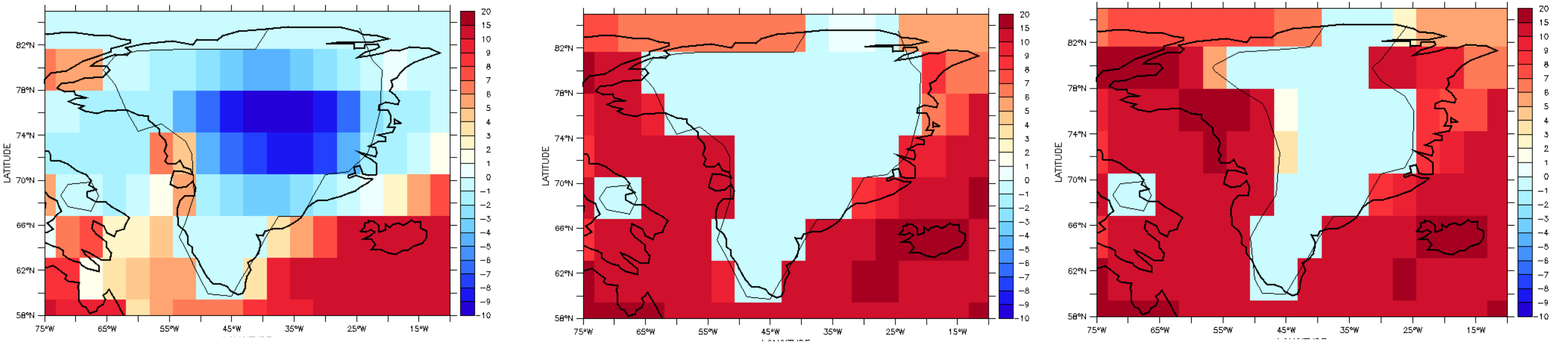


Let's look at years 1,500-2,500 (half-size)

Surface temperature, July

absolute [deg C]

preindustrial **uncoupled $4xCO_2$** **coupled $4xCO_2$**

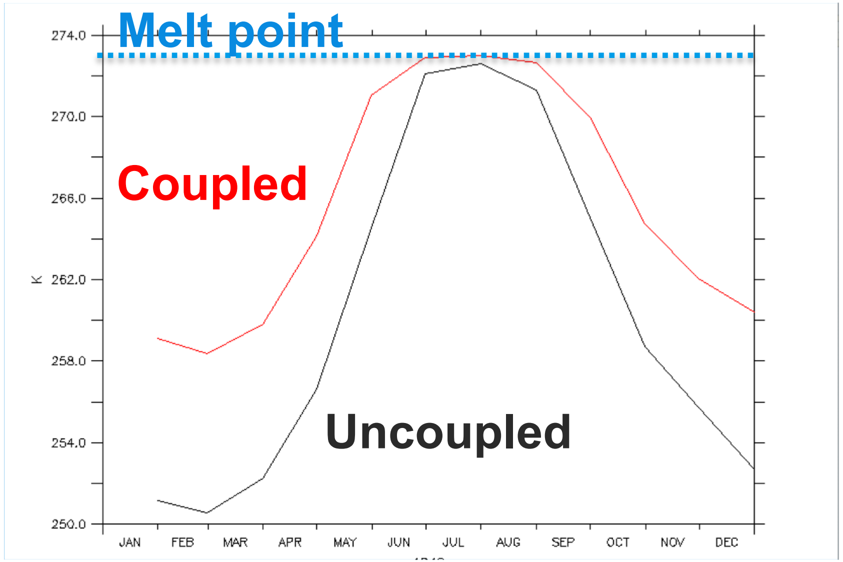


contour: 50% ice sheet cover

Seasonal variation at the Summit

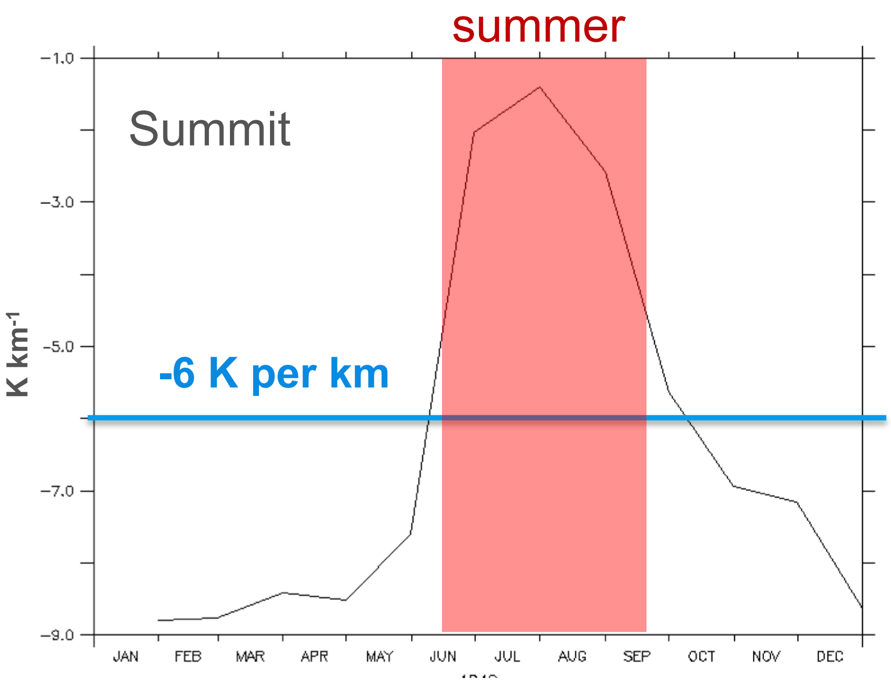
(37 W, 72 N)

Surface temperature



- Elevation change is 850 m
- Surface temperatures largely differ in winter, but I in summer are **close to melt point <u>in both simulations</u>**

$$lapse\ rate = \frac{T2m(coupled) - T2m(uncoupled)}{z(coupled) - z(uncoupled)}$$



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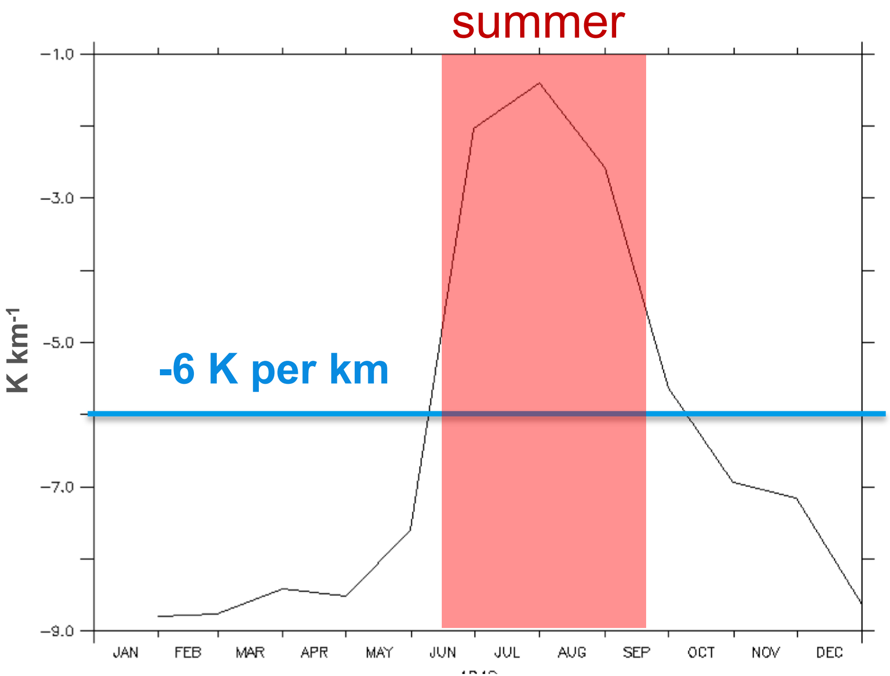
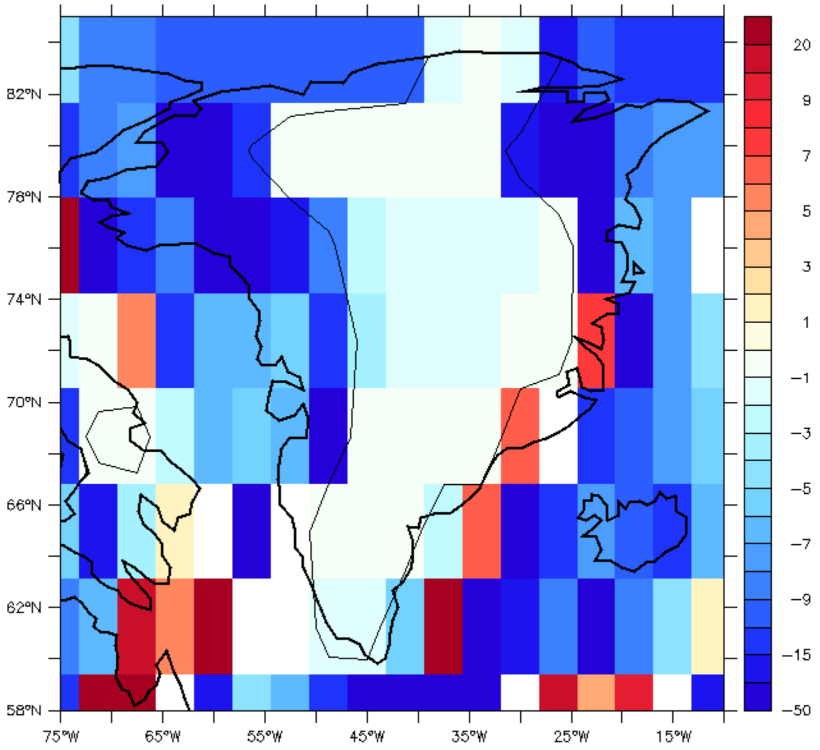


Yes, the magnitude of the lapse rate is <u>much lower in summer than winter !!</u>

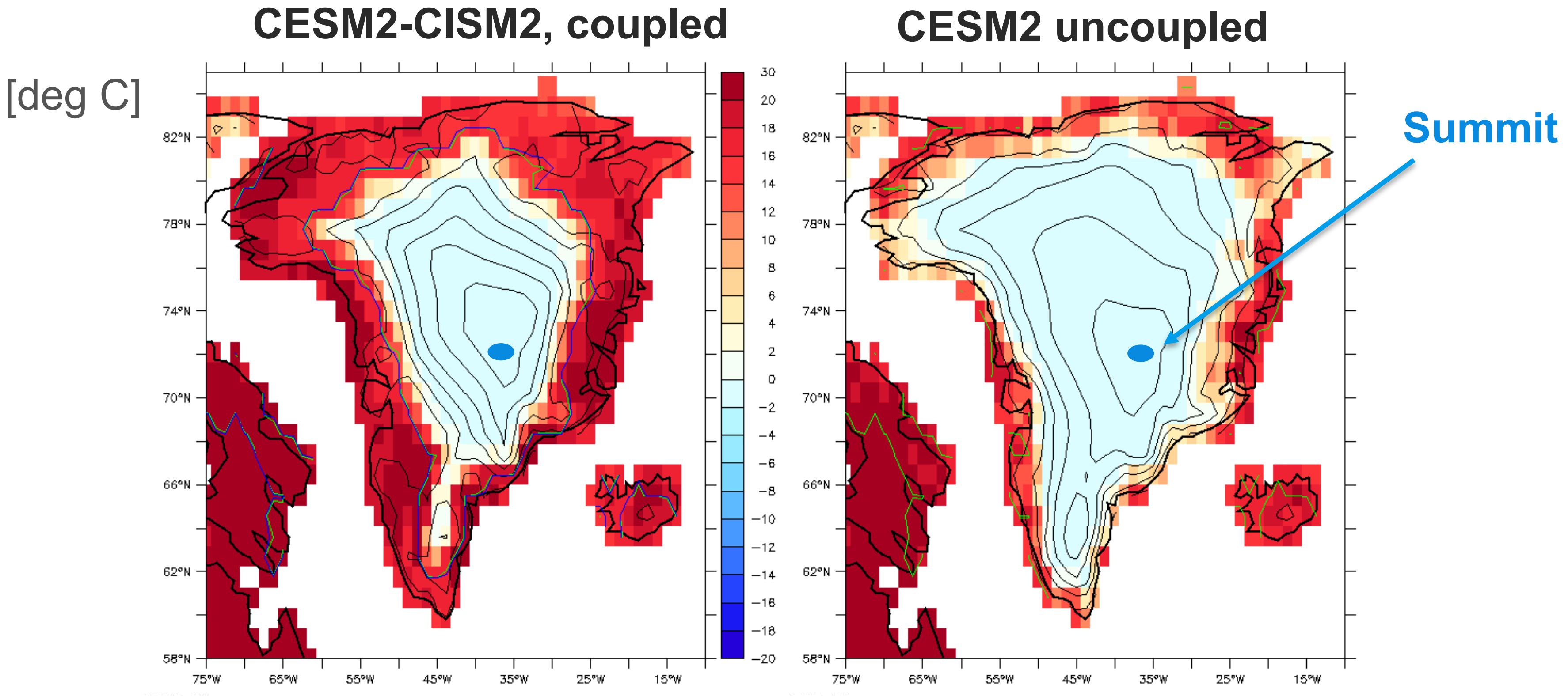
Map of July temperature lapse rate

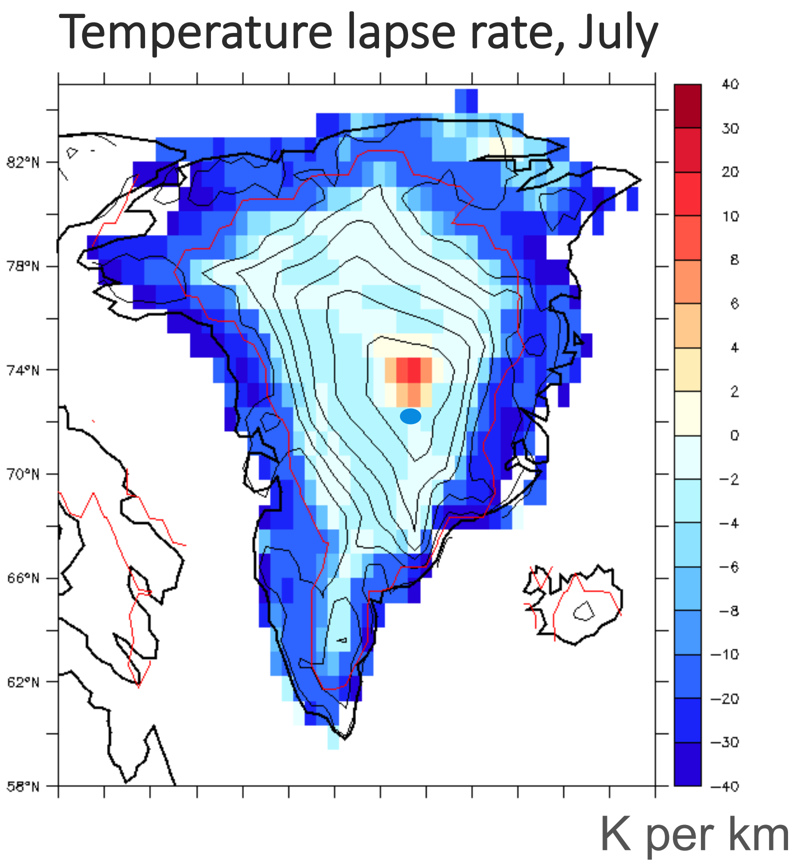


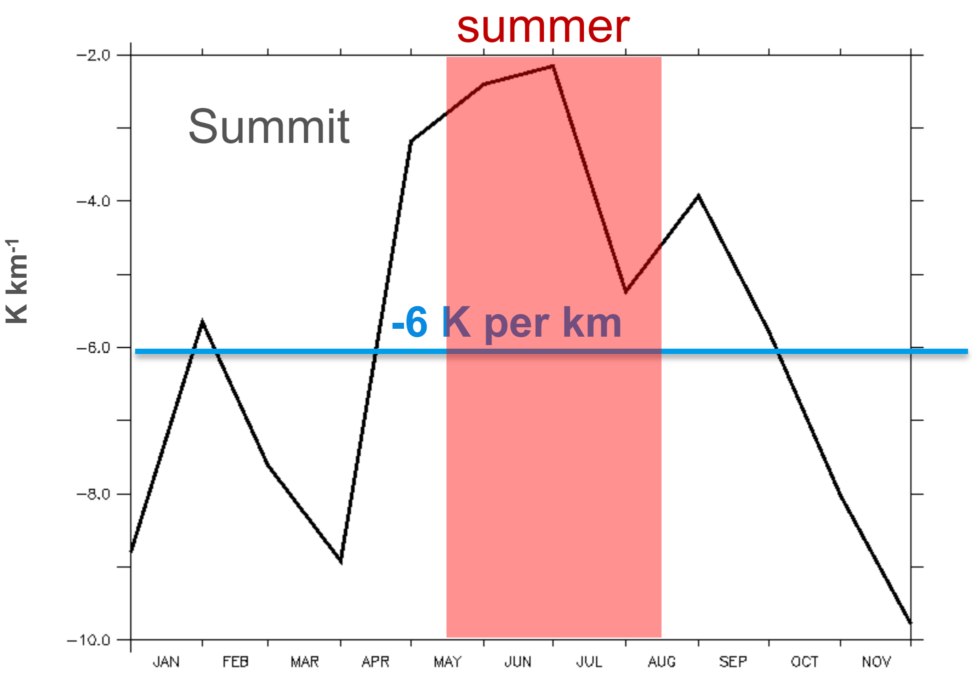
[K per km]

*Please mind: values over deglaciated areas **do not** reflect the lapse rate as land type change effects are included.*

July surface temperature, Model 2




Temperature lapse rate, July
82°N
78°N
74°N
70°N
66°N
62°N
58°N
40
30
20
10
8
6
4
2
0
−2
−4
−6
−8
−10
−20
−30
−40
K per km


summer
Summit
-6 K per km
K km-1
−2.0
−4.0
−6.0
−8.0
−10.0
JAN
FEB
MAR
APR
MAY
JUN
JUL
AUG
SEP
OCT
NOV

- Is **-6 K km^{-1}** an **adequate** lapse rate? **Not over a melting surface**
- **Why** do **uncoupled simulations overestimate** deglaciation rates? **Elevation feedback on melt is overestimated**

Take home message: near-surface atmosphere warms less if it is transferring heat for surface melt

For more detail, particularly on the Methods (Models), see online materials

Lapse rate concept

Different meanings for these disciplines: *

- Atmospheric physics: change of atmospheric variable (e.g., near-surface temperature) as distance to surface increases

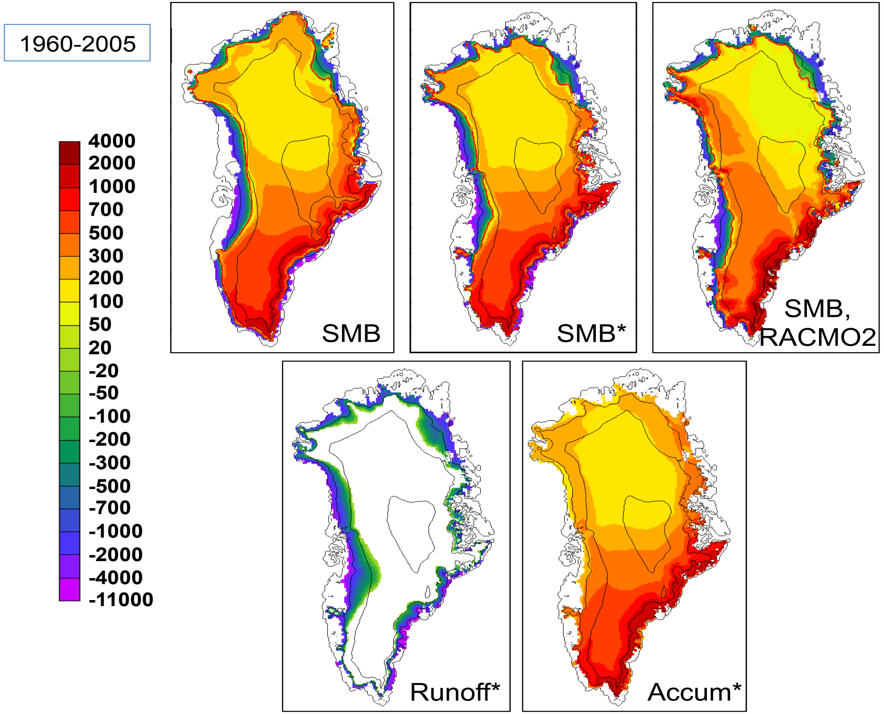
across atmospheric layers (across sigma level)

- Glaciology: change temperature as of atmospheric variable as the elevation of the surface changes

same near-surface atmospheric layer

Model 1: ECHAM5/MPIOM/LPJ/SICOPOLIS T31-10 km

(Vizcaino et al. 2015)



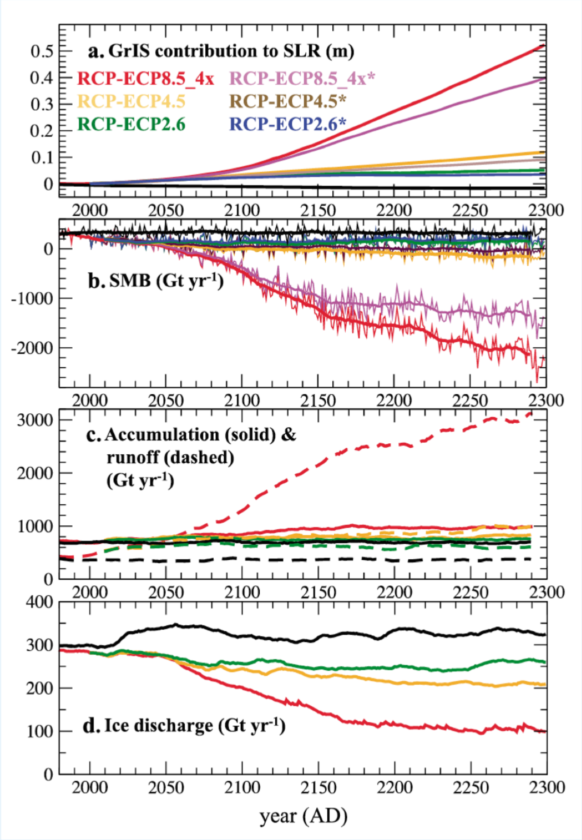
- SMB is calculated offline from radiation, temperature, precipitation & pressure
- Melt is calculated with **energy balance scheme**
- Albedo is prescribed as a function of near surface temperature
- Refreezing considers snow thermal state (but not pore space)

Model 1: ECHAM5/MPIOM/LPJ/SICOPOLIS T31-10 km

(Vizcaino et al. 2015)

Model was applied to three scenarios up to 2300 to quantify uncertainty from climate variability and role of elevation feedback

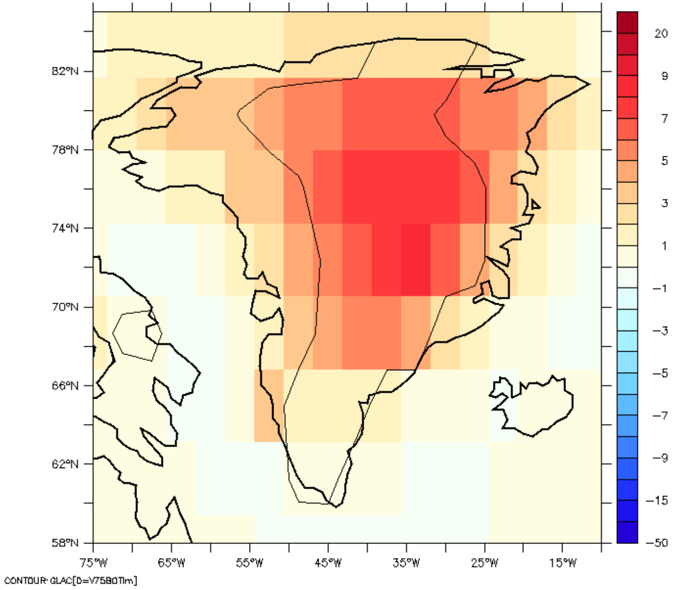
A paleo spin-up was used for initialization with climate-ice sheet coupling during the Holocene



Winter versus summer near-surface atmospheric temperature change

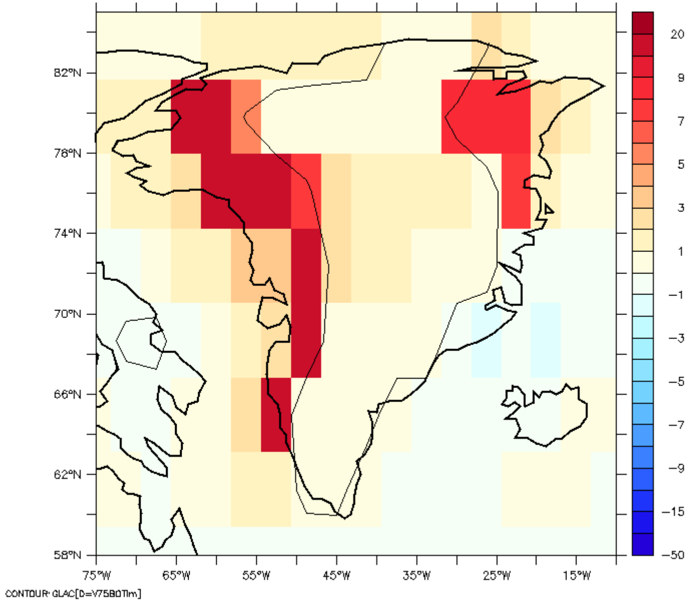
FEB

T-2m coupled minus uncoupled



JULY

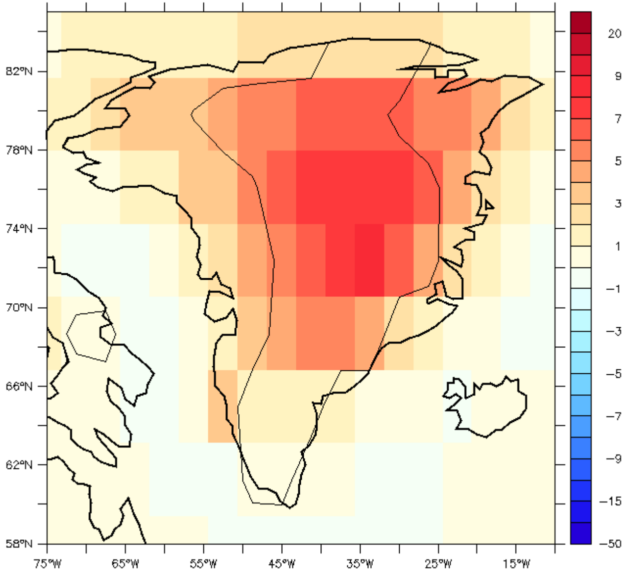
T-2m coupled minus uncoupled



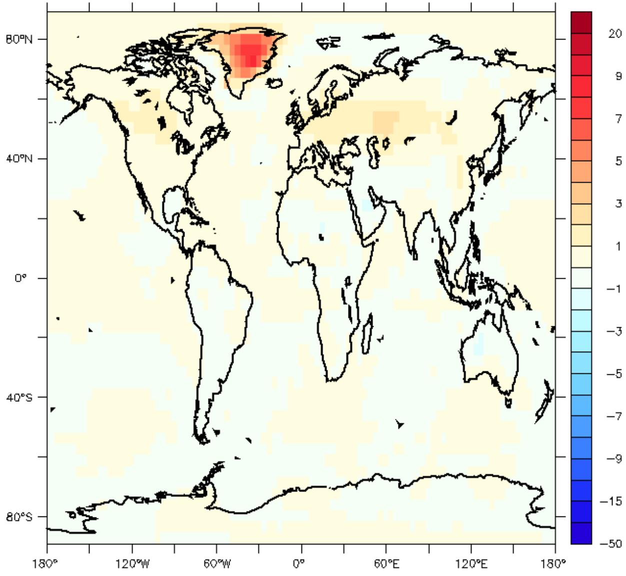
Zooming out (February)

T-2m coupled minus uncoupled

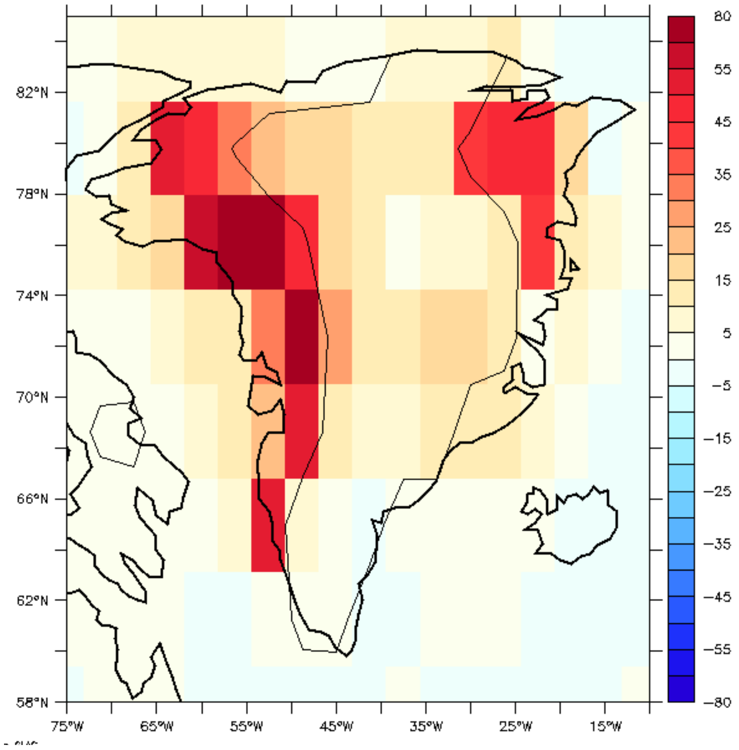
Greenland



Global

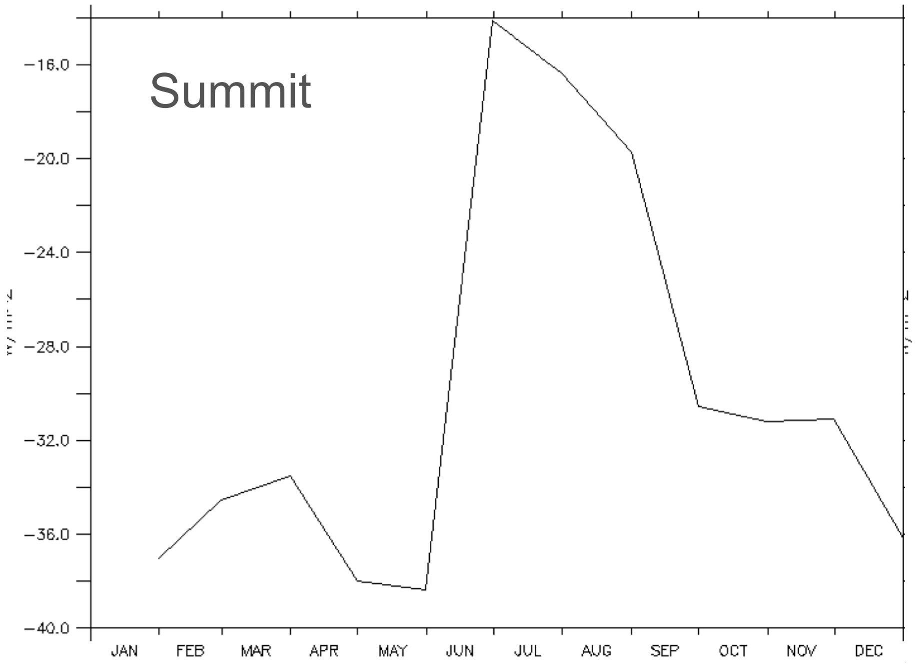


Map of incoming longwave "lapse rate" (July)

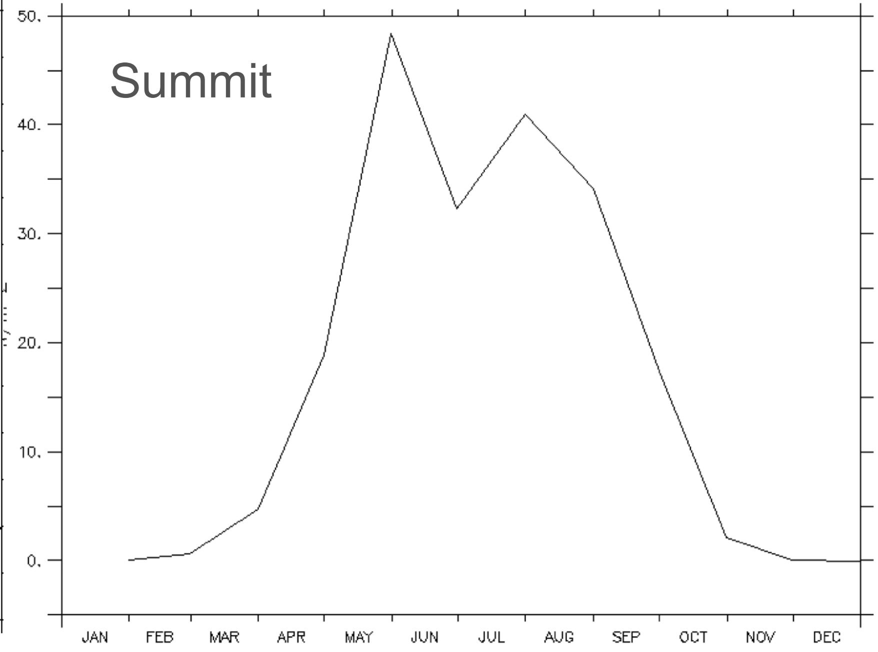


Similar pattern as for near-surface temperature

Incoming **longwave** lapse rate (W/m² per km)

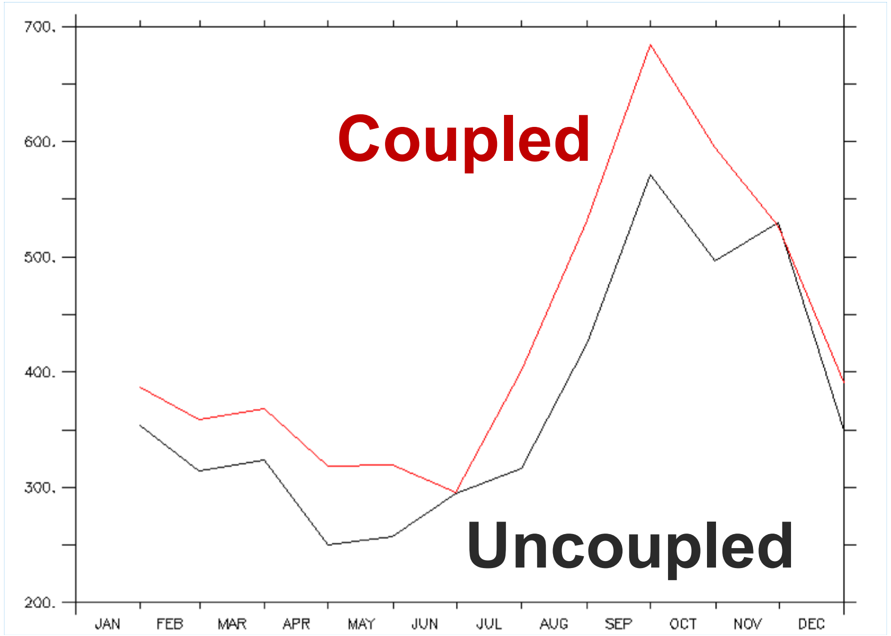


Incoming **shortwave** lapse rate (W/m² per km)



Summit, annual precipitation

absolute values (Kg m^{-2} yr^{-1})



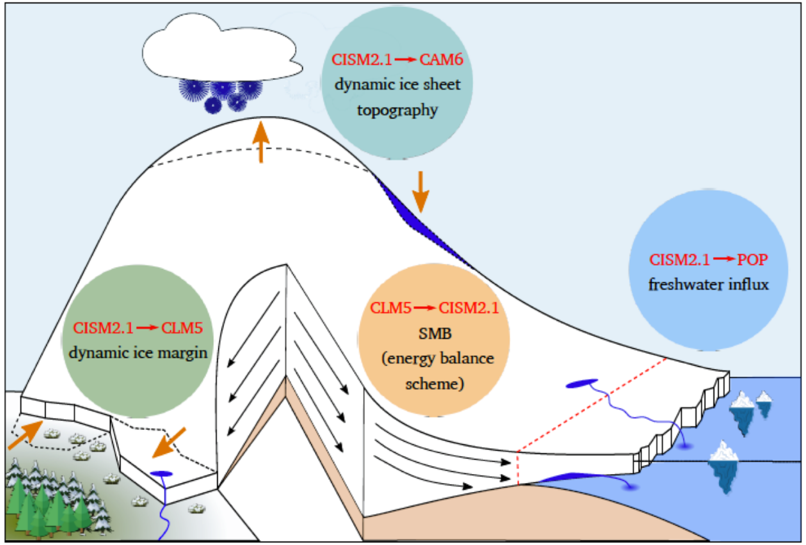
Precipitation increases as the elevation decreases

(negative feedback of precipitation on mass loss)

Model 2 :CESM2-CISM2

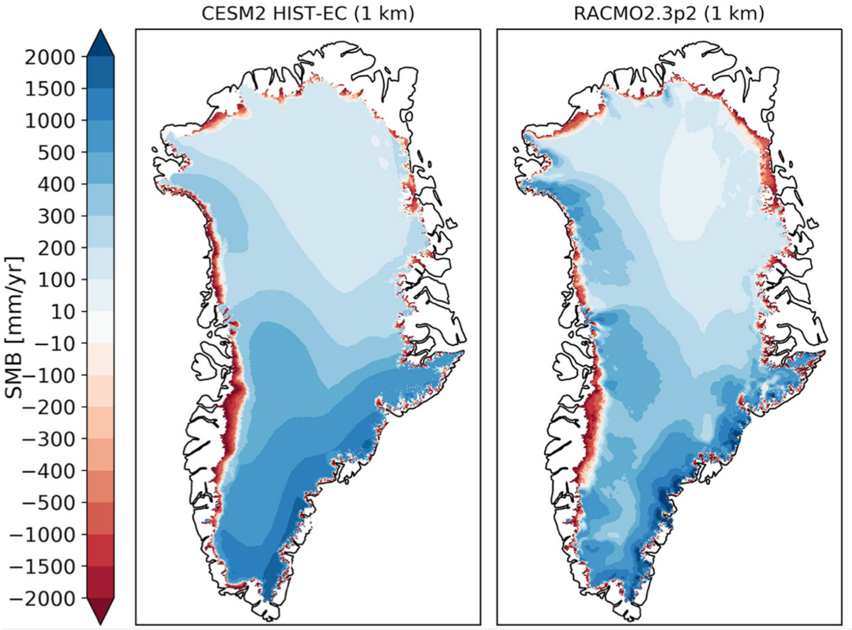
Features:

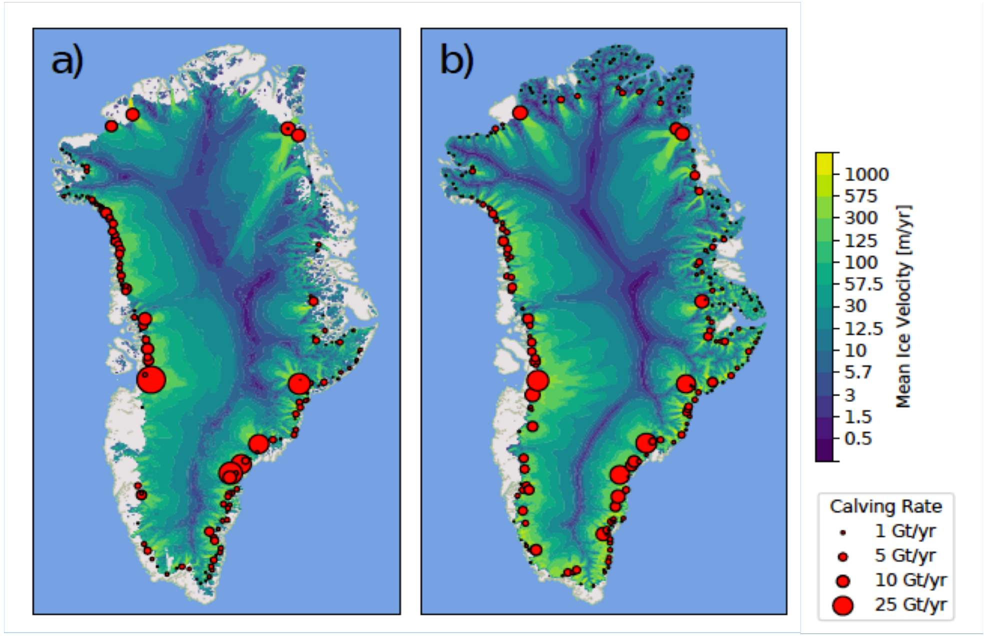
- **Coupling** of ice dynamics, SMB & climate
- **Advanced, interactive SMB** simulation: in the land component of CESM2 with explicit albedo & refreezing calculation
- Relatively **advanced ice flow** (HO approx.) simulation for a coupled simulation
- **High resolution** (4km/**1 deg**) for a coupled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



Muntjewerf et al, JAMES, 2021

Model 2 :CESM2-CISM2

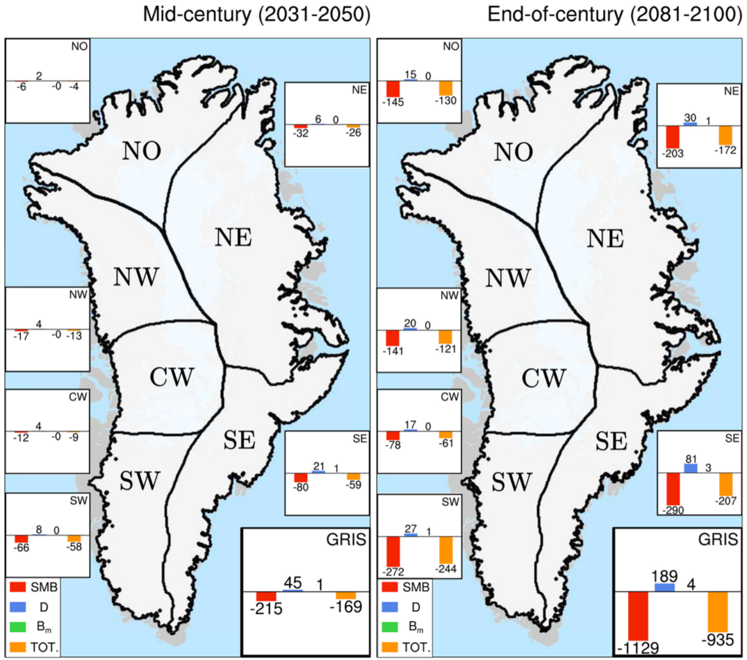


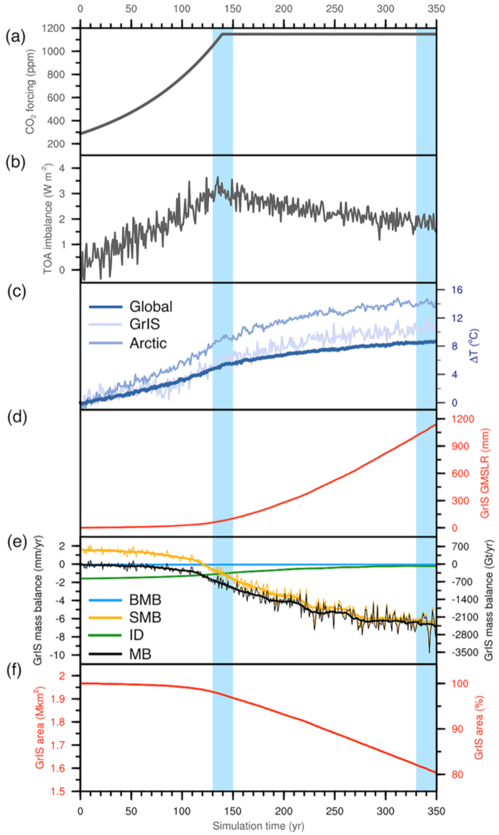


Observations
(Joughin et al.; Enderlin et al, 2014)

CESM2-CISM2

Applied to century and multi-century assessments





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Accelerated Greenland Ice Sheet Mass Loss Under High Greenhouse Gas Forcing as Simulated by the Coupled CESM2.1-CISM2.1

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