Simulation of LGM NH ice sheets climate and SMB with CESM2-CAM5

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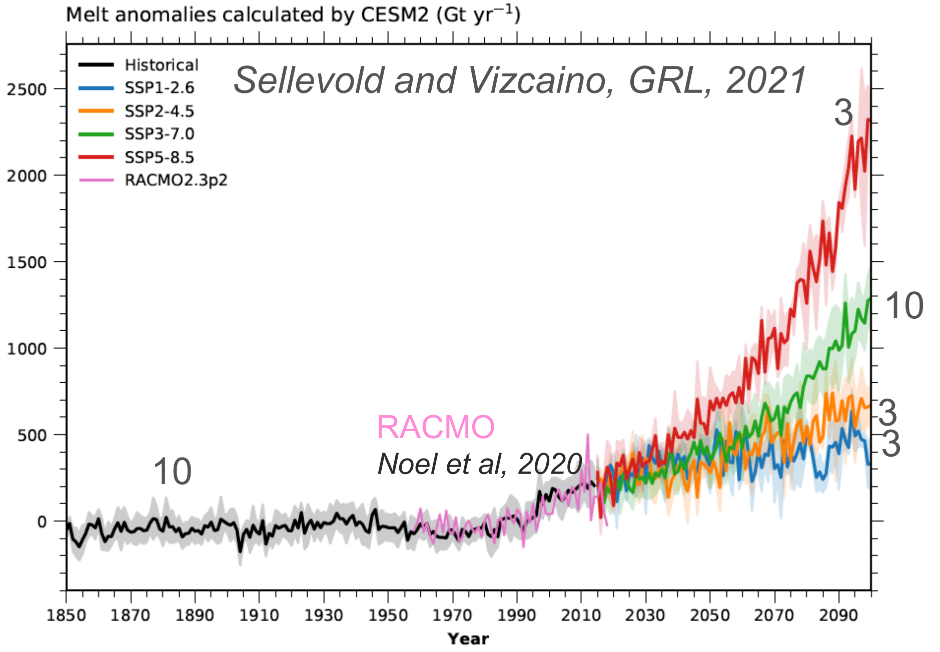
- CESM2 includes default melt and SMB calculation for all CMIP simulations
- CESM2-CISM2 provided first CMIP coupled GrIS-climate projection
- Here, we use CESM2 at same resolution as for projections to simulate LGM climate and ice sheet SMB
- CAM6 replaced by CAM5



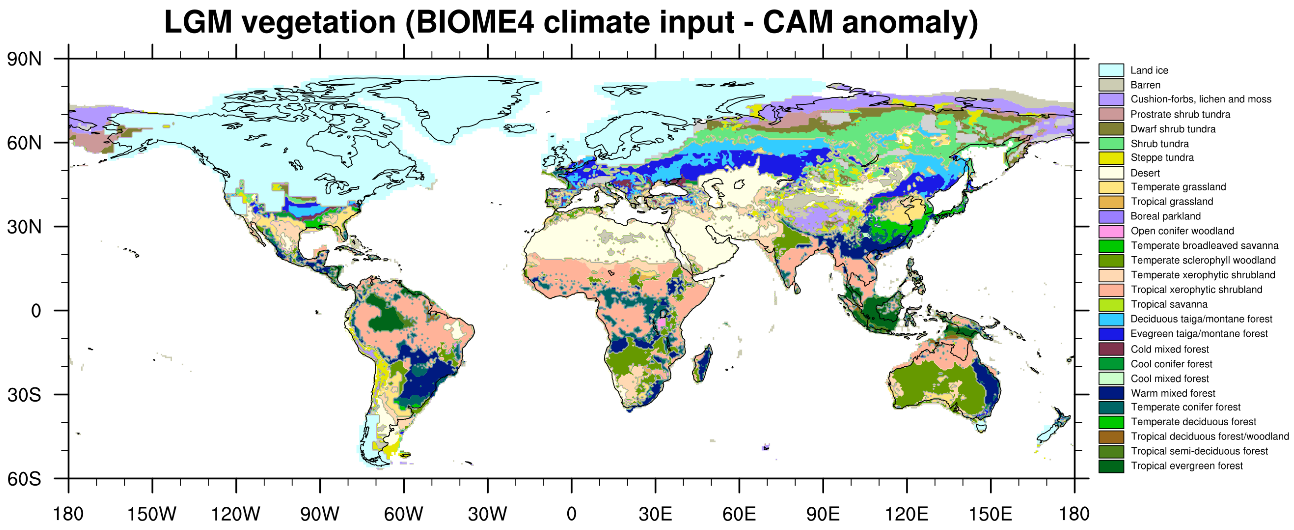
method

Simulation design

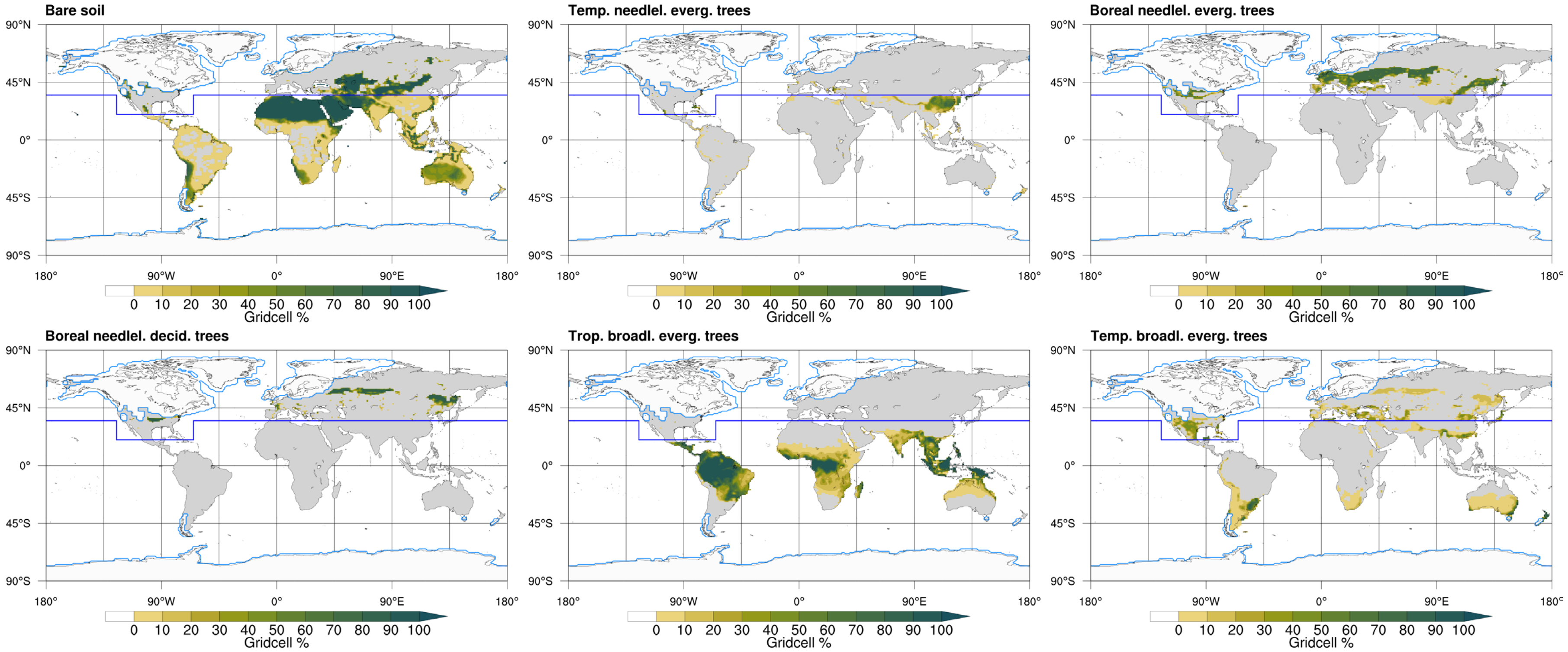
- We compare 21 ky and 26 ky runs to PI
- Ice sheet reconstruction from GLAC-1D (North American) and British-CHRONO (Eurasia)
- Forcing from PMIP

Parameter setting	LG-21 ka	LG-26 ka
Solar constant	Pre-industrial	Pre-industrial
Eccentricity	0.018995°	0.017742°[1]
Obliquity	22.949°	22.31°[1]
Perihelion-180	114.42°	32.09°[1]
CO_2 (ppm)	190	184[2]
CH_4	375	355[3]
N_2O (ppb)	200	199[4]
Others (CFC)	0	0
Ozone	Pre-industrial	Pre-industrial
Vegetation	21 ka[5]	21 ka[5]
Land surface topography	21 ka	21 ka
Ice sheets	21 ka	21 ka
Ocean restart	CESM1 21ka[6]	LG-21 ka
Climate restart	CESM2 21 ka[7]	LG-21 ka
Simulation length	500 years	500 years

[1] Berger (1978). [2] Bereiter et al. (2015). [3] Loulergue et al. (2008). [4] Schilt et al. (2010). [5] Offline BIOME4 simulation (Kaplan et al., 2003). [6] DiNezio et al. (2018). [7] Zhu et al. (2021).



- Vegetation types for high and mid NH latitudes was taken from model BIOME4 with LGM atmospheric forcing
- For other regions, PFTs were left unchanged with respect to PI simulation

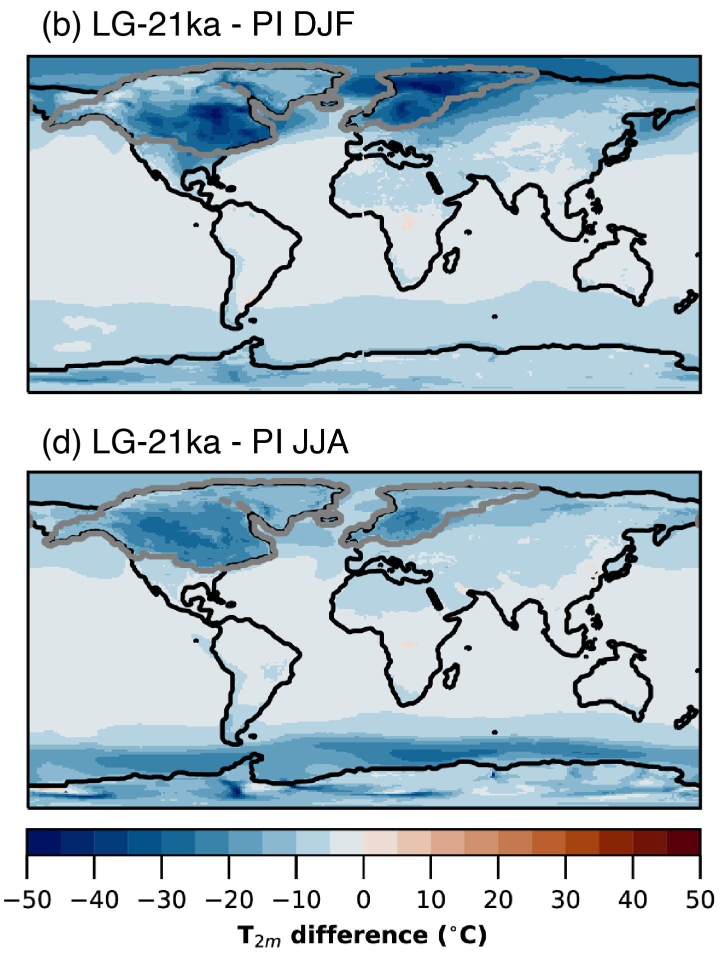

Bare soil
Temp. needlel. everg. trees
Boreal needlel. everg. trees
Boreal needlel. decid. trees
Trop. broadl. everg. trees
Temp. broadl. everg. trees
90°N
45°N
0°
45°S
90°S
180°
90°W
0°
90°E
180°
0 10 20 30 40 50 60 70 80 90 100
Gridcell %

climate

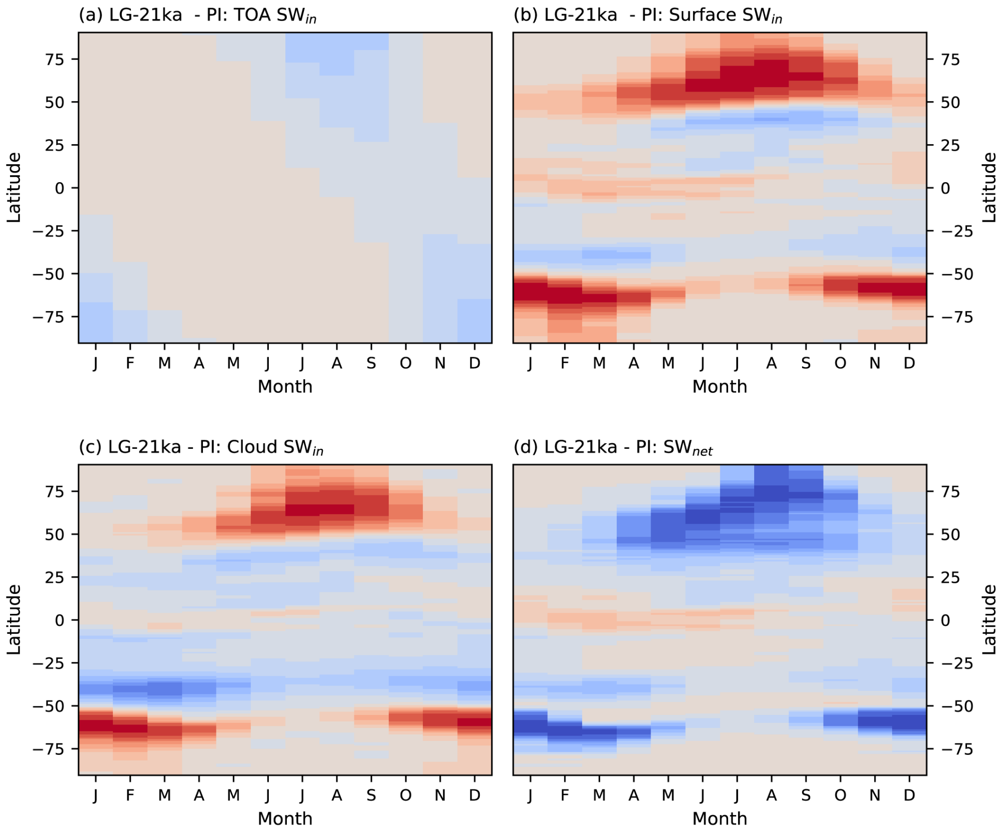
-6.8 K w.r.t. pre-industrial

	LG-26 ka	LG-21 ka	CCSM4	PMIP4	Proxy
Global precipitation ($mm\,d^{-1}$)	2.50 {0.01} (−0.58)	2.59 {0.01} (−0.49)	2.61 (−0.32)	2.72[1]	
Tropical precipitation ($mm\,d^{-1}$)	3.26 {0.01} (−0.48)	3.32 {0.02} (−0.42)	3.93 (−0.36)		
Global near-surface T (°C)	6.47 {0.09} (−8.30)	7.93 {0.11} (−6.84)	9.83[1]		6.40 (−7.10)[5]
Global surface T (°C)	7.39 {0.09} (−8.26)	8.86 {0.11} (−6.79)	9.04 (−4.97)	11.54[2]	
Tropical land surface T (°C)	21.42 {0.16} (−4.42)	22.28 {0.18} (−3.56)	20.89 (−2.61)		(−3.9)[8]
GRIP (°C)	−42.38 {1.51} (−14.39)	−38.35 {1.48} (−11.36)	−37.76 (−8.54)		(−11.5)[7]
Vostok (°C)	−62.35 {0.58} (−12.39)	−60.31 {0.72} (−10.35)	−62.84 (−9.97)		(−12)[6]
Global precipitable water (mm)	17.14 {0.10} (−8.69)	18.30 {0.18} (−7.53)	18.84 (−5.09)		
Tropical SST (°C)		23.14 {0.14} (−3.35)	24.78 (−2.16)	23.30[3]	(−3.5)[8]
AMOC at 30° N (Sv)	17.1	18.4	22	16–24	
Sea ice area NH ($\times 10^6\,km^2$)	12.54 {0.39} (2.74)	9.39 {0.21} (−0.41)	8.64 (−3.06)		9.40[4]
Sea ice area SH ($\times 10^6\,km^2$)	29.65 {0.47} (20.65)	25.87 {0.41} (16.87)	27.88 (10.9)		24.72[4]

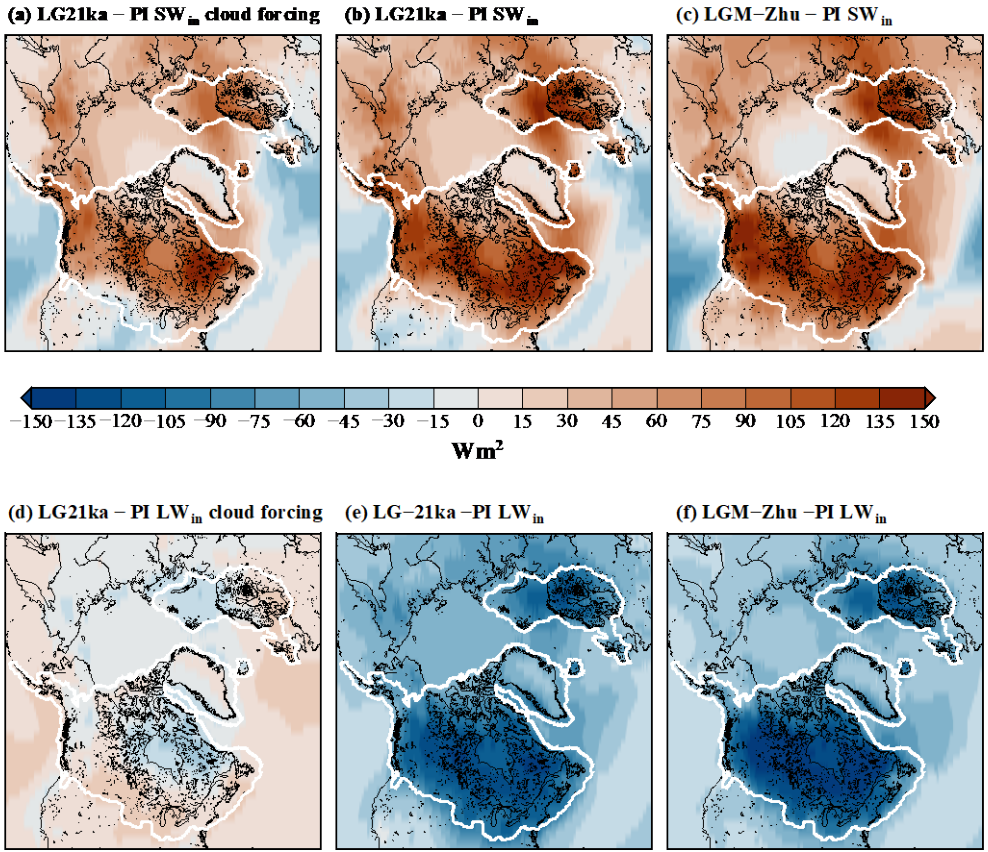
[1] AWI-ESM-1-1-LR, INM-CM4-8, MIROC-ES2L, MPI-ESM1-2-LR. [2] MIROC-ES2L. [3] MIROC-ES2L, MPI-ESM1-2-LR. [4] Paul et al. (2021). [5] Osman et al. (2021). [6] Petit et al. (1999). [7] Lecavalier et al. (2014). [8] Tierney et al. (2020).



- Largest cooling with respect to PI is simulated over ice sheets, in connection with higher elevation and albedo



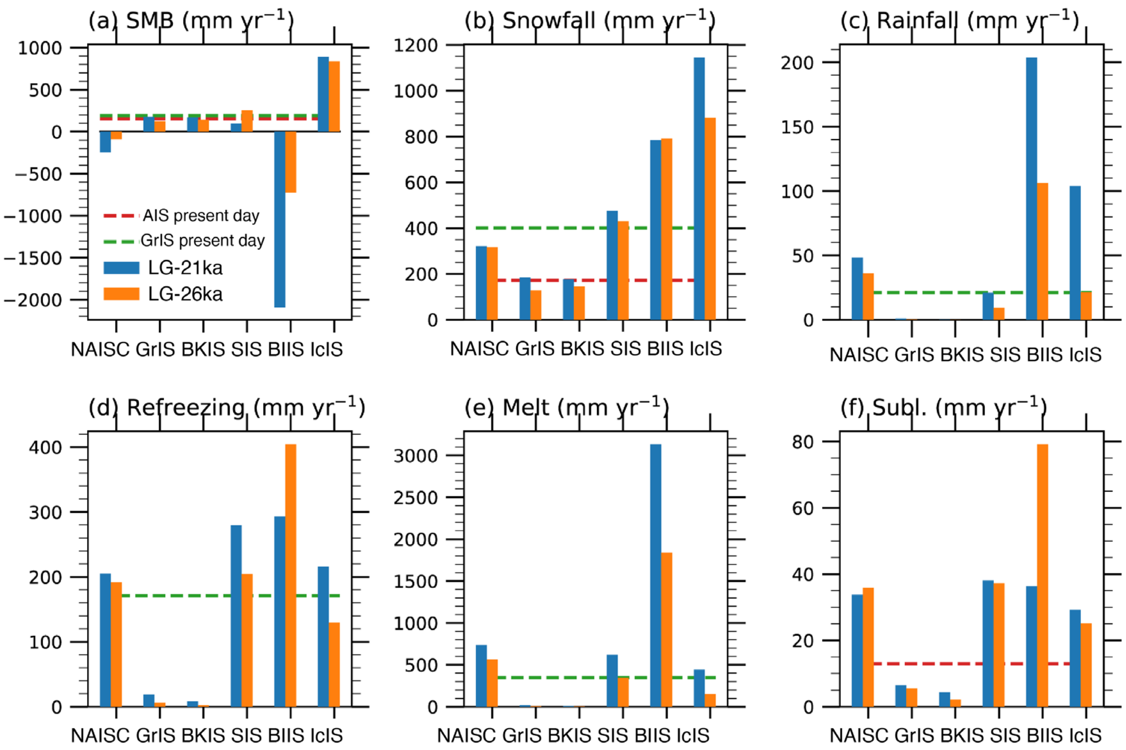
- Reduced summer TOA solar radiation with respect to PI
- However, less cloud cover and increased surface albedo result in increased incoming solar radiation at the surface
- Summer net solar radiation is less than PI due to higher albedo

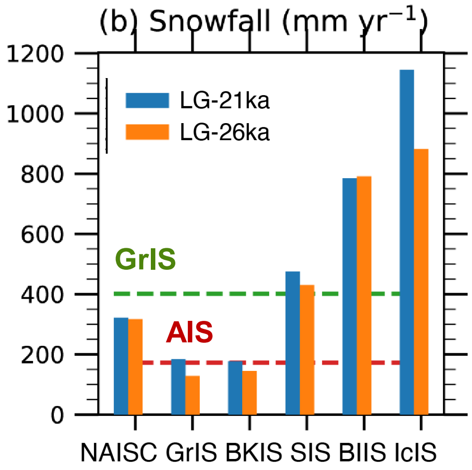


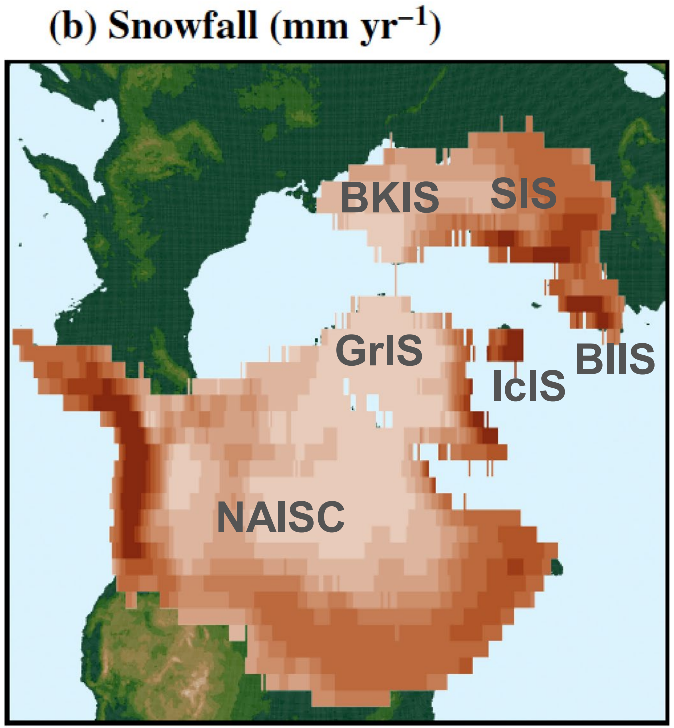
- Cloud forcing increase surface solar radiation with respect to PI except in the margin
- Incoming longwave radiation largely reduced with respect to PI over the ice sheets due to increased surface elevation

surface mass balance

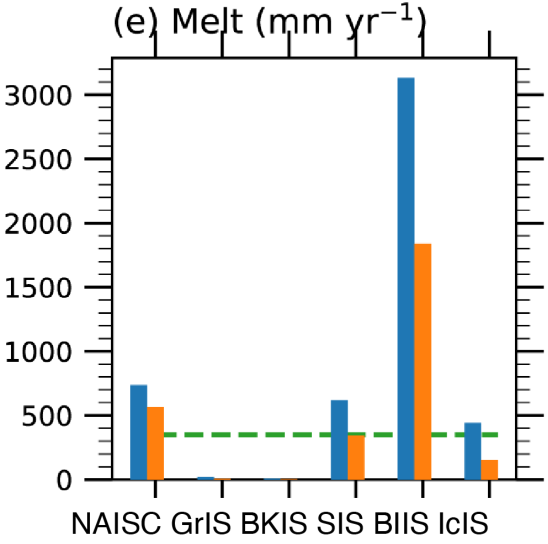
SMB=Snowfall-Melt+Refreezing-Sublimation

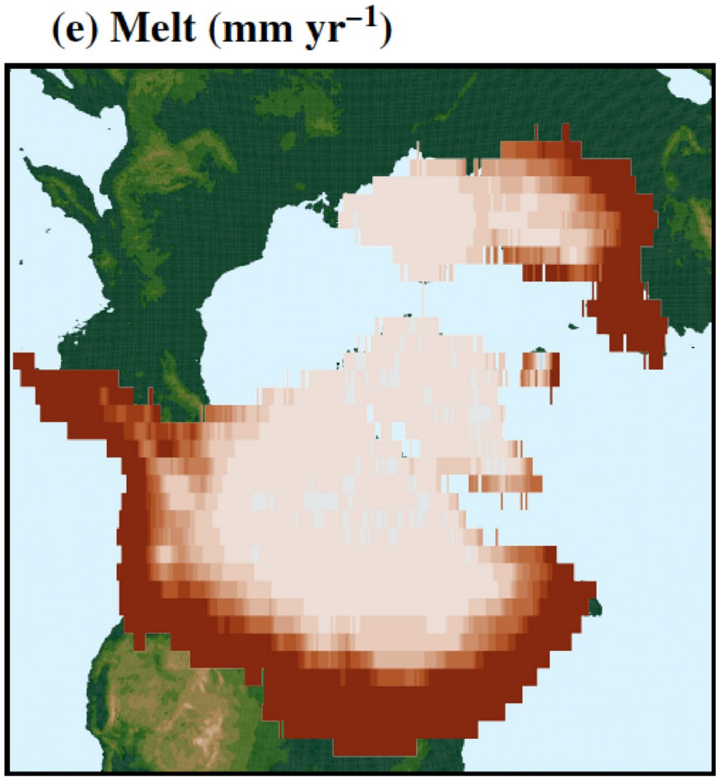




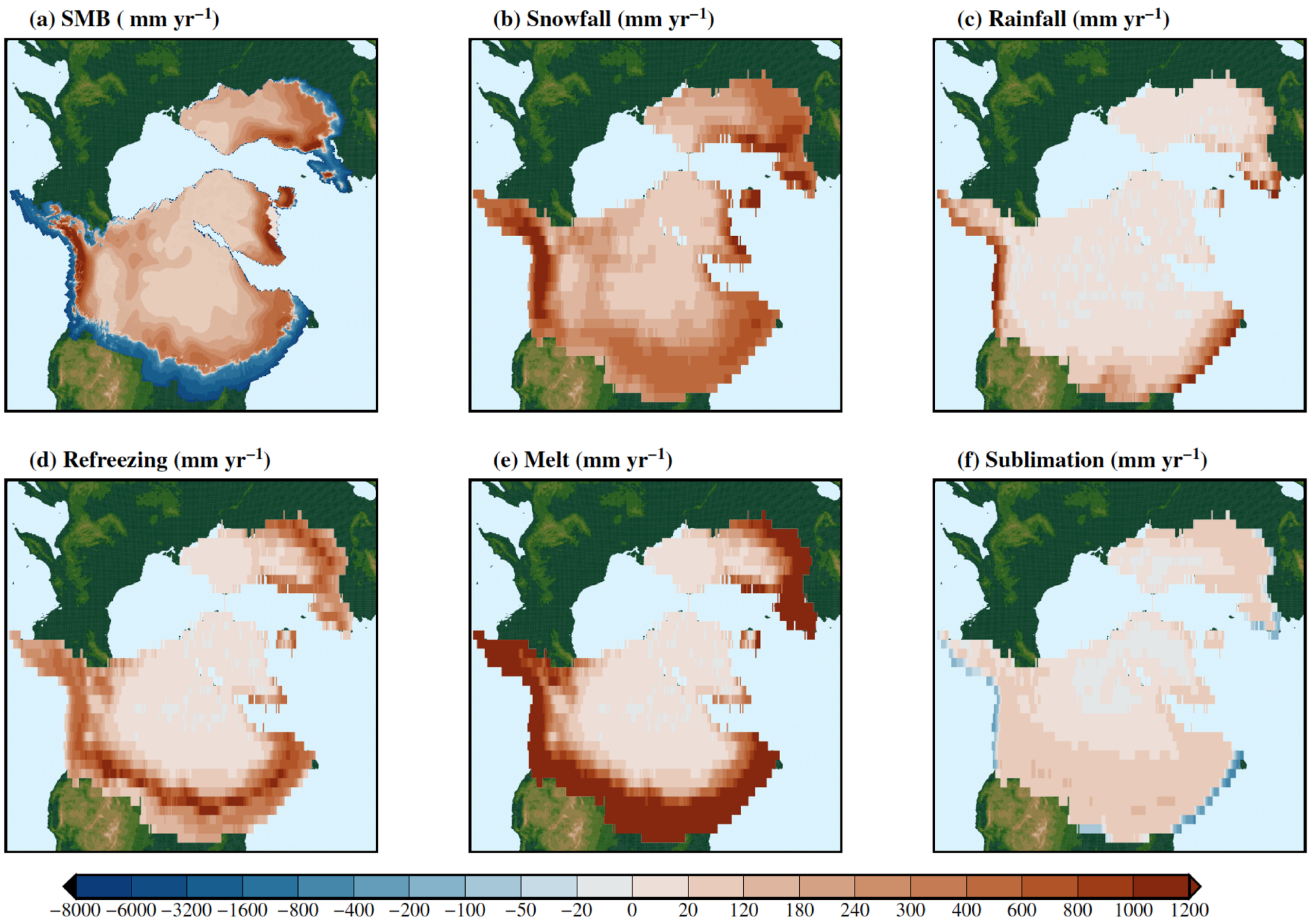


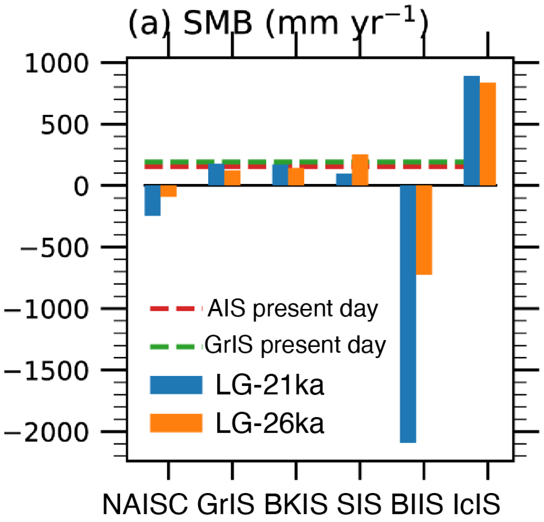
- Greenland & Barents are the dryest
- Scandinavian similar to present-day Greenland
- North American in between present-day Antarctica and Greenland
- British and Icelandic have highest snowfall



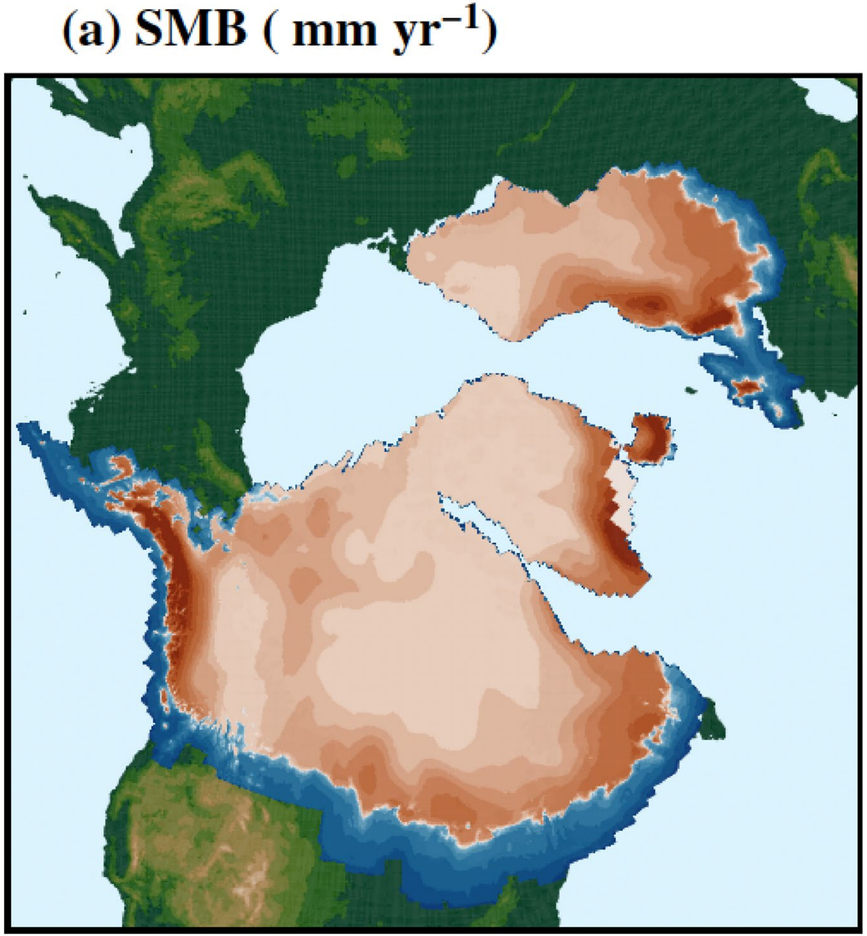


- No melt for Greenland and Barents
- North American, Scandinavian and Icelandic moderately over present-day Greenland
- Very large melt for the British ice sheet

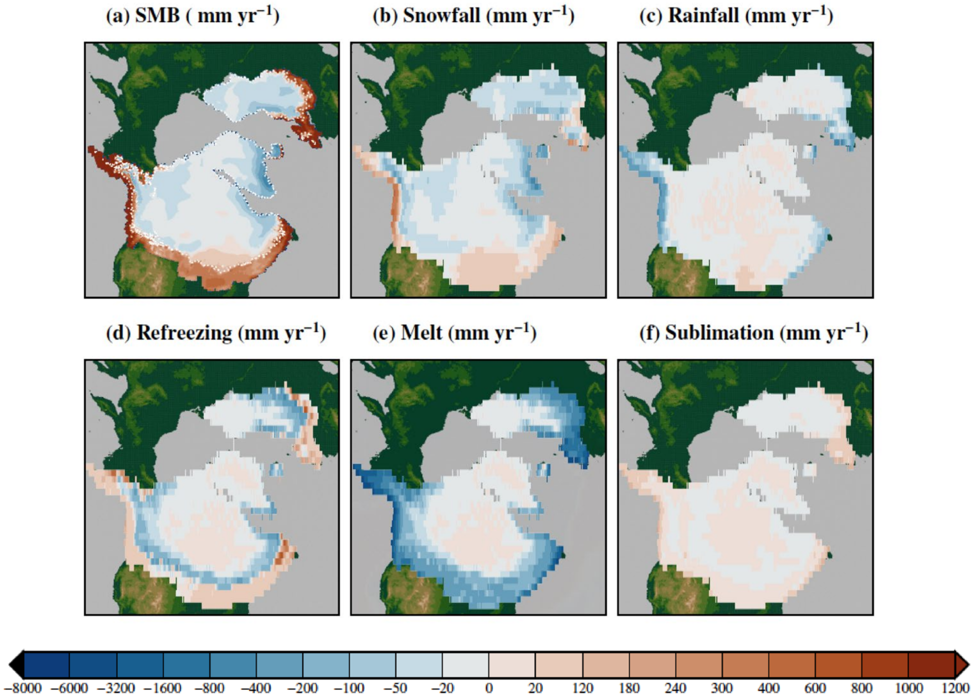

(a) SMB (mm yr−1)
(b) Snowfall (mm yr−1)
(c) Rainfall (mm yr−1)
(d) Refreezing (mm yr−1)
(e) Melt (mm yr−1)
(f) Sublimation (mm yr−1)
−8000 −6000 −3200 −1600 −800 −400 −200 −100 −50 −20 0 20 120 180 240 300 400 600 800 1000 1200

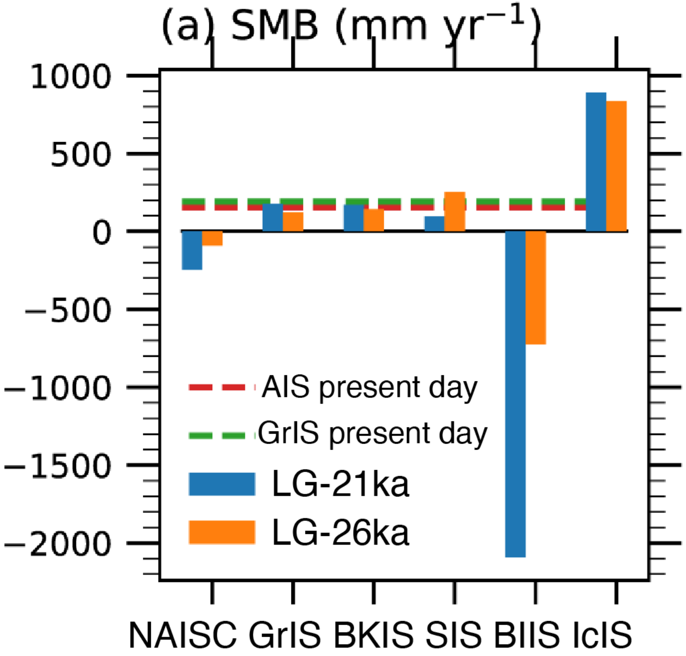


- Greenland and Barents SMB similar to present-day GrIS
- North American Complex has negative SMB
- Very low British ice sheet SMB
- High Icelandic ice sheet SMB



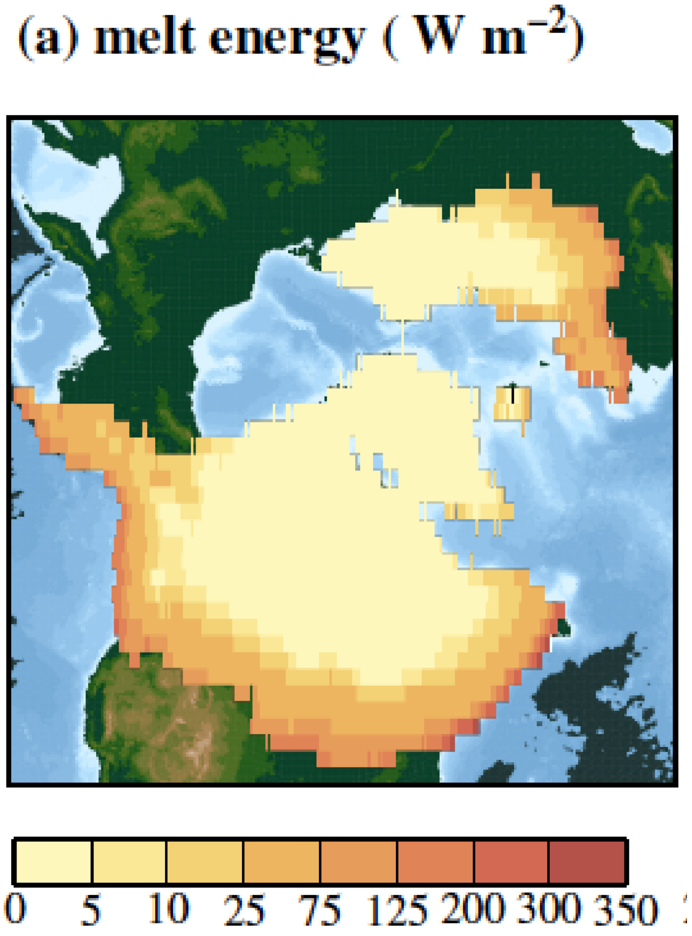
26 ky minus 21 ky



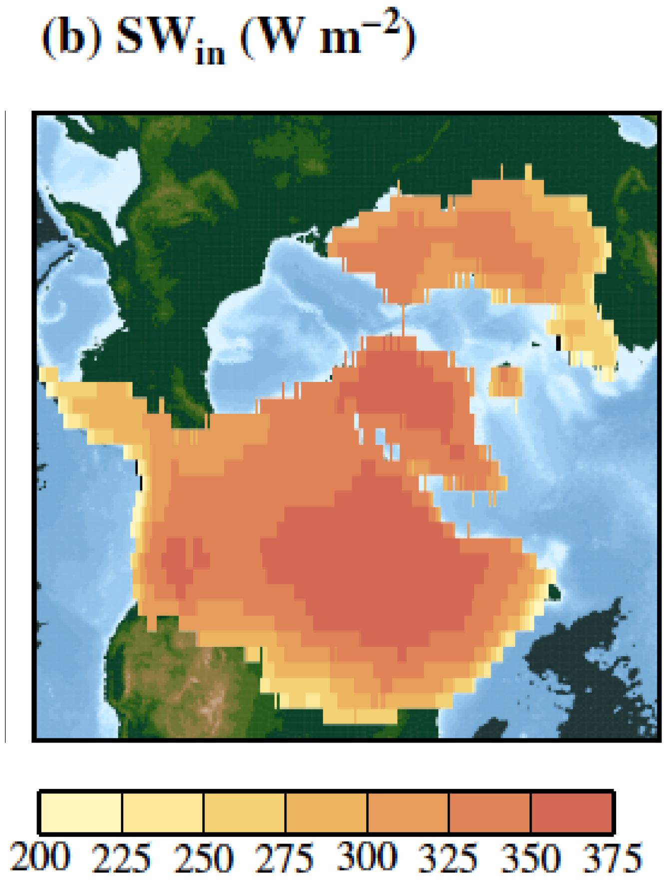


- Less melt and precipitation in 26 ky
- Higher SMB in 26 ky

melt energy sources

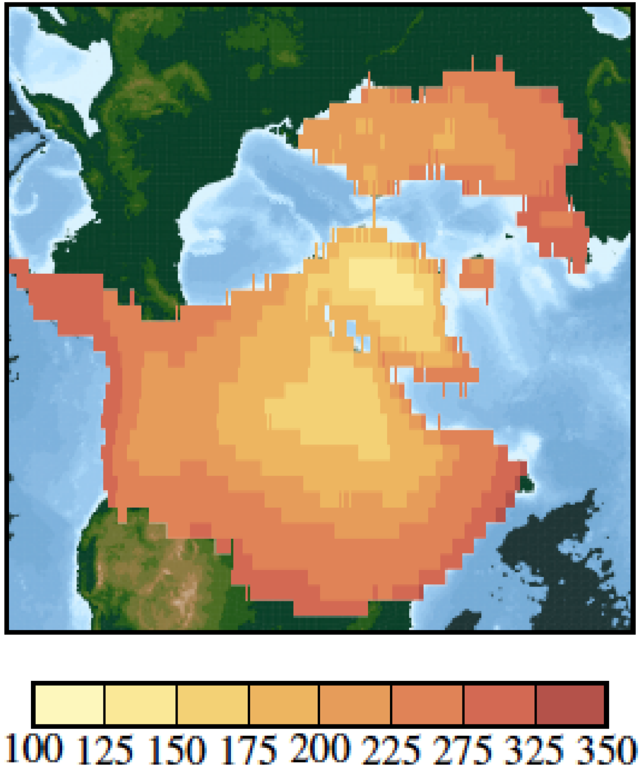


Melt energy sources are
radiation
sensible heat
latent heat

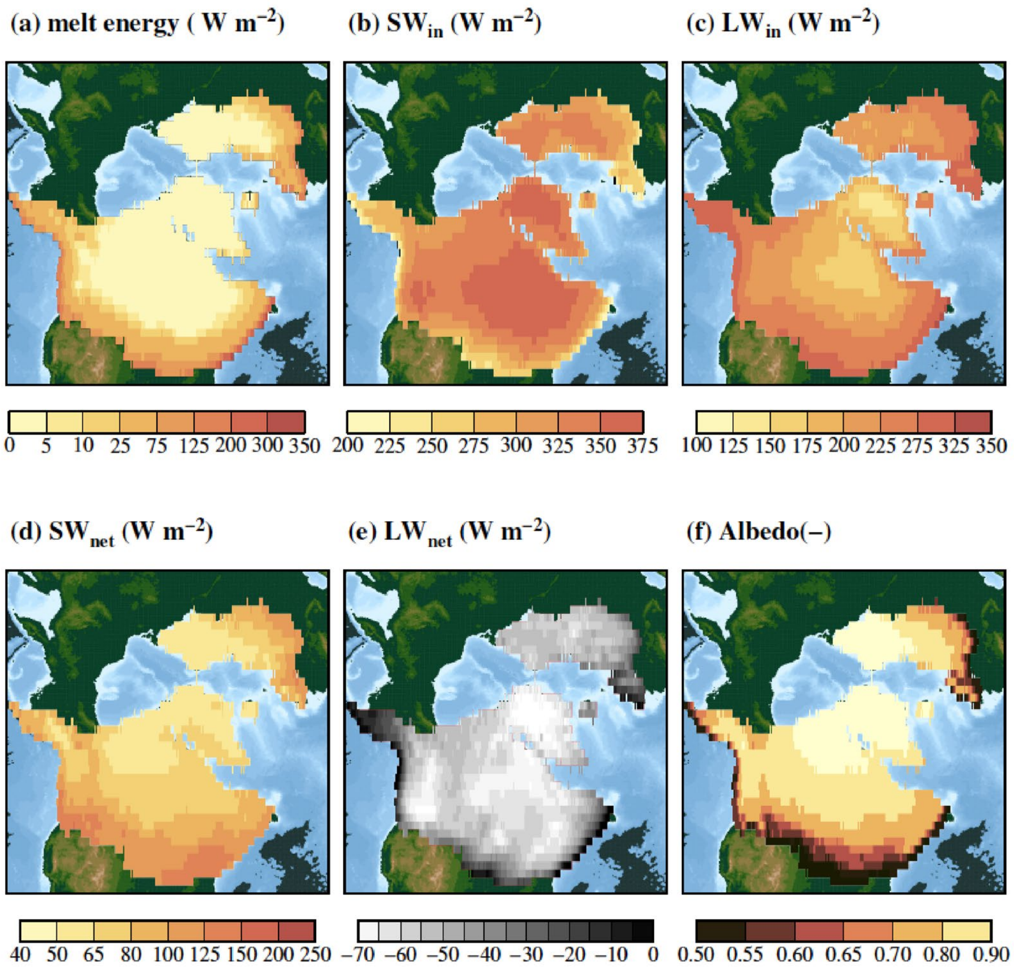


- Highest incoming solar radiation in the interior of the ice sheets, as for present-day Greenland

(c) LW_{in} ($W\ m^{-2}$)

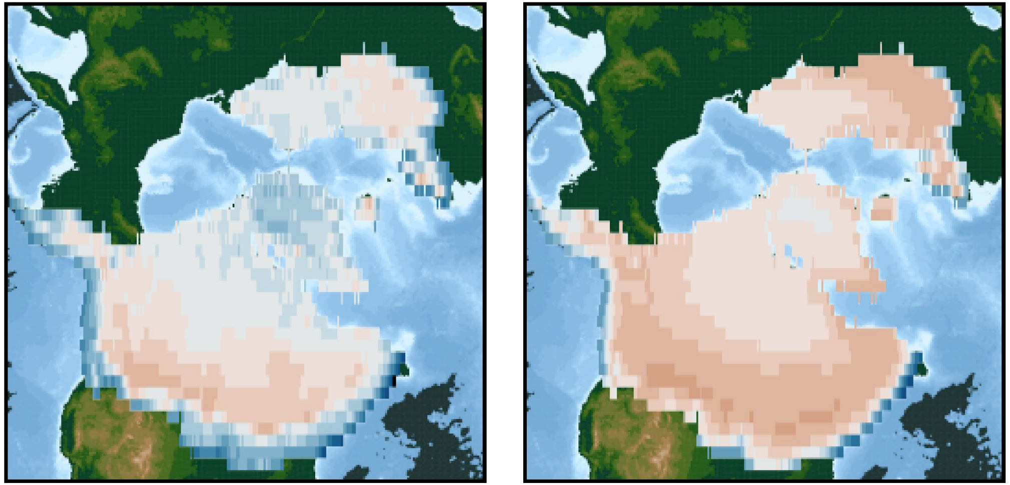


- Highest incoming longwave radiation in the southern margins of the ice sheets and Pacific and Antarctic margins of North American



- Highest solar net over melt areas due to lowest albedo values
- Highest net longwave roughly over same areas

(g) sensible heat flux ($W\ m^{-2}$) (h) latent heat flux ($W\ m^{-2}$)

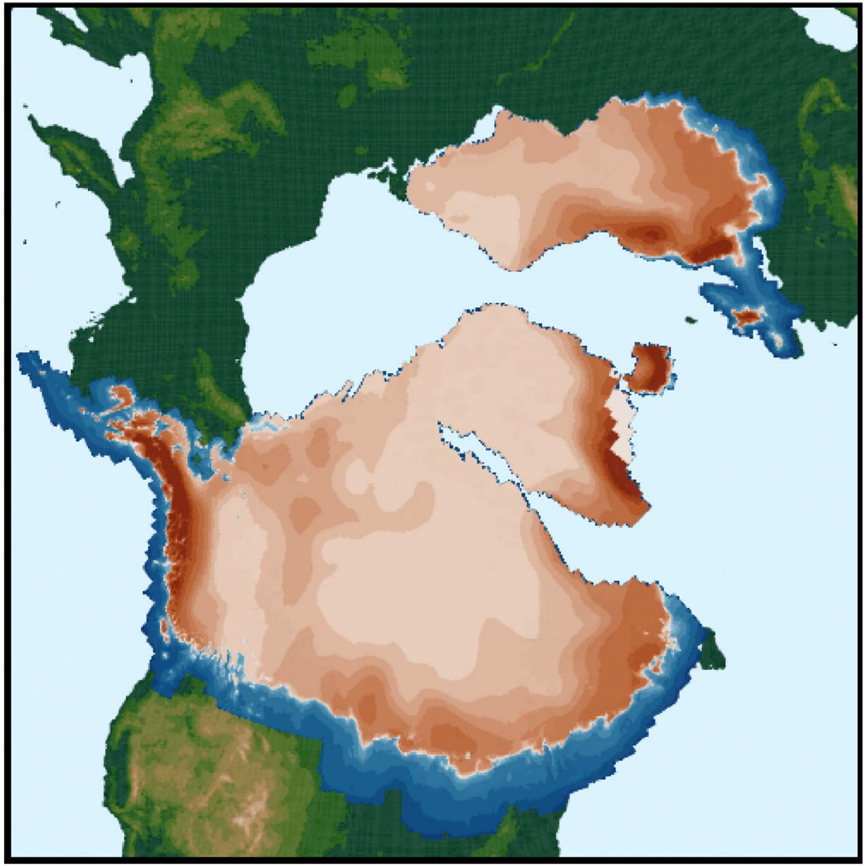


- Highest inputs of sensible and latent heat over the margins

conclusions

- First LGM analysis of surface mass and energy components at CMIP resolution
- GrIS & BKIS average snowfall similar to present-day AIS; SIS similar to GrIS
- NAIS snowfall between present-day GrIS & AIS
- No melt for GrIS and BKIS; NAIS & SIS higher than present-day GrIS
- Very large ablation in the southern margin of Laurentide due to low albedo and large sensible heat flux regardless of low incoming SW due to cloudiness

(a) SMB (mm yr^{-1})



- Follow-up: large ablation area and amount connected with large low elevation areas from reconstruction?

(a) SMB (mm yr^{-1})