

dEBM: A surface mass balance scheme including the diurnal cycle of solar radiation for ice sheet simulations on long time scales

Technical Box

The surface mass balance model

$$\text{SMB} = (\text{SF} + \text{ME} - \text{RFR}) \cdot \text{dt}$$

Snow Fall **SF**, Melting **ME**, Refreezing **RFR**, time step **dt = 1 month**

melting **ME** and *potential* refreezing **RFR_{pot}** according to energy balance (see below)

$$\text{ME} = \max(0, Q/h_{\text{fus}})$$

$$\text{RFR}_{\text{pot}} = \min(0, Q/h_{\text{fus}}), \quad h_{\text{fus}} \text{ specific enthalpy of fusion}$$

The actual refreezing rate **RFR** \leq **RFR_{pot}** due to two additional limitations:

$$\text{RFR} \leq \text{ME} + \text{Rain} \quad (\text{refreezing is only possible, if liquid water is available})$$

$$\text{RFR} \cdot \text{dt} \leq 0.6 \cdot \text{snow height} \quad (\text{limited water storage of snow, no refreezing on ice})$$

Energy balance of a melting ice surface

$$Q = (1-A) \text{SW} \downarrow + c_1 T + c_2$$

with albedo **A**, downwelling short wave radiation **SW**↓, near surface air temperature **T**

c_1, c_2 depend on atmospheric emissivity and turbulent exchange coefficients
(Krebs-Kanzow et al, 2018)

Albedo **A** depends on energy balance and snow height

We distinguish: new snow, dry snow, wet snow and ice

Implicit representation of diurnal freeze – melt cycles under clear sky conditions

Under clear sky conditions strong heat loss due to long wave radiation $\rightarrow (c_2 < 0)$

daily melt period: sun is above a critical elevation angle ϕ
nocturnal refreezing: sun is below a critical elevation angle ϕ

The elevation angle ϕ can be estimated, \rightarrow nocturnal refreezing and daily melting can be estimated from **monthly mean forcing** (Krebs-Kanzow et al, 2018), also Fig. 1

Distinguishing clear sky and overcast conditions

$$\text{Monthly mean cloud cover (\%)} = (\text{overcast days per month}) / (\text{days per month})$$

Different emissivities for clear sky, overcast conditions $\rightarrow c_{1,\text{clear}}, c_{2,\text{clear}}, c_{1,\text{cloudy}}, c_{2,\text{cloudy}}$

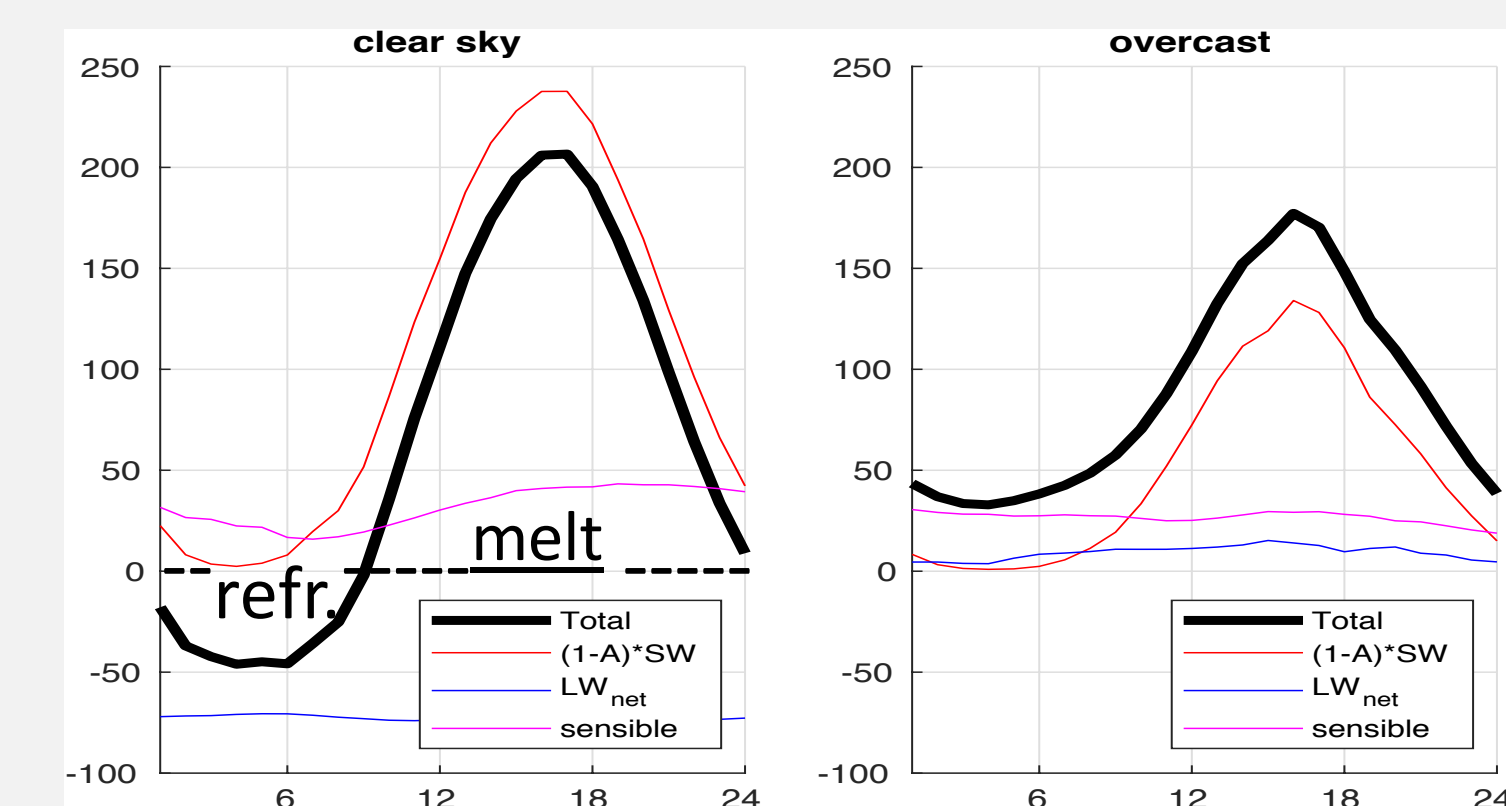


Fig.1 Example for mean July diurnal cycle in Western Greenland (PROMICE⁽²⁾ station KAN) for overcast and clear sky

dEBM scheme

- monthly forcing
- all parameters are physically constrained
- sensitive to latitude and month
- globally applicable for (paleo) ice sheets

Abstract

We present the surface mass balance scheme for ice sheets, dEBM, which only requires monthly mean short wave radiation, temperature and precipitation, but implicitly accounts for the diurnal cycle of short wave radiation. The scheme may be particularly suitable for long ice-sheet simulations of past and future climates. It is computationally inexpensive and can account for changes in the Earth's orbit and atmospheric composition. For evaluation, the scheme is applied to the Greenland ice sheet, forced by monthly reanalysis data from the ERA-Interim project.

We then investigate the sensitivity of the surface mass balance of northern hemispheric ice sheets to multi-millennial variations in the solar radiation using a climate simulations of the last glacial maximum as a forcing.

1. Application to ERA-Interim⁽³⁾ forcing

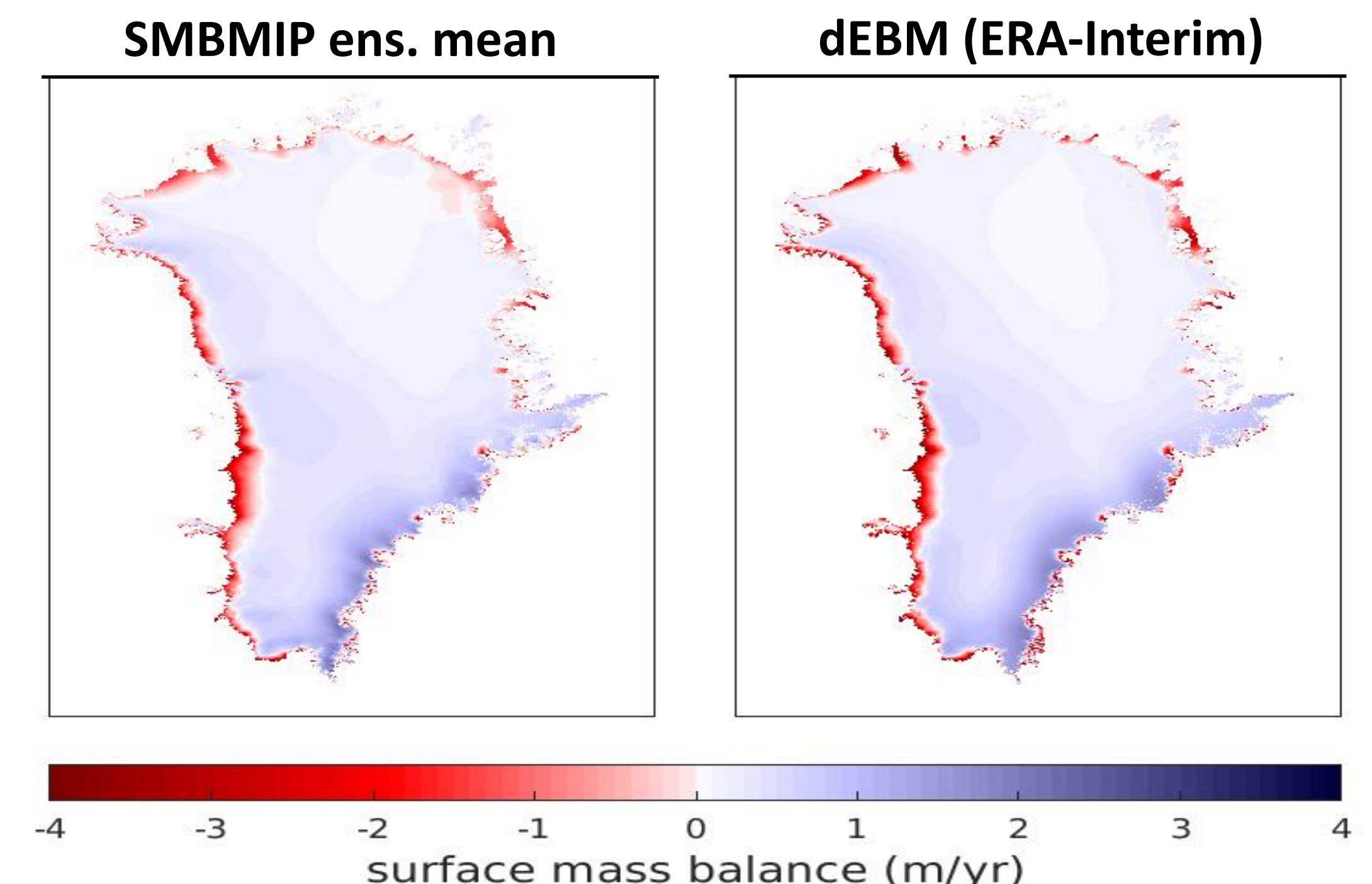
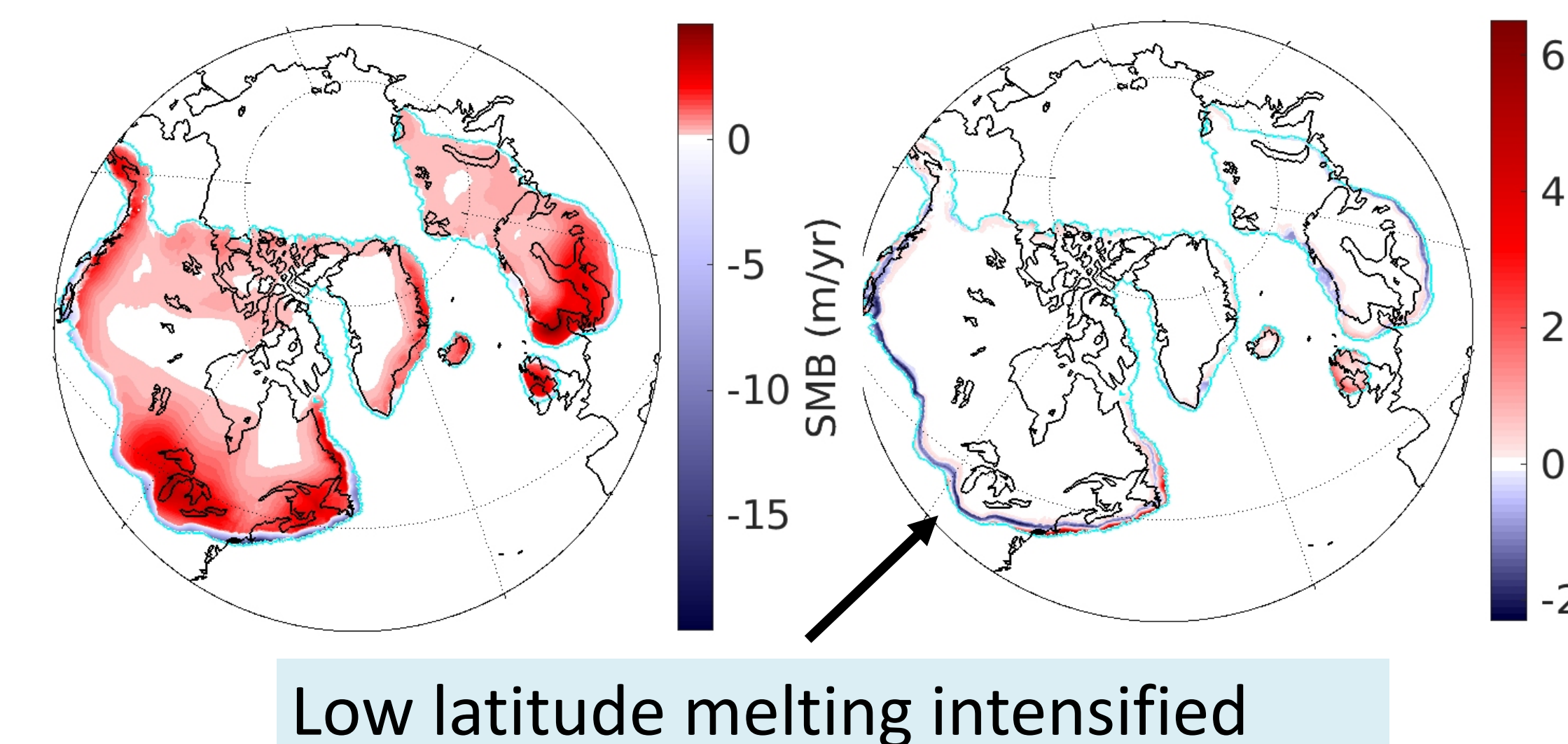


Fig.2, left: Ensemble mean surface mass balance (SMB) for the 1980-2012 period from the surface mass balance model intercomparison project SMBMIP⁽⁴⁾, **right:** mean 1980-2012 SMB from the dEBM scheme with ERA-Interim forcing downscaled to 1km resolution.

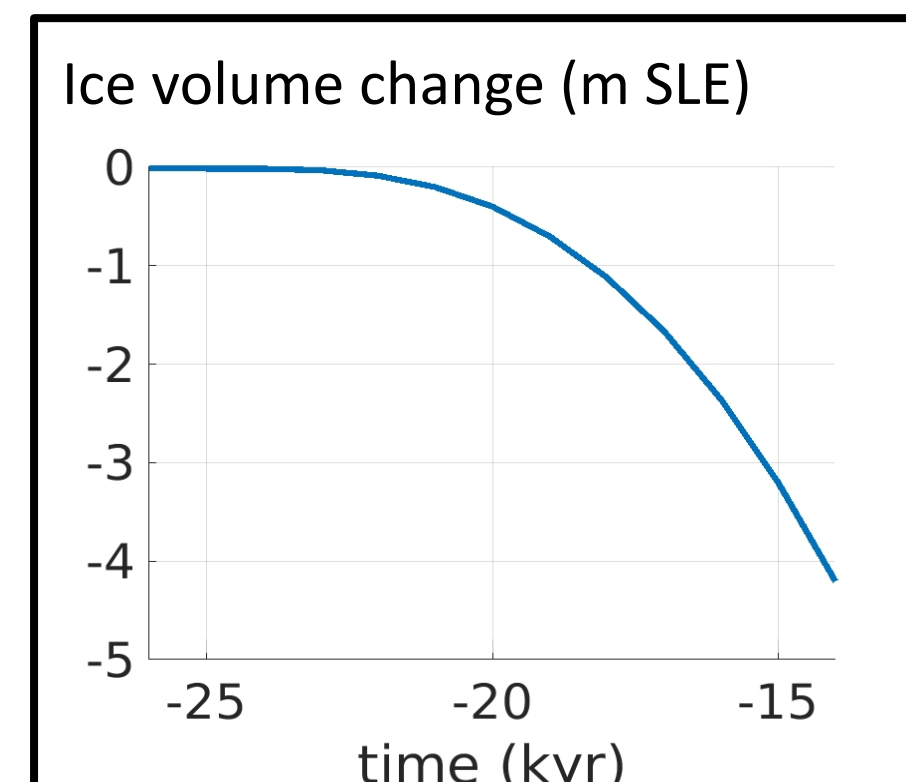
2. Application to last glacial maximum (LGM) forcing



Low latitude melting intensified

Fig.3, left: dEBM surface mass balance (SMB) with atmospheric forcing from a last glacial maximum (LGM) simulation with the climate model AWI-CM⁽⁵⁾; **right:** bias of the dEBM SMB versus the positive degree day scheme⁽⁶⁾ as implemented in PISM.

Fig.4: Contribution of radiation changes to Northern hemispheric ice mass change as inferred from dEBM surface mass balance for insolation orbitally changing between 26 and 14 kyr BP in combination with invariant temperature and precipitation forcing from one and the same LGM simulation from the climate model AWI-CM⁽⁵⁾.



Orbital insolation changes contribute <10 cm/100years to the sea level rise at the end of the last glacial period, which was O(1m/100years)

Positive feedbacks (lapse rate feedback, accelerating ice streams) may enhance the sensitivity to insolation changes

Additionally, rising air temperatures, ocean-ice interaction, dust deposition contribute to deglacial sea level rise \rightarrow coupled modelling in preparation

References

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