Uta Krebs-Kanzow, Shan Xu, Paul Gierz and Gerrit Lohmann
Alfred-Wegener-Institut, Helmholtz Centre for Polar and Marine Research (AWI)

ALFRED-WEGENER-INSTITUT
HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG

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

SMB = (SF+ ME- RFR)*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)

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

$RFR_{pot} = \min(0, Q/h_{fus})$, h_{fus} specific enthalpy of fusion

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

$RFR \leqq ME + Rain$ (refreezing is only possible, if liquid water is available)

$RFR * dt \leqq 0.6 * \text{snow height}$ (limitied water storage of snow, no refreezing on ice)

Energy balance of a melting ice surface

$Q = (1-A)\, SW\downarrow + c_1 T + c_2$
with albedo **A,** downwelling short wave radiation **SW↓**, near surface air temperature **T**

c1, c2, 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 → ($c_2 < 0$)

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 → insolation of diurnal refreezing and melting periods calculated from **monthly mean forcing (***Krebs-Kanzow et al, 2018), Fig. 1*

Distinguishing clear sky and overcast conditions

Monthly mean cloud cover (%) = (overcast days per month) / (days per month)

Different emissivities for clear sky, overcast conditions → $c_{1,clear}$, $c_{2,clear}$, $c_{1,cloudy}$, $c_{2,cloudy}$

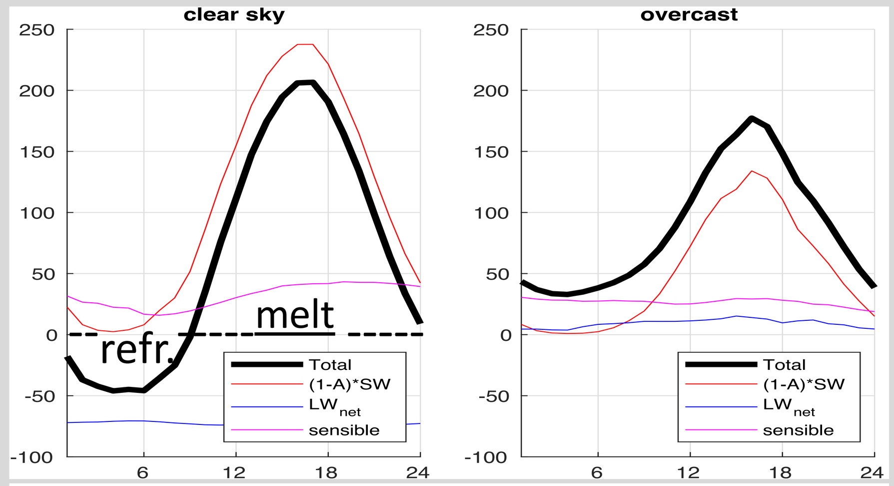


Fig.1 *Example for mean July diurnal cycle in Western Greenland (PROMICE[2] station KAN) for overcast and clear sky*

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-millenial variations in the solar radiation using a climate simulations of the last glacial mximum as a forcing.

1. Application to ERA-Interim[3] forcing

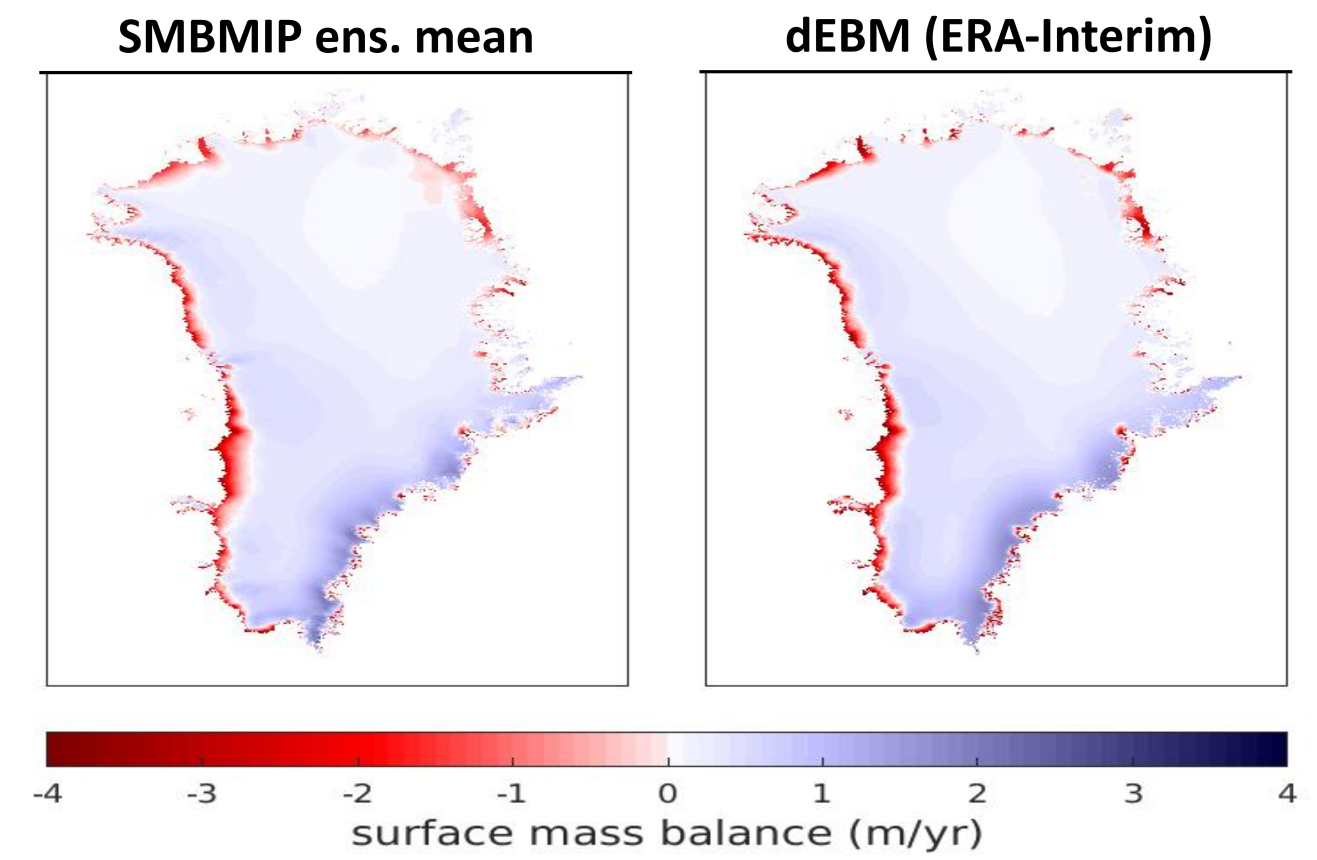
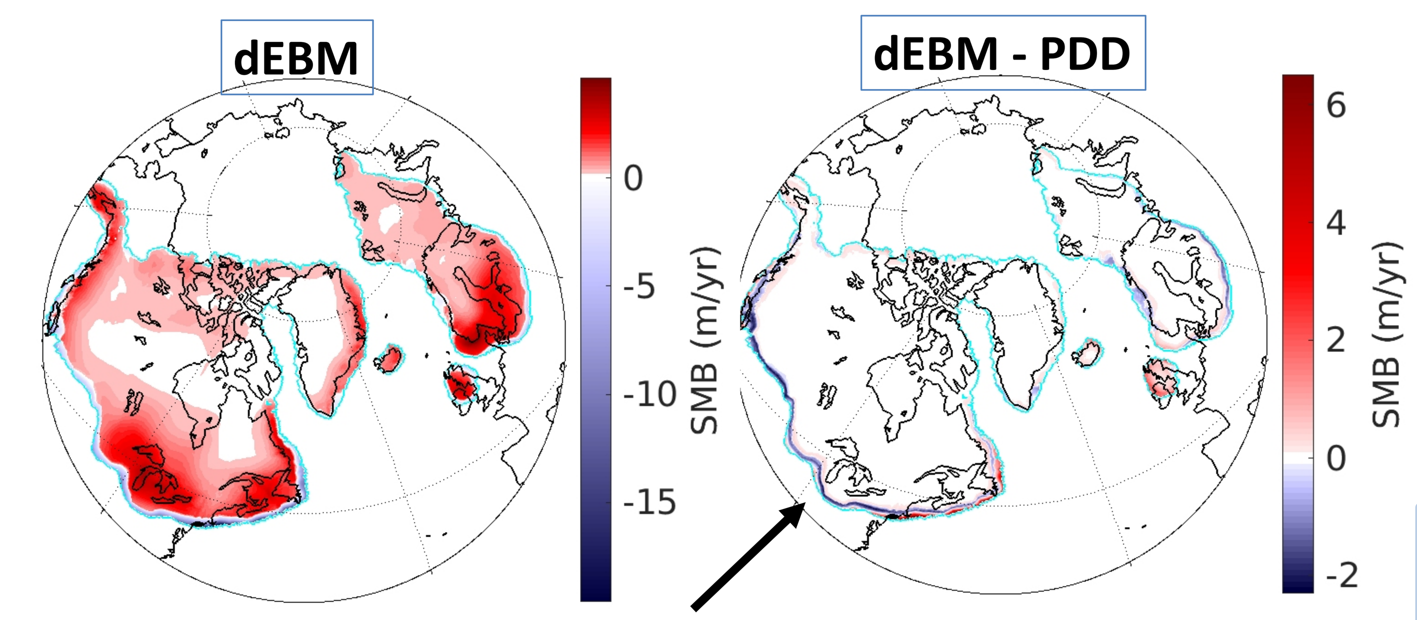


Fig.2, left: *Ensemble mean surface mass balance (SMB) for the 1980-2012 period from the surface mass balance model intercomparison project SMBMIP[4], **right**: mean 1980-2012 SMB from the dEBM scheme with ERA-Interim forcing downscaled to 1km resolution.*

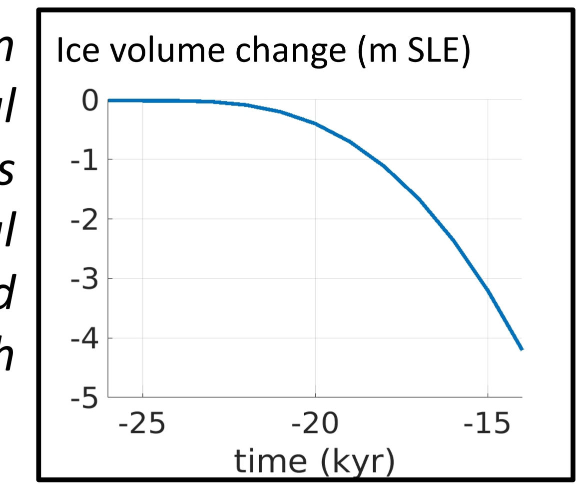
2. Application to last glacial maximum (LGM) forcing



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 Northen hemispheric ice loss at the end of the last glacial period. Between 26 and 14 kyr BP, the dEBM was forced with insolation changing according to orbital parameters, and with (invariant) temperature and precipitation forcing from a LGM simulation with the AWI-CM[5] climate model.*



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 → coupled modelling in preparation

References

(1) Krebs-Kanzow, U., Gierz, P. and Lohmann, G. (2018). Brief communications: Ice surface melt scheme including the diurnal cycle, The Cryosphere, https://doi.org/10.5194/tc-12-3923-2018
(2) Sørensen, L. S., Simonsen, S. B., Forsberg, R., Stenseng, L., Skourup, H., Kristensen, S. S., & Colgan, W. (2019). Programme for monitoring of the Greenland ice sheet (PROMICE): Airborne survey. Dataset published via Geological Survey of Denmark and Greenland and DTU-Space. https://doi.org/10.22008/promice/data/airbornesurvey.
(3) ERA-Interim: https://www.ecmwf.int/en/forecasts/datasets/reanalysis-datasets/era-interim
(4) SMBMIP: http://climato.be/cms/index.php?climato=SMBMIP
(5) Sidorenko, D., Rackow, T., Jung, T., Semmler, T., Barbi ,D., Danilov, S., Dethloff ,K., Dorn, W., Fieg, K., Goessling, H. F., Handorf, D., Harig, S., Hiller, W., Juricke, S., Losch, M., Schröter, J., Sein, D. V., Wang, Q. 2015. Towards multi-resolution global climate modeling with ECHAM6–FESOM. Part I: model formulation and mean climate. *Climate Dynamics*, *44*(3-4), pp.757-780.
(6) Krebs-Kanzow, U., Gierz, P. and Lohmann, G. (2018). Estimating Greenland surface melt is hampered by melt induced dampening of temperature variability. Journal of Glaciology, doi:10.1017/jog.2018.10

SPP SeaLevel
REKLIM Helmholtz-Verbund Regionale Klimaänderungen
ALFRED-WEGENER-INSTITUT HELMHOLTZ-ZENTRUM FÜR POLAR- UND MEERESFORSCHUNG
HELMHOLTZ GEMEINSCHAFT
BREMERHAVEN
Am Handelshafen 12
27570 Bremerhaven
Telefon 0471 4831-0
www.awi.de