Numerical simulations of major ice streams in western Dronning Maud Land, Antarctica, under wet and dry basal conditions

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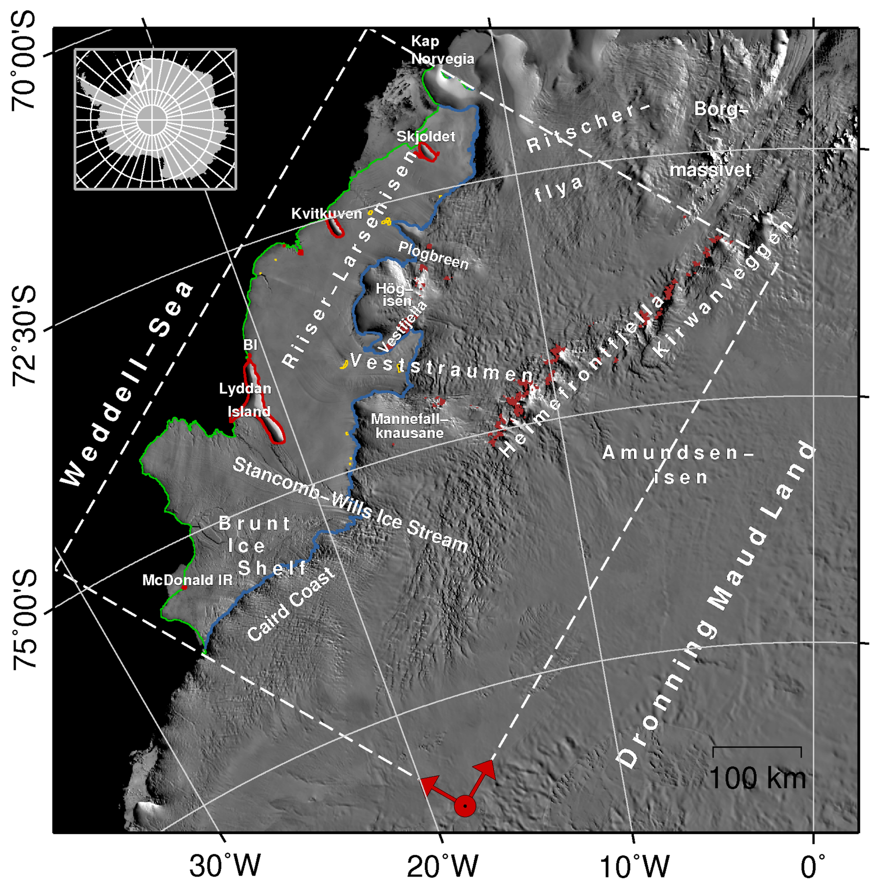
Introduction

We present numerical simulations of the present day ice flow using the three-dimensional thermo-coupled full-Stokes model TIM-FD3 on a 2.5 km horizontal grid in the area of the western Dronning Maud Land, Antarctica, including the three major ice streams Stancomb-Wills, Veststraumen and Plogbreen and the adjacent Brunt and Riiser-Larsen ice shelves (see figure below).

We estimate the distribution of subglacial water based on flux routing methods and compare the contribution of the basal sliding velocity to the general flow for wet and dry conditions at the ice base.



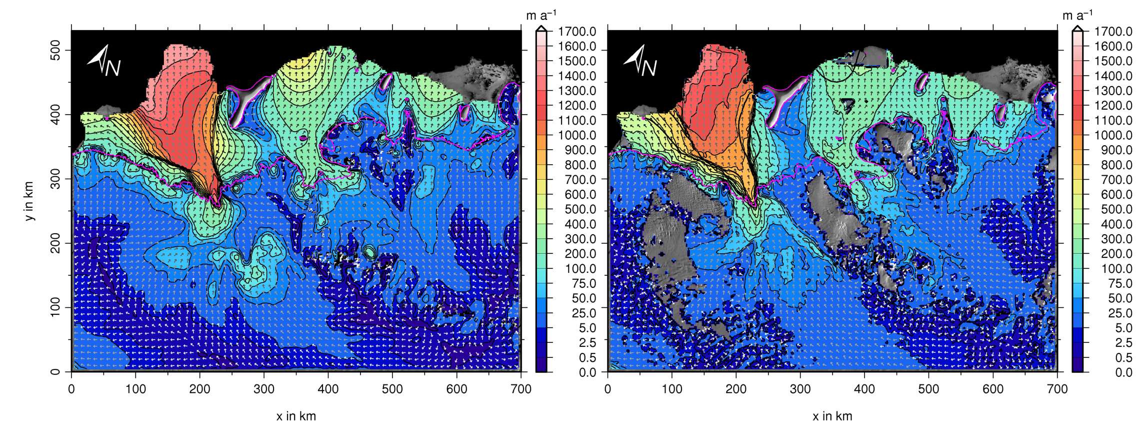
MOA image (Haran et al. 2005) of the study area including feature names. The dashed white rectangle shows the extend and orientation of the model domain.

Method: ice flow modelling

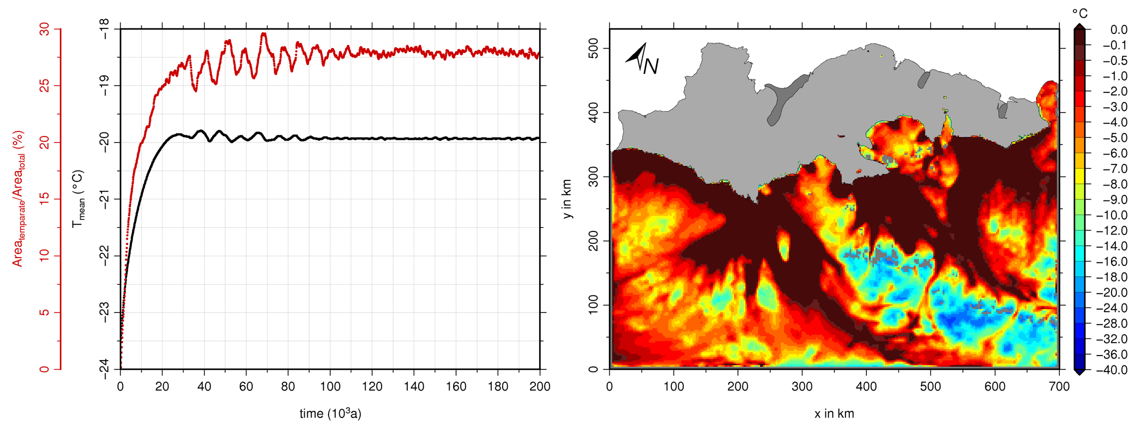
The finite-difference full-Stokes TIM-FD3 model (Kleiner, 2011) is based on the general continuum mechanical balance equations of mass, momentum, and energy for an incompressible power-law fluid (Glen, 1955). The viscosity depends on stress, temperature and micro-scopic water content. The temperature distribution within the ice is calculated with the general time dependent heat transfer equation, neglecting horizontal conduction. Spatial derivatives are approximated on a horizontal equidistant grid with vertical sigma coordinates. All physical properties are co-located. We use a semi-implicit Crank-Nicholson scheme to evolve the tempe-rature in time.

Model spin-up (200ka)

Geometry: mainly based on GPR measurements 1994-2008 (AWI, BAS), laser altimeter ICESat/GLAS 2003 and digital image map MOA 2003-2004
Boundary conditions: surface temperatures (Comiso, 2000), surface accumulation rates (van de Berg et al., 2006), geothermal heat flux (Shapiro & Ritzwoller, 2004)
Model domain: 2.5 km resolution, 21 vertical layers



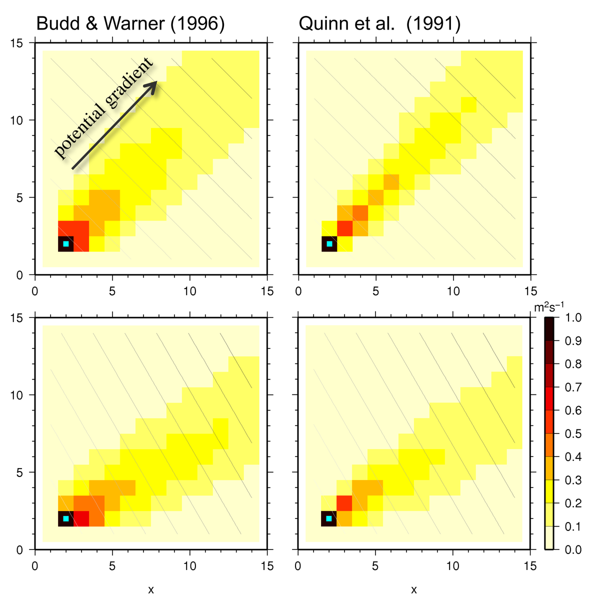
Simulated surface velocities (left) at the end of the 200ka model spin-up with present day boundary conditions and Antarctic surface velocities (right) derived from satellite radar interferometry (Rignot et al., 2011). Ice thickness evolution and basal sliding are numerically suppressed.



The temporal evolution of the total mean temperature and the fraction of the warm base area to the total grounded ice area (left) and the homologous temperature at the base (right).

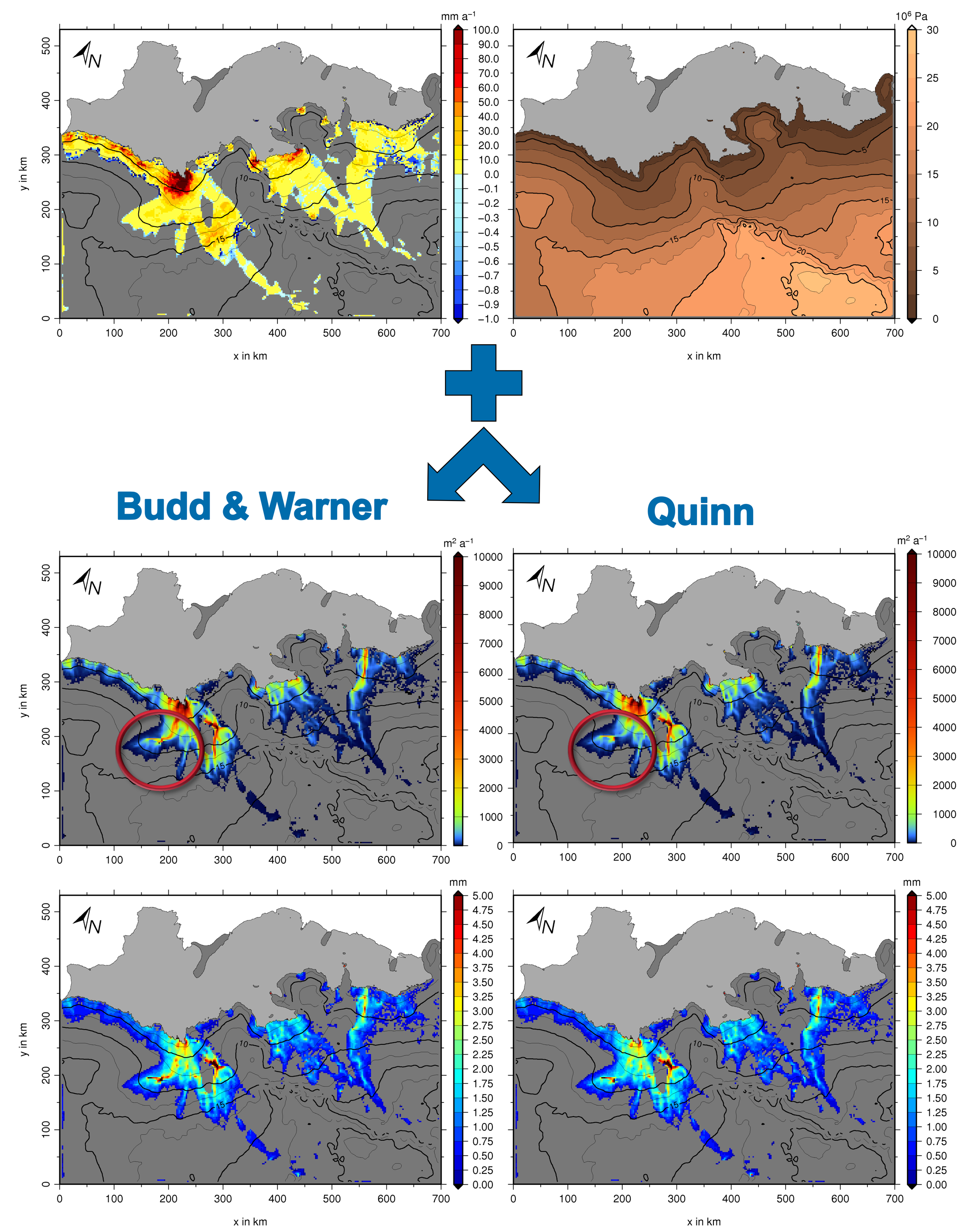
Method: flux routing

The subglacial water flow model assumes that water flows in a thin film of water in the order of mm thickness. Two different flux routing schemes considering 4 (left column) and 8 neighbors (right column) have been used.
The schemes have been tested with different simplified subglacial pressure potential fields and one unit source on a grid with unit area.



Results

Basal melt rates (left) and and subglacial pressure potential (right) at the end of the 200ka spin-up.



Simulated water fluxes (upper row) and derived thickness of the basal water layer (lower row). Main differences between both methods can be found in the Stancomb-Wills Glacier area (red circle).

Subglacial sliding

Weertman-type sliding: $u_b = f_T\,(1+f_w)\,C_b^0\,\frac{|\tau_b|^{p-1}}{N^q}\tau_b$

Submelt sliding: $f_T = \exp\left(\nu\,(T - T_{pmp})\right)$

Effect of subglacial water: $f_w = A\left(1 - \exp\left(H_w/H_w^0\right)\right)$

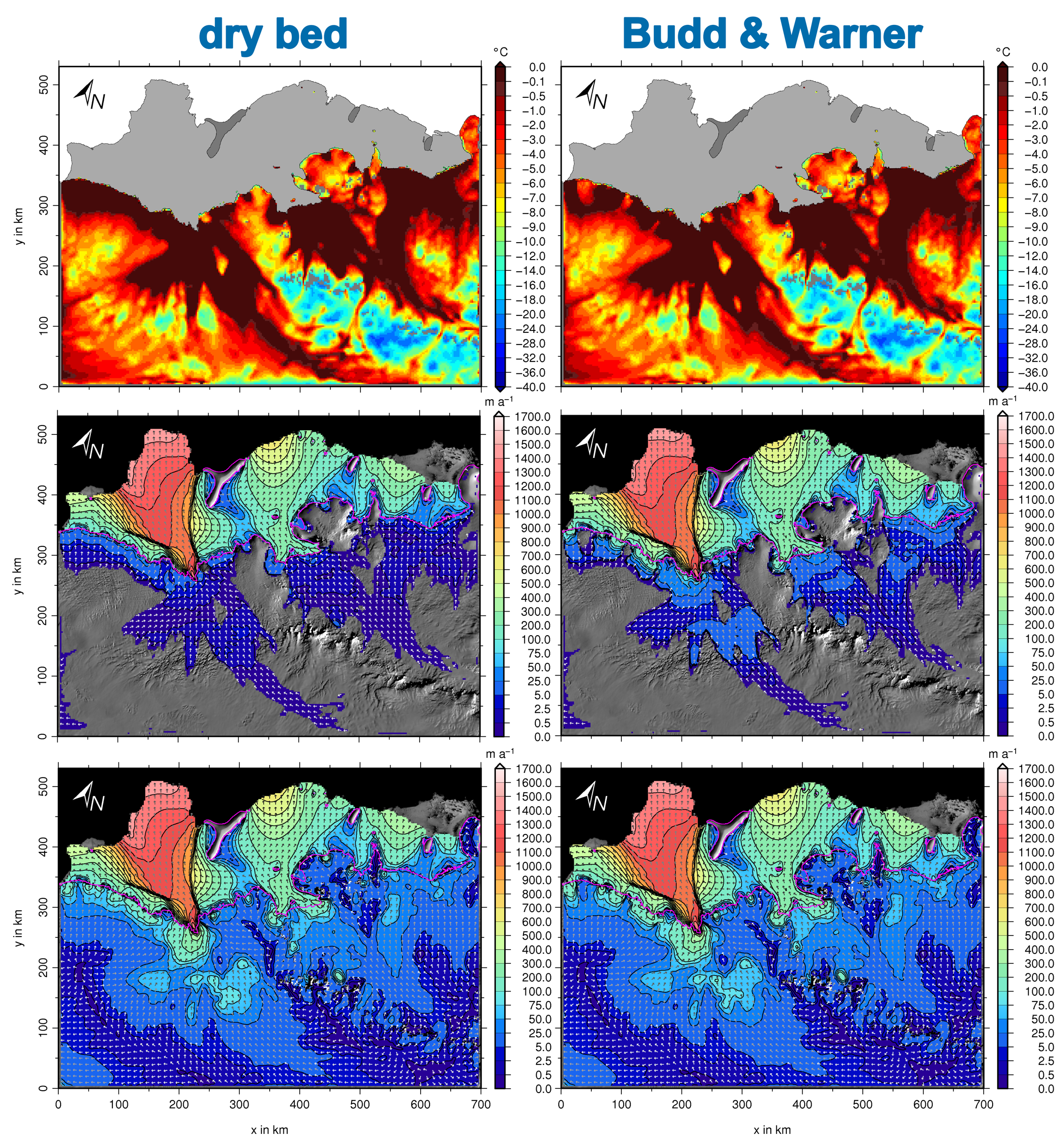
Robin-BC: $\underbrace{\mathbf{t}_b\cdot(\mathbf{S}\cdot\mathbf{n}_b)}_{=\tau_b} = \beta^2\,\underbrace{\mathbf{t}_b\cdot\mathbf{u}}_{=u_b}$

Parameters: $C_b^0 = 10^3\,\mathrm{a}^{-1}/(\rho g), p = 3, q = 2, N = \rho g H, \nu = 4, H_w^0 = 1\,\mathrm{mm}$

We use a zero water layer thickness (H_w = 0) for dry bed simulations.

Coupled simulations (10ka)

Subglacial water coupled to ice flow dynamics via the sliding law.



Simulated basal temperatures, basal velocities and surface velocities at the end of a 10ka model run restarted from the spin-up are shown in the figure above (from top to bottom). Water flux routing with the Budd & Warner (1996) scheme leads to similar results as in the Quinn et al. (1991) case (not shown here).

Conclusion

At the end of the spin-up approx. 27.5% of the grounded ice area is at the pressure melting point, thus melt water is available to lubricate the glacier bed. In the upstream region of the Stancomb-Wills Glacier a sticky spot with ice frozen to the ground exists. Observed surface velocities are in agreement with this finding. The incorporation of a water layer thickness dependent factor in the sliding law has an effect on the sliding velocities and hence the surface flow field. The drainage of Coats Land into the Brunt Ice Shelf is channelized into glaciers by using the water thickness dependent sliding law. We conclude that the resulting flow field matches the reality considerably better, taking the water layer thickness into account.

Acknowledgements
We thank D. Steinhage (AWI) and D. G. Vaughan (BAS) for providing GPR measurements, and R. Warner and S. Vogel (ACE CRC) for discussions related to the basal hydrology and flux routing.
This work was supported by the Cluster of Excellence CliSAP at the KlimaCampus, University of Hamburg.

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