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# Modelling basal conditions of ice sheets


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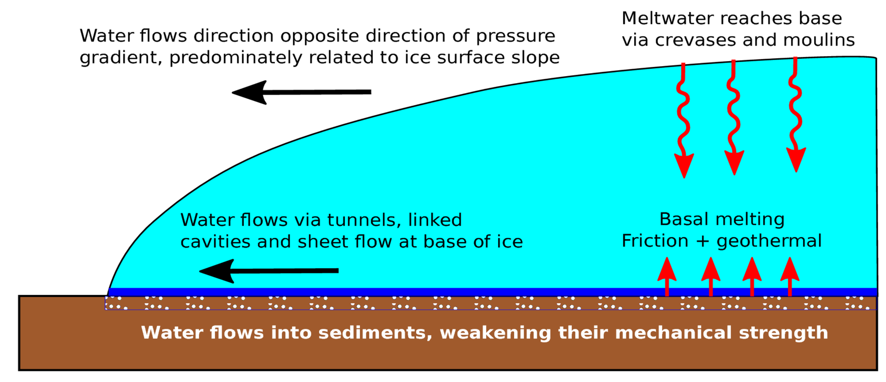
## Basal conditions: the key to ice flow

Greenland and West Antarctica are experiencing a disproportionate increases in temperature due to global warming. There are already observations that this is coinciding with increased velocity of ice streams in these ice sheets.

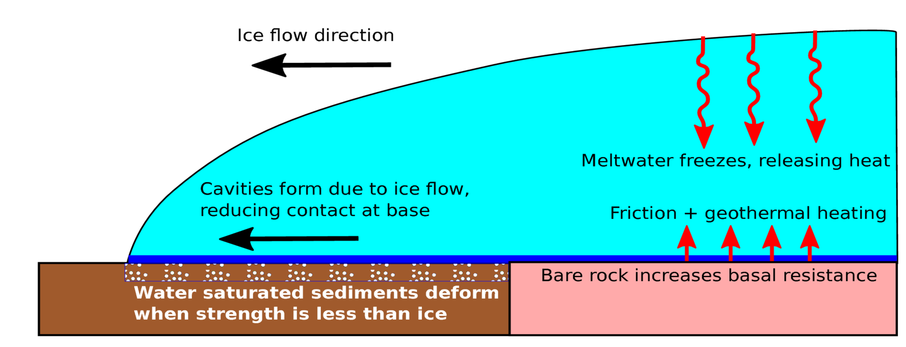
The flow of large ice sheet masses is dependent on the conditions at the base. Direct observations of the base of ice sheets are extremely limited. Due to this, is is instructive to look at how past ice sheets behaved during periods of rapid warming.

In order to investigate ice sheet basal conditions, we use the Parallel Ice Sheet Model (PISM; Bueler and Brown, 2009). This next generation ice sheet model allows for the modeling of ice sheet dynamics by coupling the shallow ice approximation in regions with low velocity, and the shallow shelf approximation in places where sliding occurs. The goal of our project is to create a model that accounts for changes in basal conditions such as sediment distribution and hydrology, but still fast enough to work over the millennial time scales that paleo-ice sheets existed.

### Ice Sheet Hydrology




### Ice Sheet Dynamics

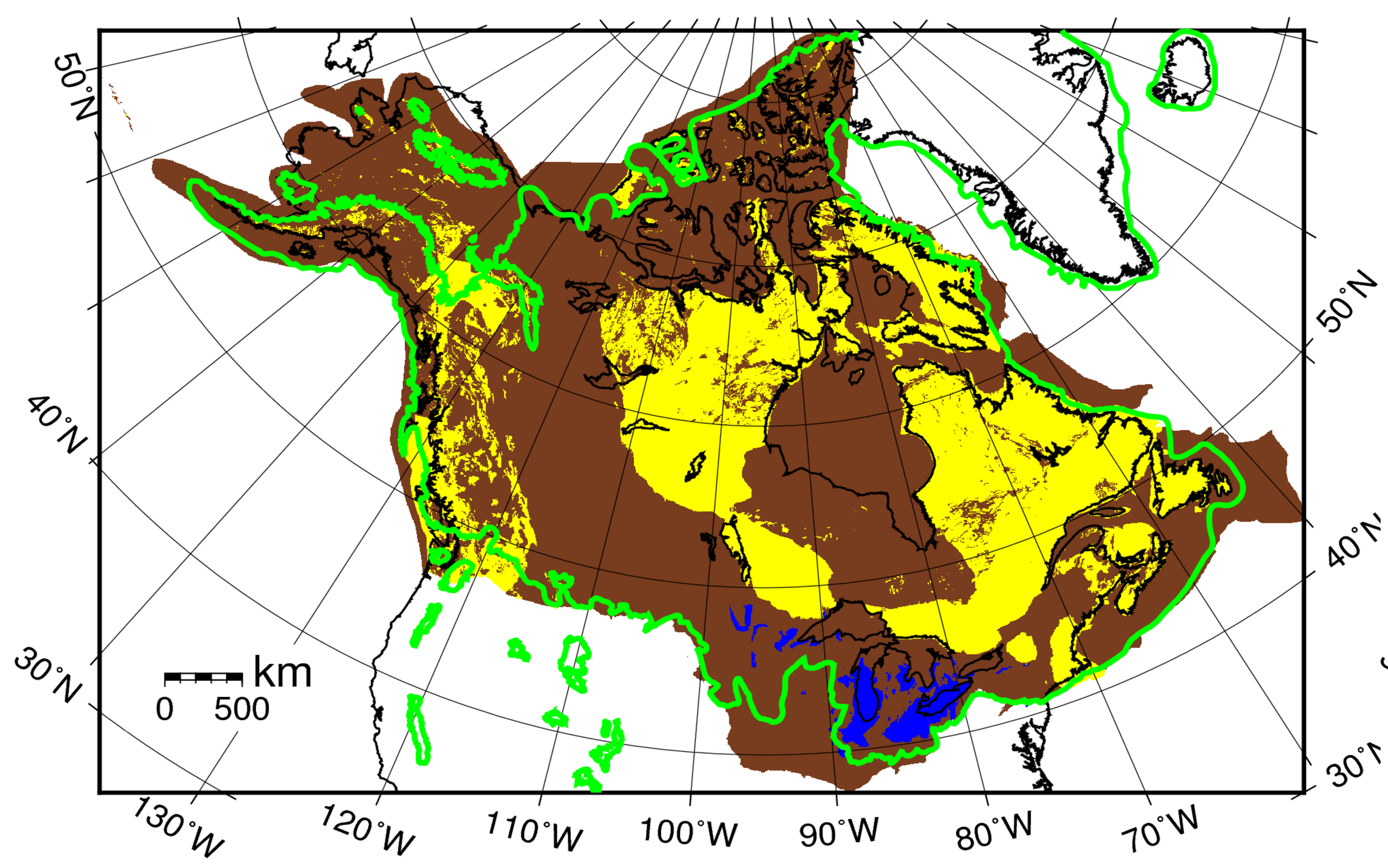



The flow of large ice sheet masses is largely dependent on the conditions at the base. Some factors include:

- **Temperature** – ice becomes softer and easer to deform when it reaches the pressure melting point
- **Presence of liquid water** – Water acts as a lubricant to allow the ice to flow. Produced from melting due to frictional and geothermal heating, and from water that reaches the base from surface melting
- **Presence of sediments** – deformation of water saturated sediments are theorized to be a dominant mechanism to allow ice to flow.
- **Contact with the base** – ice flow opens up gaps and cavities, reducing contact with base, and also gives a conduit for water flow

## Sediments properties in areas glaciated by the Laurentide Ice Sheet

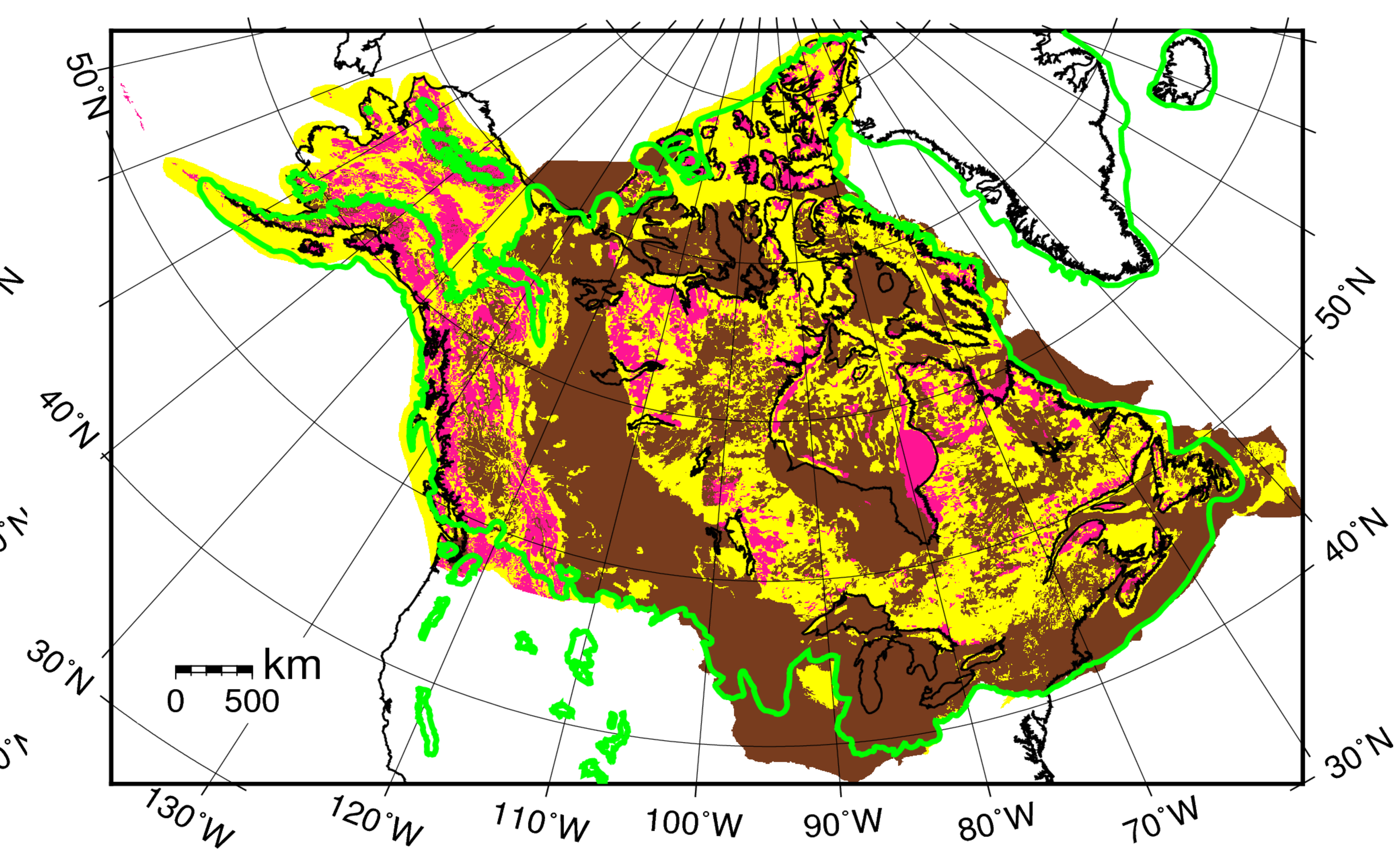
### Basal sediment composition




Clay   Silt   Sand

~21 ka extent (Dyke 2004)

### Basal sediment distribution




Blanket (continuous)   Veneer (discontinuous)   Rock

~21 ka extent (Dyke 2004)

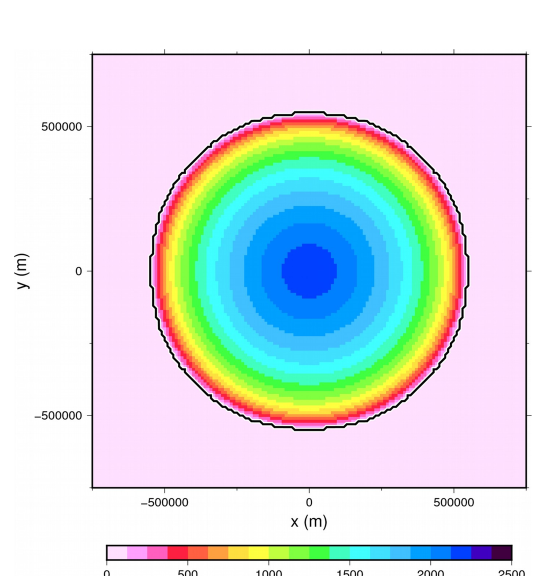
The Laurentide ice sheet had notable differences in behaviour depending on whether the active part of the ice sheet laid on the "hard bedded" Canadian Shield, or the "soft bedded" sedimentary basins at the southern and western peripheries and Hudson Bay. In the "soft bedded" regions, the ice sheet profile was lower, and there were numerous ice streams, possibly aided by sediment deformation. In "hard bedded" regions, the hydrological regime was dramatically different, as water escaped the subsuface through vast esker systems.

We have made a compilation map of the distribution and composition of sediments. We intend to test the hypothesis that the change in basal conditions from hard bedded regions where the ice sheet nucleated to areas where sediments could deform was a major control on ice sheet growth and retreat.

## Preliminary Modeling Experiments

Our preliminary experiments use a modified version of the EISMINT B experiment (Payne *et al*. 2000). The idealized dome ice sheet is allowed to grow to an approximate equilibrium after 5000 years, when the ice sheet is about 2500 m thick (see below). The grid resolution used in these tests is 10 km.

The water is allowed to flow via a Darcy's Law relationship, with an "equivalent water layer thickness" of 0.2 m (equivalent to about 1 m of sediment assuming 20% porosity), and an average basal melting rate of 1 m/yr. The water is transported completely in the direction opposite of the surface elevation gradient. To increase the speed of calculation, the mechanisms that allow water flow are not considered. thermodynamic processes are also not considered.




Ice sheet thickness
after 5000 years

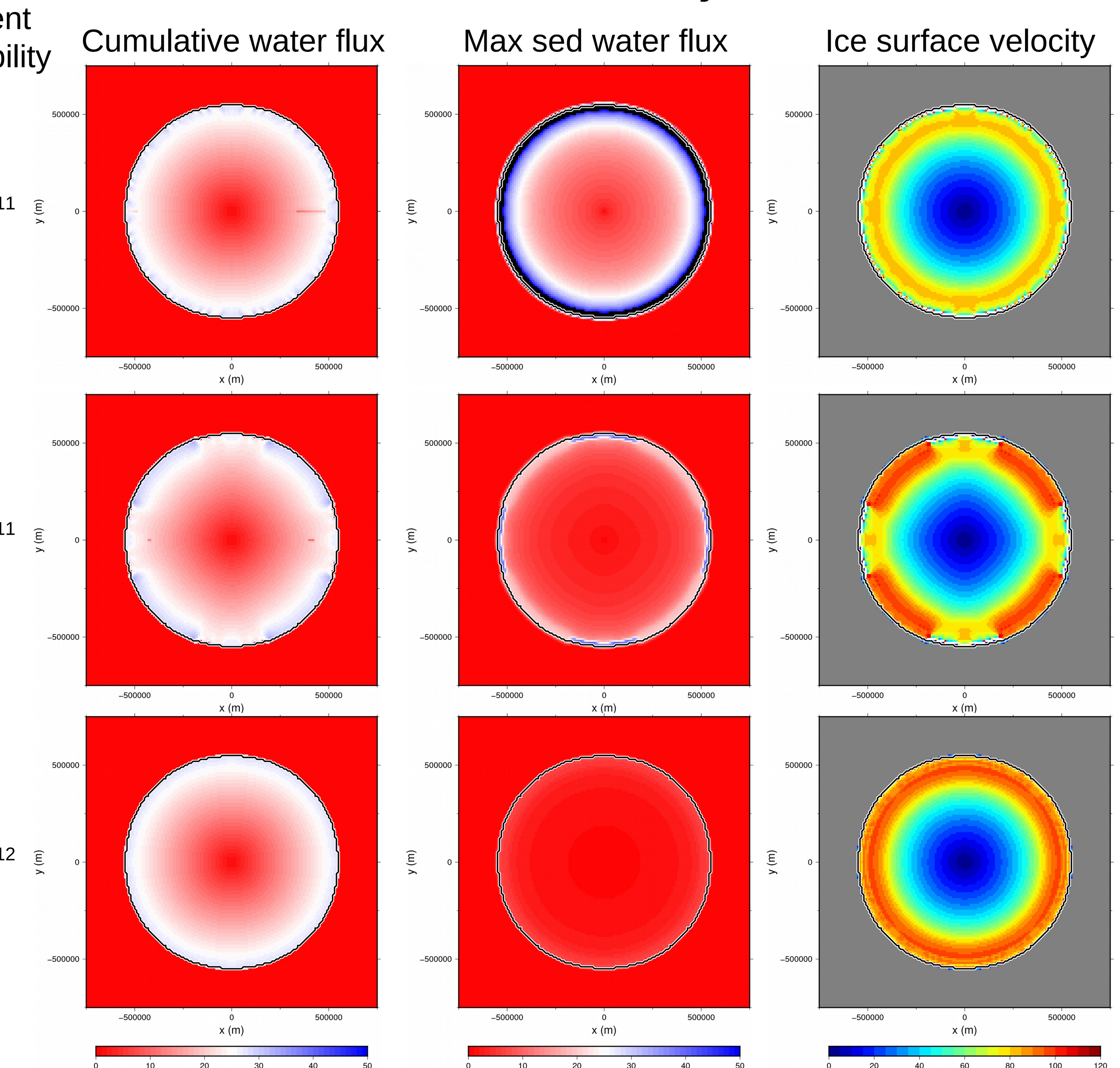
### Sediment Permeability Test

Sediment Permeability (m/s) | Cumulative water flux | Max sed water flux | Ice surface velocity

$3.2 \times 10^{-11}$

$1.0 \times 10^{-11}$

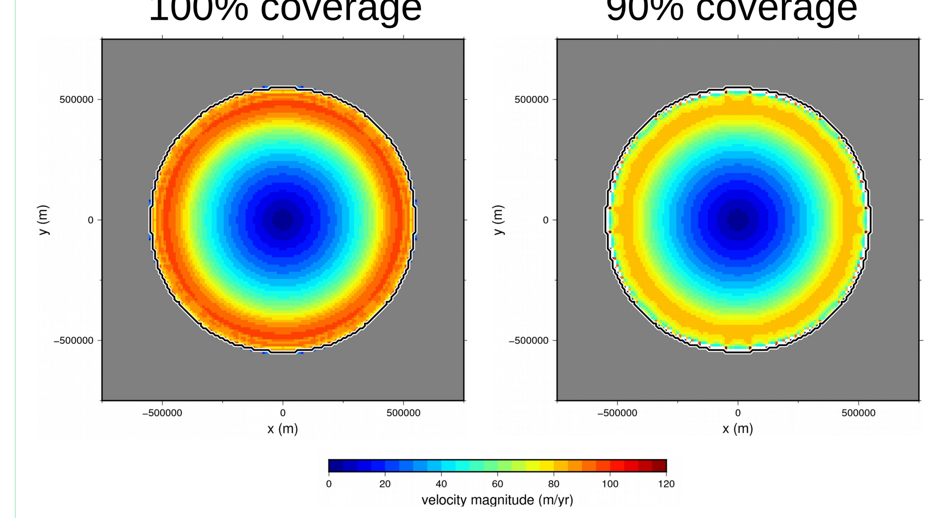
$3.2 \times 10^{-12}$




If the ice sheet is completely underlain by sediments, it is possible that those sediments can completely accommodate the water flowing at the base. In the above test, the permeability of the sediments is changed to show that even though the sediments are very impermeable, it can still accommodate the 1 m/yr basal melting rate. Due to the geometry of the ice sheet, the intermediate case shows places where the sediment water flux is sufficient to drain all the water at the cardinal directions, and shows increase surface velocity where it does not.

### Sediment Distribution Test

100% coverage   90% coverage




Using the previous example with a permeability of $3.2 \times 10^{12}$ m/s, simply reducing the distribution of sediments from 100% of the area to 90% is sufficient to return to the ice sheet to the low velocity state.

### Outlook

Initial tests indicate that sediments play a role in governing the velocity of the ice sheet, but only if they are completely saturated and cover the entire base of the ice sheet.

In order to have an effect, the sediments must have sufficiently low permeability, otherwise the meltwater will simply flow through the sediments and they will not become saturated.

For the Laurentide ice sheet, this may indicate that the combination of low ice sheet profile (to reduce the pressure gradient and therefore water flow rate) and low permeable sediments must have combined to explain the change in dynamics from the Canadian Shield to the sediment covered peripheries.


References:
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Payne, A.J., Huybrechts, P., Abe-Ouchi, A., Calov, R., Fastook, J.L., Greve, R., Marshall, S.J., Marsiat, I., Ritz, C., Tarasov, L. and Thomassen, M.P.A., 2000. Results from the EISMINT model intercomparison: the effects of thermomechanical coupling. Journal of Glaciology, 46(153), pp.227-238.



Acknowledgements:
Thanks to Constantine Khroulev for help in model development. Development of PISM is supported by NASA grants NNX13AM16G and NNX13AK27G. This study is funded as part of REKLIM (Regionale Klimaänderungen/Regional climate change)



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