Project: **1405**
Project title: **Reconstruction of ice streams in polar ice sheets**
Principal investigator: **Paul Bons**
Allocation period: **2023-11-01 to 2024-10-31**

Overview

Fast-flowing ice streams drain most of the inland ice from the Antarctic and Greenland ice sheets. However, the formation mechanism of an ice stream and its shear margins is still controversial, such as the huge North-East Greenland Ice Stream (NEGIS). Here we introduce the full-Stokes code "Underworld2" (Beucher et al., 2024) to simulate anisotropic ice flow in 3D large-scale ice-sheet models (Sachau et al., 2022; Zhang et al., 2024), especially how ice streams form and behave now, in the past and in the future. For the first time, the formation of an ice stream is modeled successfully without external forcing such as basal melting. A large-scale ice stream like NEGIS can be initiated in only a few thousand years by anisotropic rheology of ice and evolving c-axis orientations of ice crystals. This work may contribute to better explaining and predicting future ice drainage into the oceans and resulting sea-level rise during global warming.

In this report, we show the preliminary model results. A final and detailed comparison of all model results would later be accessed and published in the revising manuscript '*Rapid ice stream formation due to mechanical anisotropy*', where computing resources from Deutsches Klimarechenzentrum (DKRZ) will be mentioned in the Acknowledgments.

Model Design

The basic model setup is shown in Fig. 1. The horizontal x-axis and z-axis represent the length and width of the model respectively (50 × 40 km), while the y-axis is the elevation (3000 m). The model consists of an air layer (500 m) and an ice layer (2500 m) with 10 internal marker horizons associated with ice temperature gradient. On one z-wall (x=50 km), there is a 'gate' with a width of 10 km ($-5 \leq z \leq 5$ km) for the outflow (v_x=100 m/yr); and another z-wall (x=0 km) represents the inland ice divide. To compensate the outflow and maintain a constant ice volume, there are low-velocity inflows (v_{z1}; v_{z2}) from the two x-walls (z=20 km; z=-20 km) and the precipitation on the ice surface (surface accumulation rate v_{pr}=0.15 m/yr).

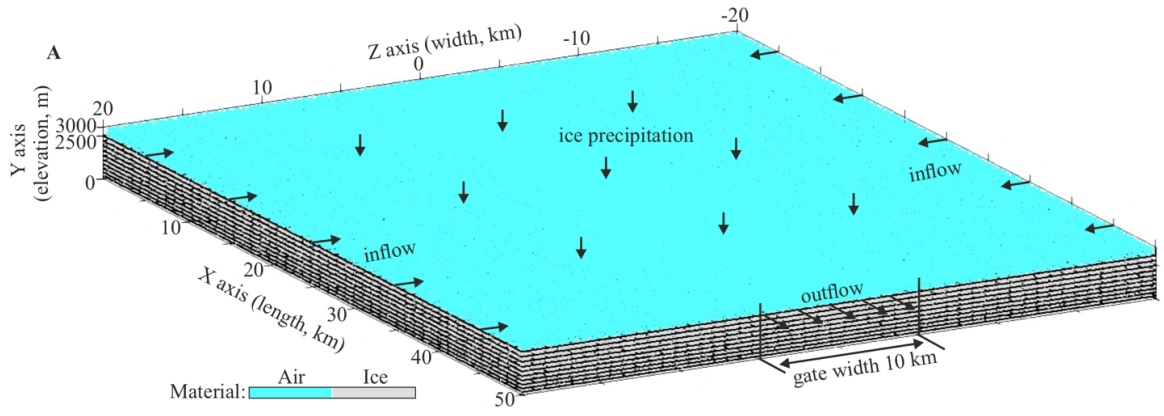

Fig. 1. 3D view of the initial model at t = 0 ka.

Model results

In the following model (Fig. 2), lateral inflows are asymmetric: the left velocity is two times

the right one. Between 1000 and 2000 years, the fast ice flow develops along the higher ice inflow side (left) and forms the initial ice stream (NEGIS-type) with a weak branch on the other side (right). At 4000 years, the ice stream grows farther inland and closes to the ice divide. From 4000 to 5000 years, the ice stream gradually narrows its width and exhibits a larger velocity difference with surrounding ice.

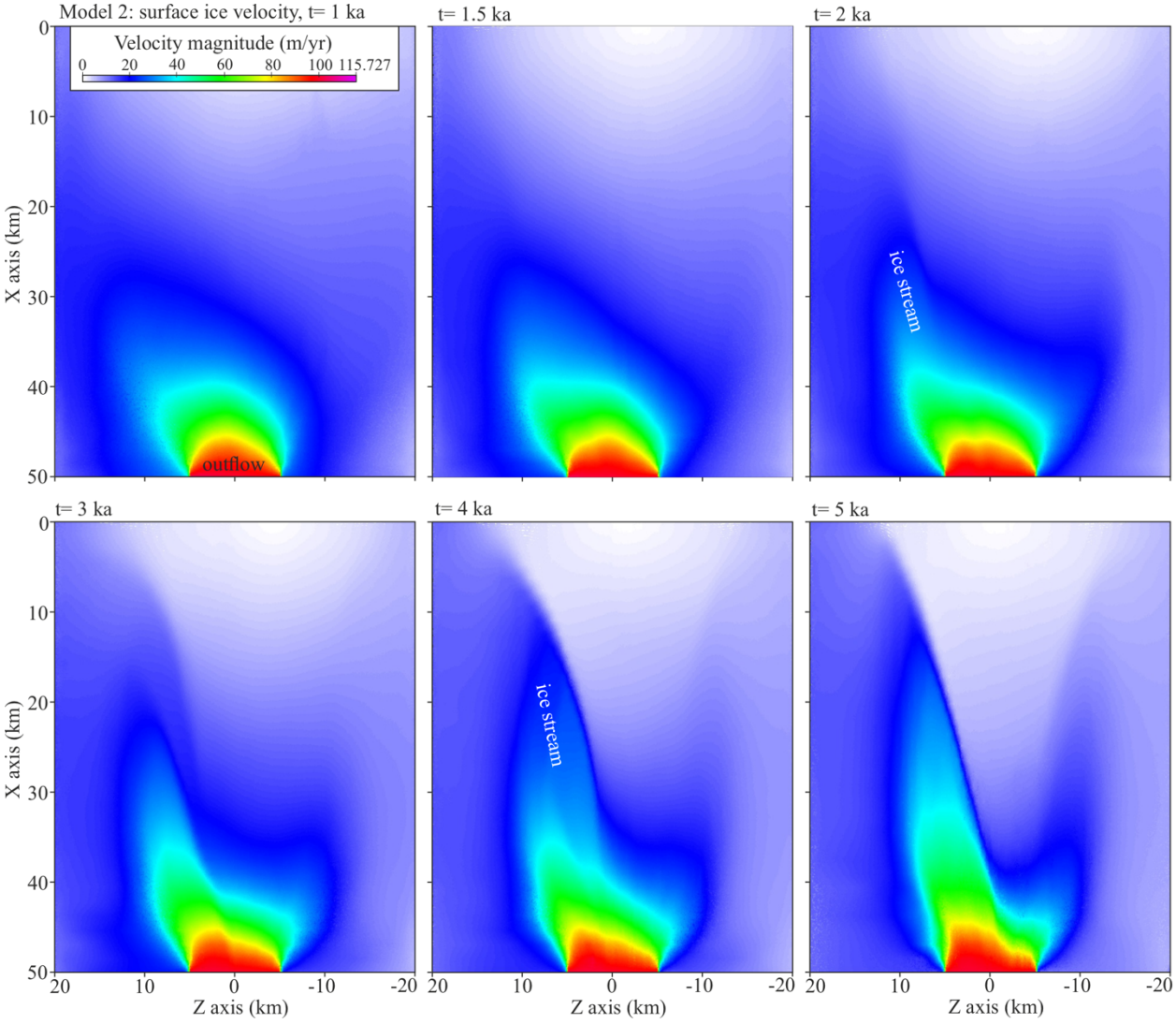

Fig. 2. Evolution of surface ice velocities from 1000 to 5000 years.

References

1. R. Beucher, J. Giordani, L. Moresi, J. Mansour, O. Kaluza, M. Velic, R. Farrington, S. Quenette, A. Beall, D. Sandiford, L. Mondy, C. Mallard, P. Rey, G. Duclaux, A. Laik, S. Morón, A. Beall, B. Knight, N. Lu, Underworld2: Python Geodynamics Modelling for Desktop, HPC and Cloud (v2.15.1b), Zenodo (2024); https://doi.org/10.5281/zenodo.10976370.
2. T. Sachau, H. Yang, J. Lang, P. D. Bons, L. Moresi, ISMIP-HOM benchmark experiments using Underworld. *Geosci. Model Dev.* **15**, 8749–8764 (2022). doi:10.5194/gmd-15-8749-2022
3. Y. Zhang, T. Sachau, S. Franke, H. Yang, D. Li, I. Weikusat, P. D. Bons, Formation mechanisms of large- scale folding in Greenland's ice sheet. *Geophys. Res. Lett.* **51**, e2024GL109492 (2024). doi:10.1029/ 2024GL109492