Simulating the impact of Antarctic subglacial hydrology on ice sheet evolution

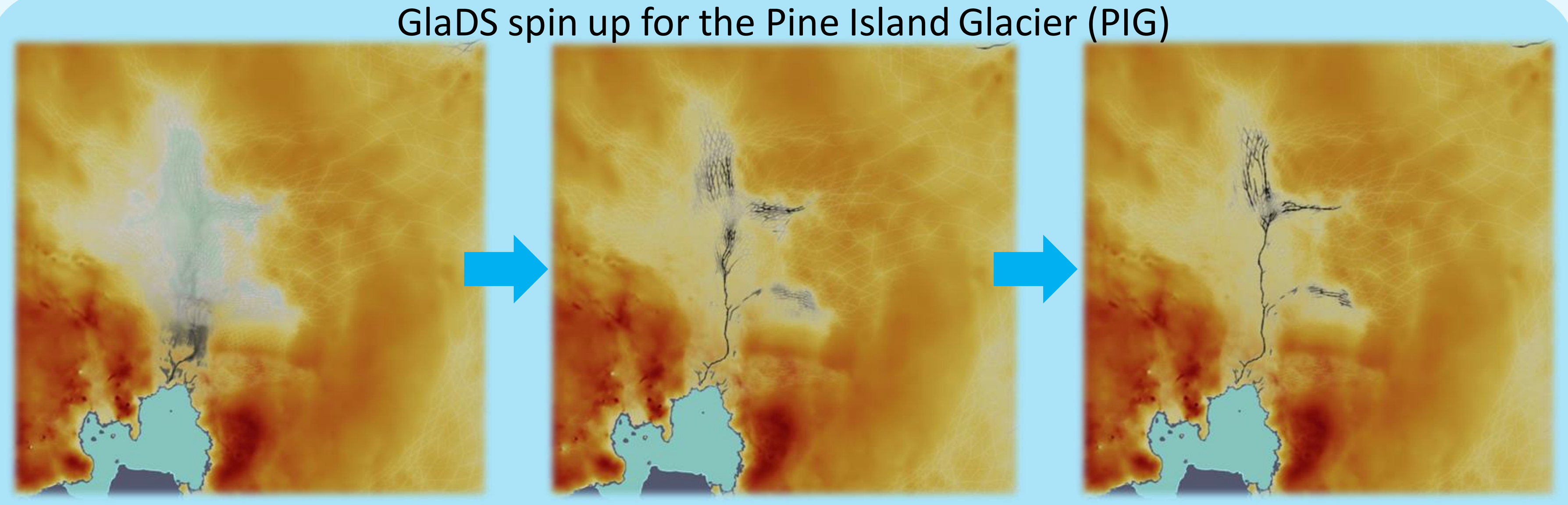
LAPIN YLIOPISTO
UNIVERSITY OF LAPLAND
For the North – For the World

Rupert Gladstone, Chen Zhao, Thomas Zwinger, Samuel Cook, Yu Wang, David Gwyther, Mauro Werder, Qin Zhou and John Moore

Antarctic hydrology modelling

- We use the Glacier Drainage System (GlaDS) model, which represents both a distributed "sheet" system (simulating a network of linked cavities) and a channel network.
- GlaDS is implemented within Elmer/Ice modelling framework and runs on Elmer/Ice's unstructured mesh of triangular elements.
- Our starting point is the Elmer/Ice initialised SSA ice dynamic model used for ISMIP6 simulations, where drag and enhancement factors have been optimised to match observations.
- GlaDS is driven by the following Elmer/Ice outputs:
- Ice thickness (used to calculate ice overburden pressure).
- Sliding velocity (used to calculate cavity opening rates).
- Melt source. Previous studies of Pine Island Glacier using full Stokes modelling and a consistent simulated thermomechanical state indicated that the dominant term in calculating basal melt water is friction heat, which is used here as the sole heat source for basal melt water input to GlaDS.

GlaDS spin up for the Pine Island Glacier (PIG)

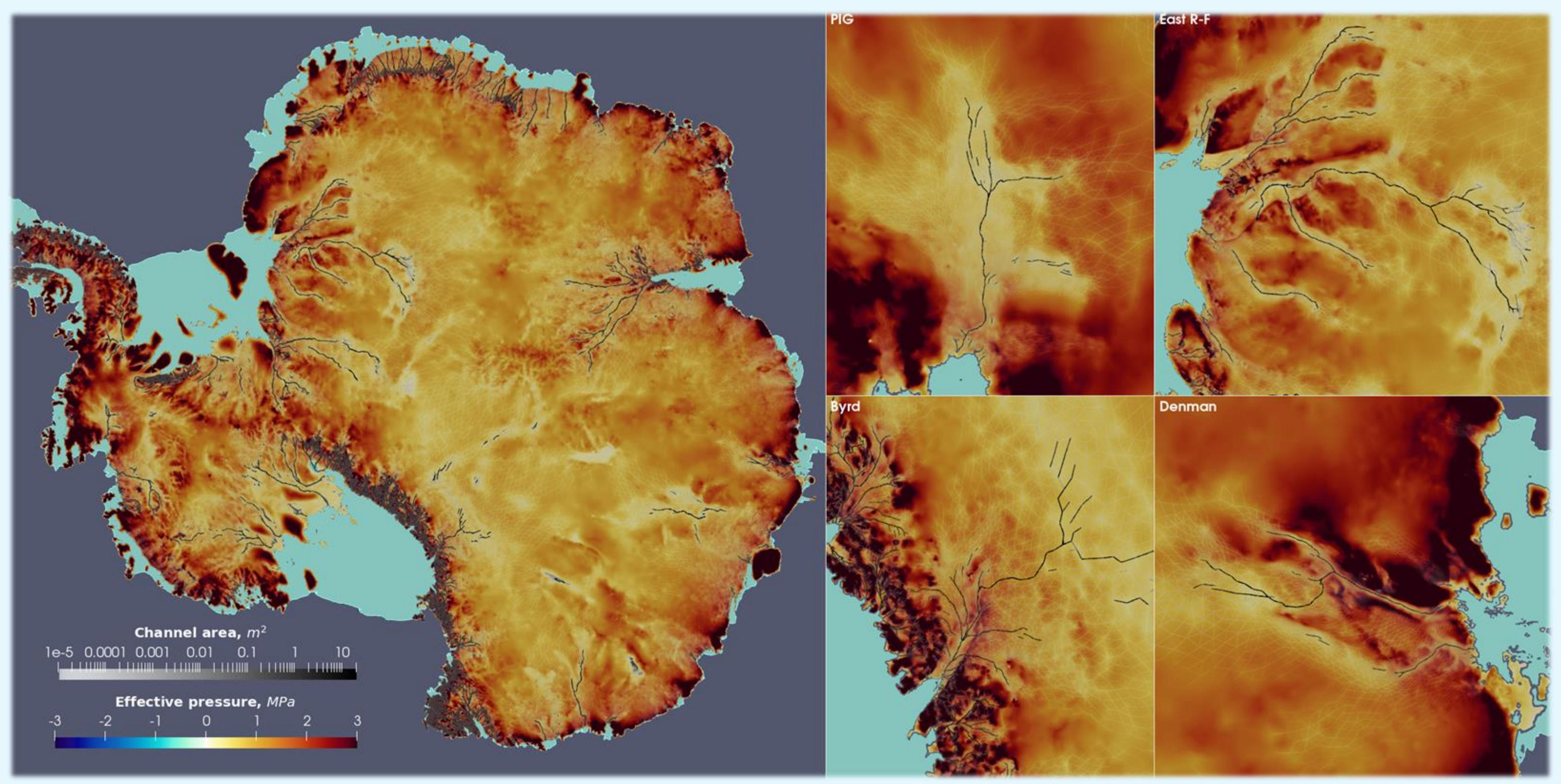


"Sheet" system spins up first, but is not efficient enough to discharge basal water, resulting in negative effective pressures.

A wide channel network starts to grow, bringing effective pressures above zero.

The channel network consolidates into a few large channels.

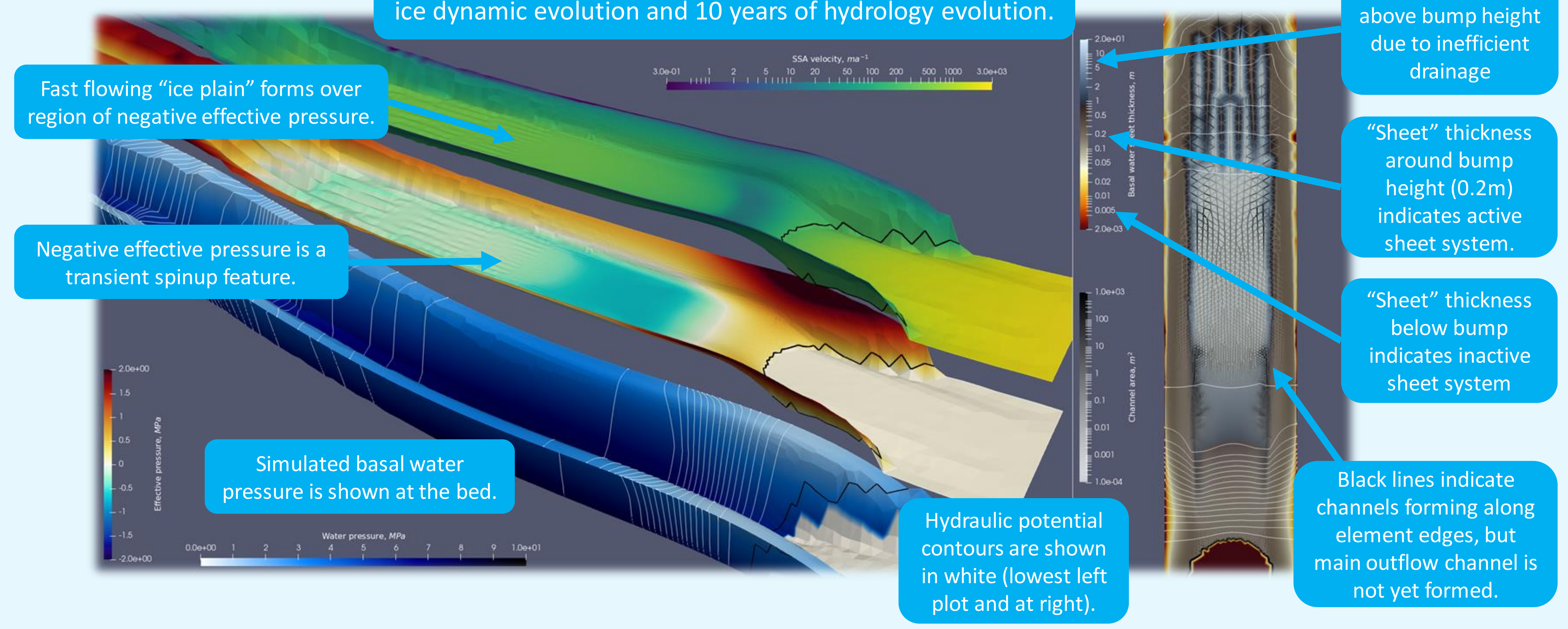
- GlaDS for the Antarctic Ice Sheet was spun up for 100 years; final state below.
- Direct validation is problematic but large channel outflow locations may be verified through observations.
- Effective pressure distribution depends significantly on relative conductivities of the "sheet" and channel systems.
- Oscillatory behaviour is not the norm but can occur.



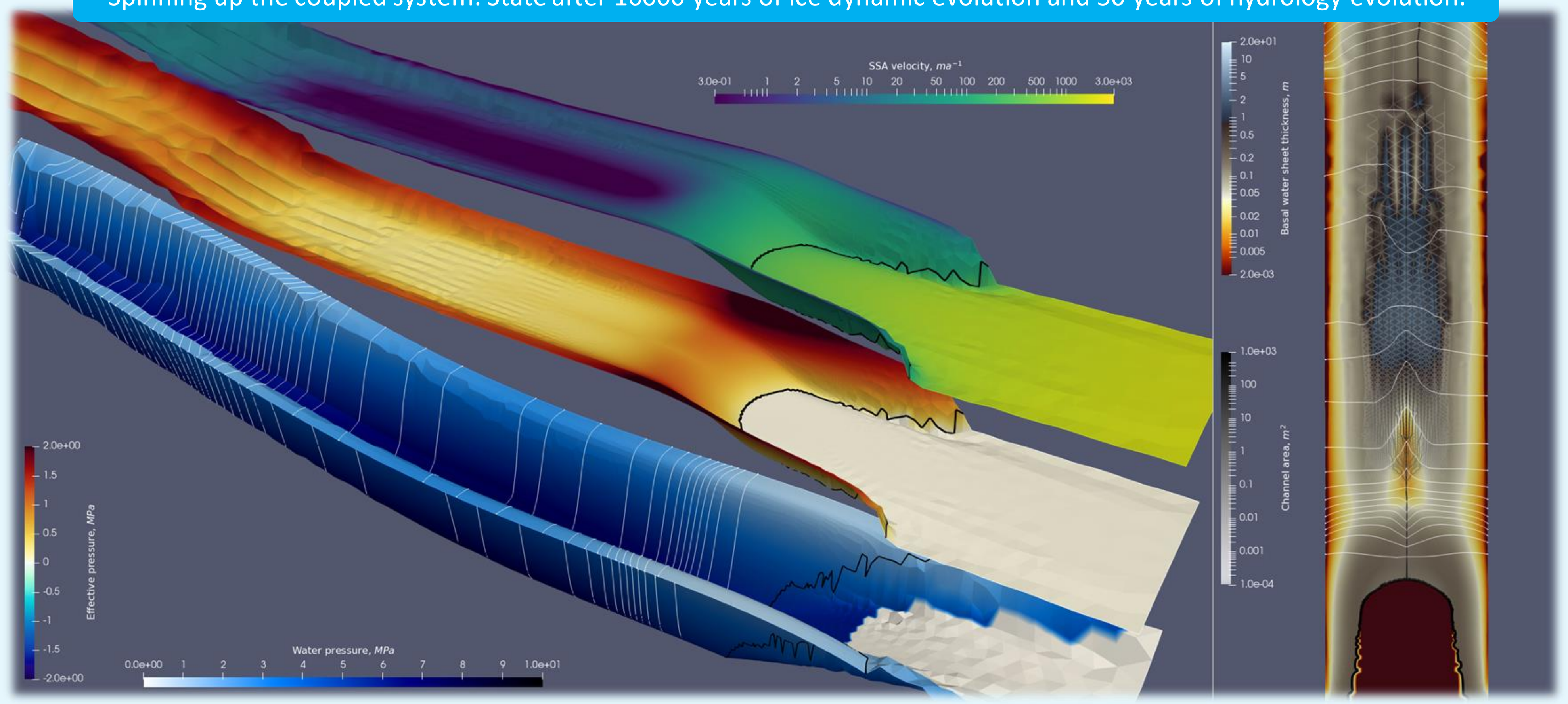
Coupled ice dynamic - hydrology modelling

- Testing coupled setup using idealised MISOMIP1 domain. Represents a marine ice sheet with overdeepening (similar to PIG).
- Ice dynamic to hydrology forcing is as described for Antarctic GlaDS spin up (at left).
- Hydrology to ice dynamic forcing is through the impact of effective pressure on sliding.
- Spin up is from a uniform slab.
- "Accelerated forcing" is used, with the hydrology model running on a smaller timestep and with shorter elapsed time than the ice dynamic model.
- Sliding is given by a "Regularised Coulomb" parameterisation with spatially uniform coefficients.
- This tends to "coulomb" behaviour for high sliding speeds and low effective pressure, decoupling resistance from sliding speed.
- It tends to power law behaviour for high effective pressure and low sliding speeds, stabilising the flow.
- This results in very different ice geometry to Weertman sliding.

Spinning up the coupled system. State after 3000 years of ice dynamic evolution and 10 years of hydrology evolution.



Spinning up the coupled system. State after 16000 years of ice dynamic evolution and 50 years of hydrology evolution.



Next steps

Learning from idealised domain

"Accelerated forcing" is described as follows in the context of ice sheet – ocean model coupling:

In this study, we introduce an "accelerated forcing" approach to address the timescale discrepancy and thus improve computational efficiency in a framework designed to couple evolving ice geometry to ice shelf cavity circulation. This approach is based on the assumption that the ocean adjusts faster to imposed changes than the ice sheet, with the ocean viewed as being in a slowly varying quasi-steady state over timescales of ice geometry change.

Is "accelerated forcing" valid in this context? What is a suitable "acceleration factor"? We used 300 for the MISOMIP simulations, and this is likely too high.

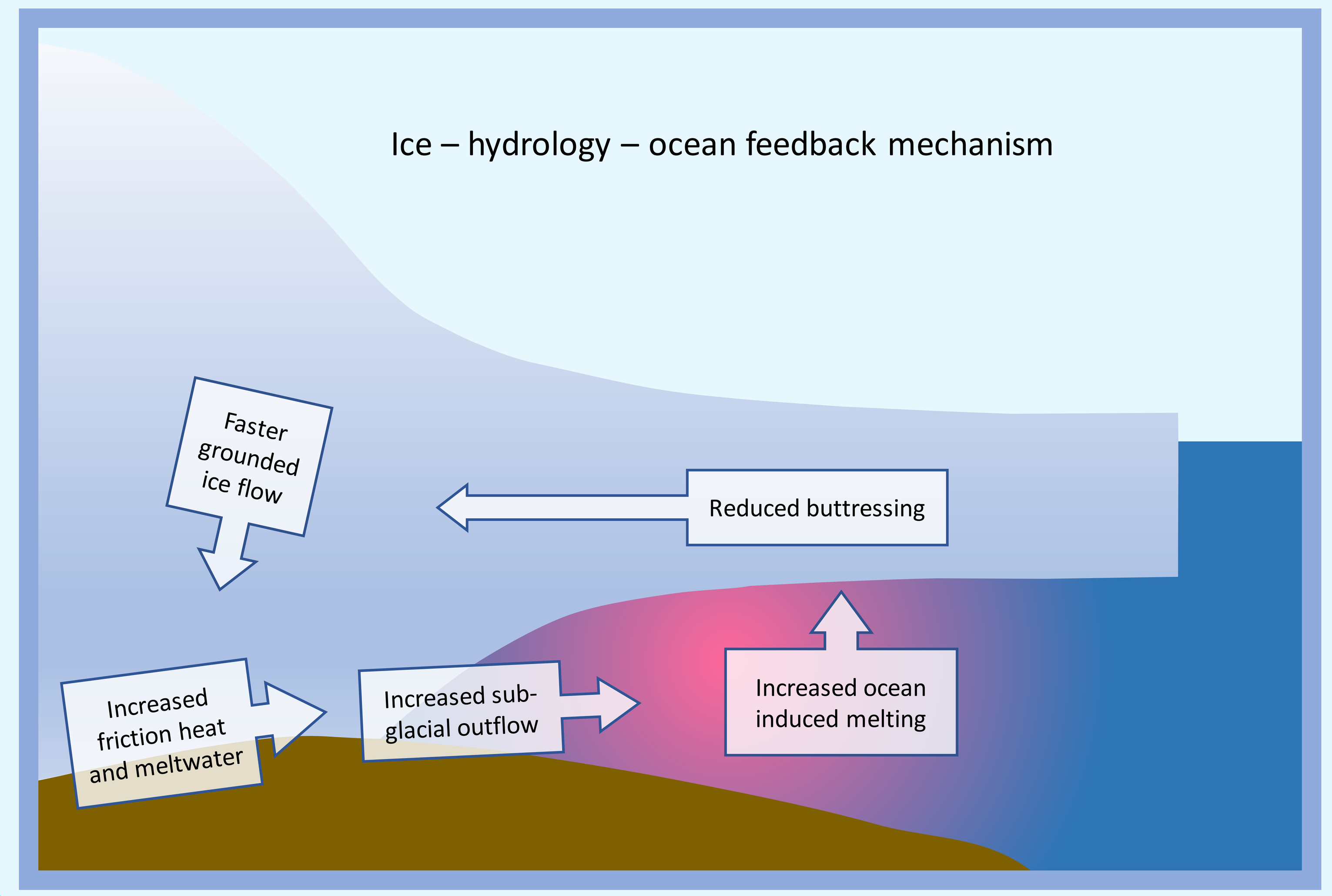
The ice geometry evolving from a coupled hydrology – ice dynamic simulation is different

Application to Antarctica

- Apply the two-way coupling implemented for the MISOMIP1 domain to the whole Antarctica domain.
- Our ISMIP6 ice dynamic starting point features a spatially tuned sliding linear sliding coefficient. How best convert this to the two coefficients used in the regularised Coulomb sliding parameterisation?
- How does the evolving effective pressure from GlaDS impact on marine ice sheet stability and Antarctica's sea level contribution?

Subglacial outflow coupling

Using the Framework for Ice Sheet – Ocean Coupling (FISOC) we can pass the subglacial outflow from GlaDS to a regional ocean model simulating the cavity circulation. Could this outflow influence the buoyancy driven cavity circulation and feedback on the ice dynamics? We will test this in the idealised MISOMIP1 domain.



This research is supported by the Finnish Ministry of Education and Culture and CSC - IT Center for Science (Decision diary number OKM/10/524/2022), Research Council of Finland ICEMAP consortium (grant no. 355572), and Academy of Finland COLD consortium (grant no. 322430).