Examining the Effects of Borehole Water Extraction on a Synthetic Glacier Model

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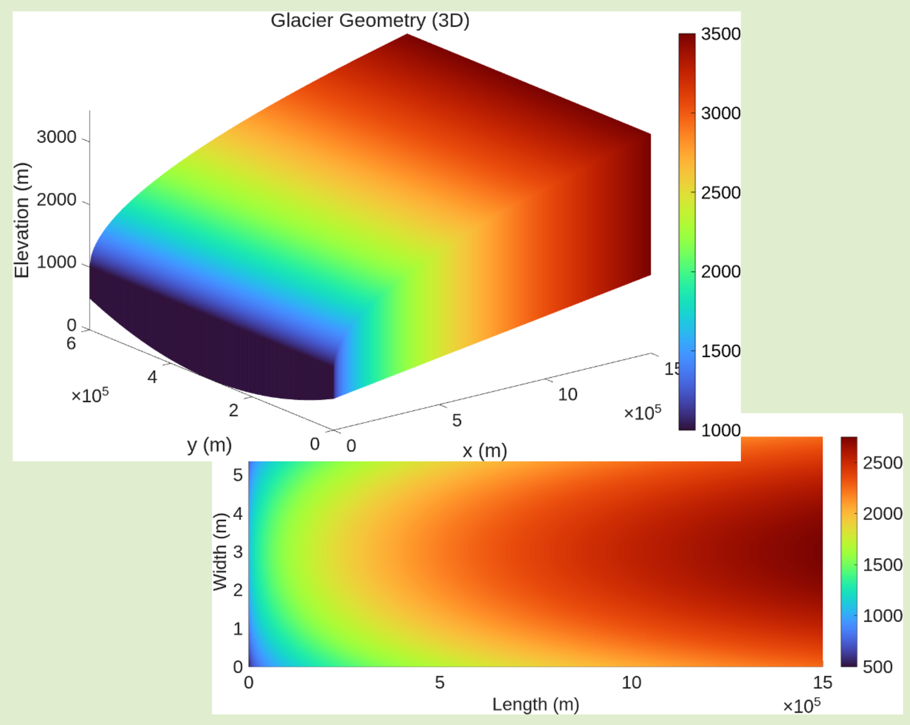
1 Introduction

Subglacial water can contribute to accelerated ice velocity by reducing friction between the glacier bed and the underlying ground. As more meltwater accumulates beneath glaciers due to rising temperatures, this effect becomes an increasing concern because it can **enhance glacier flow** and push ice more rapidly into the ocean, leading to **sea level rise**. Here, we examine the effects of **extracting water through boreholes** from beneath a synthetic glacier system to determine whether this process can reduce subglacial water pressure, increase the effective pressure, and create a higher friction force between the ice and the bed, thereby **slowing down glacier flow**.

We use the Glacier Drainage System model (GlaDS) to simulate the evolution of channelized and distributed drainage across the domain and to examine changes in effective pressure and water sheet thickness beneath the glacier during the extraction process, along with changes in ice dynamics.

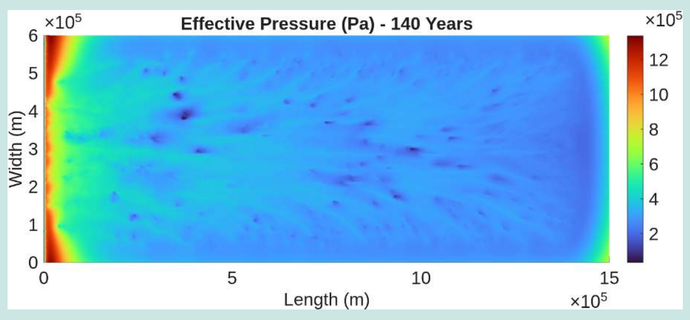
2 Idealized Glacier Geometry

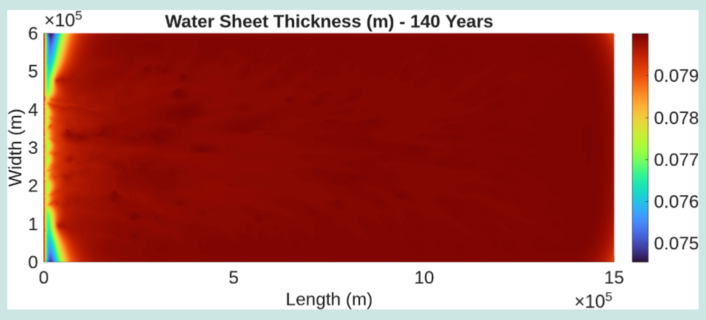
- A synthetic glacier domain was developed in the Ice-sheet and Sea-level System Model (ISSM).
- The geometry represents an idealized Antarctic-style outlet glacier system.
- The model domain is 1500 km long and 600 km wide.
- The glacier rests on a curved, gently inclined bed.
- A square-root surface profile causes the ice to thicken inland.

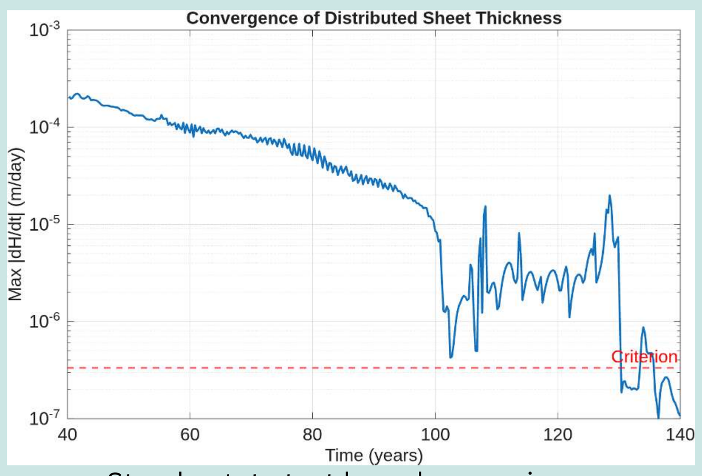


3 Methods

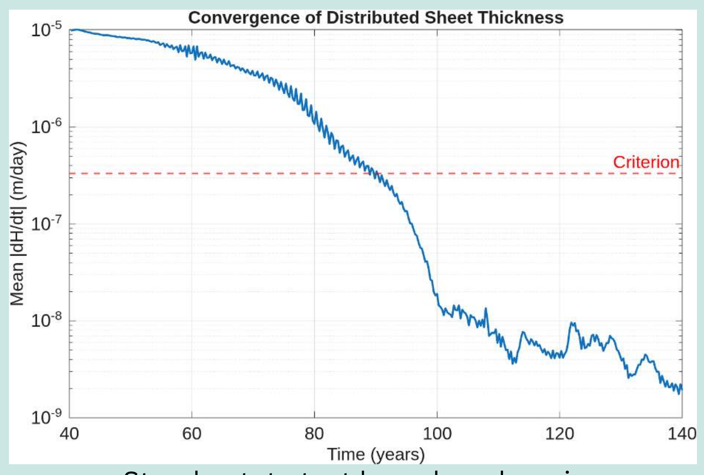
- The GlaDS model was run to steady state for 140 years.
- Steady state was defined as the point at which the change in distributed sheet thickness between the final two timesteps was less than 3.33×10^{-7} m day^{-1}.
- Establishing this baseline helped ensure that later changes in the system were caused by borehole extraction rather than ongoing natural model adjustment.
- Borehole water extraction was then added to the model.
- Multiple borehole configurations and extraction patterns were tested on the hydrology only model.
- Latest developments: Initial inversions for ice dynamics using synthetic velocity and relaxation before coupling to hydrology.







Steady-state test based on maximum local change in water sheet thickness



Steady-state test based on domain-averaged change in water sheet thickness

WORKFLOW

Synthetic geometry

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140-year hydrology evolution to steady state

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Borehole extraction tests

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Compare hydrology response

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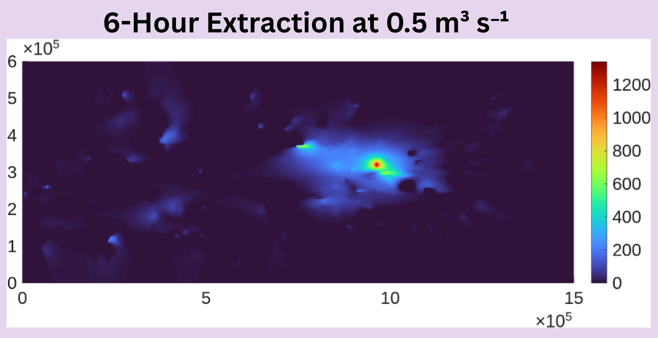
Coupled hydrology ice dynamics experiments

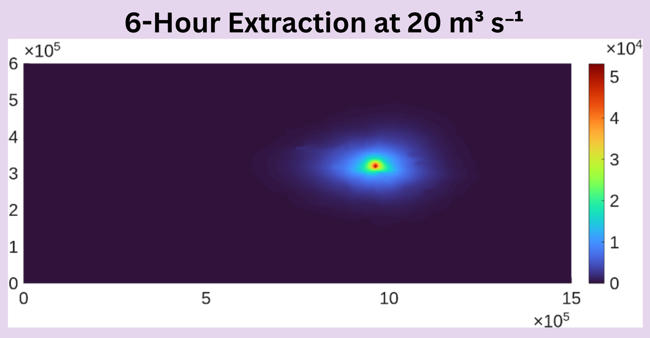
4 Results: Change in Effective Pressure - Hydrology Only Model

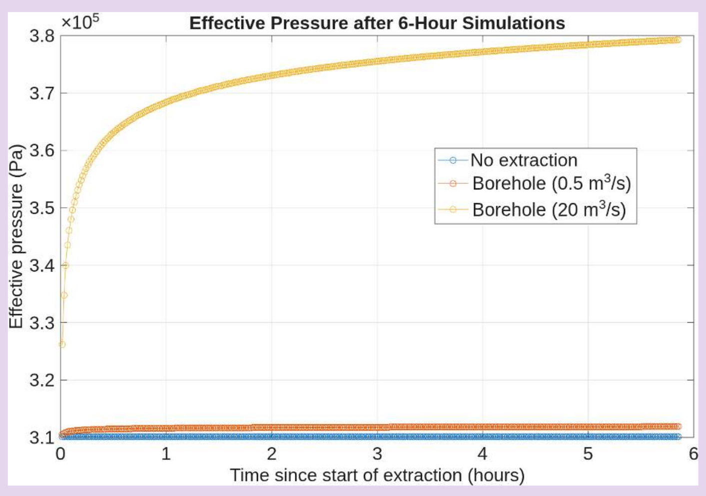
Central Borehole

6-Hour Extraction at 0.5 m³ s⁻¹



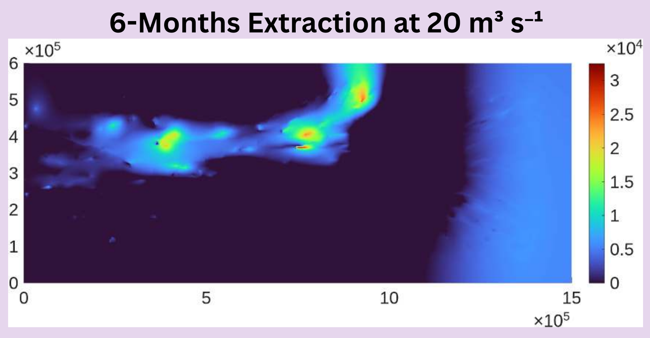
6-Hour Extraction at 20 m³ s⁻¹



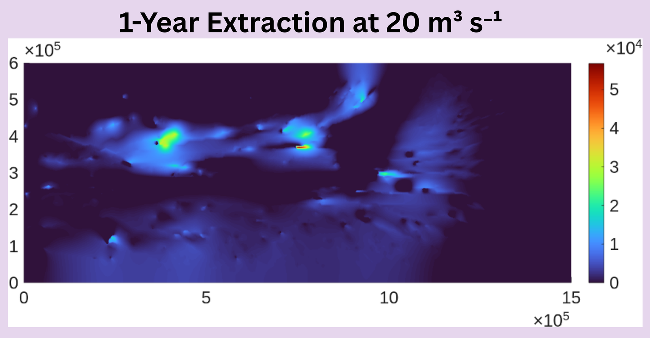


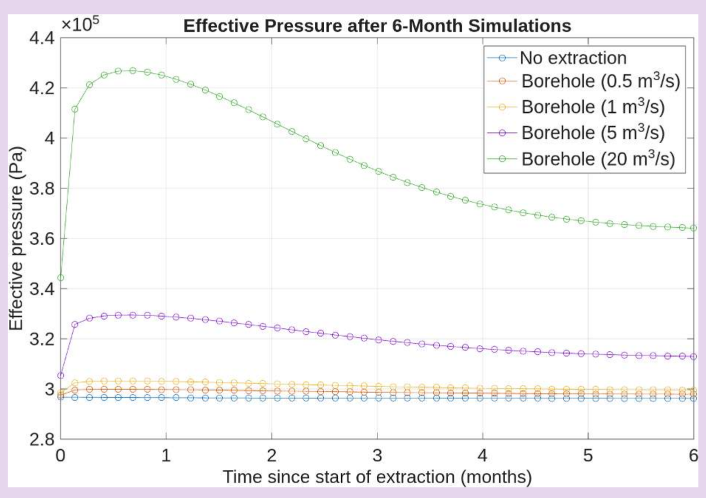
Marginal Borehole

6-Months Extraction at 20 m³ s⁻¹



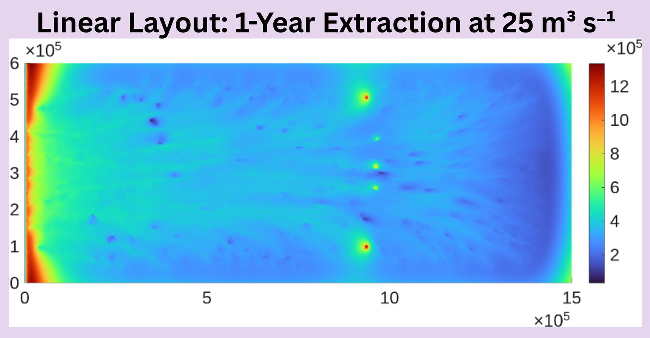
1-Year Extraction at 20 m³ s⁻¹



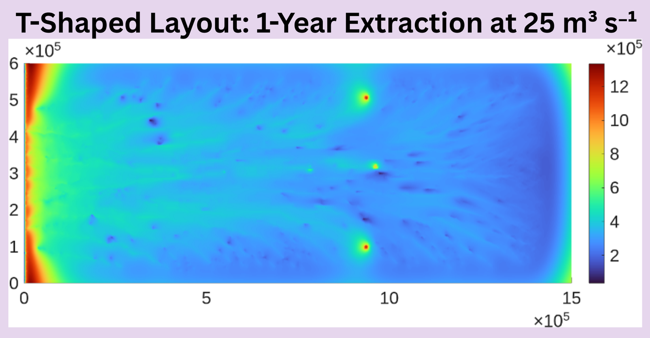


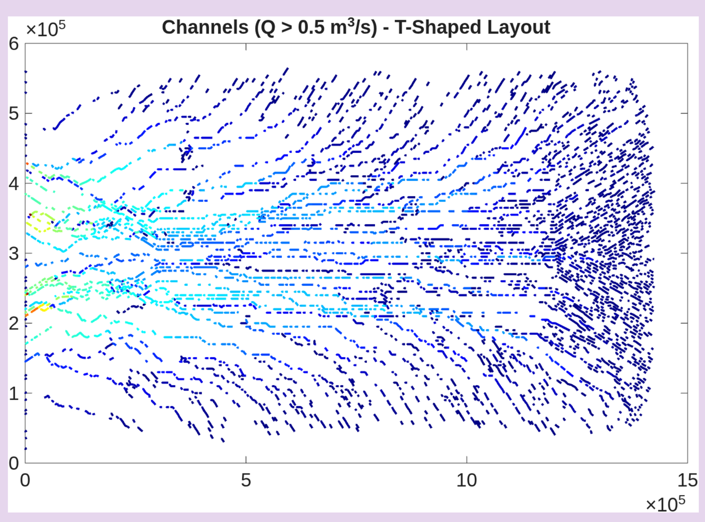
Five-Borehole Configurations with Extraction at Neighboring Nodes

Linear Layout: 1-Year Extraction at 25 m³ s⁻¹



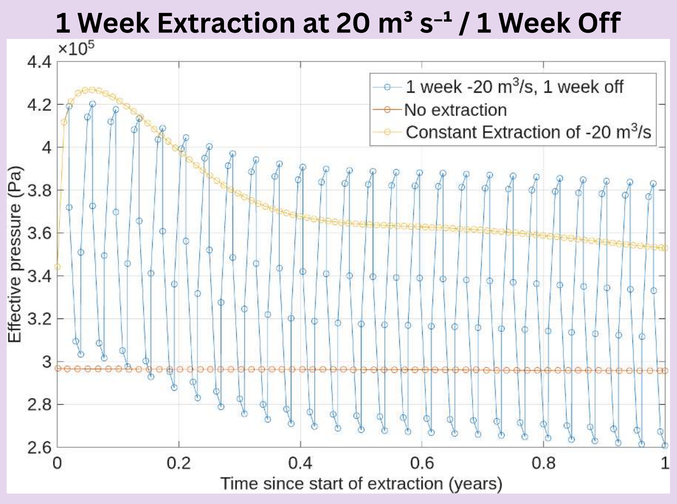
T-Shaped Layout: 1-Year Extraction at 25 m³ s⁻¹



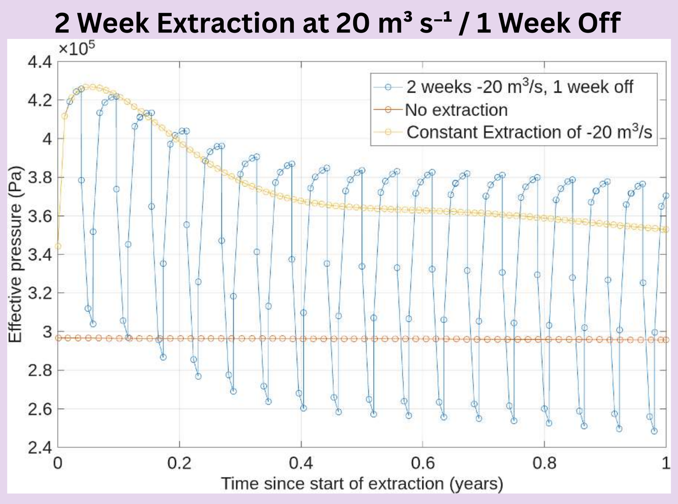


Marginal Borehole - Cylic Extraction

1 Week Extraction at 20 m³ s⁻¹ / 1 Week Off

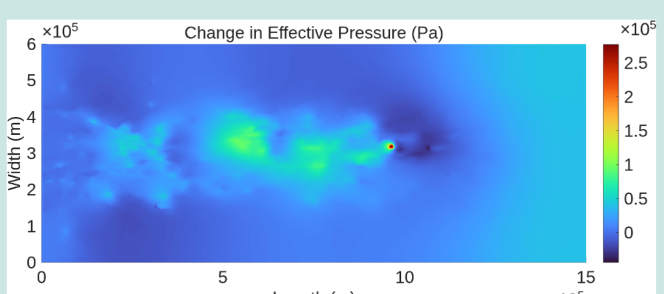


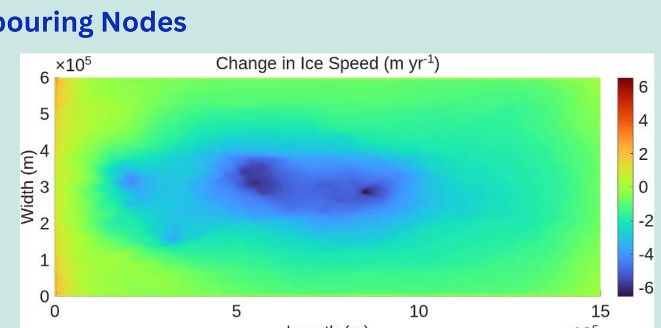
2 Week Extraction at 20 m³ s⁻¹ / 1 Week Off



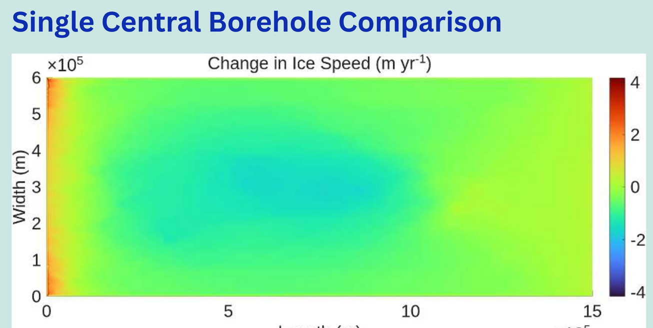
5 Results: Change in Ice Dynamics - Coupled Model

6-Month Extraction at 20 m³ s⁻¹ at Central Borehole and Neighbouring Nodes





Single Central Borehole Comparison



6 Conclusions and Future Work

The hydrology experiments show that borehole water extraction can reduce subglacial water pressure, resulting in increased effective pressure beneath the glacier. The response appears to weaken over time, likely because the drainage system adjusts toward a new hydrological equilibrium. Higher extraction rates produced stronger changes in effective pressure, water sheet thickness, and hydraulic potential, which is physically consistent with expectations. However, meaningful changes were only observed at very high extraction rates, and the cause of this limited sensitivity is still under investigation.

Ongoing work is focusing on coupling the subglacial hydrology model with ice dynamics to directly examine how borehole water extraction affects glacier velocity.

The model could also be extended to real Antarctic glacier systems using satellite-derived geometry and observational datasets, allowing the borehole extraction approach to be tested under more realistic conditions.

7 References / Acknowledgement

[1] Hayden A-M, Dow CF. Examining the effect of ice dynamic changes on subglacial hydrology through modelling of a synthetic Antarctic glacier. Journal of Glaciology. 2023;69(278):1846-1859. doi:10.1017/jog.2023.65

[2] Morlighem, M. (n.d.). Home page - Ice-Sheet and sea-level system model. https://issm.jpl.nasa.gov/

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