Simulating the impact of glaciations on continental groundwater flow systems: Model application to the Wisconsinian glaciation over the Canadian landscape

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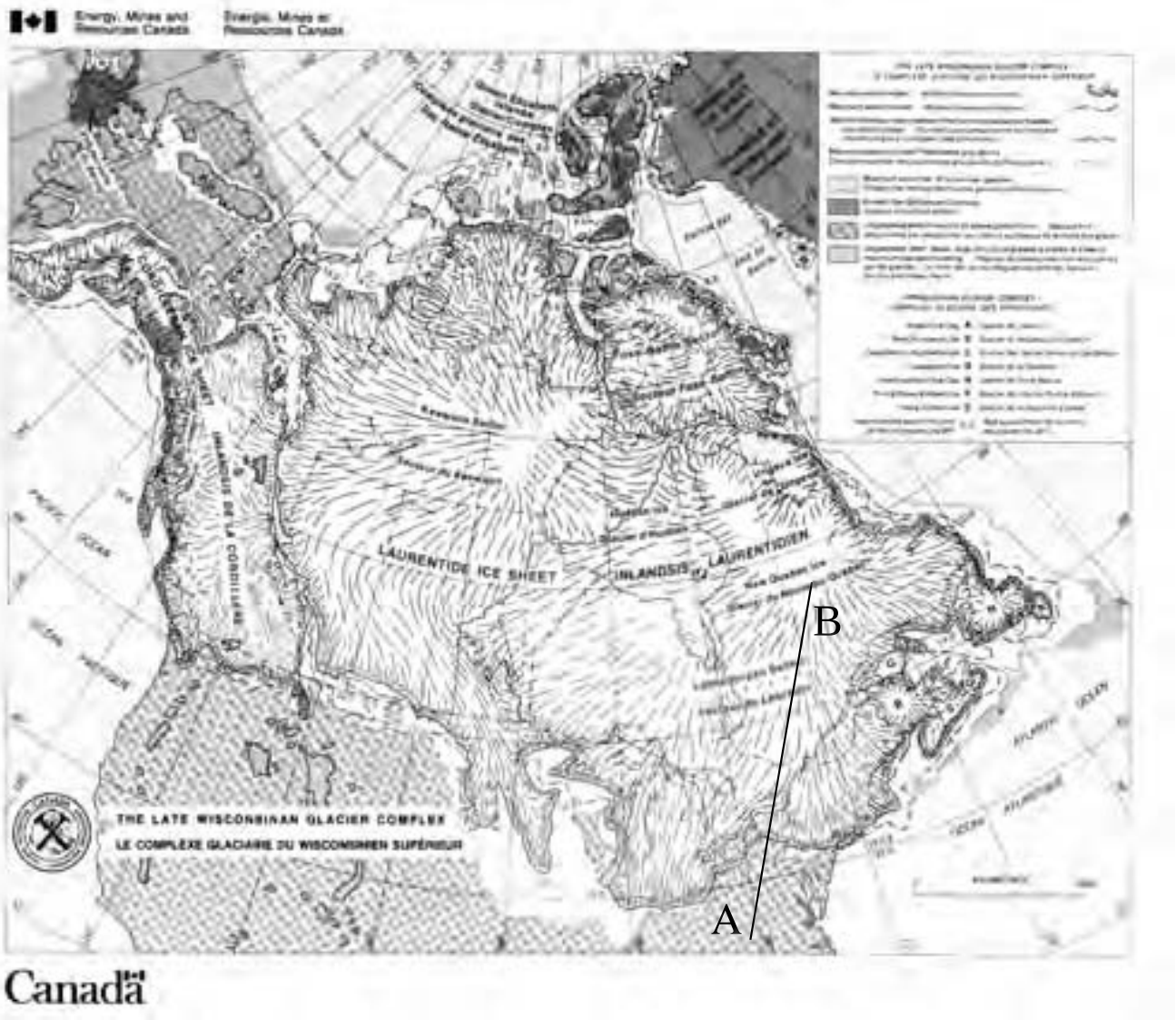
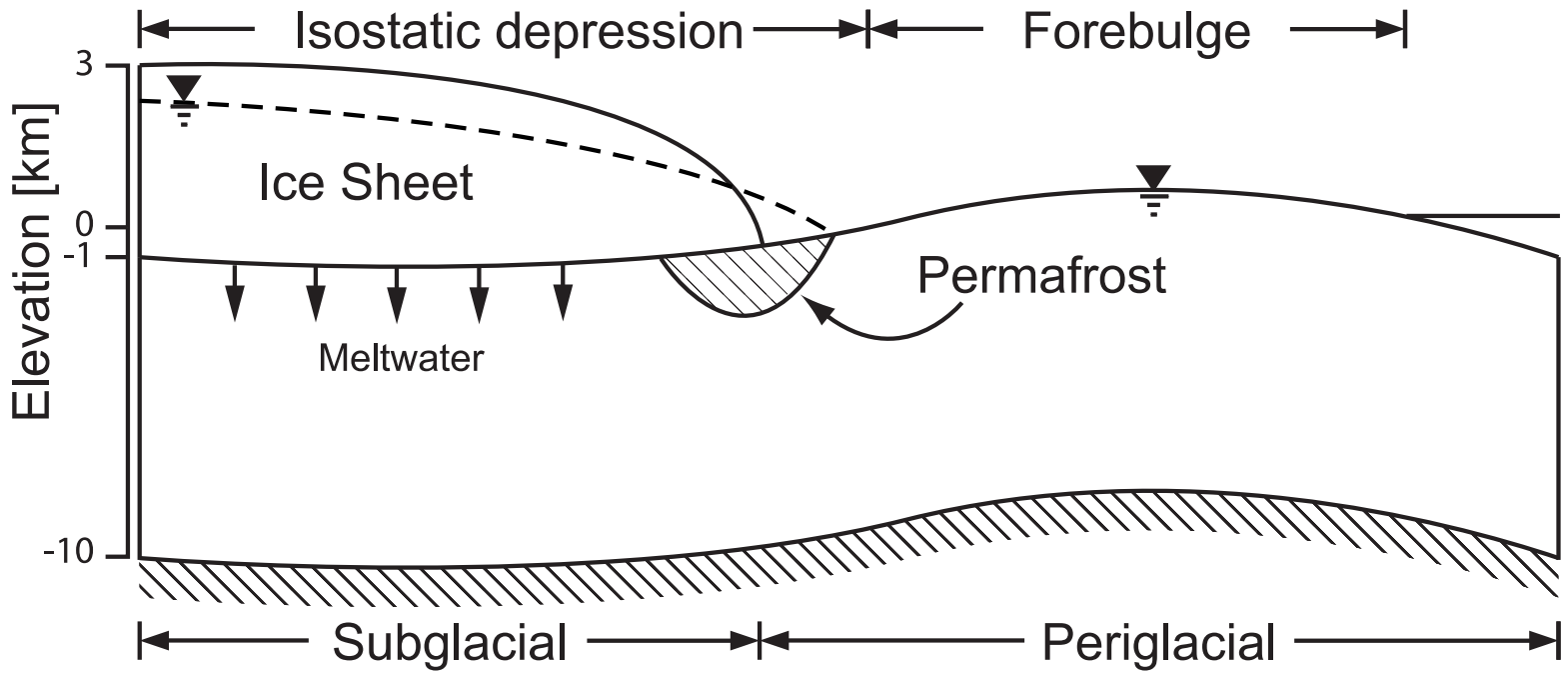
Kolloquium zum Thema glaziale Tiefenerosion, 21.01.2009

Outline

Last Glacial Maximum [-21 ka]



Simplified Cross Section



Objectives

General Objective

Reconstruct groundwater flow, age and brine evolution during the Wisconsinian (-120 ka to present) glaciation with a 3D numerical model over the Canadian landscape.

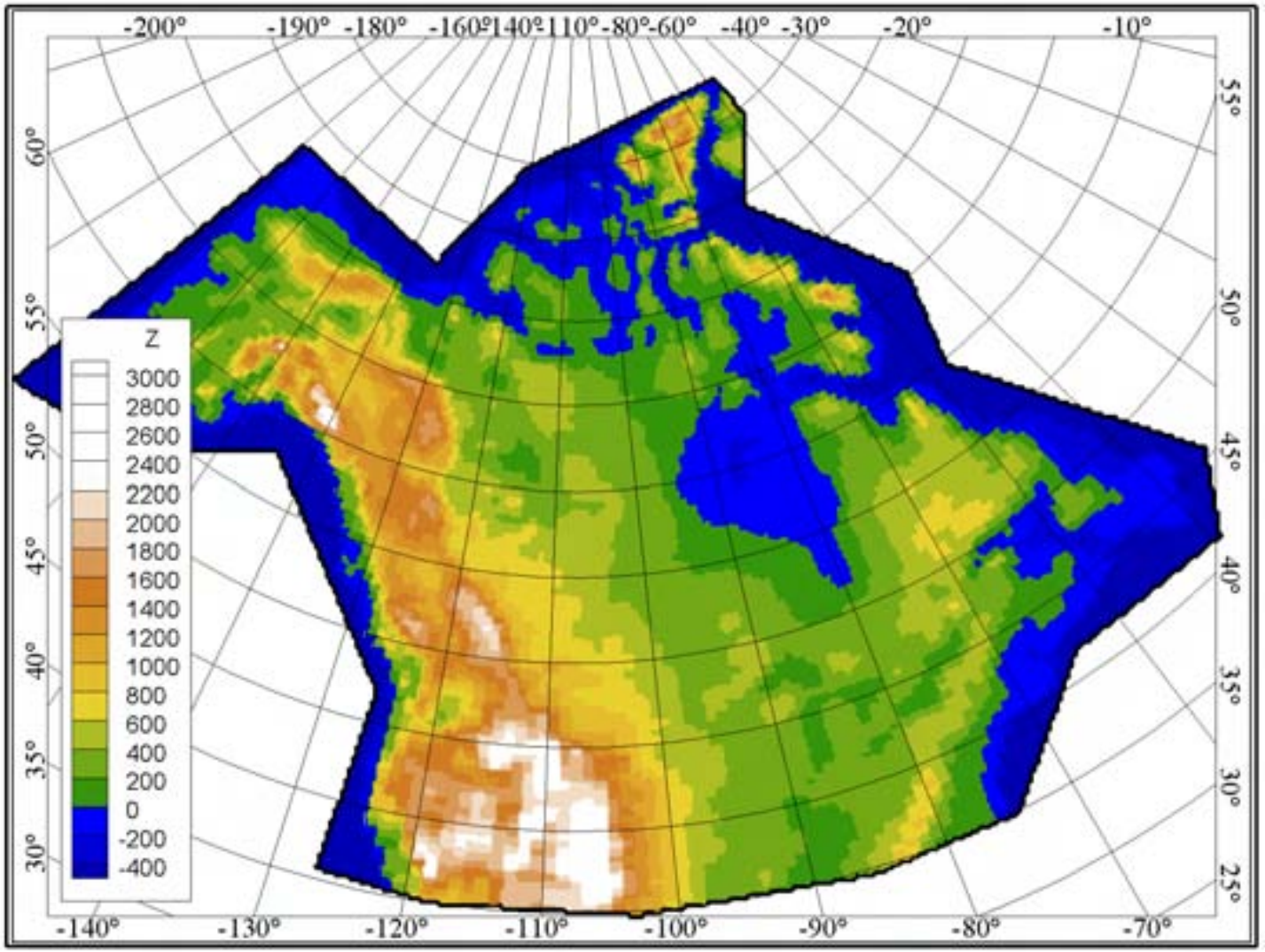
Specific Objectives

1. Process understanding
2. Subglacial pressure evolution
3. Portion of meltwater that recharged groundwater
4. Groundwater flow patterns, brine and age distribution

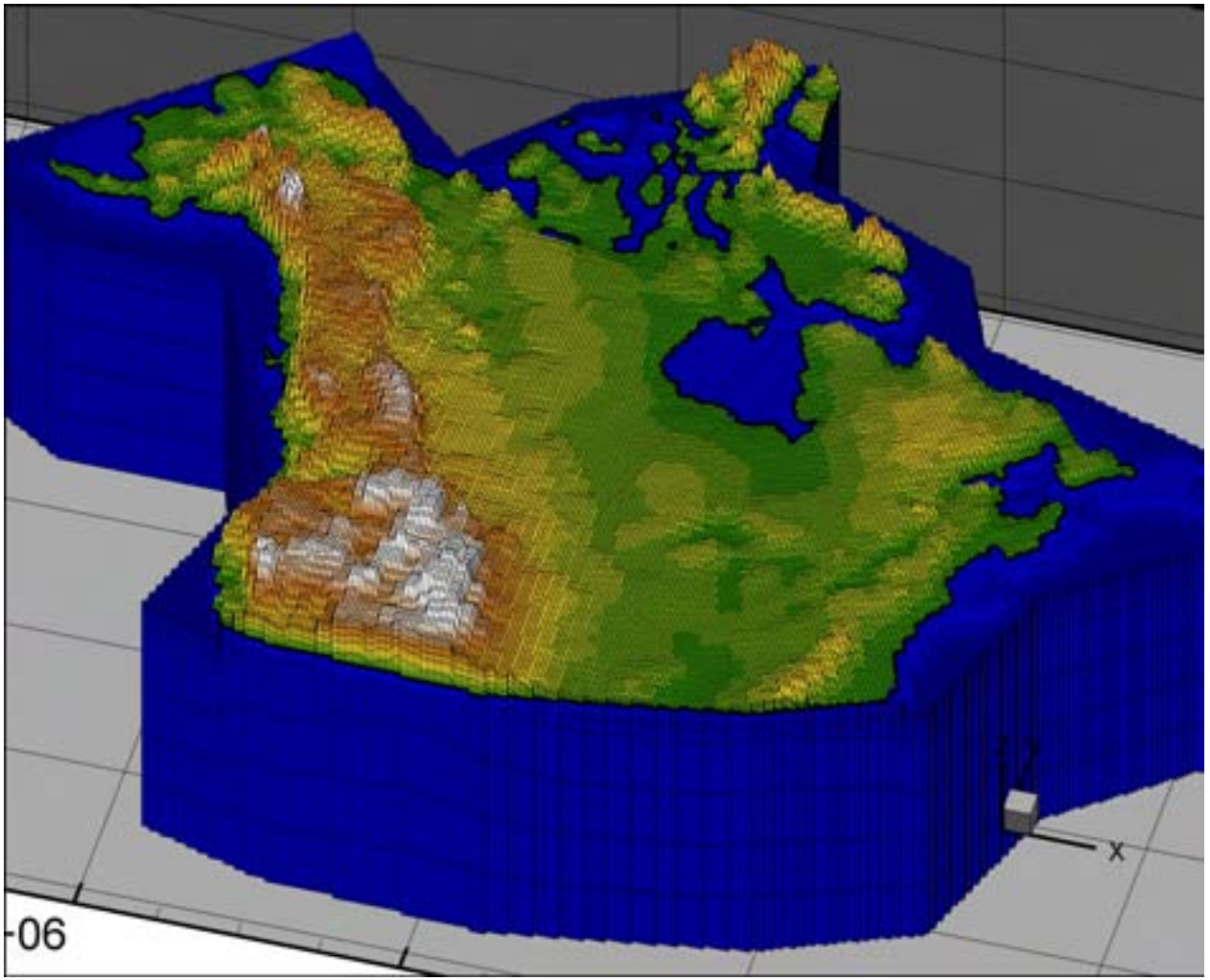
HydroGeoSphere (Therrien and Sudicky)

- Control-volume finite-element multi-continuum fully-coupled variably-saturated, surface-subsurface flow model.
- Density-dependent groundwater flow with 1D hydromechanical coupling.
- Brine transport (advection-dispersion equation) with brine generation (1rst-order source term).

Computational Domain



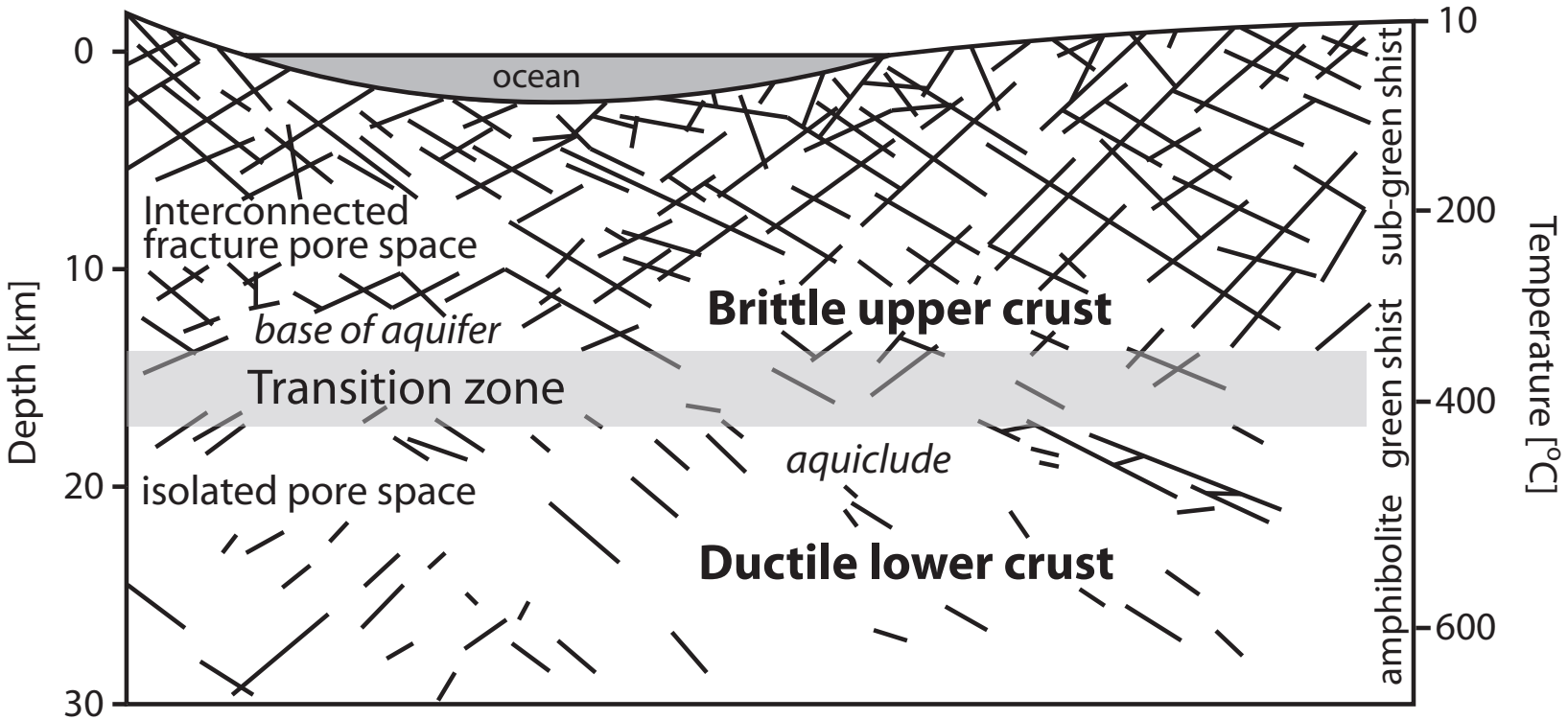
Computational Grid



Vertical exaggeration: 200 $\times$

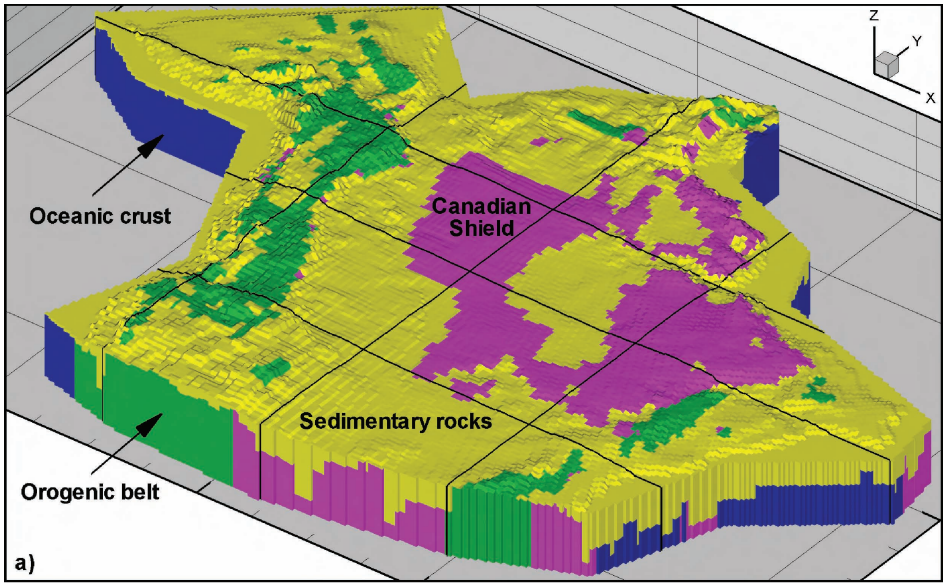
- Model extent: 10,000 km $\times$ 6,000 km
- Total 2D area: 2.5 $\times 10^7$ km^2.
- Cell size: 25 $\times$ 25 km
- ne: 402 034

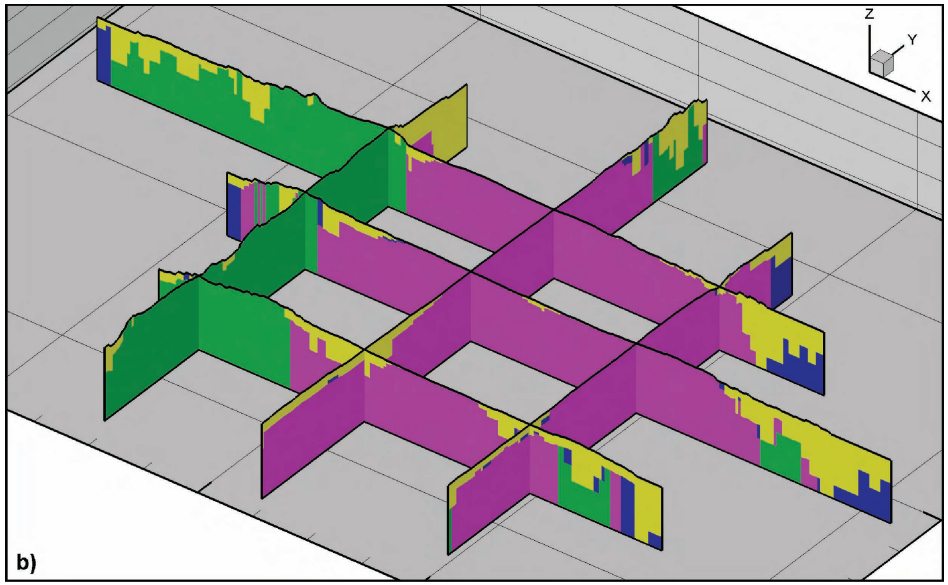
Continental Crust Hydrogeology



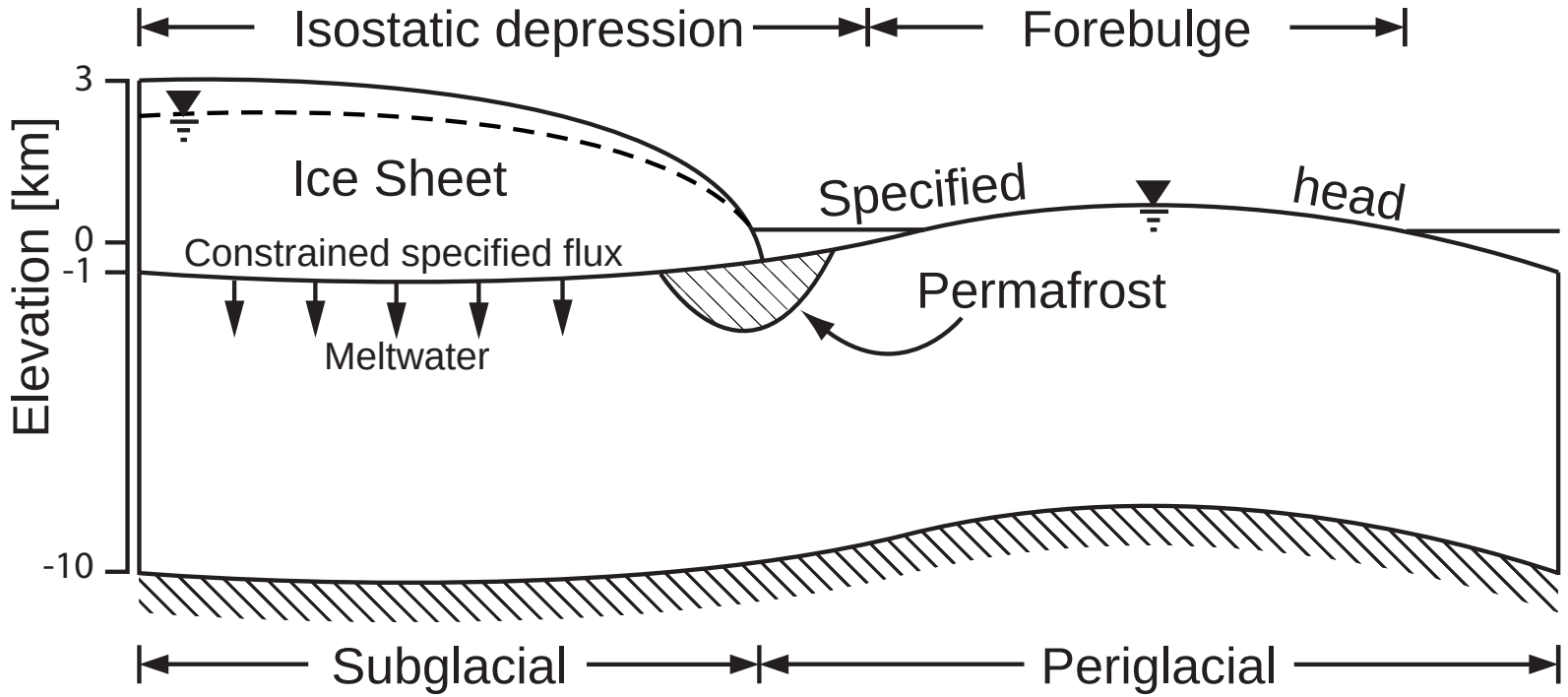
Modified from Stober and Bucher [2004]

Hydraulic Properties Distribution





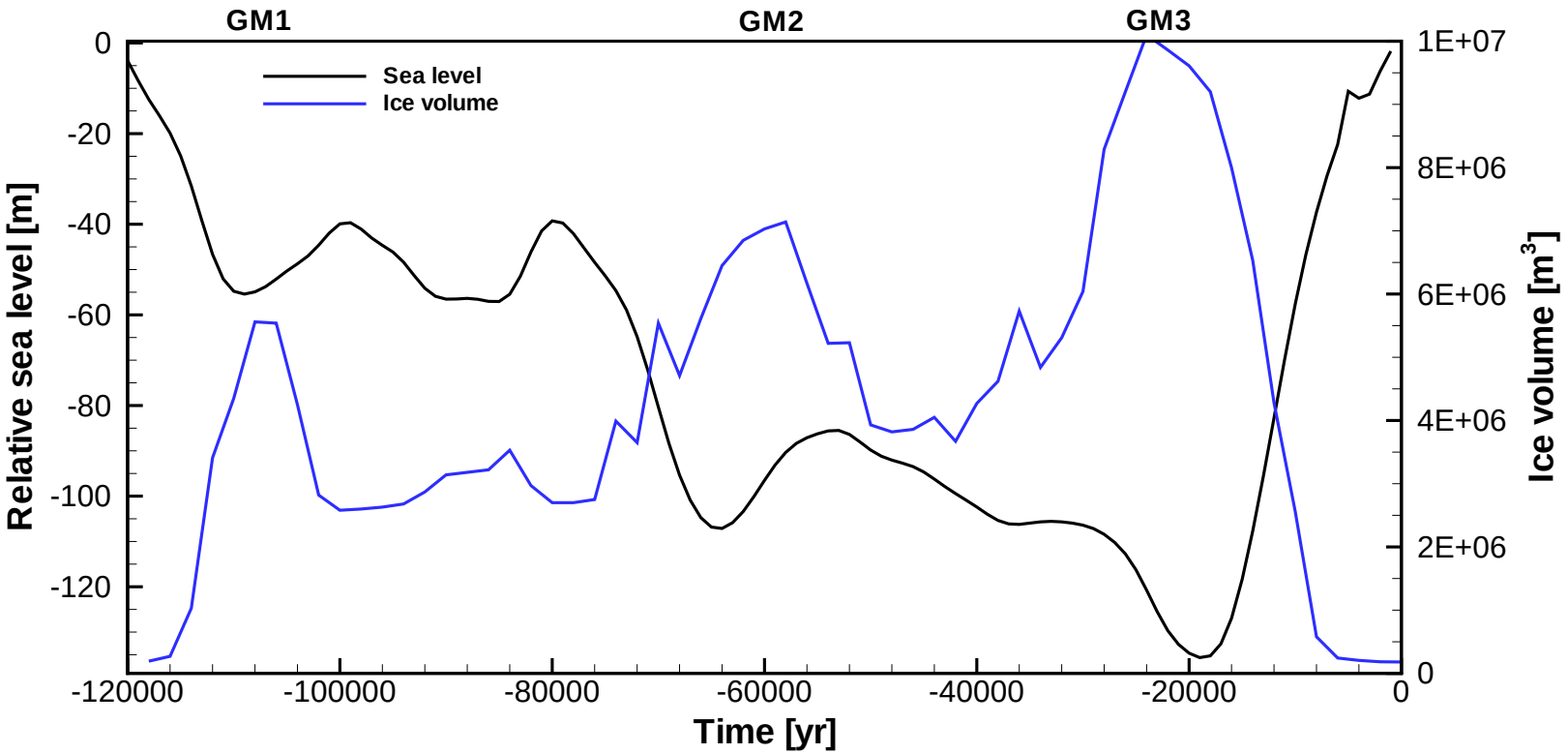
Boundary Conditions



Model Forcing: Peltier and Tarasov, U. of Toronto Glacial Systems Model:

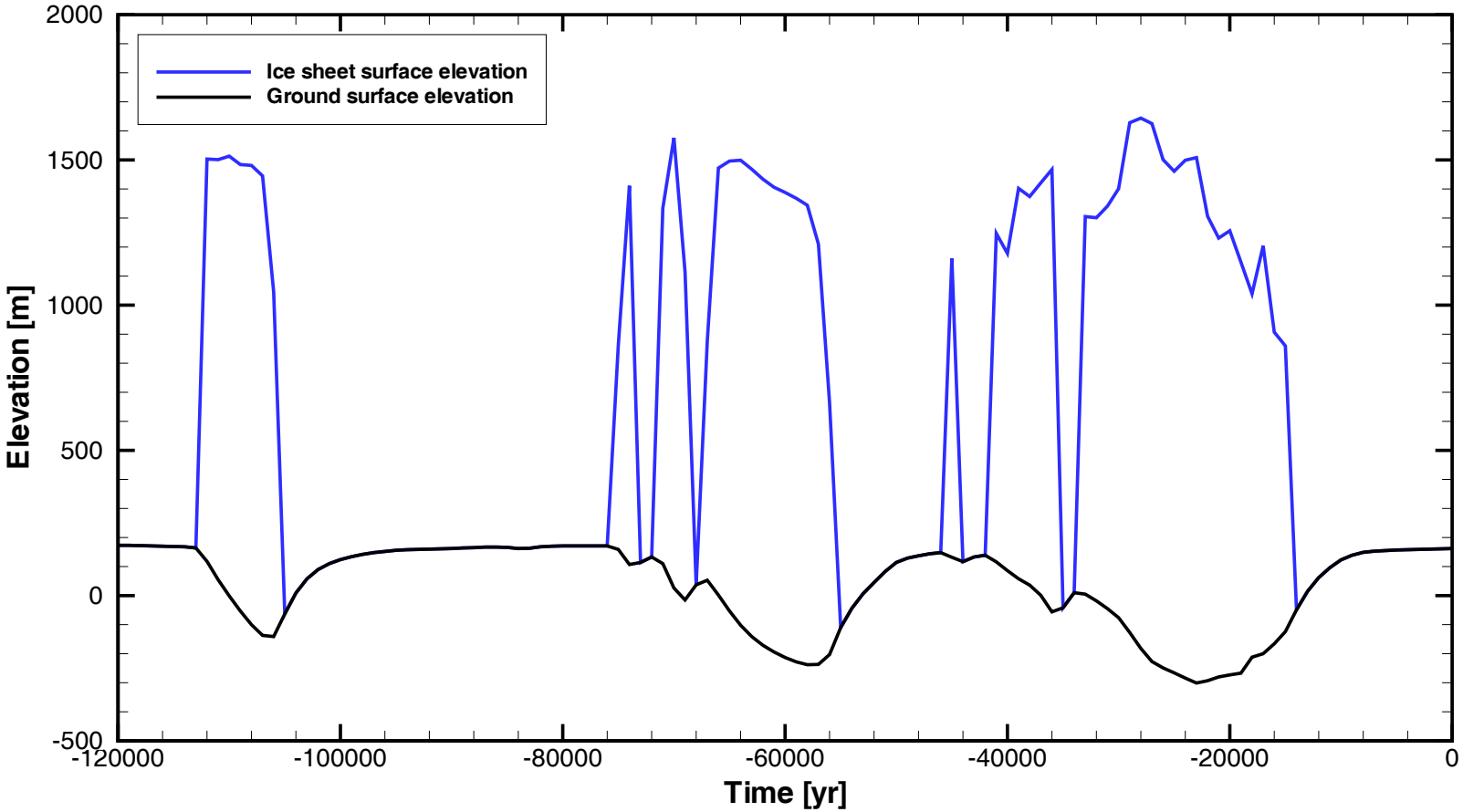
- Ground surface elevation
- Relative sea Level
- Ice thickness
- Permafrost thickness
- Meltwater rate
- Surface water depth

Sea Level Change



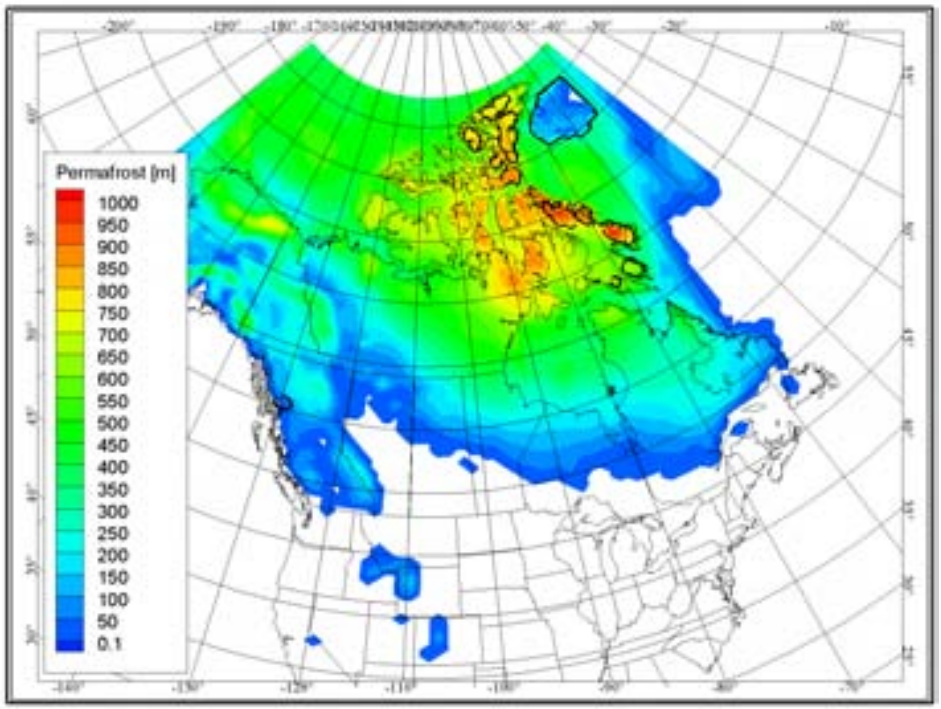
Isostasy

Surface elevation and ice thickness variation in Waterloo, Ontario:



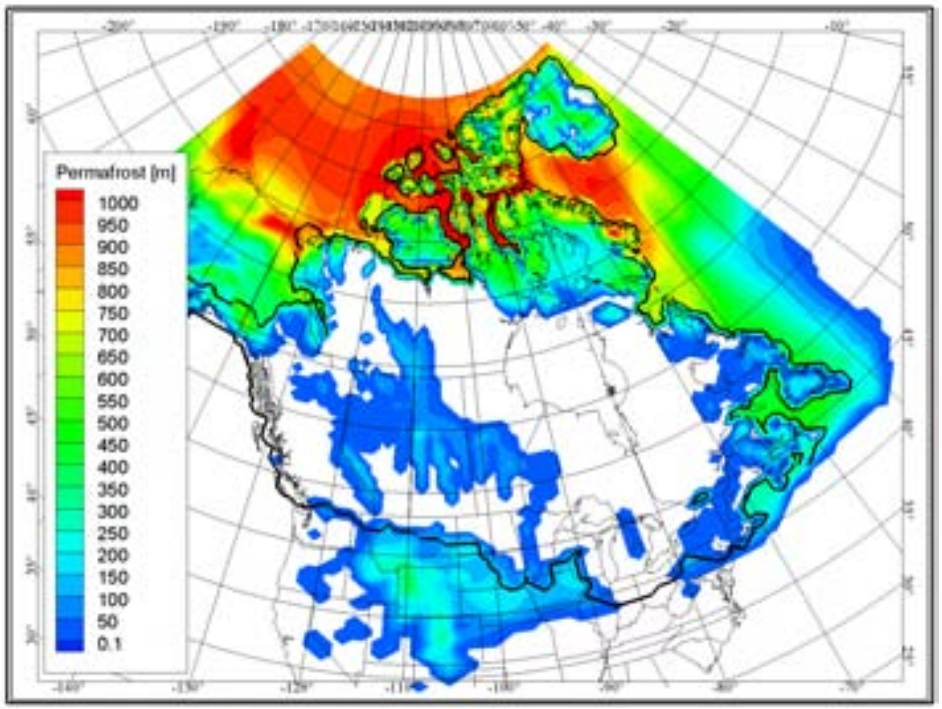
Permafrost Evolution

LIG



[Tarasov and Peltier, 2005]

LGM



[Tarasov and Peltier, 2005]

Simulation Details

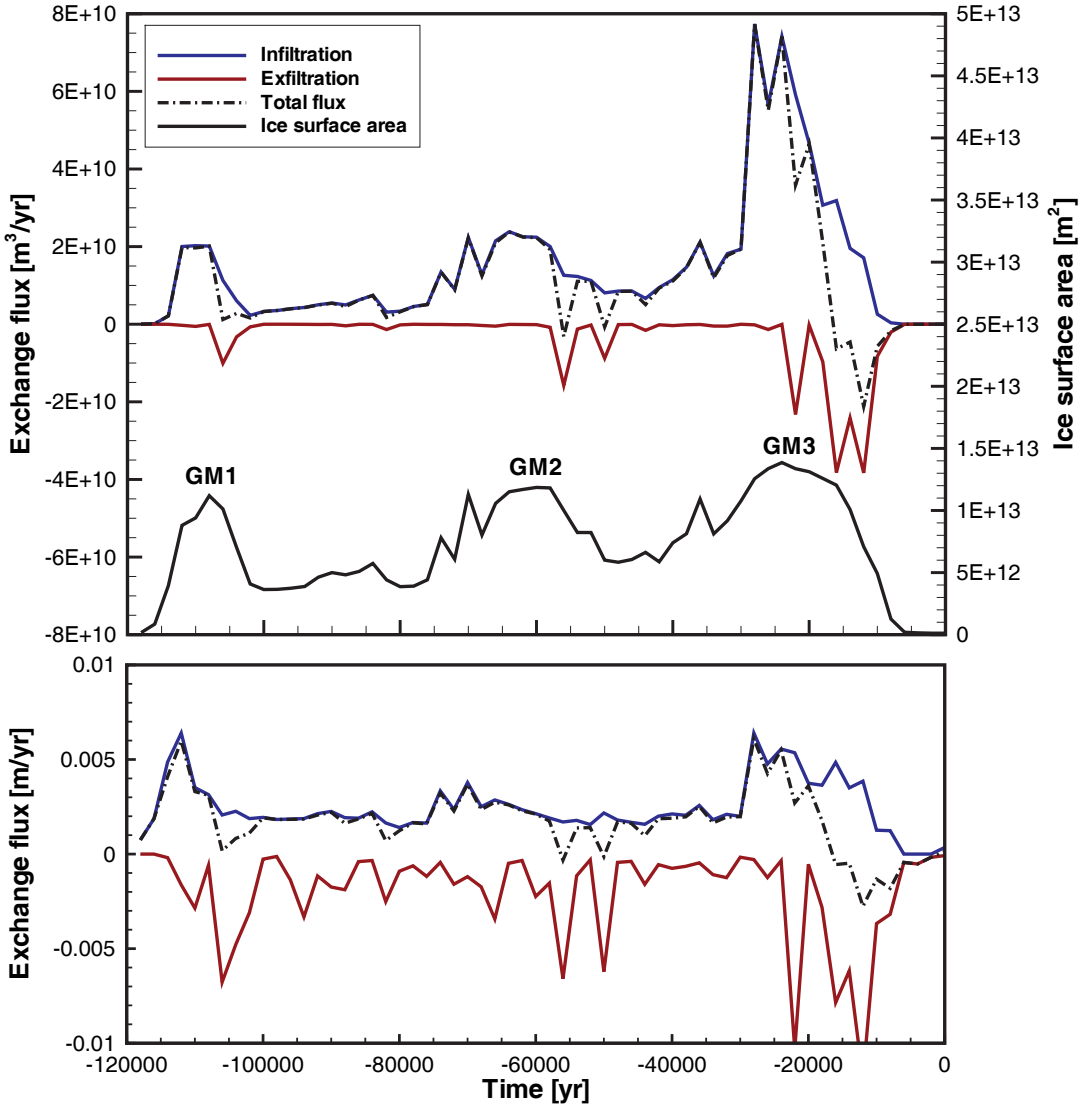
- Simulation time: 120 kyr
- Boundary conditions update: 1 kyr
- Timesteps: 0.1 kyr
- Results:
  - Surface/subsurface water interaction
  - Groundwater flow evolution
  - Mean groundwater age and brine distribution

Recharge and seepage dynamics

pgfpicture

Units: m/yr

Subglacial Exchange Flux

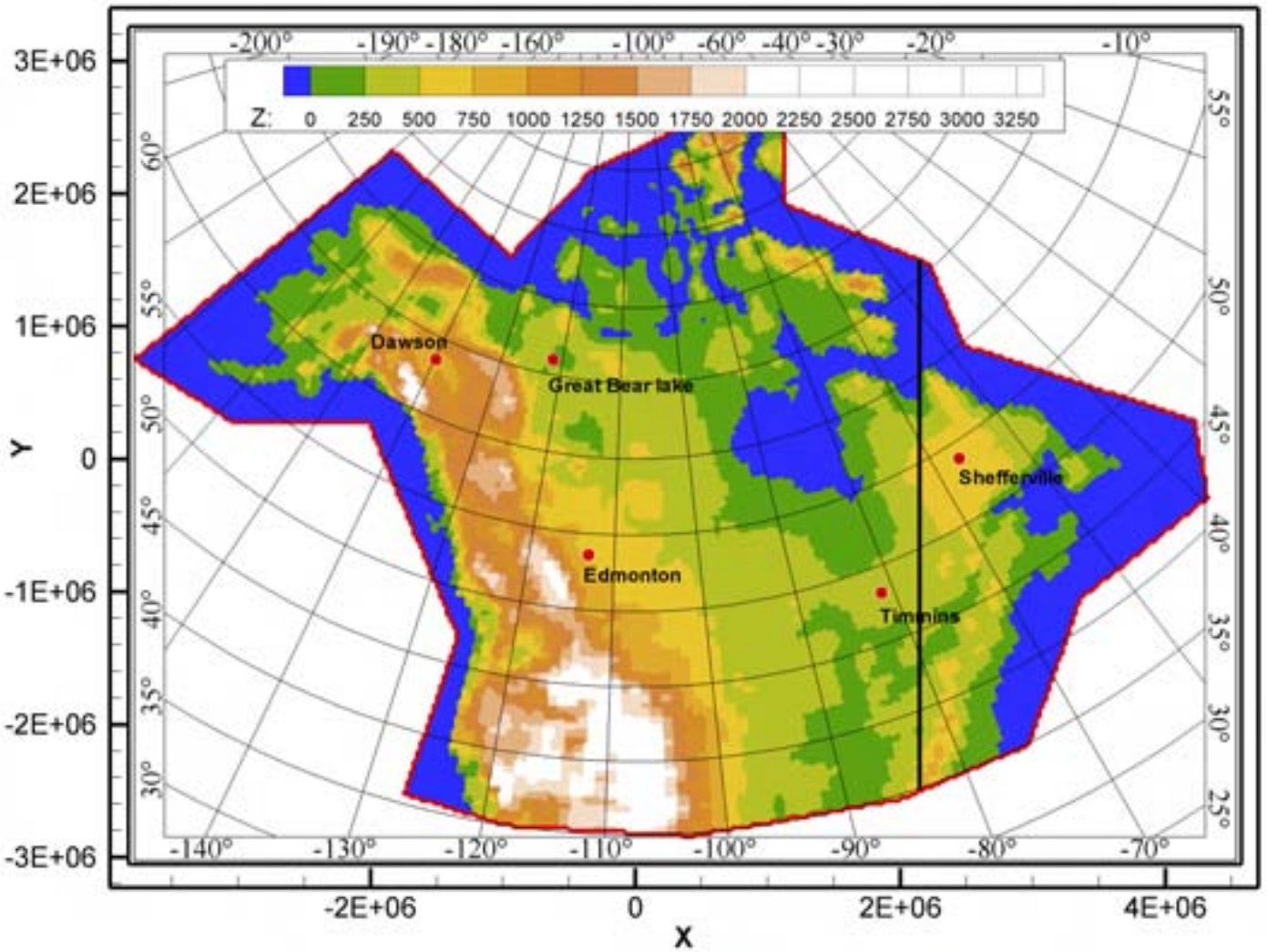


Summary

Table: Summary of the average infiltration and exfiltration rates for the subglacial and periglacial environments during the glacial cycle and the last interglacial period.

	Infiltration [m/yr]	Exfiltration [m/yr]
Subglacial environment	2.47×10^{-3}	2.03×10^{-3}
Periglacial environment	1.30×10^{-6}	7.08×10^{-6}
Interglacial period	2.87×10^{-5}	3.25×10^{-6}

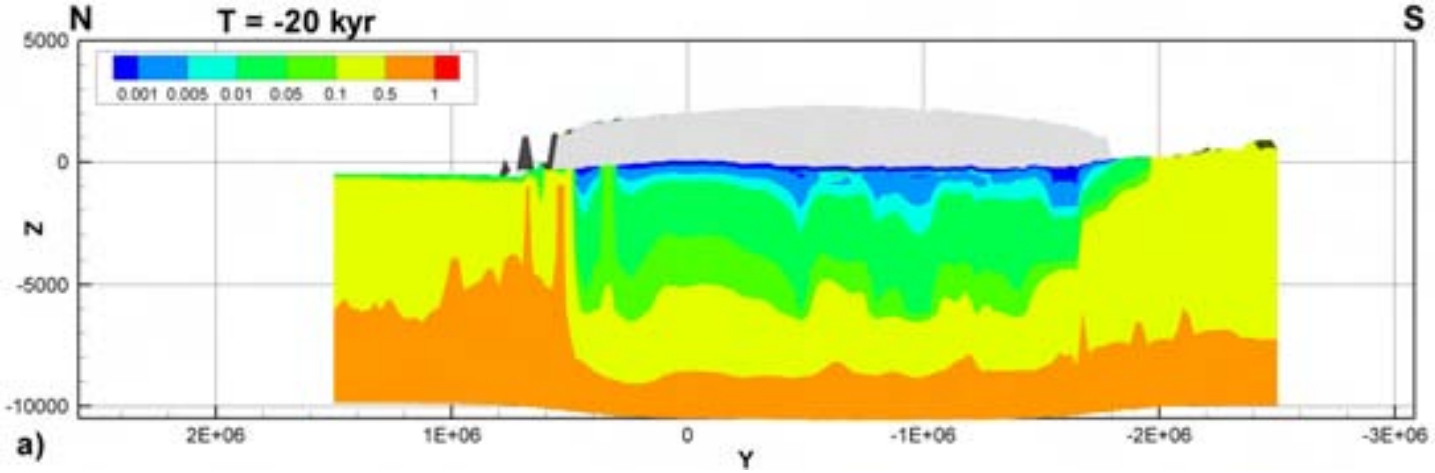
Cross Section Location



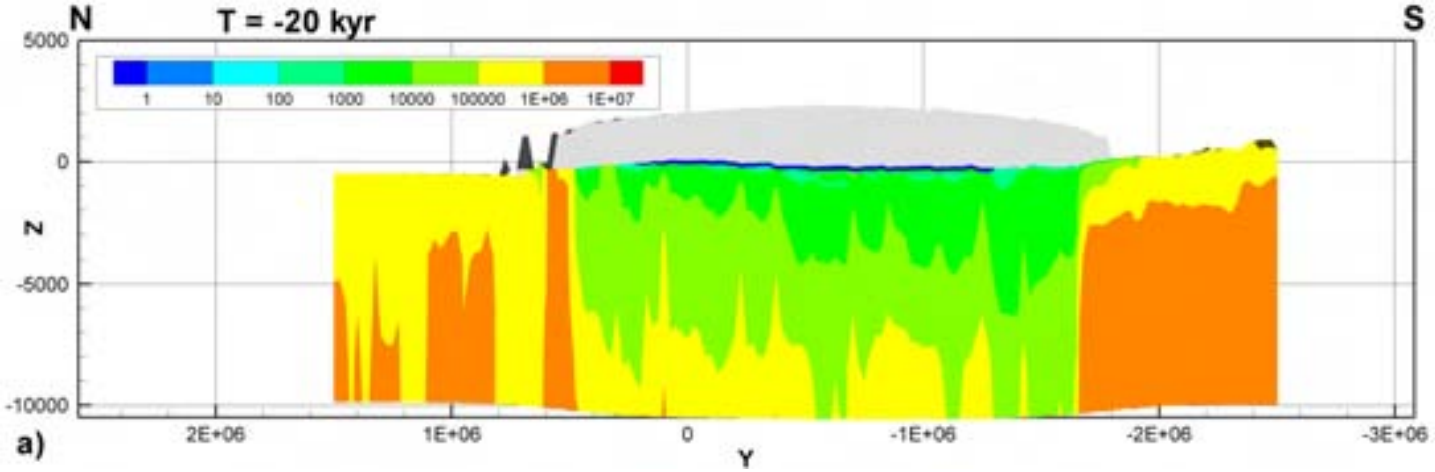
Hydraulic Head and Permafrost Distribution

pgfpicture

Relative Concentration at LGM (1 = 265 g/l)



Groundwater Age Distribution at LGM



Vertical Exaggeration: 100×

Conclusions

1. Simulation results show that the Wisconsinian glaciation had a profound impact on continental groundwater flow patters and geochemistry
2. In the subglacial environment, meltwater infiltration into the subsurface dominates when the ice sheet is growing. Conversely, groundwater exfiltrates during ice sheet regression.
3. Over the glacial period, the average subglacial infiltration rate into the subsurface ranges between 0 and 6 mm/yr with an average of 2.5 mm/yr. At LGM, $\sim$20% of subglacial meltwater recharged.
4. Permafrost evolution and distribution strongly influences groundwater circulation patterns.
5. Pressure signatures at depth due to ice loading remain and is still recovering at present.

Publications

1. Lemieux, J.-M., Sudicky, E.A, Peltier, W.R, and L. Tarasov, 2008. *Dynamics of groundwater recharge and seepage over the Canadian landscape during the Wisconsinian glaciation*, J. Geophys. Res., 113, F01011
2. Lemieux, J.-M., Sudicky, E.A, Peltier, W.R, and L. Tarasov, 2008. *Simulating the impact of glaciations on continental groundwater flow systems: 1. Relevant processes and model formulation*, J. Geophys. Res., 113, F03017
3. Lemieux, J.-M., Sudicky, E.A, Peltier, W.R, and L. Tarasov, 2008. *Simulating the impact of glaciations on continental groundwater flow systems: 2. Model application to the Wisconsinian glaciation over the Canadian landscape*, J. Geophys. Res., 113, F03018