PoLIM: an open-source 2D higher-order thermomechanically coupled mountain glacier flow model

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Introduction

As a consequence of climate change, the glacier mass loss around the globe has raised concerns about its impacts on sea-level rise, water availability, glacial hazards, and the related socio-economic services. It is, therefore, imperative to understand the responses of glaciers in a changing climate and to project their future changes. A proper numerical ice flow model, including essential physical processes and couplings (e.g., basal sliding, thermomechanical coupling), is thus highly needed. We present an open-source 2D, higher-order, and thermomechanically coupled ice flow model named PoLIM (Polythermal Land Ice Model) written in MATLAB. The model has been verified by standard benchmark problems, including the ISMIP-HOM experiments, the enthalpy benchmark experiments, and the SHMIP experiments.

Model formulation

- The momentum balance equation is simplified by Blatter-Pattyn approximation.
- The energy balance is formulated by enthalpy.
- A scheme for gravity-driven drainage of water in temperate ice is used.
- Coulomb-friction law is used at the ice-bedrock interface.
- A cavity-sheet type subglacial hydrology model is coupled to glacier dynamics.

Benchmark experiments

ISMIP-HOM

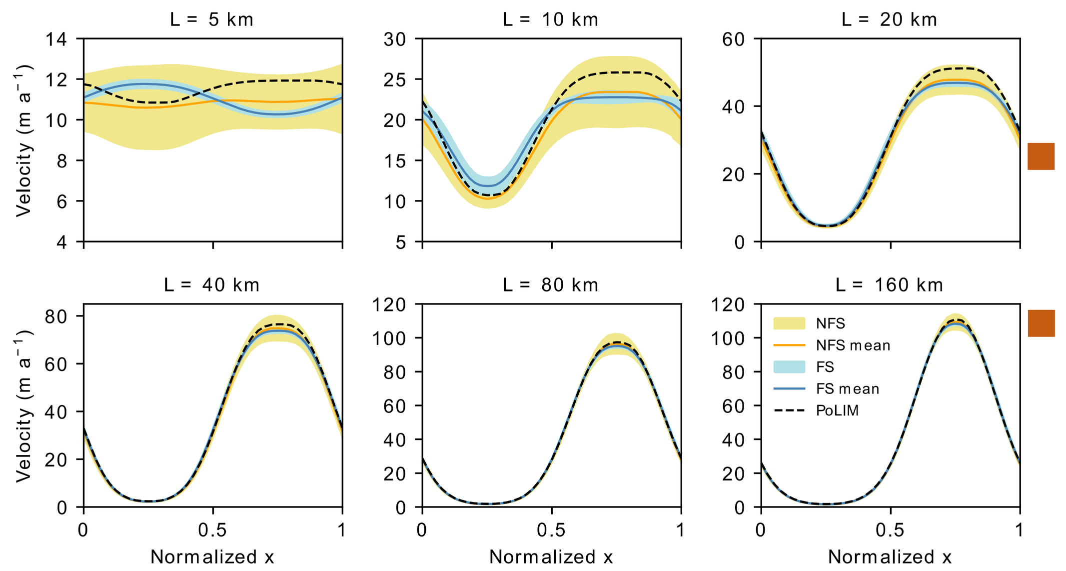


Fig. 1: Surface velocities of Exp. B for different domain length scales.

- Ice flow over a rippled bed
- No-slip

NFS: non full-Stokes model results

FS: full-Stokes model results

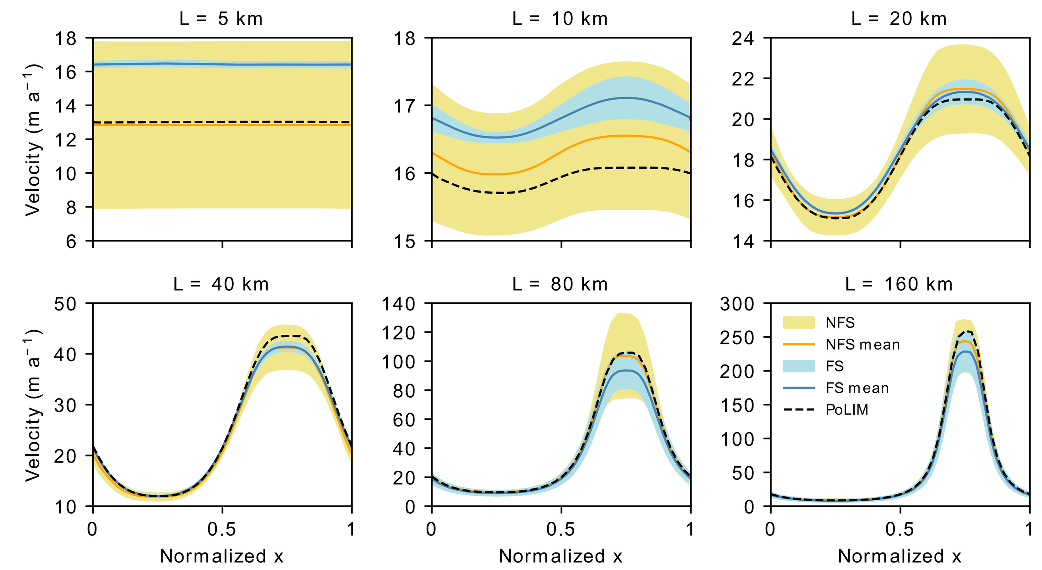


Fig. 2: Surface velocities of Exp. D for different domain length scales.

- Ice stream flow
- Slip

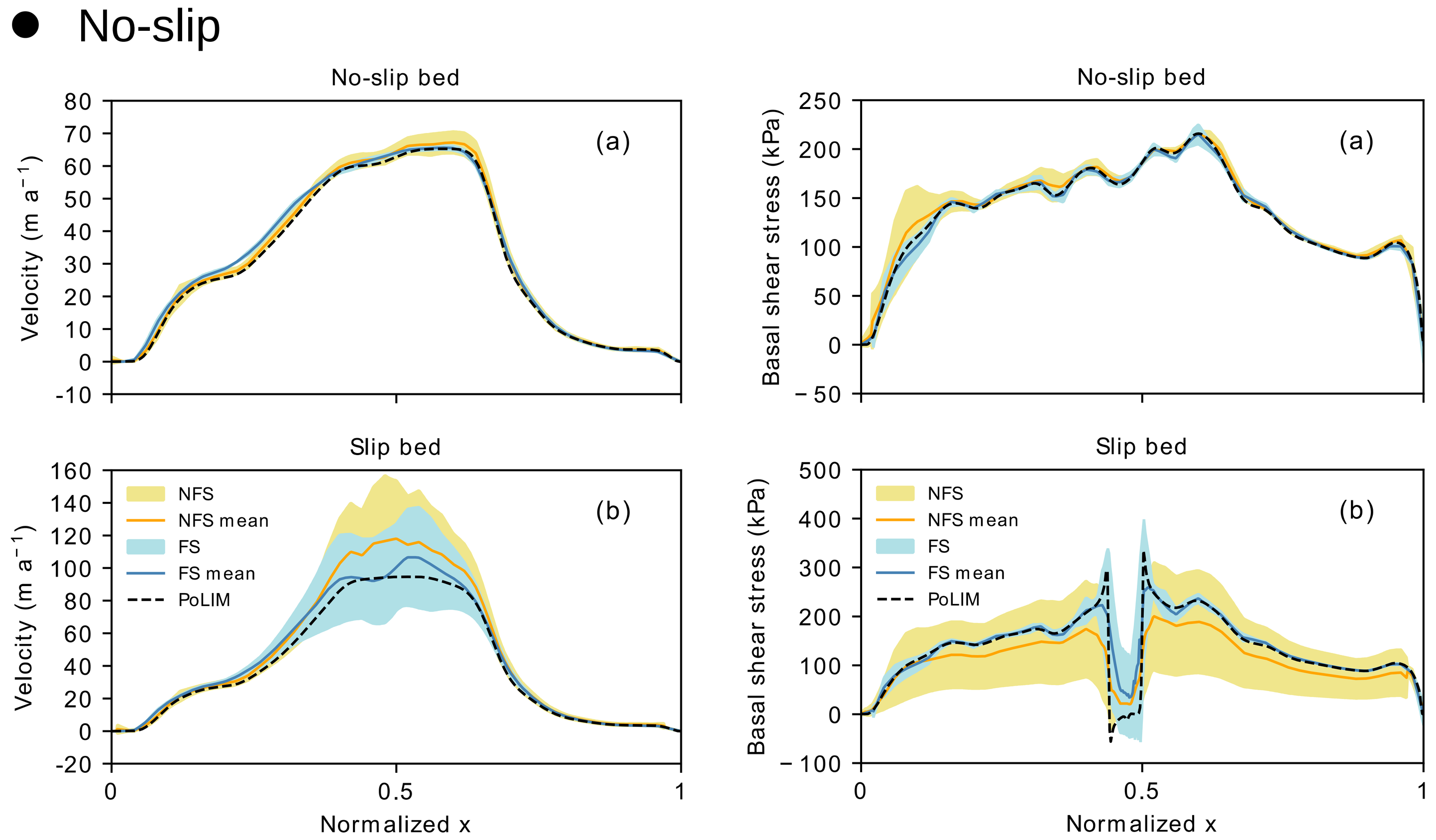


Fig. 3: Surface velocities (left colum) and basal shear stresses (right column) of Exp. E.

- Haut d'Arolla
- Upper panels: no-slip
- Lower panels: a narrow zone of zero traction

Enthalpy benchmark experiment A

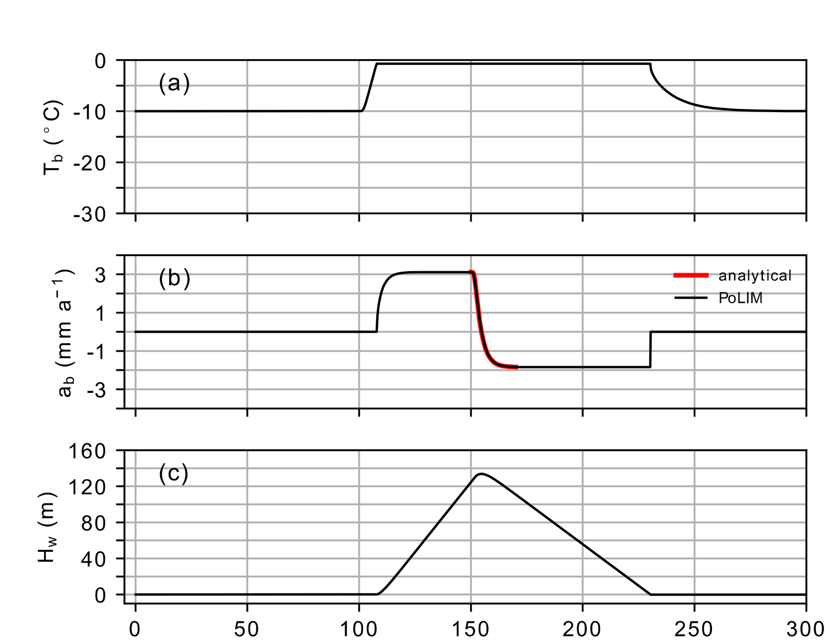


Fig. 4: Modeled basal temperature, basal melt rate and basal water layer thickness.

Enthalpy benchmark experiment B

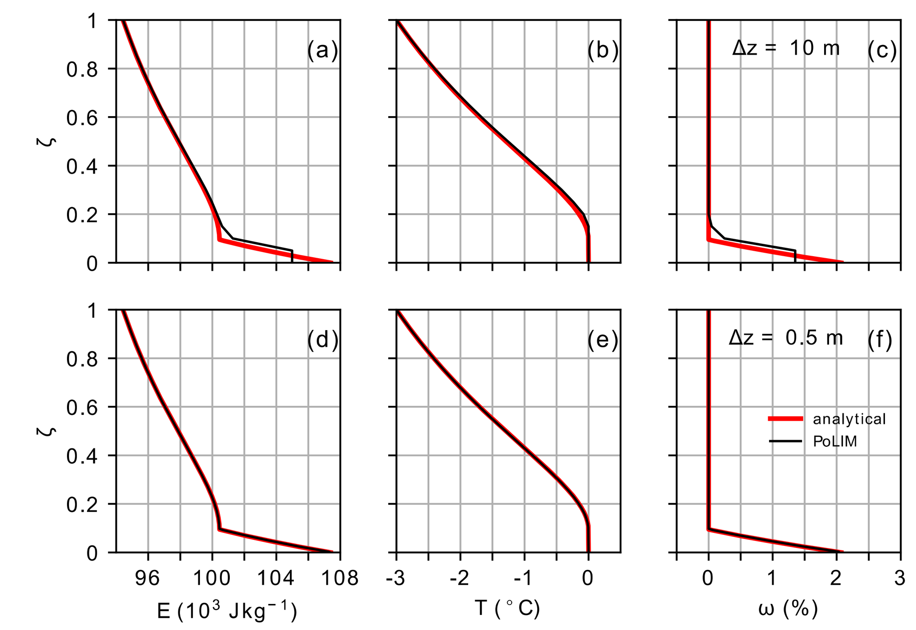


Fig. 5: Modeled steady-state profiles compared with analytical results.

SHMIP

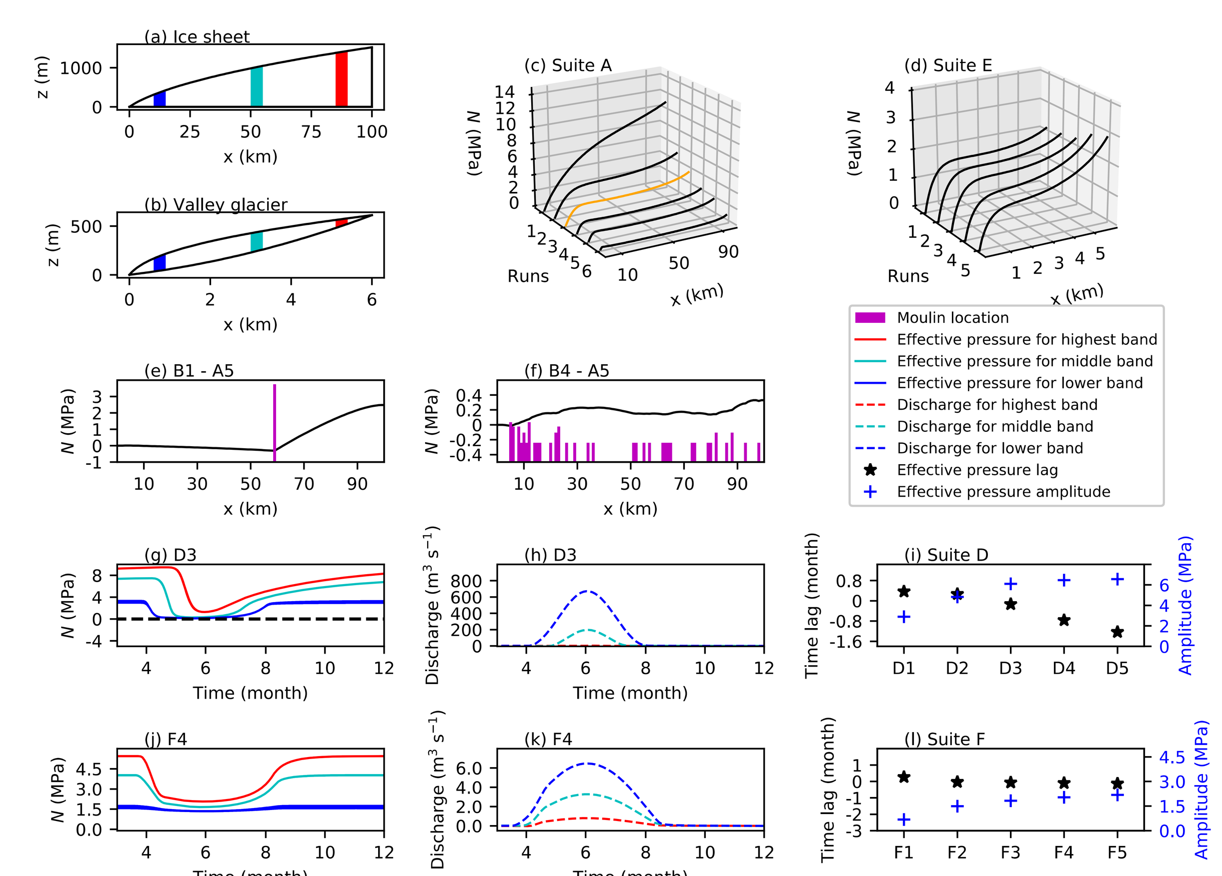
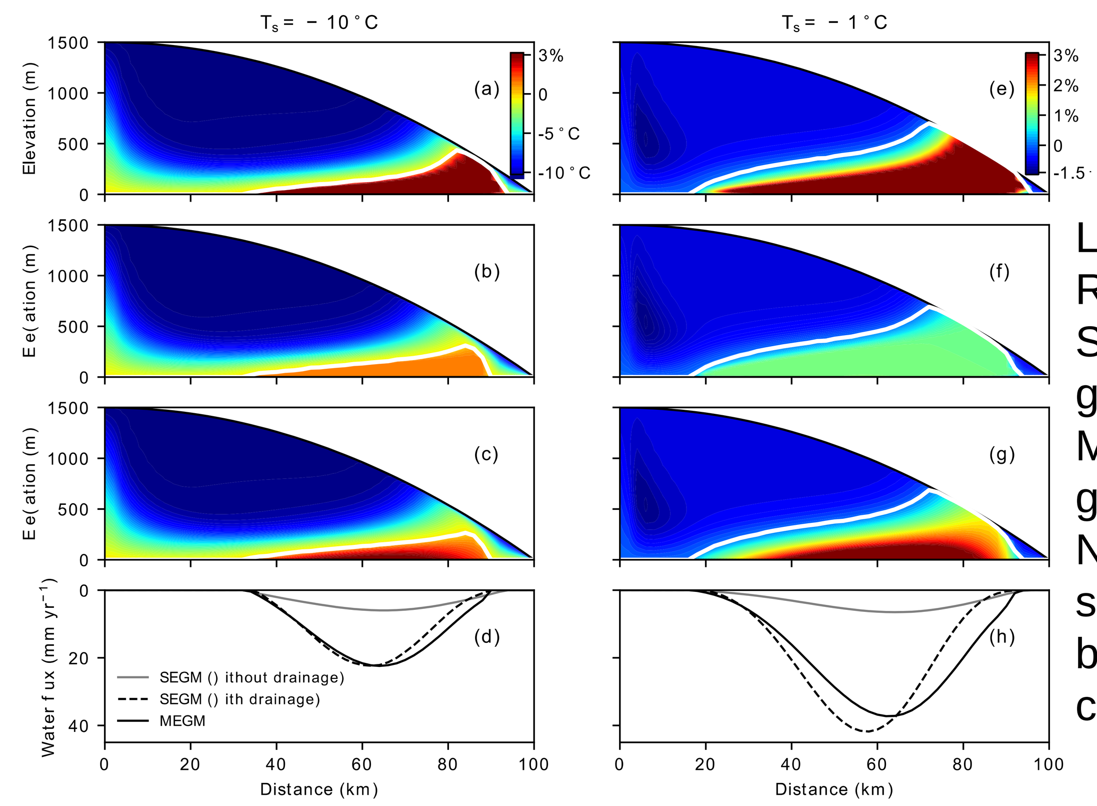


Fig. 6: Simulation results of SHMIP benchmark experiments.

Ice cap experiment



Left column: T_s = -10℃
Right column: T_s = -1℃
SEGM: standard enthalpy gradient model
MEGM: modified enthalpy gradient model
Note that the colorbar scales are different between the left and right columns.

Fig. 7: Simulated steady state enthalpy distributions and basal water fluxes by different water transport schemes.

Application to Storglaciären

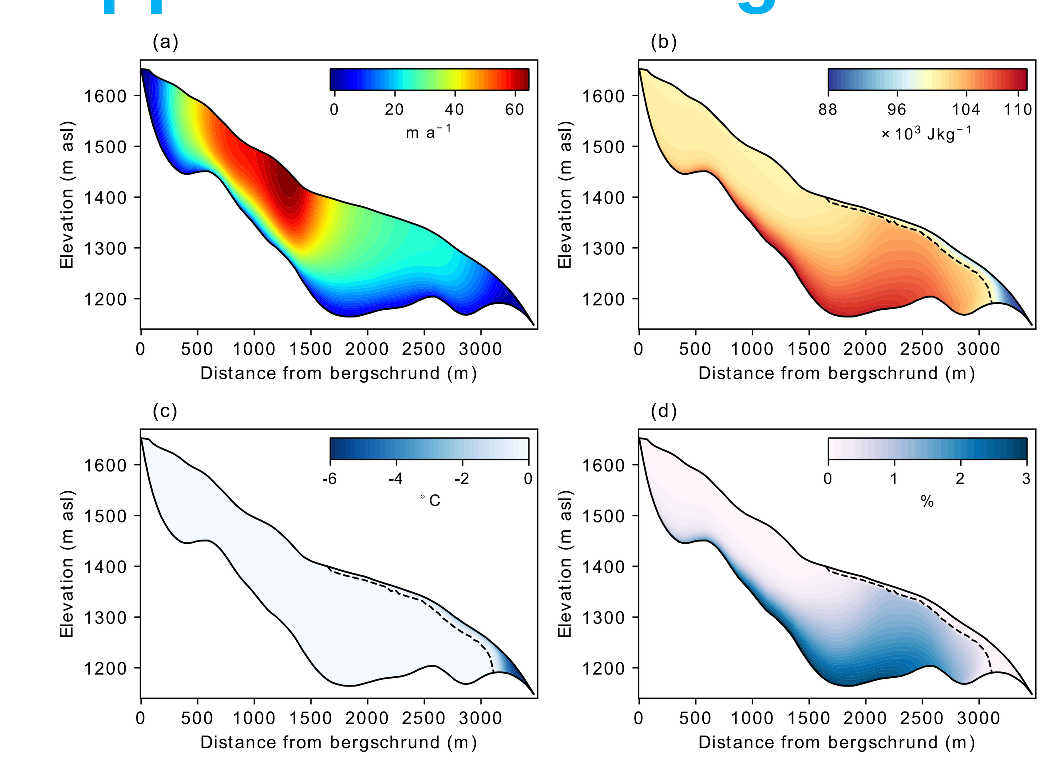


Fig. 8: Modeled horizontal velocity and thermal regime of Storglaciären.

Conclusions and outlook

- By adopting a first-order momentum balance solver, PoLIM considers the longitudinal stress gradient and can thus properly simulate glaciers with heavily undulated bed topography. With the implementation of an enthalpy model, PoLIM can simulate the polythermal structure and the transition of basal slip in the temperate ice zone. In addition, PoLIM is able to simulate the gravity-driven water transport in the temperate ice, and also includes a cavity-sheet type subglacial hydrology model, lending it more power of dealing with meltwater involved problems, e.g., glacier surges.
- We verify the physics and numerics of PoLIM against the standard benchmark experiments for the momentum balance solver, the enthalpy balance solver, and the subglacial hydrology model. PoLIM performs well in all of these benchmark experiments. We therefore have a strong confidence that PoLIM is a solid and useful tool for investigating the problems related to the evolution of mountain glaciers, the thermal features of polythermal glaciers, and the coupling between glacier dynamics and subglacial hydrology.

Github: https://github.com/WangYuzhe/PoLIM-Polythermal-Land-Ice-Model

References

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