last updated June 29, 2025

1. Installation

This model is implemented in MATLAB and requires no installation steps or third-party packages. It has been tested on MATLAB R2012b and later versions.

Simply download the repository, open it in MATLAB, and proceed with the configuration and execution steps described below.

2. Initial Configuration

To run the model, you need to prepare glacier-specific input data, including **glacier outlines, ice thickness, digital elevation model (DEM), and the glacier centerline.** All datasets should be projected to a consistent coordinate system before processing.

The main processing steps are:
1. Extract terrain profiles along the glacier centerline, including surface elevation and ice thickness.
2. Resample the data into a uniformly spaced grid along the flowline. Calculate glacier width at each point perpendicular to the flowline, based on the glacier outline.
3. Integrate all processed data into a single input file (e.g., ".mat", ".dat", or ".csv" format).

This file must include the following fields:
xi: Distance along the centerline (from the glacier head), in meters
hS: Surface elevation, in meters
H: Ice thickness, in meters
hB: Bed elevation (computed as hS - H), in meters
Wsurf *(optional)*: Glacier width at the surface, in meters

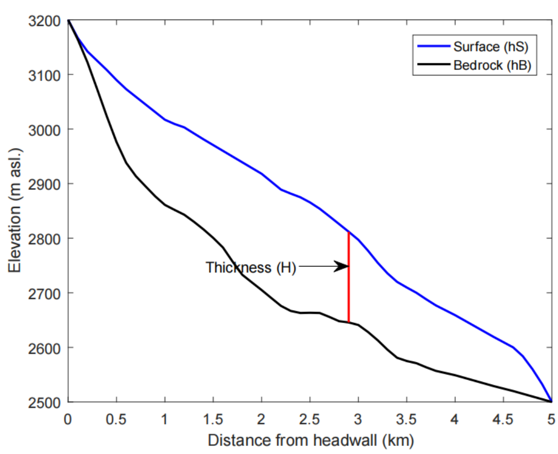

Figure 1. Terrain profile along the glacier centerline.

3. Directory Structure

3.1. Main Scripts

The model provides two main scripts for running simulations:
main_PoLIM.m: the core program for running glacier evolution simulations without subglacial hydrology.
main_PoLIM_subhydro.m: an extended version of the main script that includes subglacial hydrology processes.

In most cases, you only need to adjust a few lines in the main script based on your research needs, including the parameter settings (set_ice_parameters.m), glacier geometry (set_ice_geometry.m), and time-related values such as the time step (dt) and total simulation time (endTime). Other parts of the script generally remain unchanged.

3.2. Parameter Configuration

The main parameter configuration script for the simulation is set_ice_parameters.m. This script defines key model parameters such as physical constants, numerical settings, and model options used in the simulations.

The physical constants include gravitational acceleration (g), universal gas constant (R), ice density (rho), water density (rhow), Glen's flow law exponent (n), as well as thermal properties like conductivity (kc) and heat capacity (Cp).

In addition to these fixed constants, the script contains adjustable parameters that influence the glacier simulation. These include the stress enhancement factor (epsilon), maximum number of iterations (iter_max), the basal boundary condition type (type_BBC), valley geometry (type_valley), and thermal model selection (type_thermal_model).

You can specify different glacier geometry scenarios through the type_geometry variable, which allows the model to represent a variety of glacier environments ranging from simplified slabs to complex ice caps.

3.3. Core Function Modules

1. basalBC_[*].m: (Basal Boundary Condition Functions)
These four functions implement different basal boundary conditions for the ice sheet model, handling thermal and hydrological states at the ice-bed interface.

basalBC_cold_base_dry.m:
Handles a cold, dry basal boundary (sub-freezing temperature, no meltwater).
basalBC_cold_base_wet.m:
Handles a cold but wet basal boundary (sub-freezing with meltwater presence).
basalBC_temperate_base.m:
Handles temperate base (ice at pressure-melting temperature).
basalBC_temperate_layer.m:
Models temperate ice layer (not necessarily basal) with zero water flux at the base.

2. calc_tauxz.m
Calculates the shear stress component in an ice sheet, which describes the resistive forces acting parallel to the ice flow direction.

3. drainageFunc.m
Calculates the meltwater drainage rate from temperate ice based on water content (ω). Models how efficiently liquid water drains through porous ice as water saturation increases.

4. get_[*].m: (Retrieve or compute quantities)
get_AGlen.m:
Computes Glen's flow law rate factor (A) based on temperature-corrected pressure conditions.
get_evolution_continuity.m:
Solves ice thickness evolution using continuity equation in diffusion form.
get_evolution_kinematic.m:
Updates surface elevation using kinematic boundary condition.
get_ice_viscosity.m:
Computes effective ice viscosity and strain heating.
get_ice_w.m:
Computes vertical velocity field from incompressibility condition.
get_initial_enthalpy.m:
Initializes the enthalpy field by solving the steady-state thermal diffusion equation with geothermal flux basal boundary condition.

5. set_[*].m : (Initialize or configure model state)
set_staggered_grid.m:
Computes grid transformation metrics, calculates surface/bed slopes (dhSdx_s, dhBdx_s), updates derivatives for coordinate transforms (dzetadx_s)
set_thermalSBC.m:
Computes surface boundary condition for enthalpy model, implements elevation-dependent temperature parameterization.
Output: Esbc (surface enthalpy boundary values)
set_time_step.m:
Generates time discretization array.
Output: [arrayTime, numTimeStep] for simulation loop.

6. solver_[*]:
These solver functions address fundamental physical processes in glacier/ice-sheet simulations.
solver_u.m
Computes the horizontal ice velocity field by solving the full-Stokes stress balance equations.
solver_enthalpy_MEGM.m (Modified Enthalpy Gradient Method)
Implements Hewitt's enhanced polythermal model with Darcy flow physics. Adds buoyancy-driven water transport to better simulate temperate ice dynamics.
solver_enthalpy_SEGM.m (Standard Enthalpy Gradient Method)
Implements Aschwanden's enthalpy-based polythermal ice model with diffusion-only water transport. This solver handles cold-temperate transitions and basal melting using physics from the original enthalpy gradient framework.

7. staggerX2main.m: (Grid Conversion Utility)
Converts variables from the staggered grid (used for velocity computations) to the main grid (used for thermodynamics and storage). This is essential for coupling ice dynamics with thermal processes in PoLIM's polythermal framework.

8. subHydro_storage_Hoffman.m: (Subglacial Hydrology Module)
Implements the subglacial water sheet evolution model based on Hoffman (2014) formulation. This module calculates subglacial water pressure, effective pressure, water flux, and water layer thickness for polythermal ice sheet modeling.

9. plot_[*].m: (Visualization Scripts)
plot_enthalpy_field.m:
Generates 2D vertical cross-sections of key thermodynamic fields.
Experiment-Specific Plotters:
plot_enthalpy_ExpA.m: Time-series analysis
plot_enthalpy_ExpB.m: Vertical profile validation
plot_field_MEGM.m:
Full diagnostic plots for Modified Enthalpy Gradient Model (MEGM).
plot_field_SEGM[*].m:
Plotters for Standard Enthalpy Gradient Model.
plot_field_SEGM0.m: Without Greve drainage
plot_field_SEGM1.m: With Greve drainage
plot_uField_uSurf.m:
Specialized ice velocity visualization.

4. Running the Simulation

4.1. Arolla Glacier Example

This example demonstrates how to simulate a real mountain glacier using the model.

The input geometry for the Haut d'Arolla Glacier is provided in the file arolla100.dat, which contains surface elevation (hS), bed elevation (hB), and distance along the centerline (xi) sampled along the central flowline.

To run this simulation, users can simply execute the script main_PoLIM.m in MATLAB. No additional modification is required, as both the geometry and parameter settings have been pre-configured.

Key physical settings for this example are defined in the parameter file set_ice_parameters.m, including:
The glacier valley shape is set to *rectangular* (type_valley = 3);
The model operates in *flowband mode* (isFlowband = 1);
The basal boundary condition (BBC) is defined as *Coulomb friction law* (type_BBC = 2).

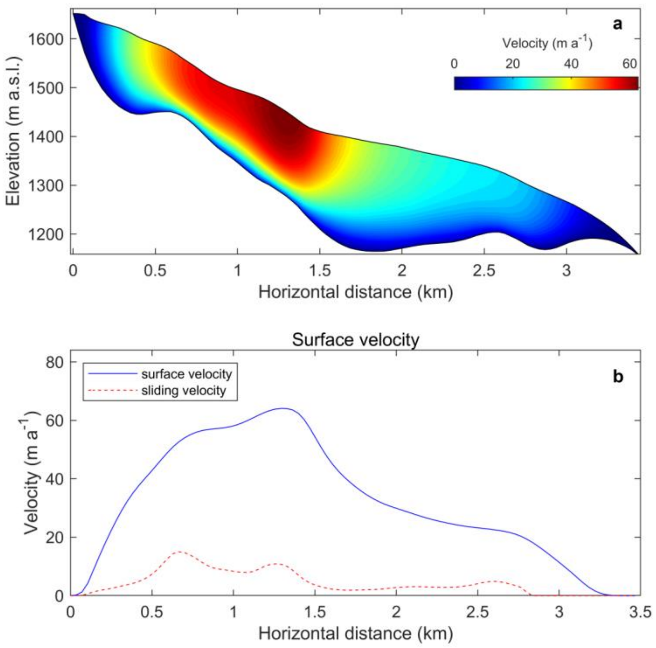

Figure 2. Simulated velocity field along the central flowline of the Arolla Glacier. Panel (a) shows the internal velocity distribution (m a^{-1}) within the glacier, with surface and bed profiles plotted in black. Panel (b) compares surface velocity (blue solid line) and basal sliding velocity (red dashed line) along the flowline.

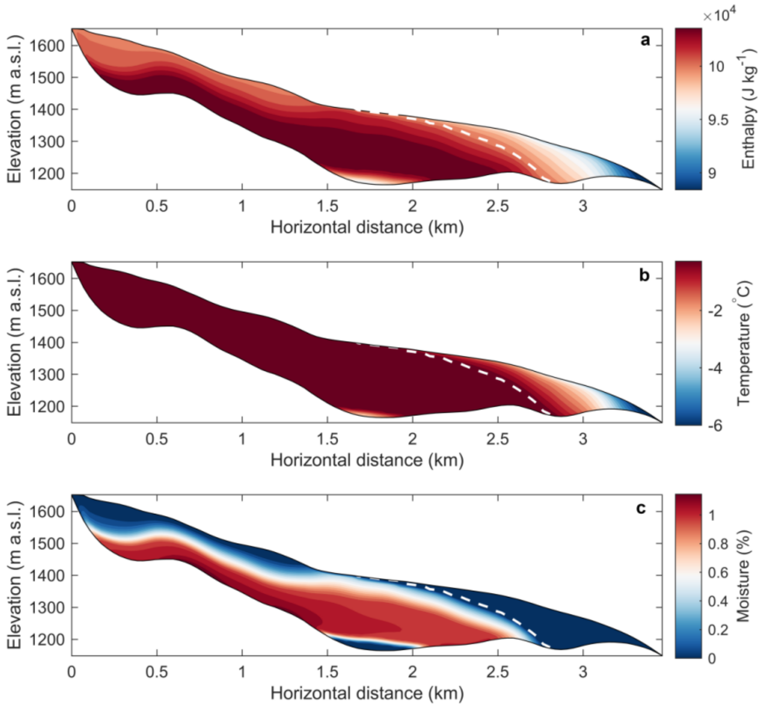

Figure 3. Thermodynamic state along the central flowline of the Arolla Glacier. From top to bottom, the subplots show the distribution of (a) enthalpy (J kg^{-1}), (b) temperature (℃), and (c) moisture content (%). Black lines indicate the glacier surface and bed, while the white dashed line marks the cold-temperate transition surface.

The model can output the glacier state for each simulated year, including geometry, flow dynamics, and thermodynamic properties. Specifically, outputs include ice thickness, surface and bed elevation, surface and basal velocities, enthalpy, temperature, moisture content, and the cold-temperate transition surface. This example serves as a reference for users applying the model to real mountain glaciers.

4.2. Benchmark Experiments

4.2.1. ISMIP-HOM Experiment

The ISMIP-HOM (Ice Sheet Model Intercomparison Project for Higher-Order Models) benchmarks were developed to evaluate and compare the performance of higher-order ice flow models. These experiments focus on simplified geometries and flow conditions to provide controlled test cases that help validate ice dynamics models.

In this work, we use Experiment E, which simulates a real glacier - the Haut Glacier d' Arolla in the European Alps. This experiment assumes an isothermal glacier with no basal sliding, serving as a diagnostic benchmark to test model capability under realistic glacier geometry without basal motion.

The simulation for Experiment E can be run using the script run_ISMIP_HOM_ExpE.m in MATLAB.

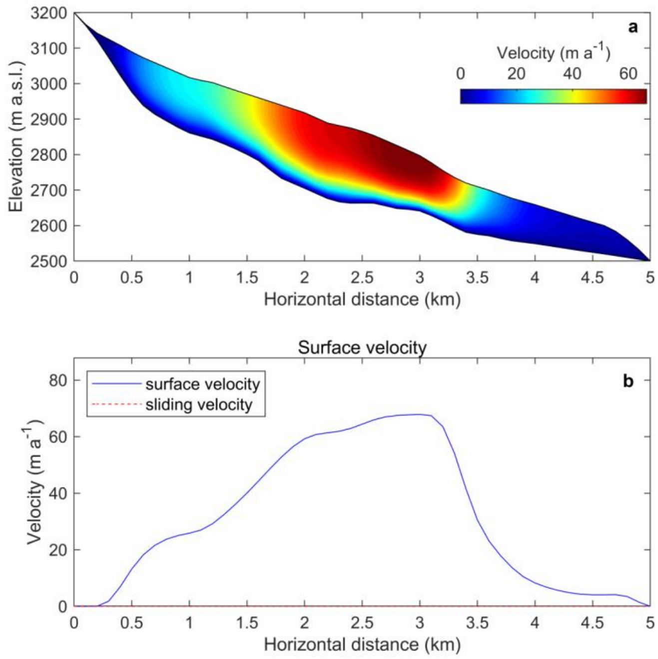

Figure 4. Simulated velocity field along the central flowline of the Arolla Glacier in ISMIP-HOM Experiment E.

4.2.2. Enthalpy Experiment

The PoLIM model includes two benchmark experiments introduced by Kleiner et al. (2015) to validate the numerical implementation of the enthalpy-based thermodynamics.

Experiment A simulates thermomechanical wave propagation in cold ice. It uses a parallel-sided slab geometry with constant ice thickness (H = 1000 m) and no surface slope.

Experiment B evaluates polythermal ice dynamics under an inclined slab geometry. It assumes a constant thickness (H = 200 m) with an inclination angle of 4°.

These experiments are configured to run via the scripts run_Kleiner_ExpA.m and run_Kleiner_ExpB.m, respectively. They provide standard test cases for assessing energy transport and phase transition processes within the model framework.

4.2.3. Ice Cap Experiment

This benchmark is based on the experiment proposed by Hewitt and Schoof (2017) and is used to validate the numerical implementation of water transport through temperate ice in the PoLIM model. The setup features an idealized ice cap geometry under thermally complex and hydrologically active conditions.

In the experiment, the ice surface is maintained at a constant temperature, while the basal ice is assumed to be at the pressure melting point throughout. The simulation starts with an initial enthalpy field corresponding to a temperature of -11°C and no liquid water content. It is then run to a steady state to assess the model's ability to handle water transport processes in temperate ice.

The experiment is preconfigured and can be run using the script run_Hewitt_icecap.m in MATLAB.

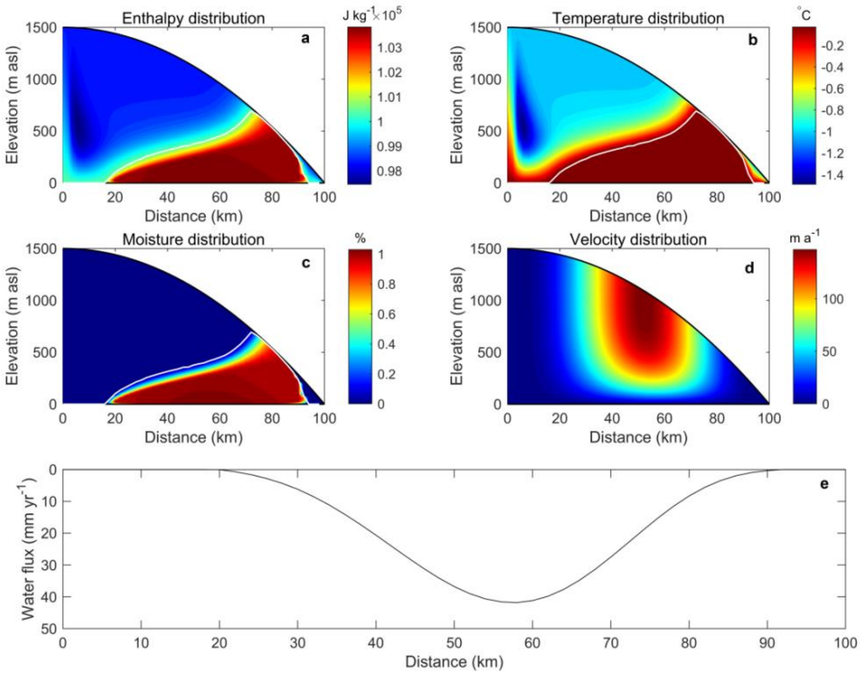

Figure 5. Results of the Hewitt ice cap benchmark experiment. This figure presents the steady-state simulation output using the SEGM (Standard Enthalpy Gradient Model) enthalpy scheme. The subplots (a-e) show the enthalpy distribution (J kg^{-1}), reflecting the combined thermal and water content state of the ice; temperature field (°C), representing the internal thermal structure; moisture content (%), indicating the fraction of liquid water in temperate ice; horizontal ice velocity (m a^{-1}), describing glacier flow dynamics; and vertically integrated drainage to the bed (mm yr^{-1}), representing basal water flux. In subplots (a) through (c), the white dashed line marks the cold-temperate transition surface, while the black solid lines indicate the surface and bedrock profiles.

4.2.4. SHMIP Experiment

The Subglacial Hydrology Model Intercomparison Project (SHMIP) provides a comprehensive set of six synthetic experiments (A-F) designed to evaluate and compare subglacial hydrology models. These benchmarks assess the ability of models to simulate subglacial water flow and its effects on glacier dynamics.

The SHMIP experiments are preconfigured and can be executed using the MATLAB scripts found in the run_SHMIP directory.