Automatized large-scale 3D THM simulations capturing glacial cycle effects on German nuclear waste repositories in salt rock

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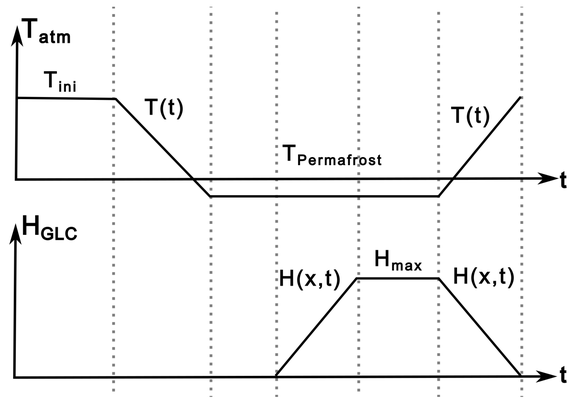
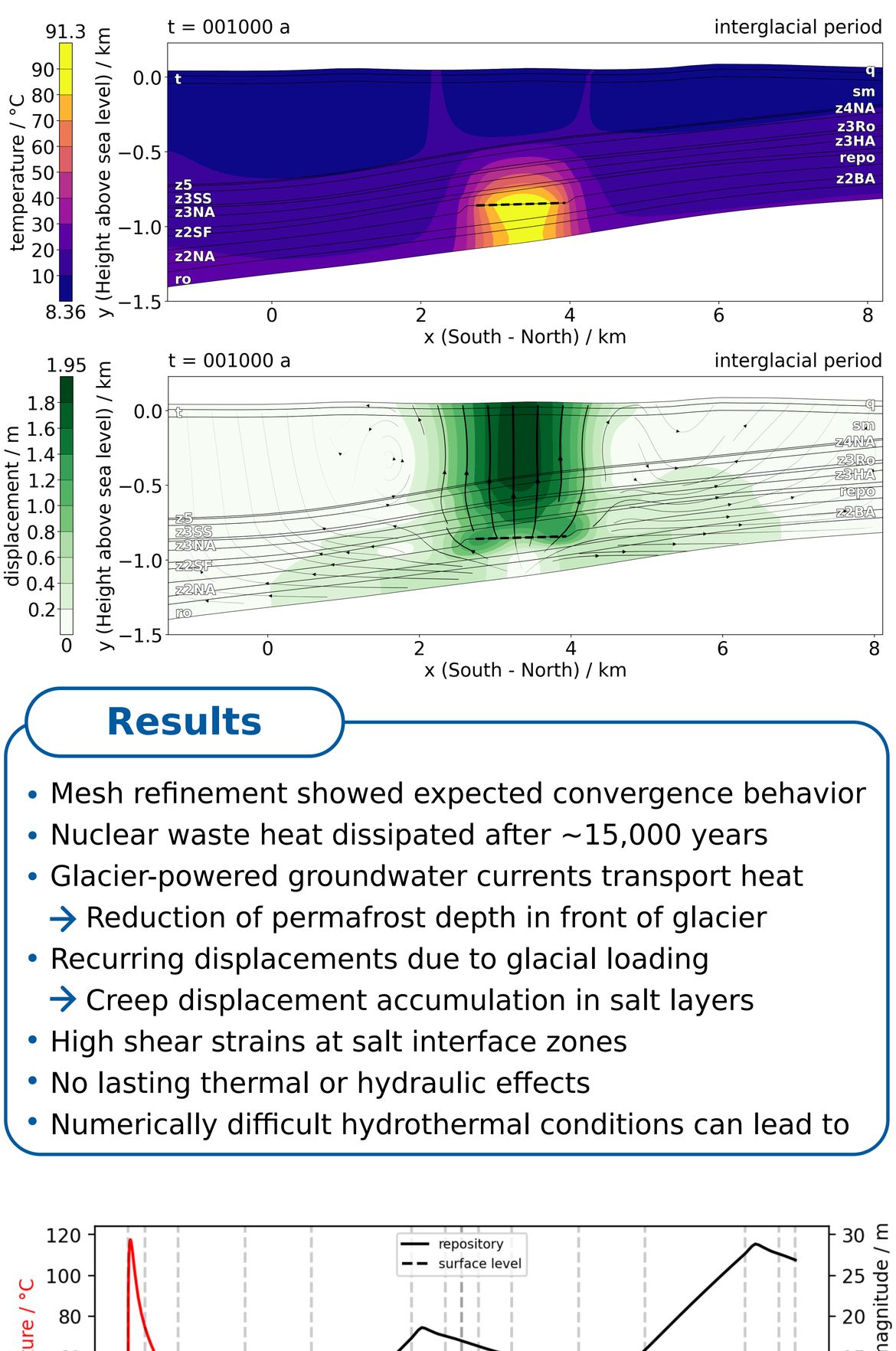
Introduction

- Glaciation cycles may be critical for safety assessment of nuclear waste repository sites
- We studied time-dependent boundary conditions with thermo-hydro-mechanical coupling
- Complex THM-simulation studies are performed on layered geological models
- Open-source multi-field finite element code **Open**GeoSys is used





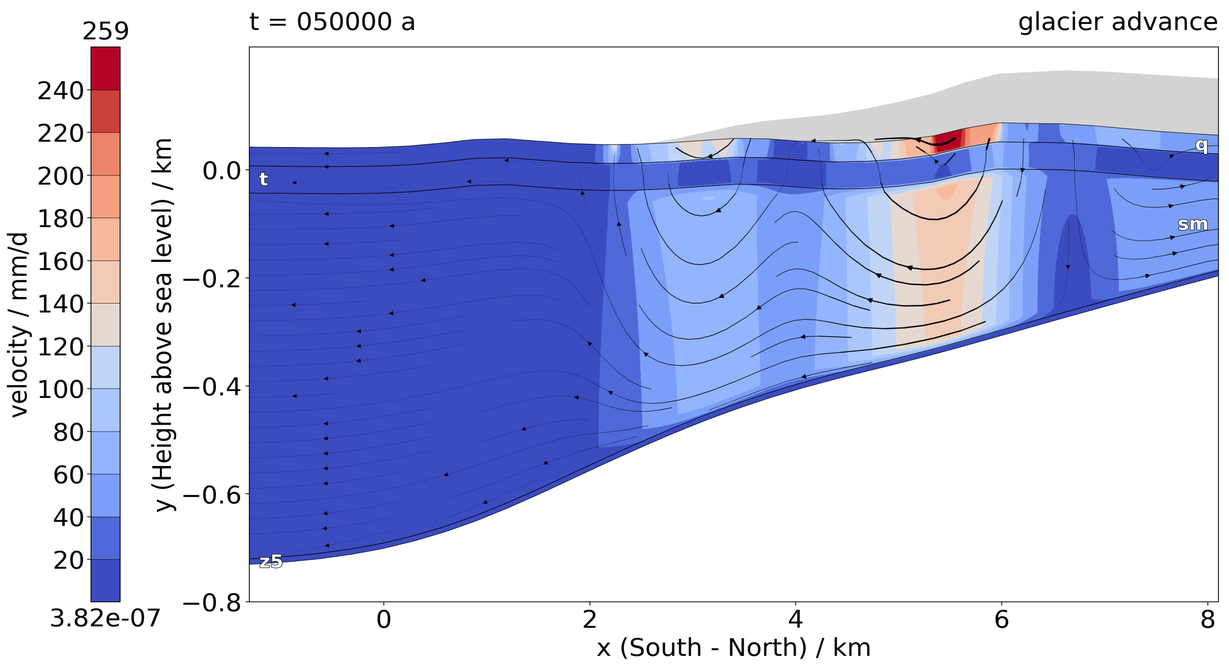
Methodology

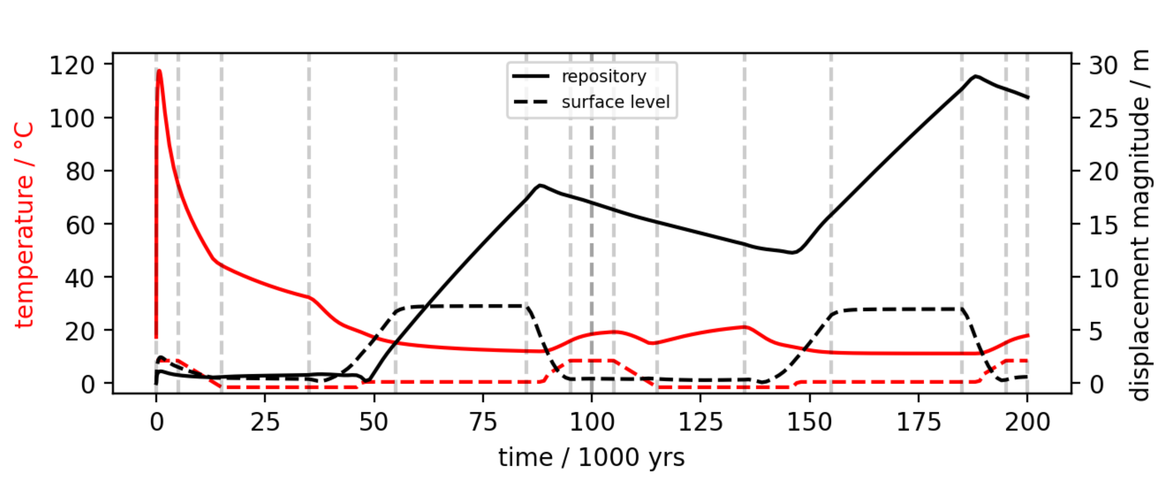
- Complete simulation workflow automatized via snakemake (preprocessing, simulation, postprocessing)
- Finite element meshes from geological data
- 14 different stratigraphic layers, individual material properties
- Glacial cycles as complex time-dependent boundary conditions
  → Temperature evolution, permafrost inhibits hydraulic flow
  → Glacier-induced mechanical load and hydraulic pressure
- Repository as planar heat source with exponential decay
- Model is fully implicit THM coupled
- Salt rock hydraulically deactivated, viscoplastic material model
  → Linear term corresponds to pressure solution creep

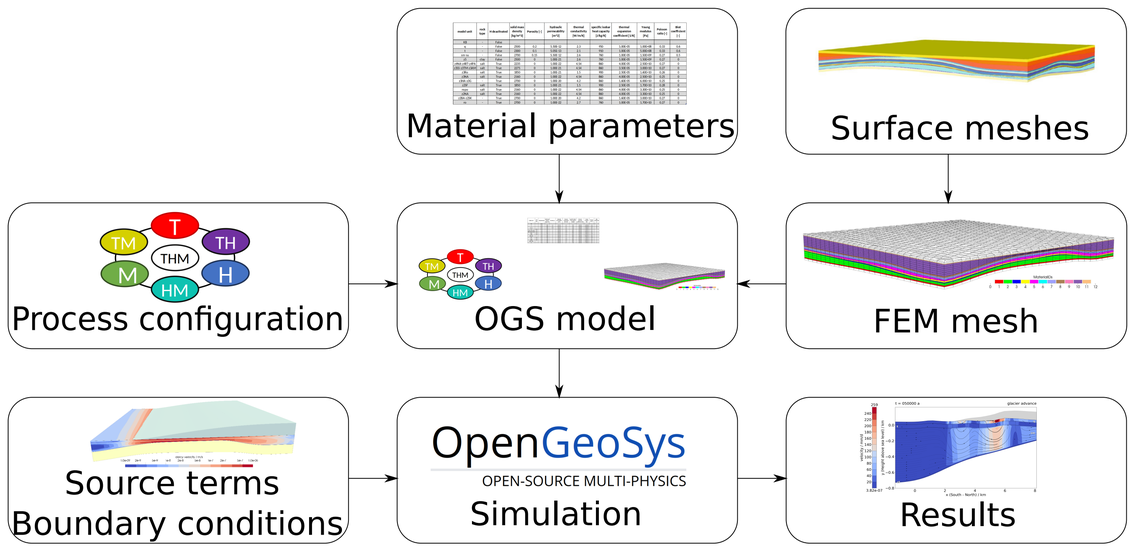
$$\dot{\varepsilon}^{cr} = A \exp(-Q/RT) \left(\frac{\sigma}{\sigma_f} \right)^n + \frac{A_2}{D^3 T} \exp(-Q_2/RT) \left(\frac{\sigma}{\sigma_f} \right)$$

Results

- Mesh refinement showed expected convergence behavior
- Nuclear waste heat dissipated after ~15,000 years
- Glacier-powered groundwater currents transport heat
  → Reduction of permafrost depth in front of glacier
- Recurring displacements due to glacial loading
  → Creep displacement accumulation in salt layers
- High shear strains at salt interface zones
- No lasting thermal or hydraulic effects
- Numerically difficult hydrothermal conditions can lead to







Conclusions & Outlook

- workflow automatization greatly improved our research in speed and quality
  → testing different model setups quickly boosts problem understanding
- salt creep rate outperformes deviatoric stresses (parameters need further research)
- large shear strains → interface elements or a large deformation FEM approach
- far-field simulation results might be used as boundary conditions for embedded near-field models
  → permeabilty or fracture models can be applied on this scale

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