PhD thesis: Numerical simulation of permafrost thaw impacts on infrastructure stability and water resources in the Arctics

Near Abisko in Northern Sweden, March 2025

Place: Geosciences Environment Toulouse (GET) laboratory

Duration: 3 years (September 2026 – August 2029)

Salary: ~2300 euros/month (including French social and medical insurance 'sécurité sociale')

Funding: ANR project PERMACHANGE

Advisor: Laurent Orgogozo (email: laurent.orgogozo@get.omp.eu)

Collaborations: Processes and Engineering in Mechanics and Materials (PIMM) laboratory
Navier laboratory, Mechanics and physics of materials, structures and geomaterials
Alfred Wegener Institute (AWI)
Swedish Polar Research Secretariat (SPRS)
Arctic Danish Technical University (Arctic DTU)

Scientific overview:

This PhD thesis aims at studying the impacts of climate change-induced permafrost thaw in the Arctics, by using advanced thermo-hydro-mechanical modelling capabilities developed in the framework of the PERMACHANGE project. Permafrost is soil permanently frozen in depth, covering a quarter of Northern Hemisphere lands. Due to climate warming, it is experiencing fast and widespread thawing, and this induces essential impacts in the Arctics, both on the environment (e.g., water resources) and on societies (e.g., infrastructure destabilisation). These permafrost thaw impacts are expected to generate significant additional financial costs for maintaining key human activities, up to hundreds of billions of dollars by the end of the century. Moreover, permafrost thaw will likely trigger critical climatic feedback. Thus, anticipating permafrost thaw by numerical simulations is paramount for ensuring the resilience of Arctic environments, societies and activities while controlling the associated costs. Meanwhile, numerical simulations of permafrost dynamics

are highly complex and challenging due to the strong non-linearities and couplings involved in the related physics.

The PERMACHANGE project builds on high performance computing (Orgogozo *et al.*, 2023, Xavier et *al.*, 2024) and hydrid modelling (Chinesta *et al.*, 2020; Champaney *et al.*, 2022) for developing a site scale (~10's of km^2) permafrost thermo-hydological hybrid twin, to be coupled with state of the art freezing/thawing soil mechanics machine learning-based surrogate models (Richa *et al.*, 2024, Tristani *et al.*, 2024) using symbolic regression approaches (e.g. Guayacán-Carrillo and Sulem, 2024). By doing so, PERMACHANGE will enable unprecedented high fidelity and high efficiency numerical simulations of subterranean heat and water transfers and terrain stability under permafrost thaw.

This PhD thesis aims at applying this advanced modelling chain to three sites of long-term permafrost monitoring in the European Arctics: Abisko in Northern Sweden, Ny-Ålesund in Svalbard and Ilulissat in Greenland. In this way, projections of permafrost-thaw impacts at different time scale will be done, from the seasonal time scale to the century time scale. This will allow us to demonstrate the capabilities of the PERMACHANGE advanced modelling workflow and to provide critical information to local stakeholders as an alert for decision-making regarding emergency actions for short-term permafrost thaw hazards and information for long-term land planning, taking into account climate change. It will also enable establishing a general procedure for the operational application of this advanced permafrost modelling workflow all across the Arctics and contribute to the gathering of the relevant information needed for improving permafrost modelling in Earth System Models used for climate change simulations.

Champaney *et al.*, 2022. *Int J Mater Form* 15, 31. https://doi.org/10.1007/s12289-022-01678-4

Chinesta *et al.*, 2020. Arch Computat Methods Eng 27, 105–134 https://doi.org/10.1007/s11831-018-9301-4

Guayacán-Carrillo and Sulem, 2024. *Computers & Geotechnics*, 171, 106355. https://doi.org/10.1016/j.compgeo.2024.106355

Orgogozo et al., 2023. *Computer Physics Communications*, 282, 108541, https://doi.org/10.1016/j.cpc.2022.108541

Richa *et al.*, 2024. *In: Geotechnical engineering challenge to meet current and emerging needs of society. Proc. XVIII European Conference on Soil Mechanics and Geotechnical Engineering*. Lisbonne, August 2024. https://doi.org/10.1201/9781003431749-359

Tristani *et al.*, 2024. *International Journal for Numerical & Analytical Methods in Geomechanics.* https://doi.org/10.1002/nag.3889

Xavier *et al.*, 2024. *The Cryosphere*, 18, 5865–5885, https://doi.org/10.5194/tc-18-5865-2024

Tasks: For each of the three Arctic study sites, making:
1) thermo-hydrological projections at the century-scale by applying the hybrid twin approach, using the climate modelling results of the CMIP6 as input data.
2) real-time thermo-hydrological projections at seasonal time scale by applying the hybrid twin approach, using observed and statistically inferred possible extremum weather conditions to come.
3) mechanical projections at the century-scale by applying the machine learning based surrogate soil mechanics model, using the results of task 1) as input data.
4) real-time mechanical projections at seasonal time scale by applying machine learning based surrogate soil mechanics model, using the results of task 2) as input data.

Needed skills and knowledge:
Numerical modeling of physical processes (at best with OpenFOAM and/or AI-based modelling)
Working in linux environment (at best with experience on supercomputers)
Collaborative work in a large and diverse international team
Interest for scientific communication and writing
Although not mandatory, a background in geosciences and/or cryosciences and/or porous media physics would be appreciated.

How to apply: please send a CV and a motivation letter to the advisor.

Application dead line: 31st of May 2026