INTERFROST: A benchmark of Thermo-Hydraulic codes for cold regions hydrology

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Context and objectives

Large focus was put recently on the impact of climate changes in boreal regions due to the large amplitudes expected. Large portions of these regions, corresponding to permafrost areas, are covered by water bodies (lakes, rivers) with very specific evolution and water budget. These water bodies generate taliks (unfrozen zones below) that may play a key role in the context of climate change.
Recent studies and modeling exercises showed that a fully coupled 2D or 3D Thermo-Hydraulic (TH) approach is required to understand and model the evolution of river and lake systems in a changing climate.
However, 3D studies are still scarce while all numerical approaches can only be validated against analytical solutions for a purely thermic equation with phase change (e.g. Neumann/Stefan, Lunardini). When it comes to the coupled TH system (coupling two highly non-linear equations), the only possible approach is to compare different codes on provided test cases and/or to have controlled experiments for validation and propel discussions to try and improve the code performances.
We propose here a benchmark exercise, detail some of its planned test cases and invite other research groups to join. The benchmark will consist of some test cases inspired by existing literature (e.g. Mc Kenzie et al., 2007) as well as new ones. Some experimental cases in cold room will complement the validation approach. The benchmark is open as well to new or alternative cases reflecting a numerical or a process oriented interest or answering a more general concern among the cold region community.
A further purpose of the benchmark exercise is to propel discussions for the optimization of codes and numerical approaches in order to develop validated and optimized simulation tools allowing in the end for 3D realistic applications.

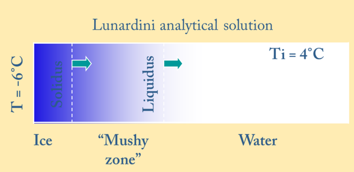
Strategy, work plan

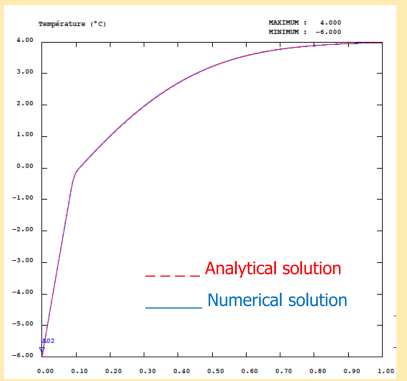
- For the test cases we will proceed from simple to complex, progressively including:
  - The various terms of the system of equations (pure thermal transfers to full coupling)
  - 1D to 2D and finally 3D problems
  - Simple geometries with homogeneous properties to more realistic systems
- Simple performance measurements will be chosen to inter-compare the simulation results among participants
- Validation is expected from analytical solutions (1D purely thermal cases) or from experiments in cold room. Evaluation of codes will come from an intercomparison of simulation results
- The intercomparison exercise is open to anybody willing to join. The present first phase of the benchmark considers simple cases. The extension to more complex and realistic cases is considered and will be discussed in the course of the first phase. A first set of test cases will be provided by Spring 2014. A kick off meeting is planned October 2014

T1: Lunardini/Osterkamp

Analytical solution:

1D semi-infinite, purely thermal (conduction, phase change, cst. properties)





Temperature profiles (Cast3M code vs Lunardini solution)

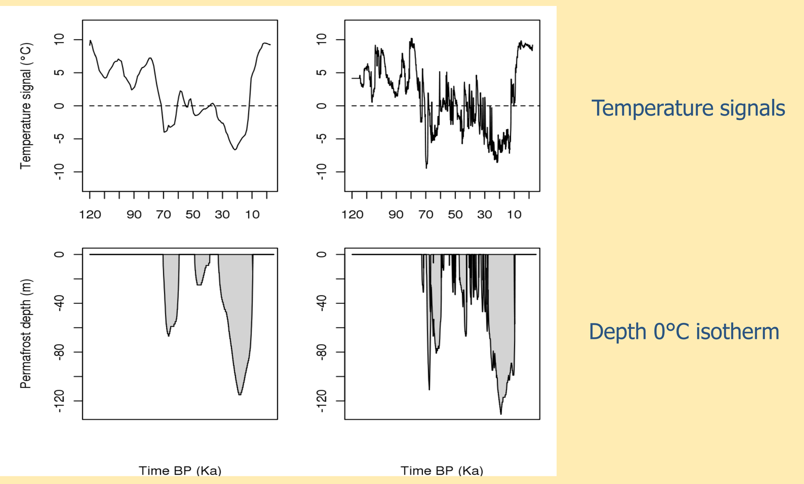
T2: Heterogeneous

Multi-layered, bounded, with geothermal flux.

Include field monitoring data.

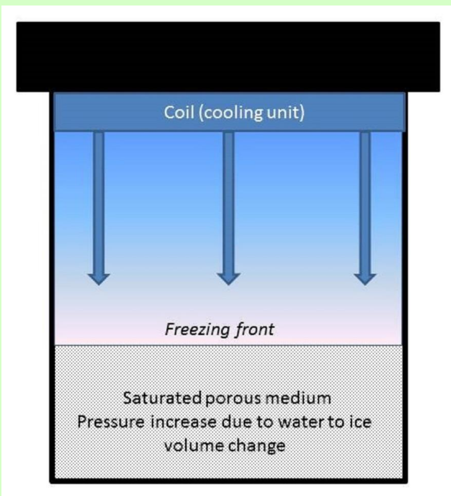
T3: geological times

Heterogeneous, with geothermal flux, long simulation times

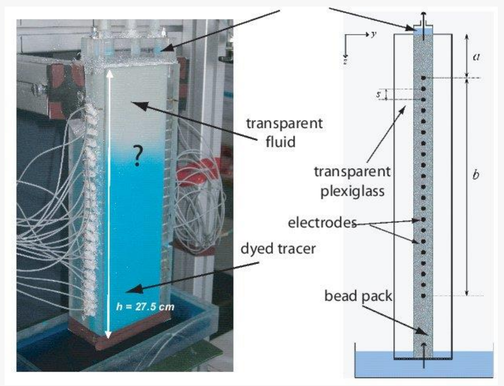


After Régnier, 2012

T→P: 1D P↑



Experiments in cold room



Lekmine et al. 2011

Facility at GEOPS with controlled room temperature

Coupled system of TH equations

Darcy water flow equation

$$\left(S_w\frac{\partial \varepsilon\rho_w}{\partial p}\right)\frac{\partial p}{\partial t}=\nabla\cdot\left[\rho_w K_w\vec{\nabla}p\right]+\nabla\cdot\left[\rho_w K_w\vec{\nabla}z\right]-\left(\varepsilon(\rho_w-\rho_i)\frac{\partial S_w}{\partial T}\right)\frac{\partial T}{\partial t}+Q_w$$

Heat transfer equation

$$\left(\rho_w S_w c_w\varepsilon+\rho_i S_i c_i\varepsilon+(1-\varepsilon)\rho_s c_s\right)\frac{\partial T}{\partial t}=$$

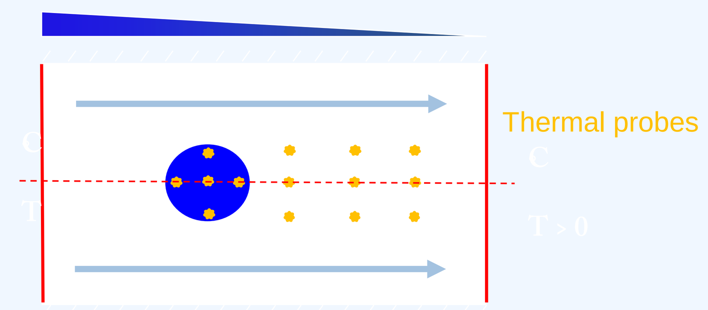
$$\nabla\cdot\left[\lambda^*\vec{\nabla}T\right]+\nabla\cdot\left[h_w\rho_w K_w\vec{\nabla}p+h_w\rho_w K_w\vec{\nabla}z\right]-\frac{\partial S_i}{\partial t}(\varepsilon\rho_i L)-\left(h_w S_w\frac{\partial(\varepsilon\rho_w)}{\partial p}\right)\frac{\partial p}{\partial t}+Q_T$$

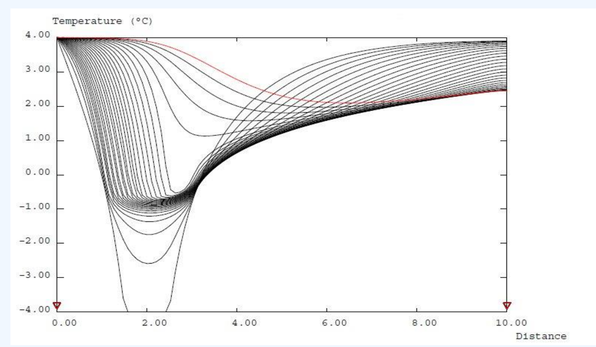
The system is similar to the one of (Mc Kenzie et al., 2007)

TH1: Frozen inclusion

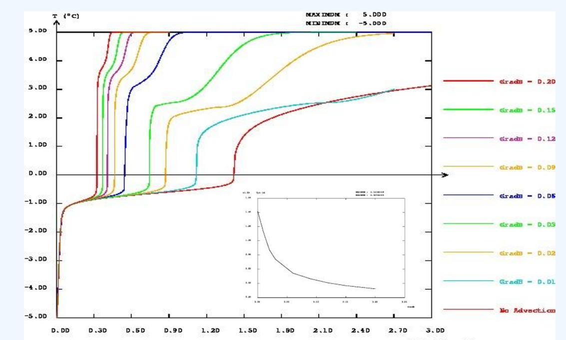
An initially 2D cold (T < 0°C) permafrost inclusion is present within a uniform water flow (T > 0°C)

Performance measurements are: 1°) time for the minimum system temperature to reach 0°C, 2°) temperature profiles along main axis for a set of control times





Longitudinal temperature profiles (Cast3M code)

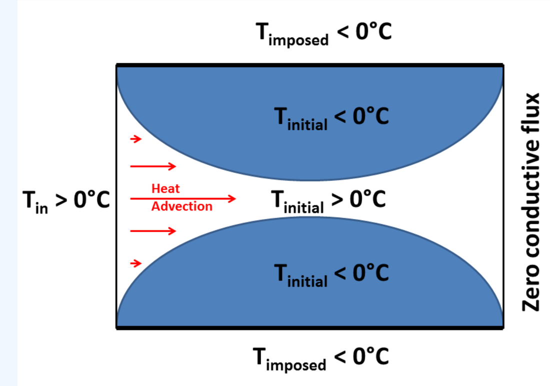


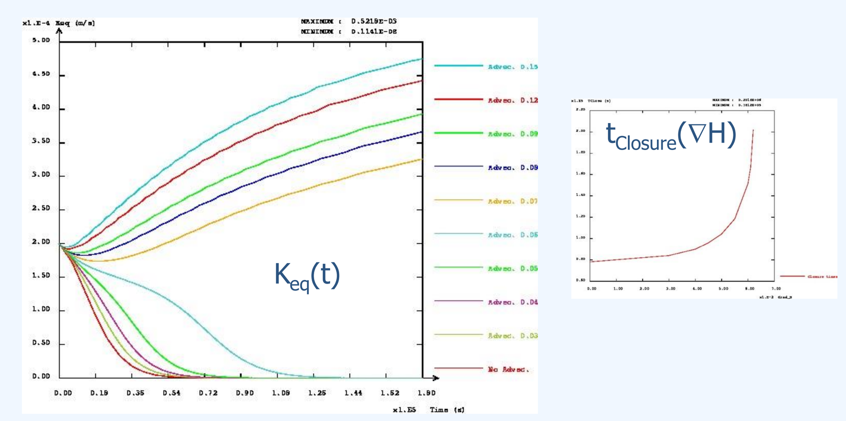
Evolution of minimal temperature (various ∇H intensities)

TH2: Talik evolution

An initially 2D cold (T < 0°C) permafrost zone is present within a uniform water flow (T > 0°C). Imposed T < 0°C for upper and lower boundaries

Performance measurements are: 1°) equivalent permeability evolution, 2°) time for the talik to close for weak advection levels





Please join! … and come to discuss the cases!

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