The InterFrost benchmark of Thermo-Hydraulic codes for cold regions hydrology – first inter-comparison results

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Coupled Thermo-Hydro processes

Rowland et al 2010

- Open field (in situ process studies) & Lab. studies
- Processes are thermally driven … Thermo-Hydro cases
- Simulation: non-linear coupled equations with steep fronts due to phase change
- Modeling issues, code improvement and validation
  1. Cases with analytical solutions
  2. Intercompare on academic cases
  3. Confront with experiments
  4. Confront with field data monitoring
- Validation vs calibration

interfrost

now 14 codes …

Kick-off Meeting, 18 – 19 Nov. 2014, Paris

Diversity of codes

- Finite elements, finite volumes, finite differences
- Various meshing strategies and choices of time steps
- Different treatment of non-linearities and coupling
- Different experiences and fields of applications

➢ Large range

Intercomparison process

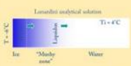
GEOSCIENCES PARIS SUD (GEOPS)

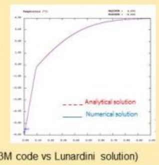
1D Thermal with advective component

T1: Lunardini/Osterkamp

Analytical solution:

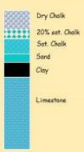
1D semi-infinite, purely thermal (conduction, phase change, cst. properties





Temperature profiles (Cast3M code vs Lunardini solution)

T2: Heterogeneous

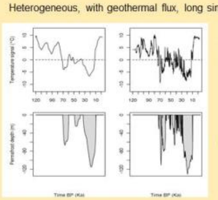


Multi-layered, bounded, with geothermal flux.

Include field monitoring data.

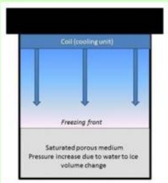
T3: geological times

Heterogeneous, with geothermal flux, long simulation times

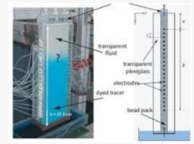


After Régnier, 2012

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

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

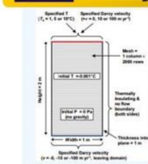
Heat transfer equation

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

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

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

TH1: Kurylyk & Lunardini

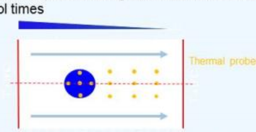


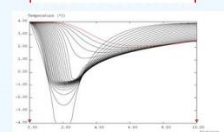
Analytical solutions including constant advection

TH2: Frozen inclusion

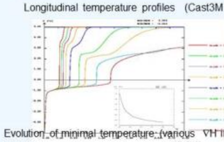
An initially 2D cold (T < 0°C) permafrost inclusion is present within a uniform water flow (T > 0°C)

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)

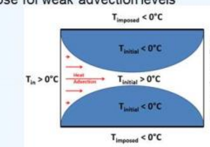


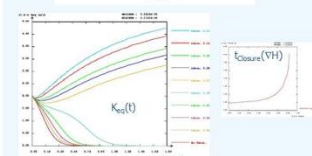
Evolution of minimal temperature (various ∇H intensities)

TH3: 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





1D Thermal

1D Thermal with impact on pressure (no motion)

2D with full TH coupling

Coupled non-linear equations TH2&3

Heat transfer

Phase change

$$\left(\rho_w S_w C_w \epsilon + \rho_i S_i C_i \epsilon + (1-\epsilon)\rho_s C_s + \epsilon \rho_i L \frac{\partial S_i}{\partial T}\right)\frac{\partial T}{\partial t} = \nabla.\left(\lambda_t \vec{\nabla} T\right) + \nabla.\left[\rho_w c_w K_w T.\vec{\nabla} p + \rho_w c_w K_w T.\vec{\nabla} z\right]$$

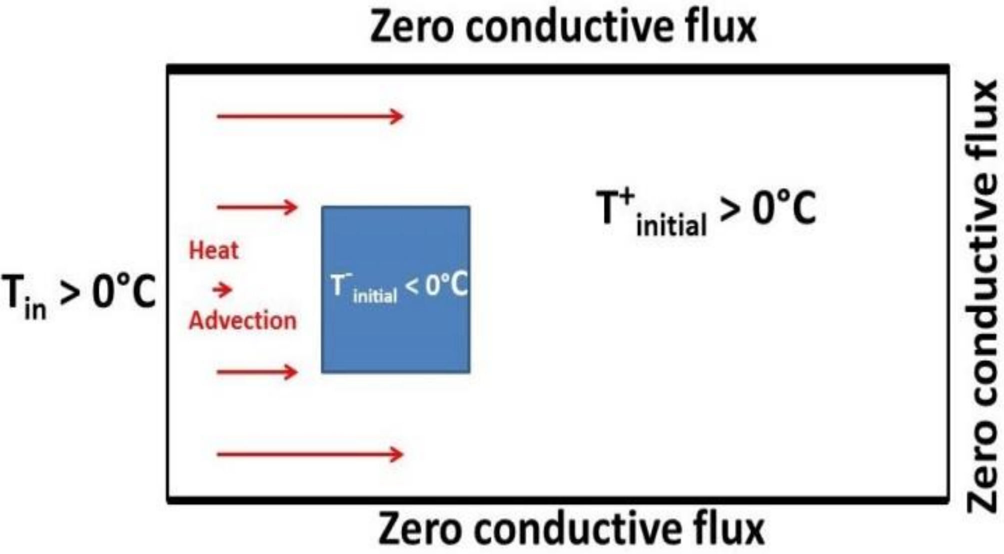
Conduction **Advection**

Water flow

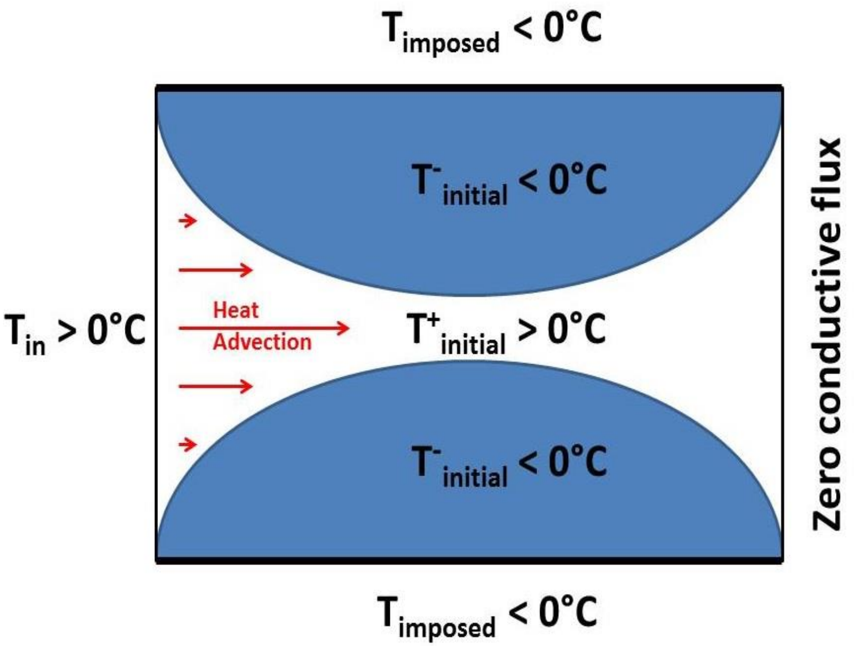
$$(S_w \epsilon \rho_w g \beta)\frac{\partial p}{\partial t} = \nabla.\left[K_w \vec{\nabla} p\right] + \nabla.\left[K_w \vec{\nabla} z\right]$$

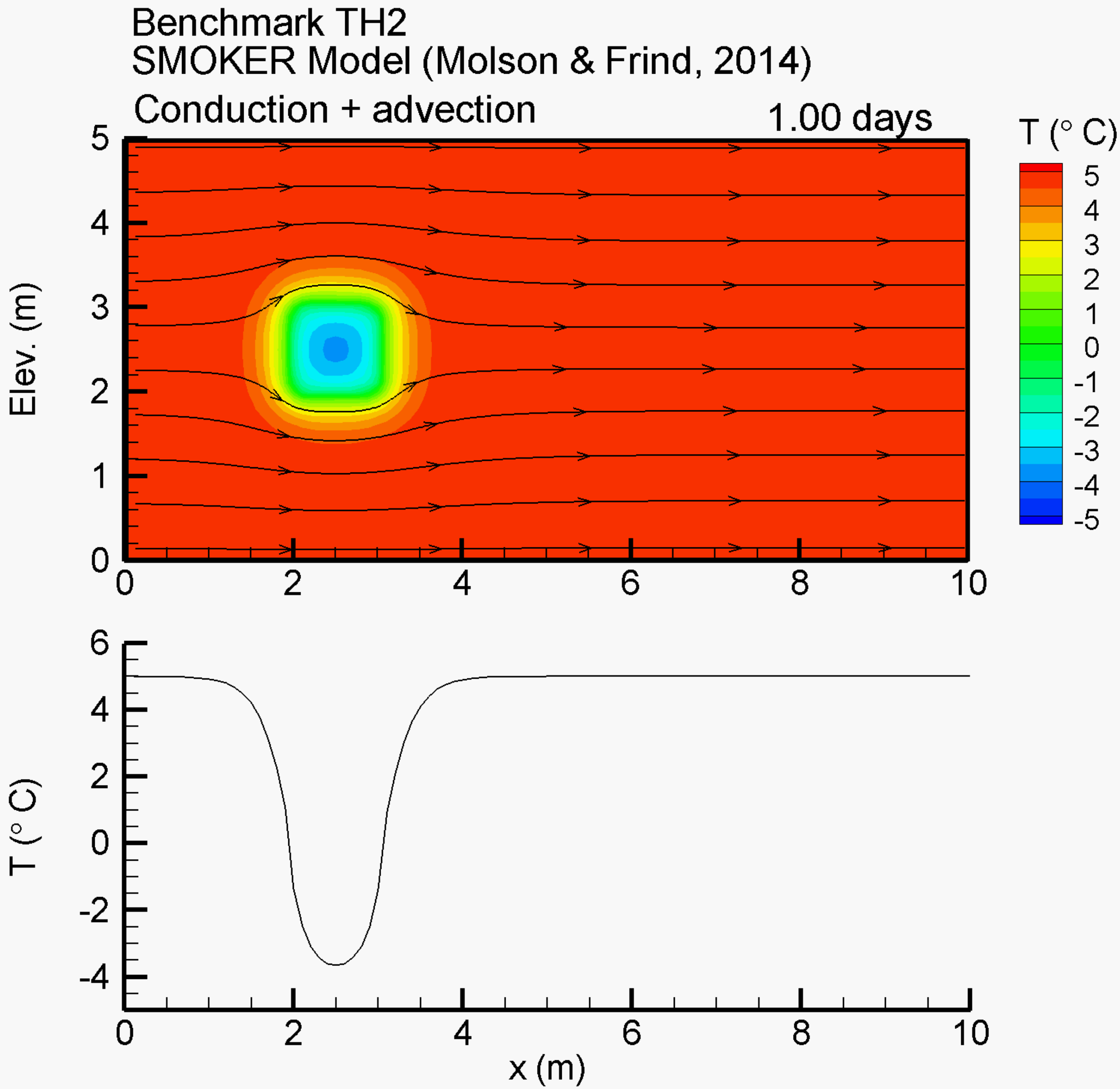
Inter-comparison TH2 & TH3 for April 2015

TH2 Case, Frozen inclusion thaw

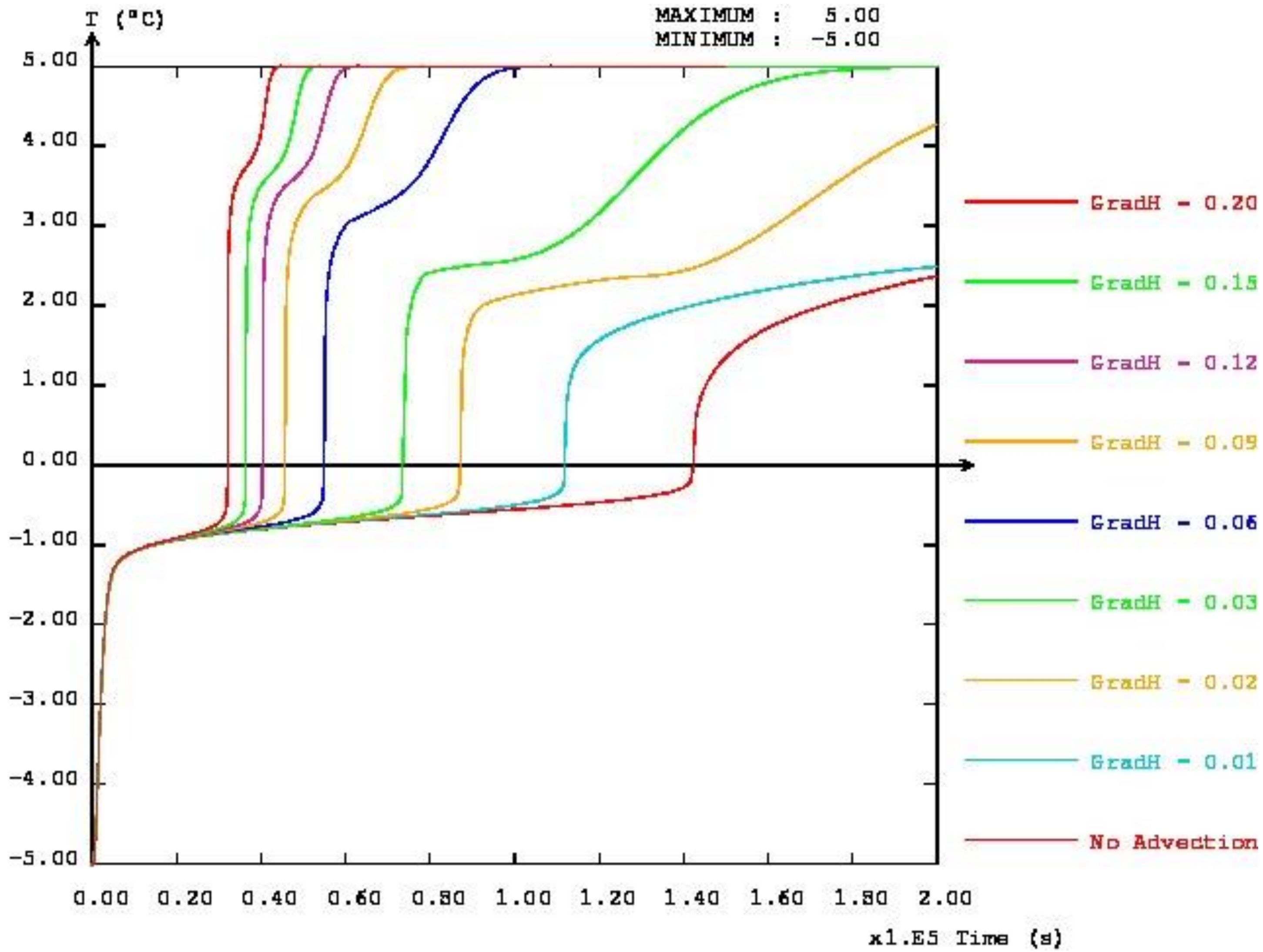


TH3 Case, Talik opening / closure



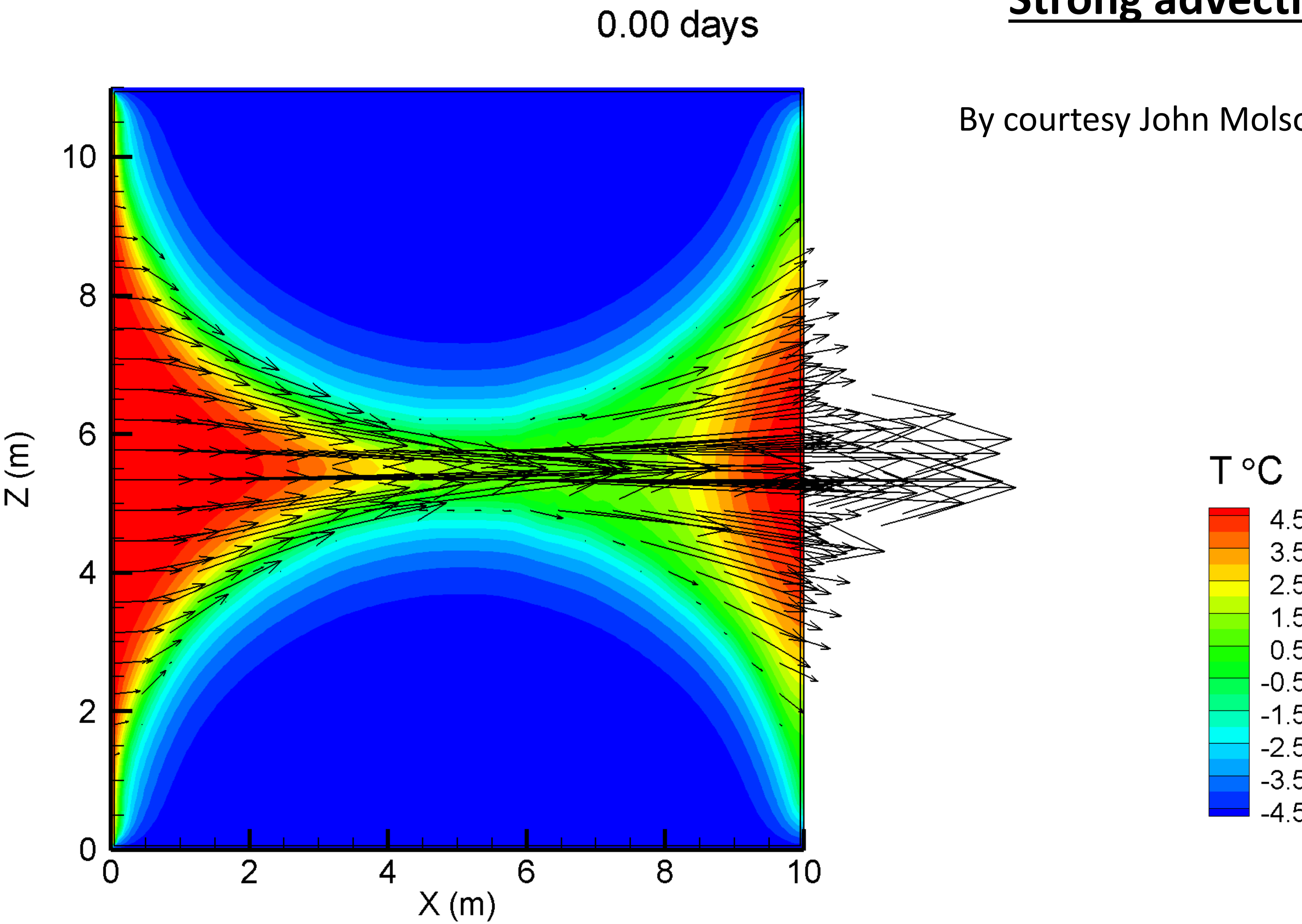

Benchmark TH2
SMOKER Model (Molson & Frind, 2014)
Conduction + advection
1.00 days
T (° C)
5
4
3
2
1
0
-1
-2
-3
-4
-5
Elev. (m)
x (m)
T (° C)

TH2: Evolution of Temperature Minimum

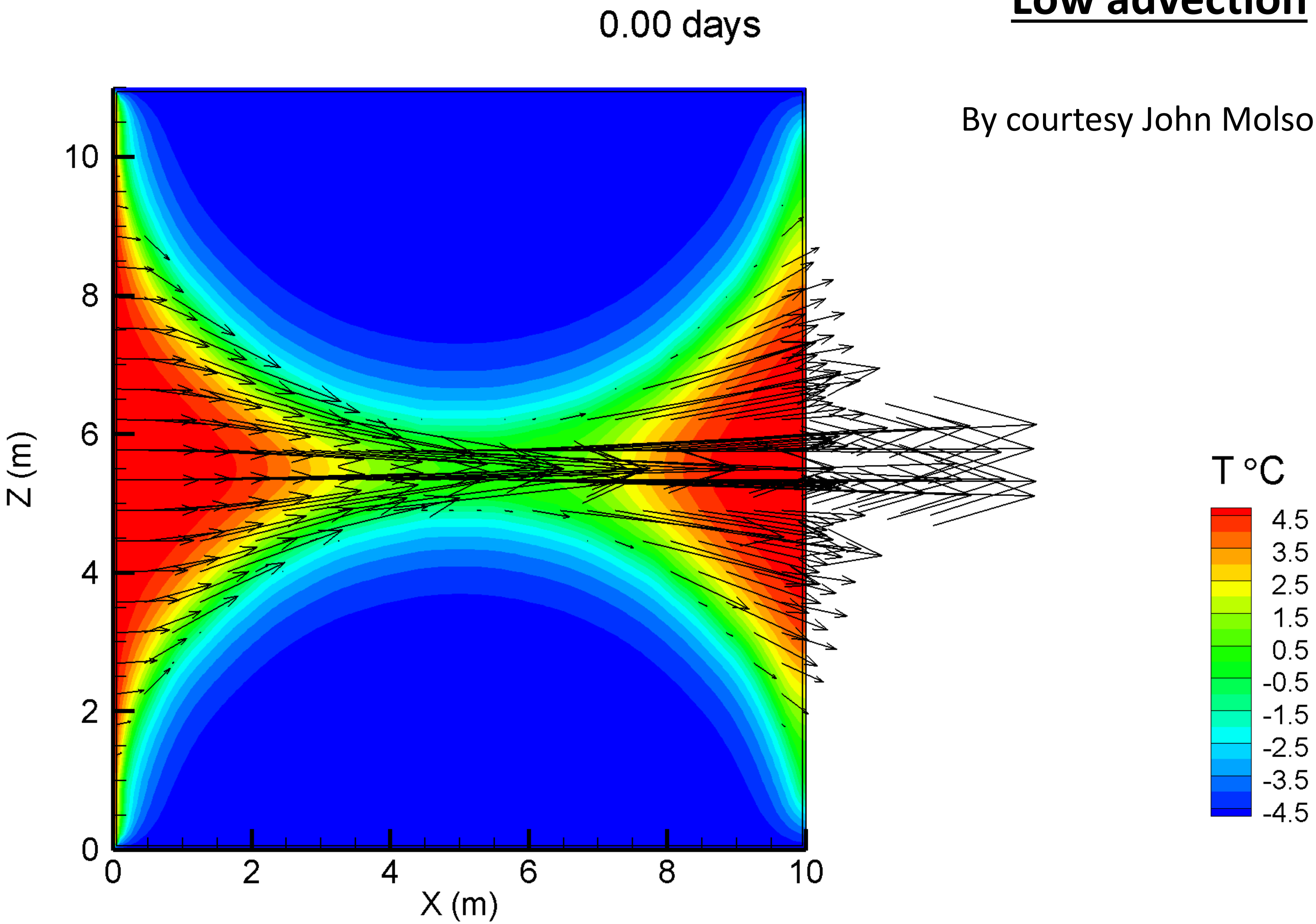


Strong advection

By courtesy John Molson

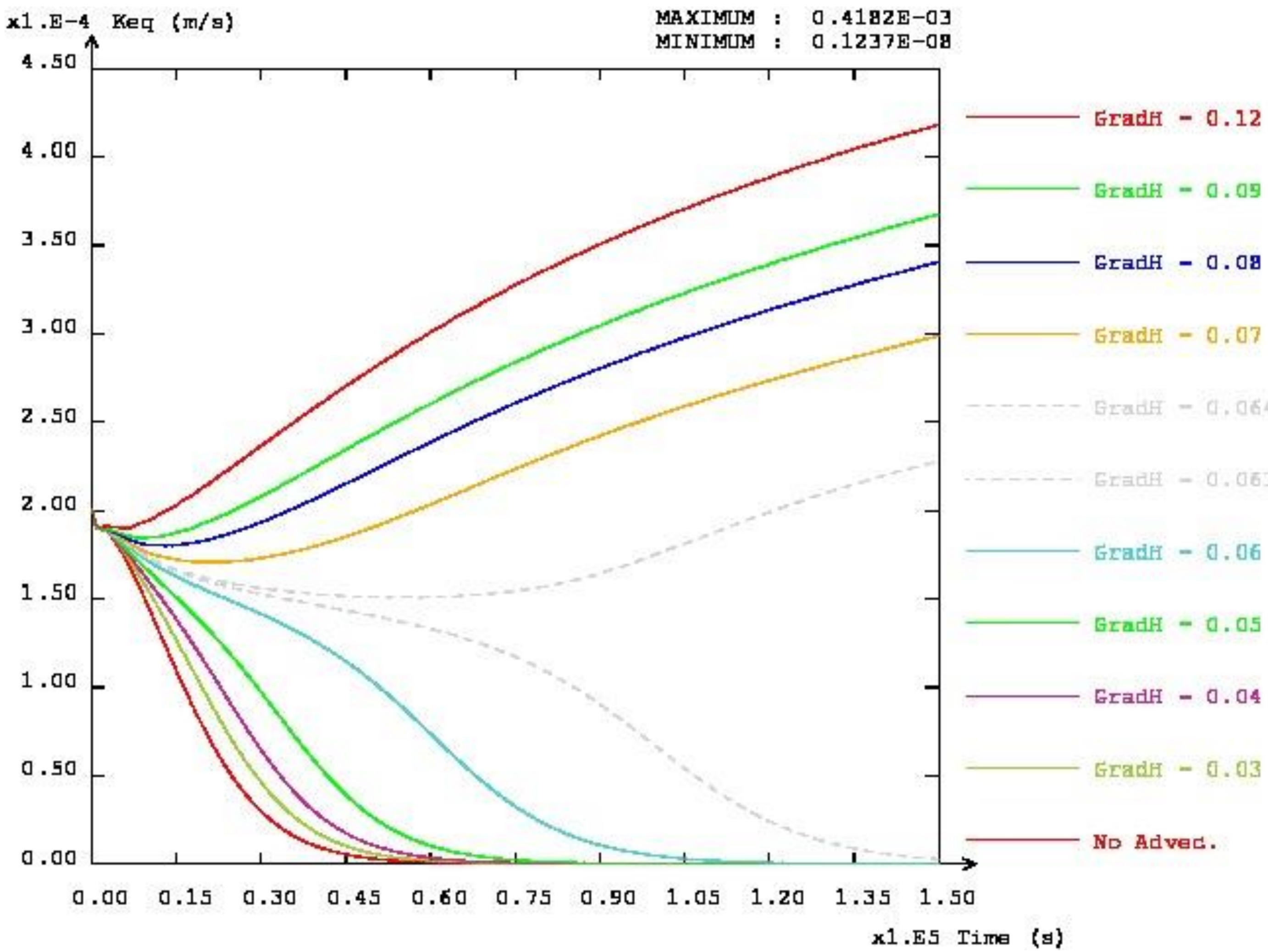


Low advection



By courtesy John Molson

TH3 : evolution of equivalent hydraulic conductivity



TH2&3 performance measures

- 3 PM for TH2
  1. **Evolution of temperature minimum**
  2. Evolution of total flux
  3. Evolution of total water volume
- 3 PM for TH3
  1. **Evolution of equivalent hydraulic conductivity**
  2. Evolution of upper and lower total heat flux
  3. Evolution of total heat in the system

➢ Compare on punctual measures vs integrated (over surfaces or volumes)

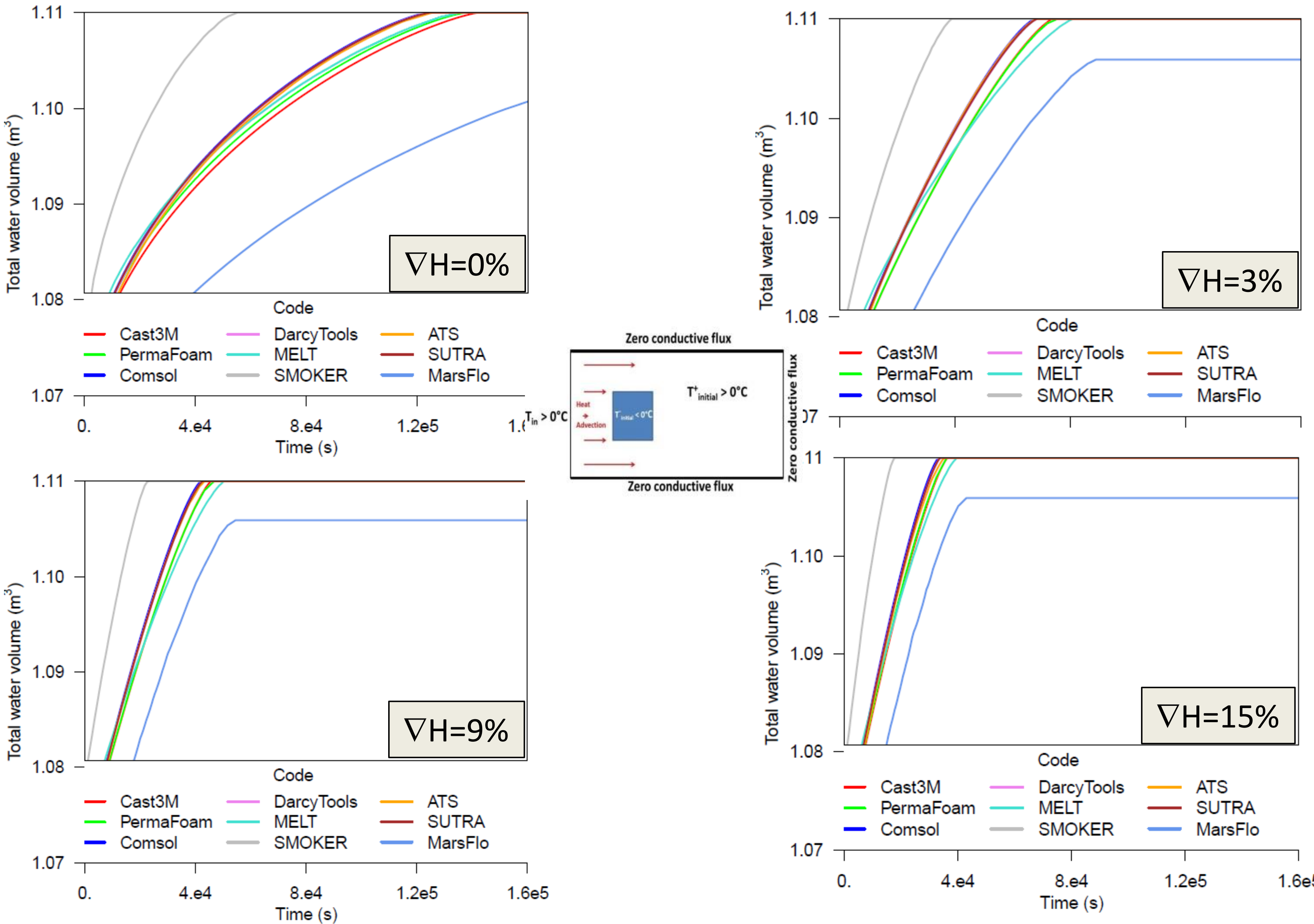
➢ Cover range of applications (e.g. threshold, exit flux, total heat)

interfrost Intercomparison Results, April 2015

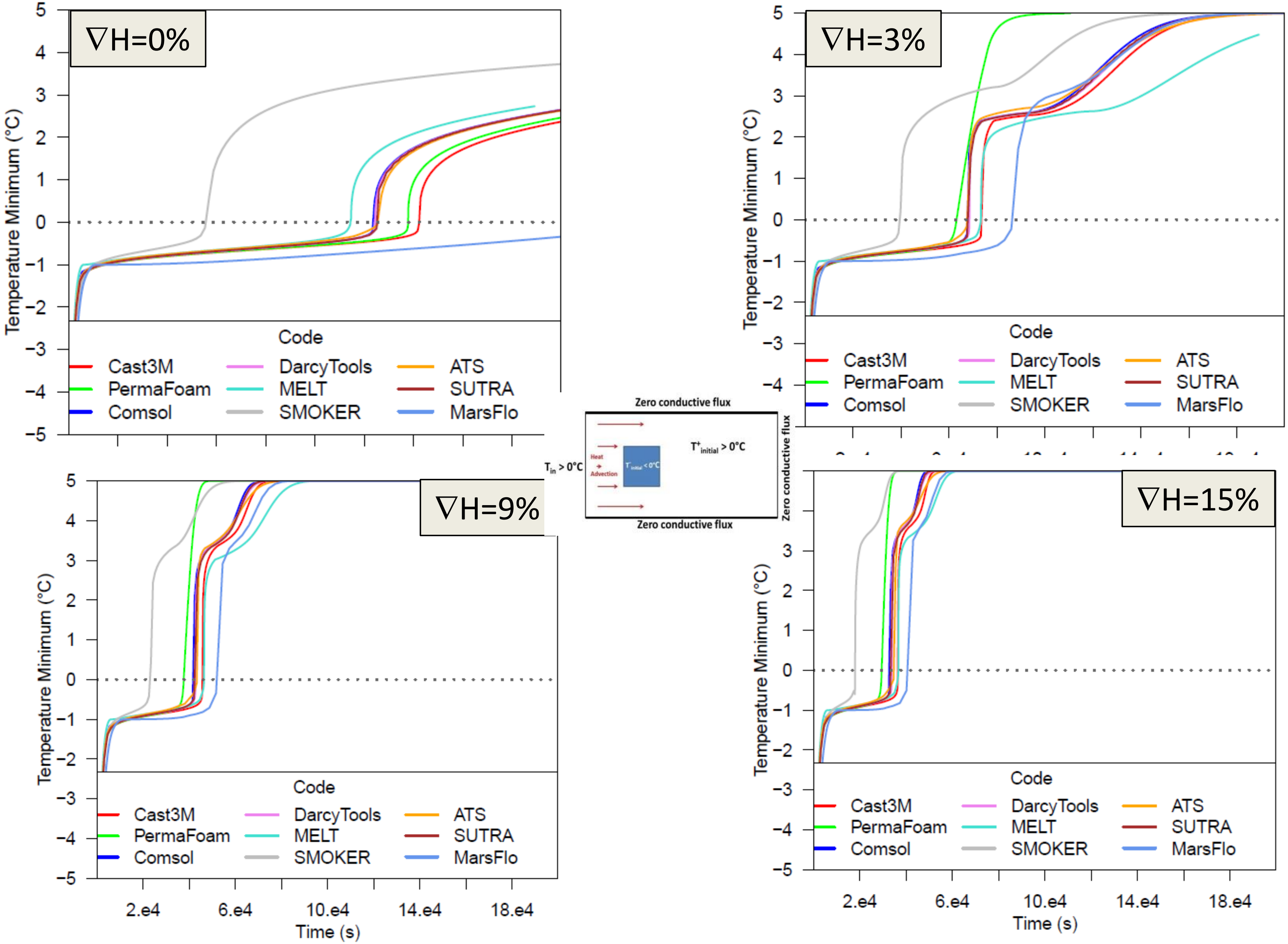
Cast3M
PermaFoam
Comsol
DarcyTools
MELT
SMOKER
ATS
SUTRA
MarsFlo

... Still preliminary!!!

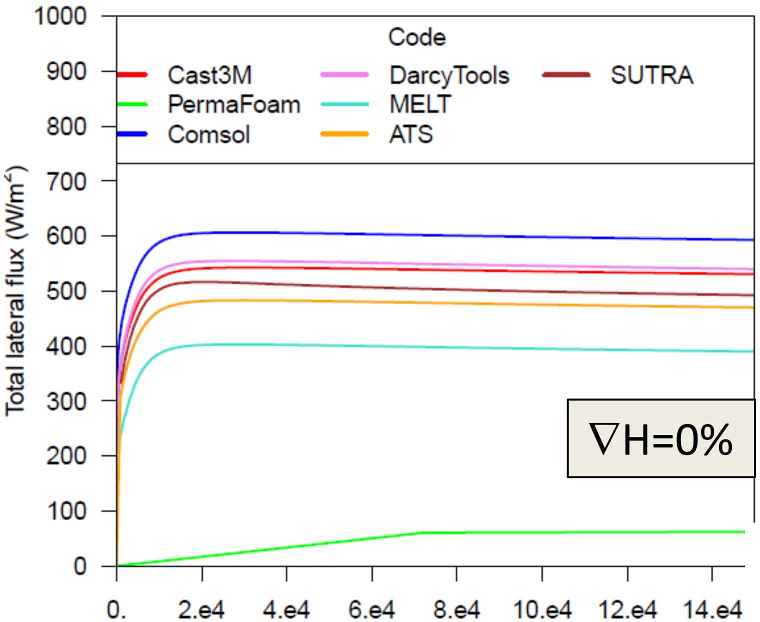
TH2_PM3 : Water volume(t)

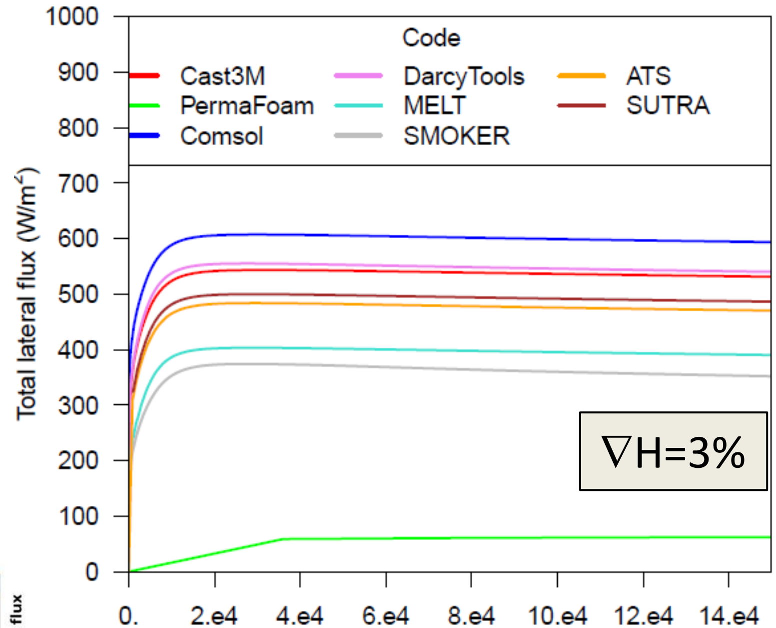


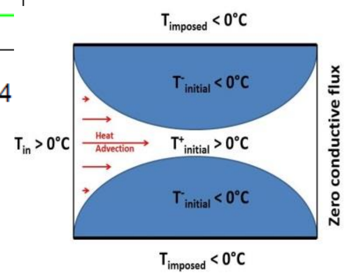
TH2_PM1 : Tmin(t)

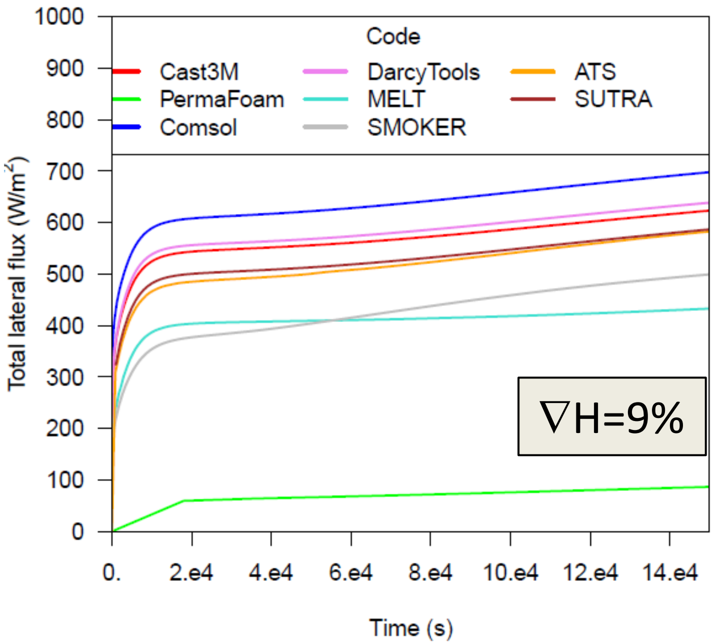


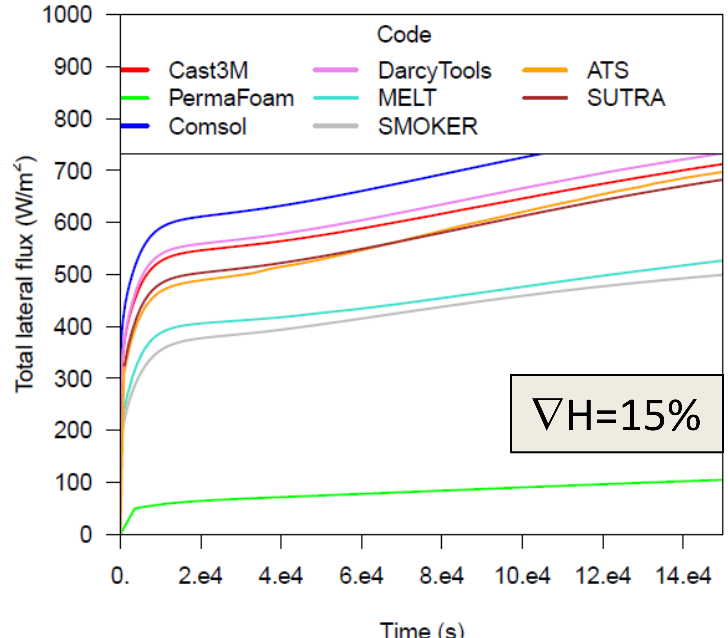
TH3_PM2 : Upper and lower Input Fluxes(t)





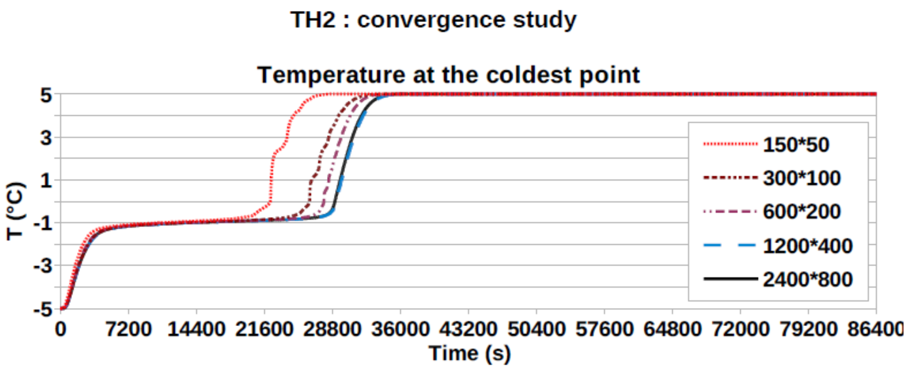






Conclusions (preliminary!)

- Performance measures integrating the whole domain are more robust thus allow to reject some simulations
- Most discrepancies were identified
  - Need for another parameter check
  - Need for complementary spatial and temporal convergence tests



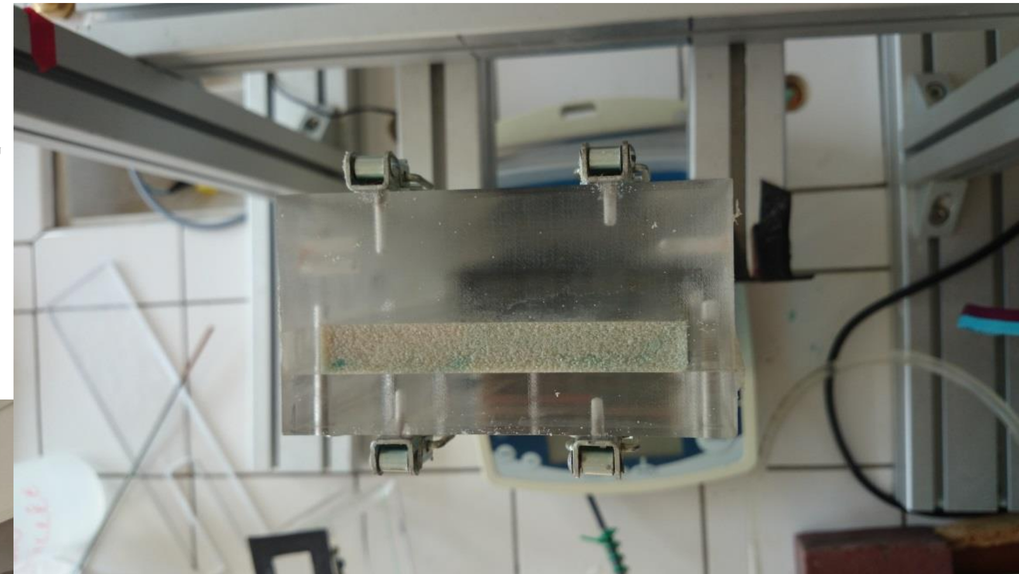
Courtesy L. Orgogozo

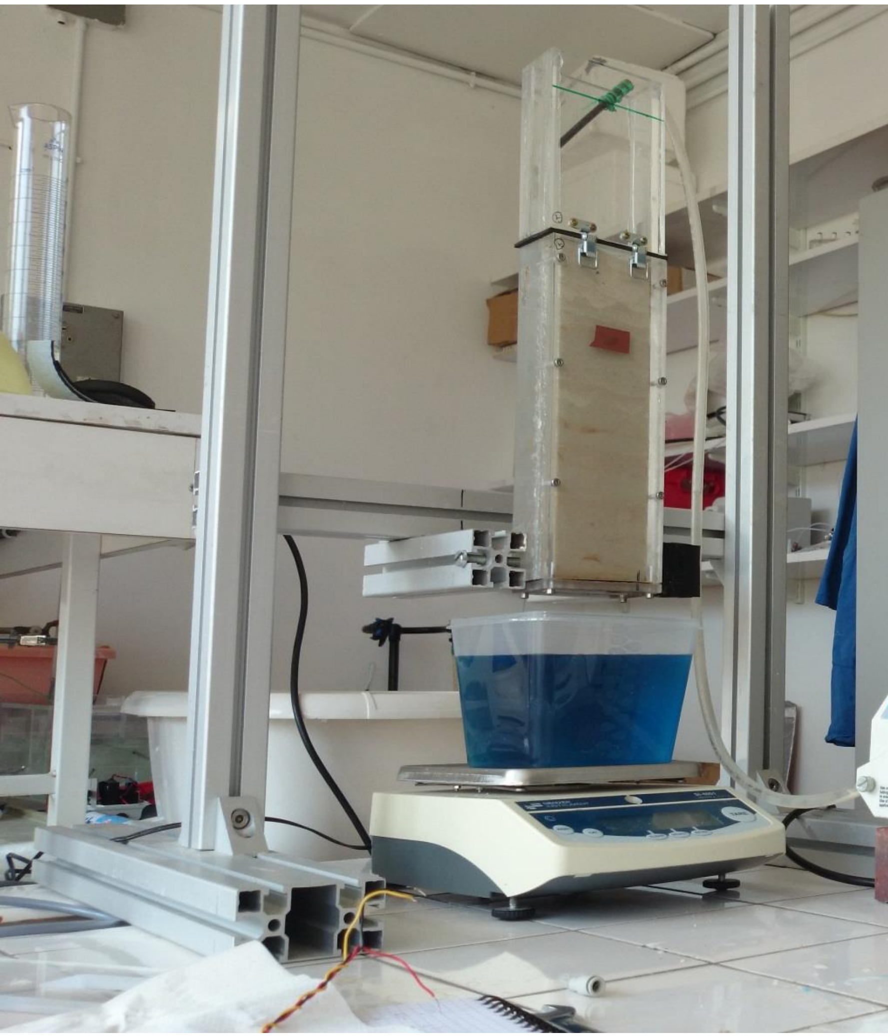
- **Results are overall similar apparently leading to a consensus … are they right?**
- **Spread does not increase by stronger advection: robust schemes or just similar schemes?**
- Some performance measures are more sensitive to time and space discretization and specific parameters requiring to push the code limits

GEOPS GEOSCIENCES PARIS SUD

LSCE

Ongoing study …
Validation vs calibration!





Guidelines

- Carry simulations choosing adequate time steps and mesh sizes according with Fourier and CFL numbers
- Verify that the iterations suite to solve the non-linearities and coupled equations is well converged
- Study the spatial and temporal convergence of the simulations (decrease time step / refine mesh)

- Good base for confidence in the results … but intercomparison at some level is better!

Future tasks or test cases

- Other experiments in cold room
- Study the decrease of simulation qualitity on
  - Large scale systems
  - Evolution of permafrost depths through geologic times
- Work with field data (monitoring, sites, …)
- Impact of climate change on a typical unit of the landscape (e.g. a lake system)

- Non-saturated systems (extensions to Richards and three phase flow)

Dead line for final TH2 & TH3 results by 30th June 2015!

Please join!

More about the InterFrost project at https://wiki.lsce.ipsl.fr/interfrost/

interfrost *at EGU 2015*

- Session SSS0.3 (EGU2015-9775, **Poster**, Monday, 13 Apr 2015, 08:00-19:30, Blue Posters B770): Thermo-hydrologic modelling of permafrost with OpenFOAM®: perspectives of applications to the study of weathering in boreal areas by **Orgogozo** Laurent et al.
- Session CR1.1/SSS0.20 (EGU2015-9723, **Oral**, room R13, Wednesday, 15 Apr 2015, 14:00): The InterFrost benchmark of Thermo-Hydraulic codes for cold regions hydrology - first inter-comparison results by Christophe **Grenier** et al.
- Session ERE3.3 (EGU2015-6340, **Poster**, Tuesday, 14 Apr 2015, 08:00-19:30, Red Posters R267): Benchmarking numerical freeze/thaw models by Wolfram **Rühaak** et al.

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