Introduction

Christophe Grenier

Coupled Thermo-Hydro processes

Rowland et al 2010

- Open field (in situ process studies)
- 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

Intercomparison process (McKenzie et al. 2007)

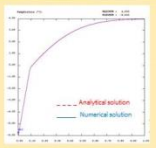
IDES Interactions et Dynamique des Environnements de Surface

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)

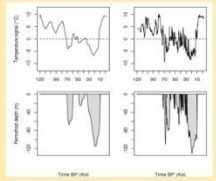
T2: Heterogeneous

Multi-layered, bounded, with geothermal flux.

Include field monitoring data.

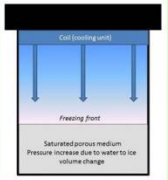
T3: geological times

Heterogeneous, with geothermal flux, long simulation times

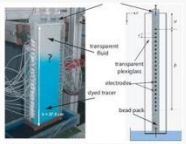


After Régnier, 2012

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

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

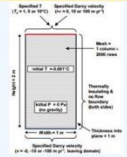
Heat transfer equation

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

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

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

TH1: Kurylyk & Lunardini

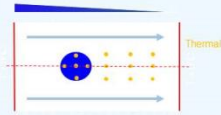


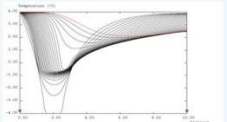
Analytical solutions including constant advection

TH2: Frozen inclusion

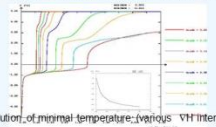
An initially 2D cold (T < 0°C) permafrost inclusion is present within a uniform water flow (T > 0°C)

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)

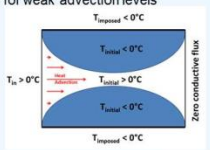


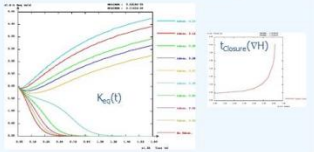
Evolution of minimal temperature (various ∇H intensities)

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

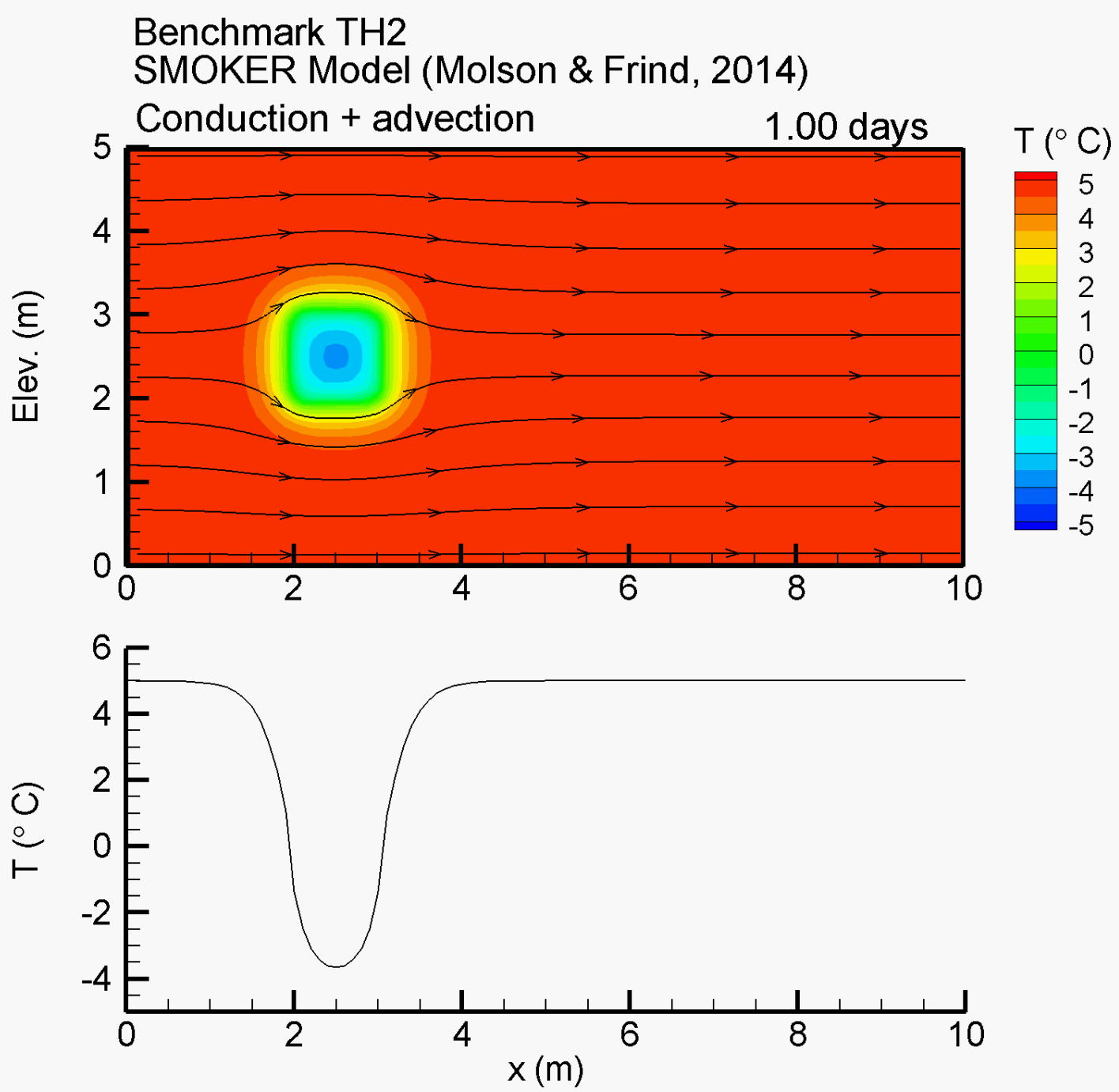
Now 14 codes …

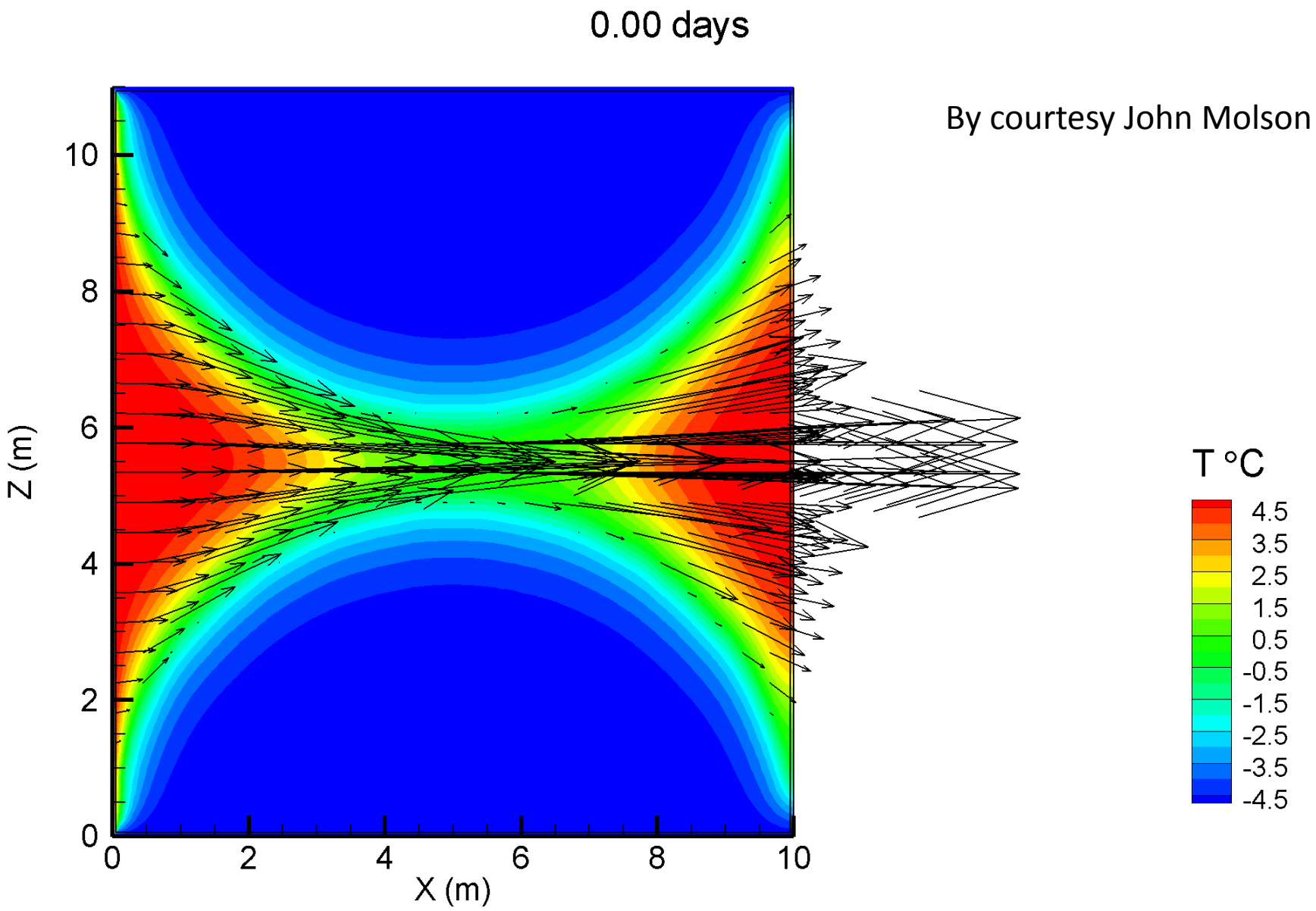
Kick-off Meeting, 18 – 19 Nov. 2014, Paris

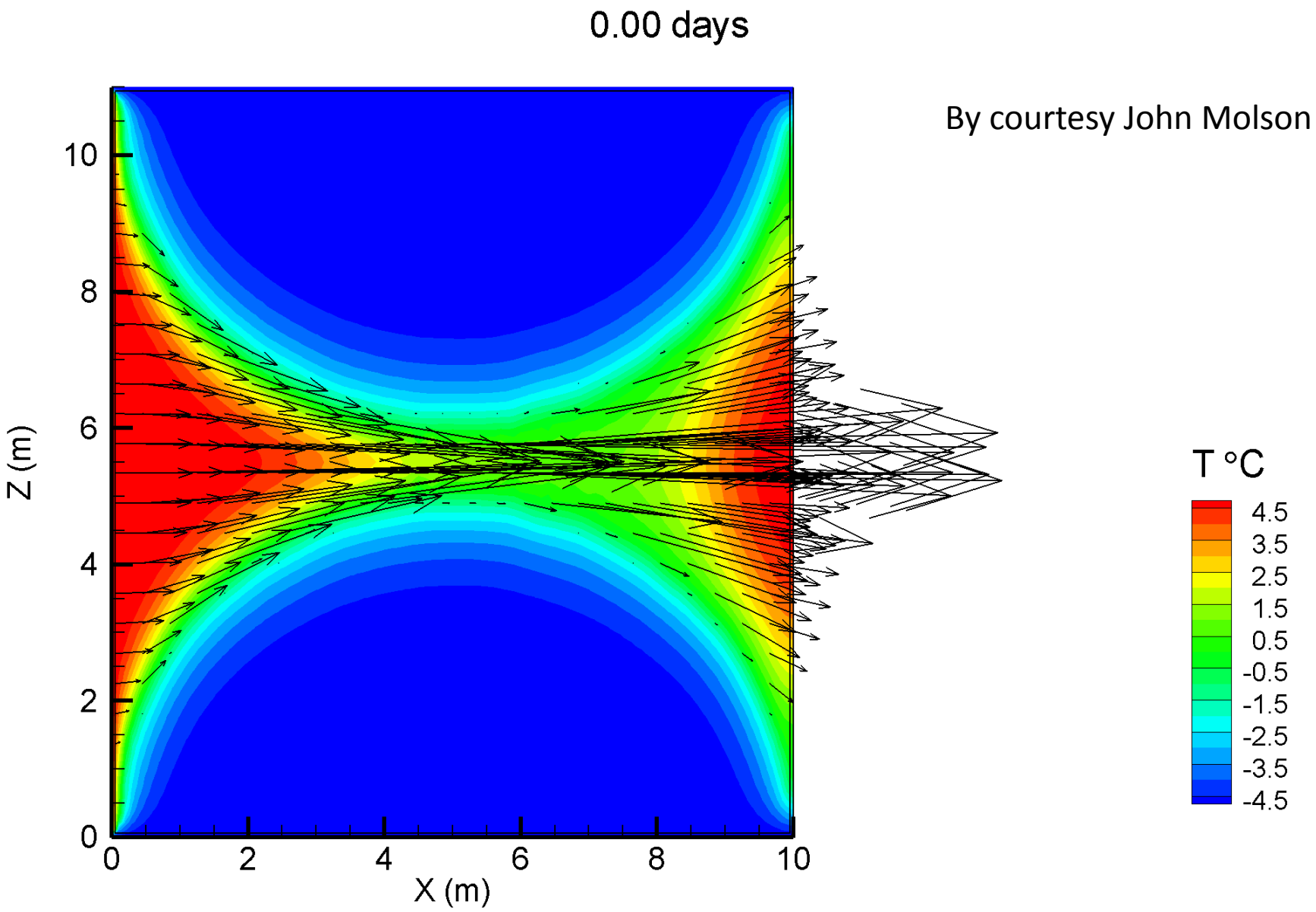
A common logo?

Intercompare 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)
0
1
2
3
4
5
0
2
4
6
8
10
T (° C)
6
4
2
0
-2
-4
0
2
4
6
8
10
x (m)


0.00 days
By courtesy John Molson
Z (m)
X (m)
0
2
4
6
8
10
T °C
4.5
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
-4.5


0.00 days
By courtesy John Molson
Z (m)
X (m)
0
2
4
6
8
10
T °C
4.5
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
-4.5

Preparation study with Cast3M

- Finite Volumes
- Picard for non-linearities and coupling
- Implicit scheme, constant time steps
- Under-relaxation to stabilize
- Base case simulations parameters:

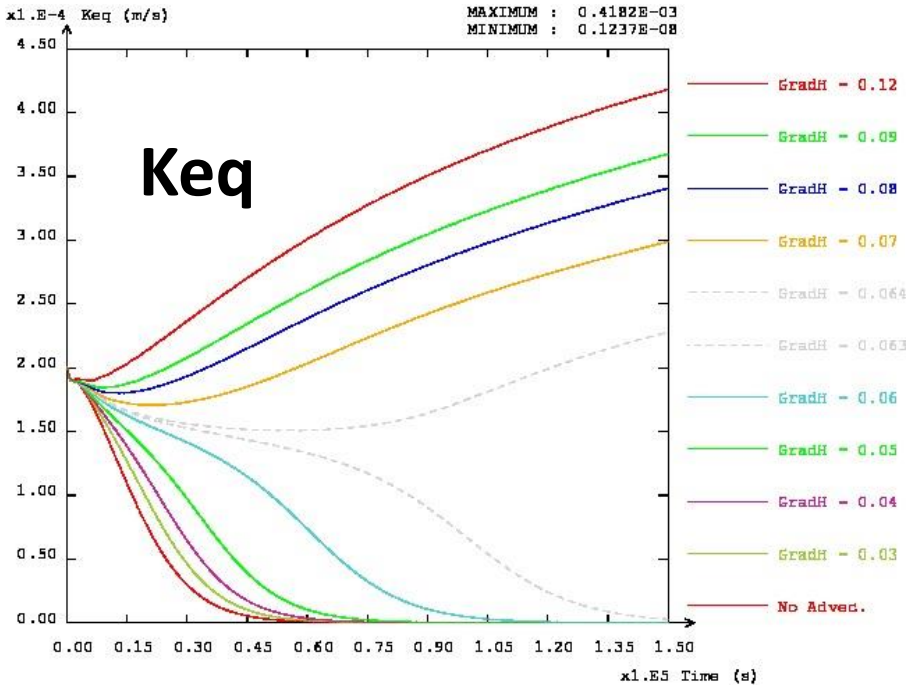
TH2

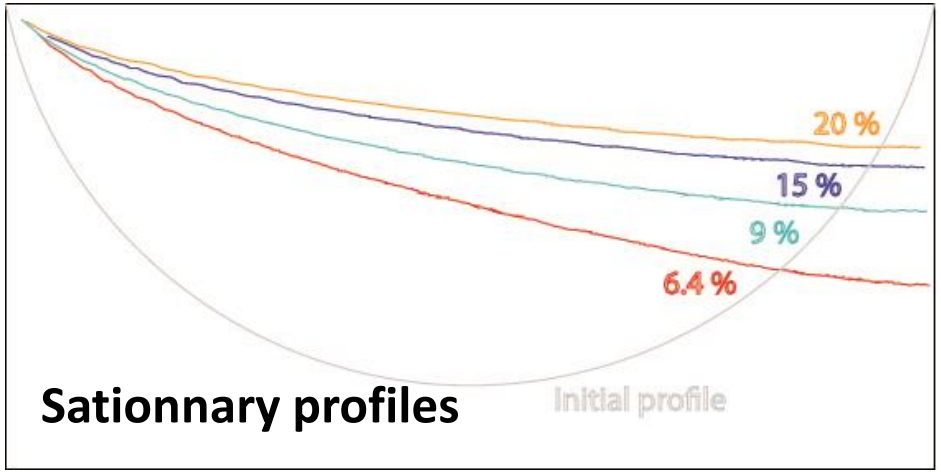
Nb Meshes	Δx	Δt	Nb time steps	CPU time	Average Nb of iterations
31014	6.94 mm	7.5 s – 60 s	3500 - 15000	38 h – 197 h	20

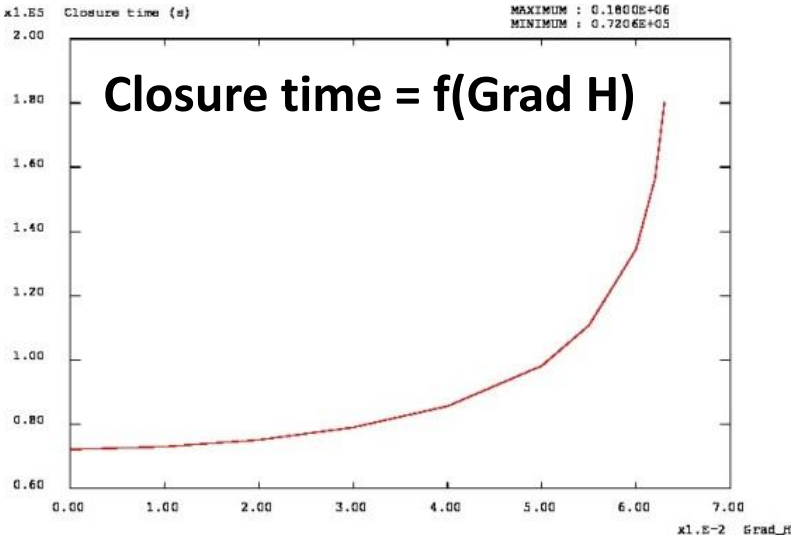
TH3

Nb Meshes	Average Δx	Δt	Nb time steps	CPU time (h)
17272	5.4 mm (2.7 – 7.6)	7.5 s – 60 s	3500 - 20000	> 7 h

TH2&3 preparation study : physical system considerations







TH2&3 preparation study : performance measures

- Compare on punctual measures vs integrated (over surfaces or volumes)
- Cover range of applications (e.g. threshold, exit flux, total heat)

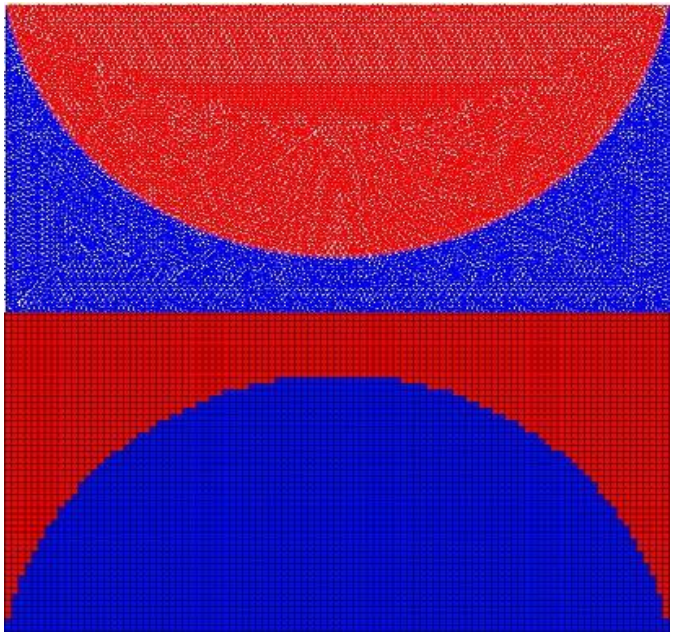
- How converged are the simulations on each performance measure?
- Associated level of uncertainty for simulation results

TH2&3 preparation study : convergence studies

- Decrease time step / refine mesh (easier on TH3): convergence achieved for both cases
- Estimate the range of variability/sensitivity for each performance measure
  - Large spatial sensitivity on TH3_PM2 (29.2%)
  - Large temporal sensitivity on TH2_PM1 (7.2%)

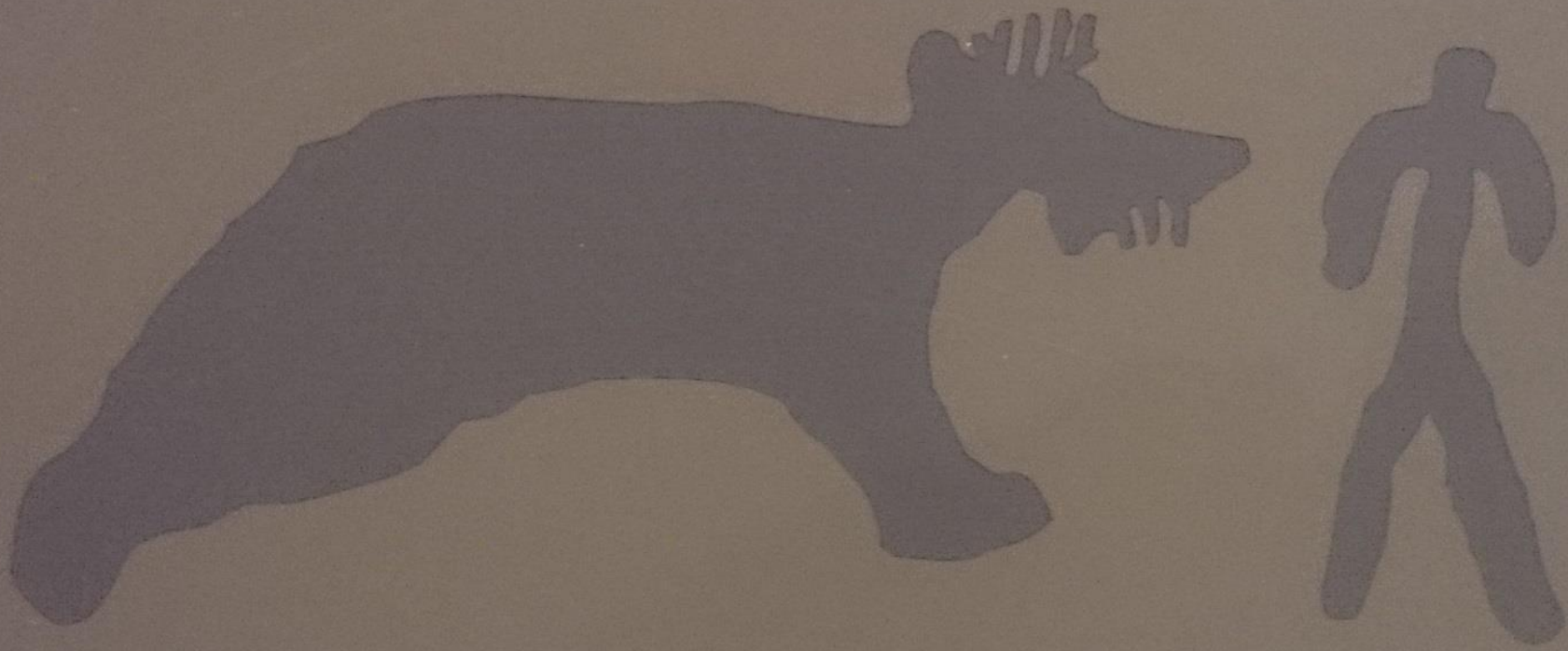
- Good base for confidence in the results … but not conducted for large levels of head gradients where problems can be expected!
- Did you carry on convergence tests?

Where do we expect a larger dispersion of results?



Case TH2 - "Frozen Inclusion"	Time for total thaw	Total Heat Flux after 9.10^4s	Total water volume after 4.10^4s
Δx sensitivity range	1.4 %	1.2 %	0.015 %
Δt sensitivity range	7.2 %	0.6 %	0.05 %

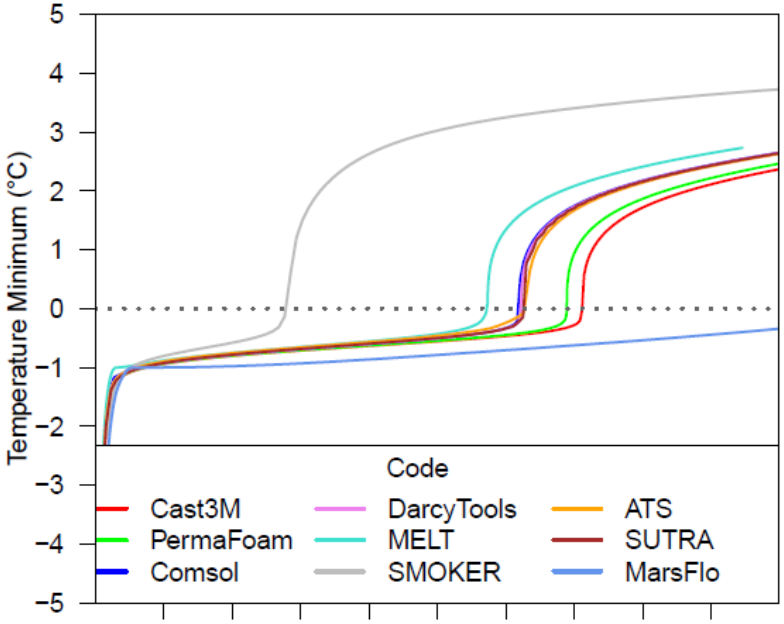
Case TH3 - "Talik Opening/Closure"	Closure time	Upper Flux after 3.10^4s	Total Heat after 3.10^4s
Δx sensitivity range	0.7 %	29.2 %	0.03 %
Δt sensitivity range	3.4 %	0.6 %	0.2 %

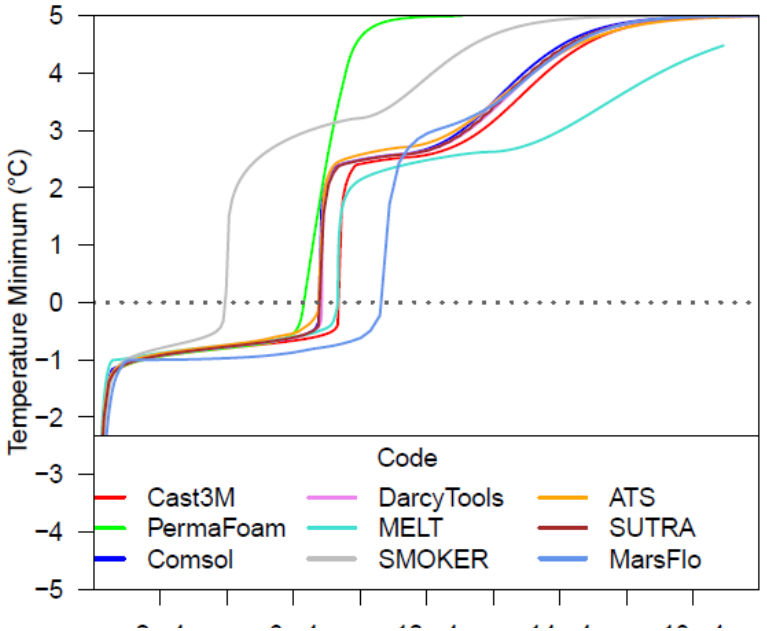


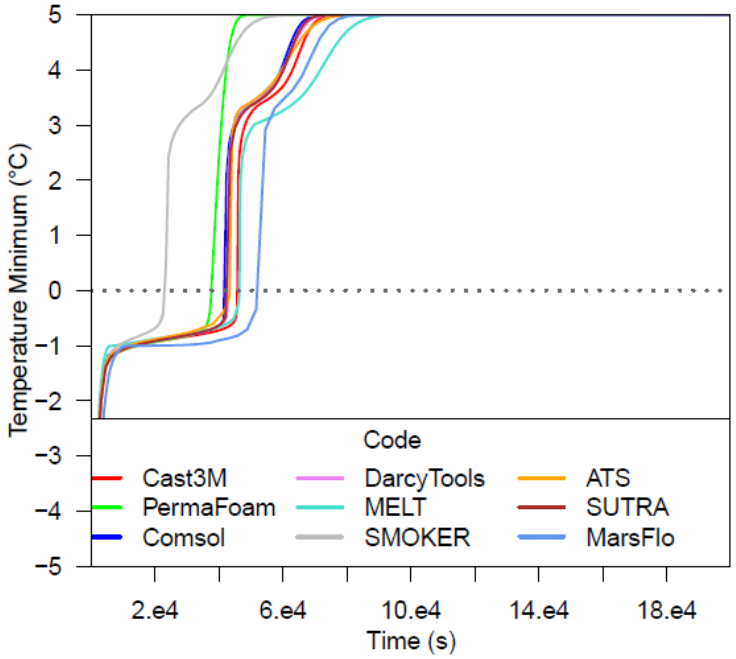
interfrost Intercomparison Results

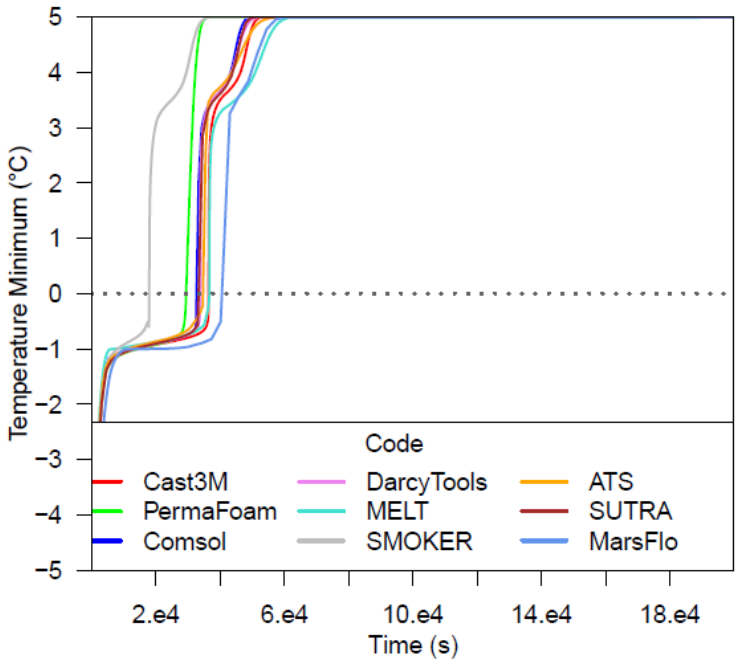
Paris, 9-10 April 2015

TH2_PM1 : Tmin(t)

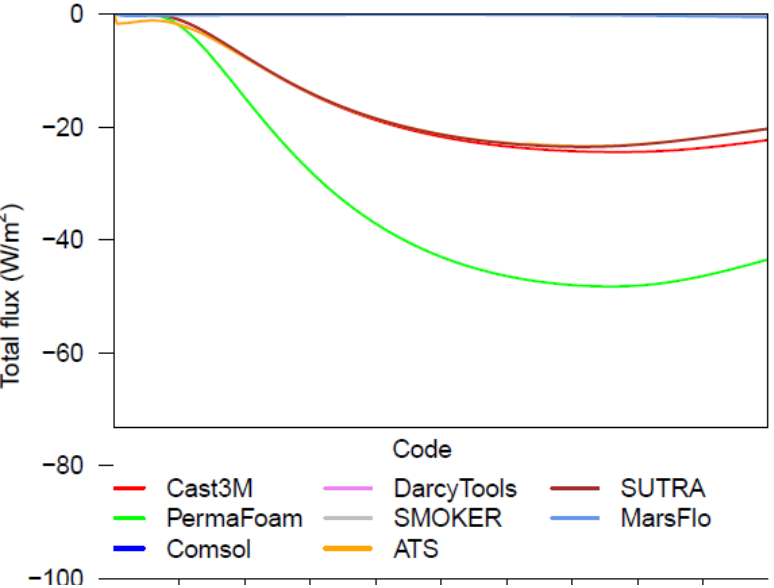


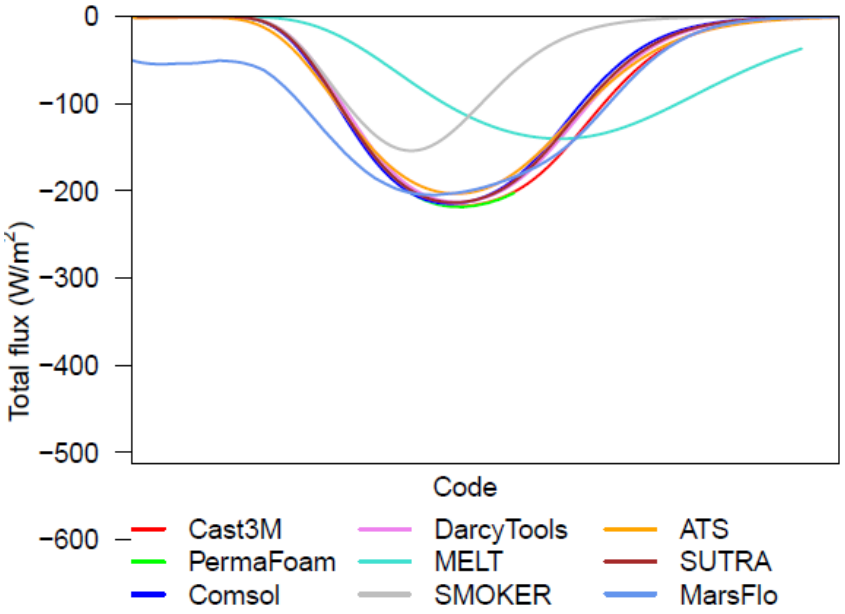


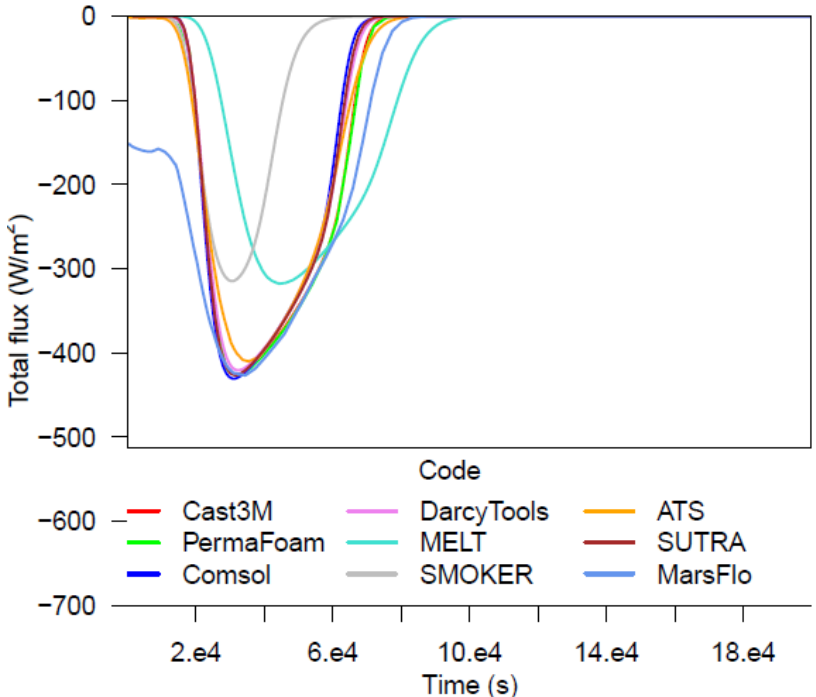


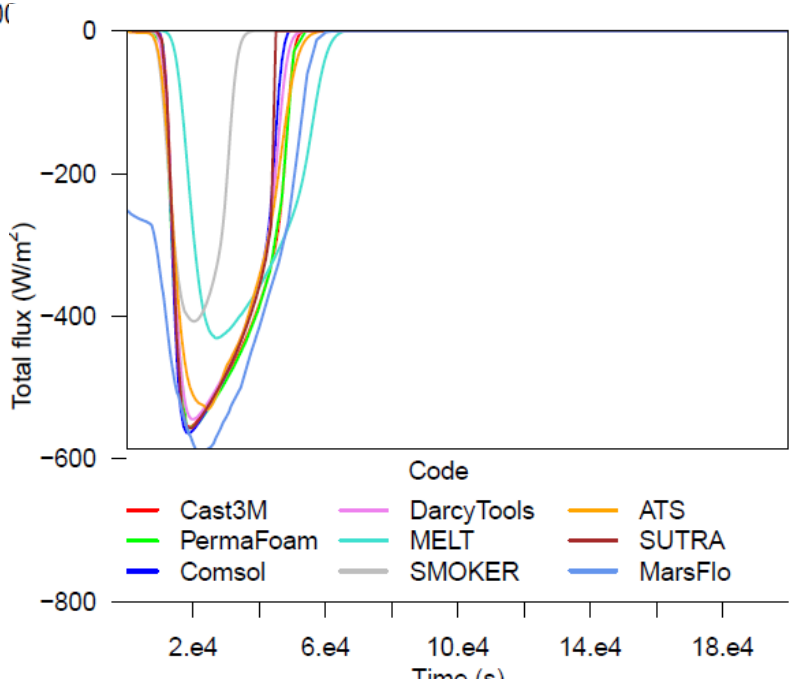


TH2_PM2 : FLux(t)

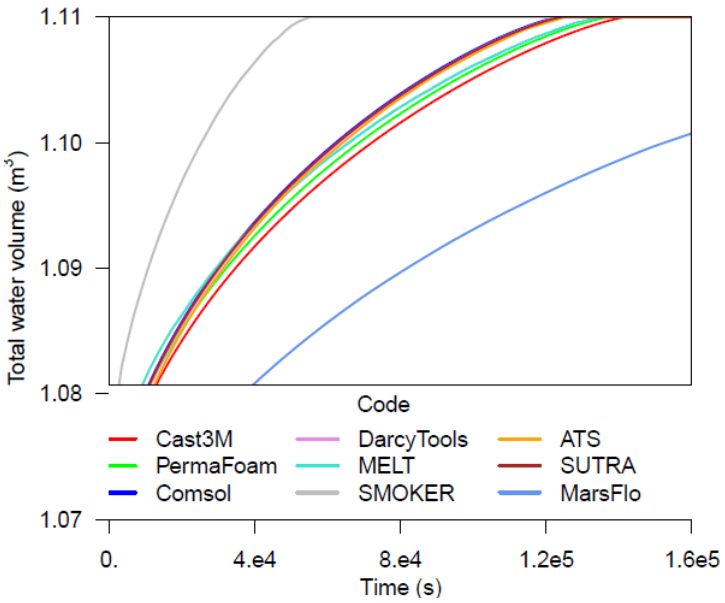


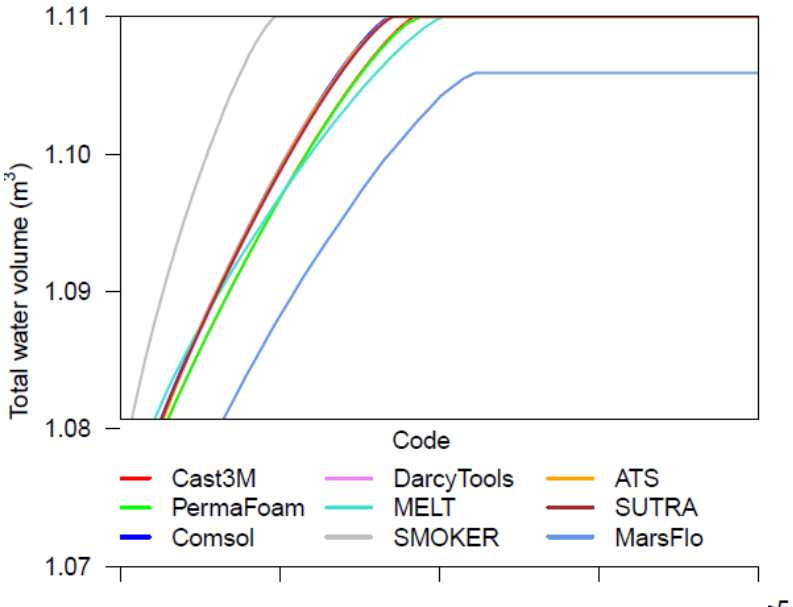


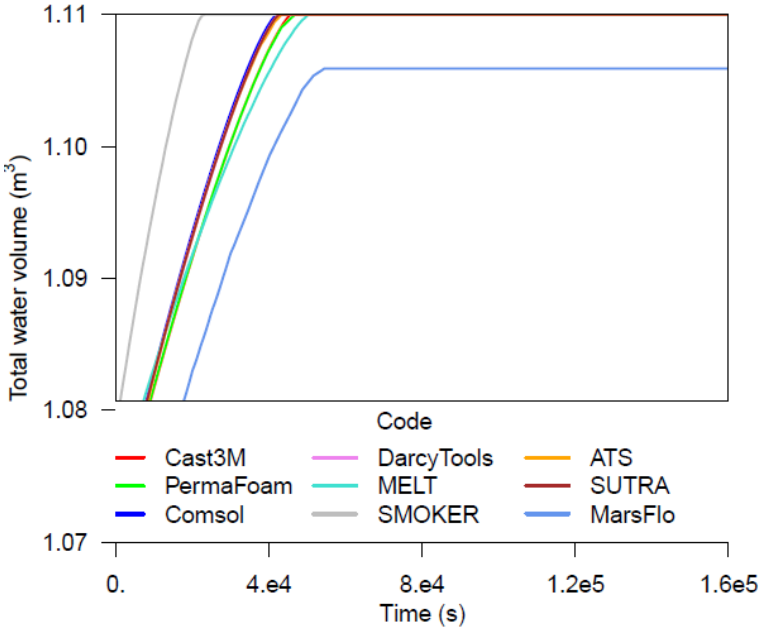


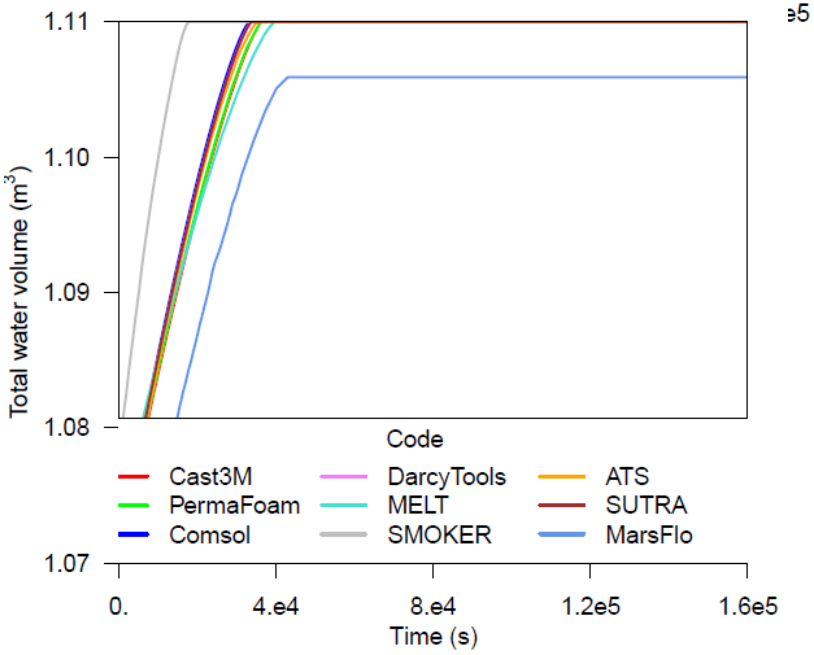


TH2_PM3 : Water volume(t)

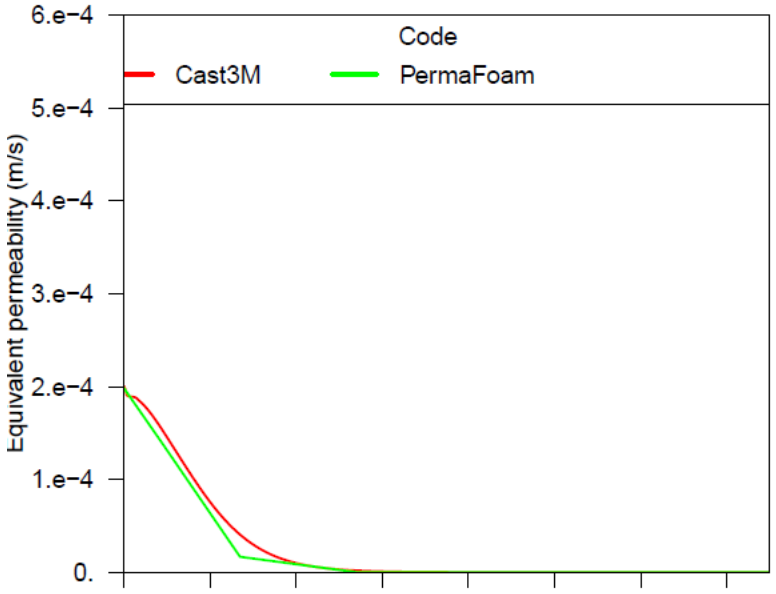


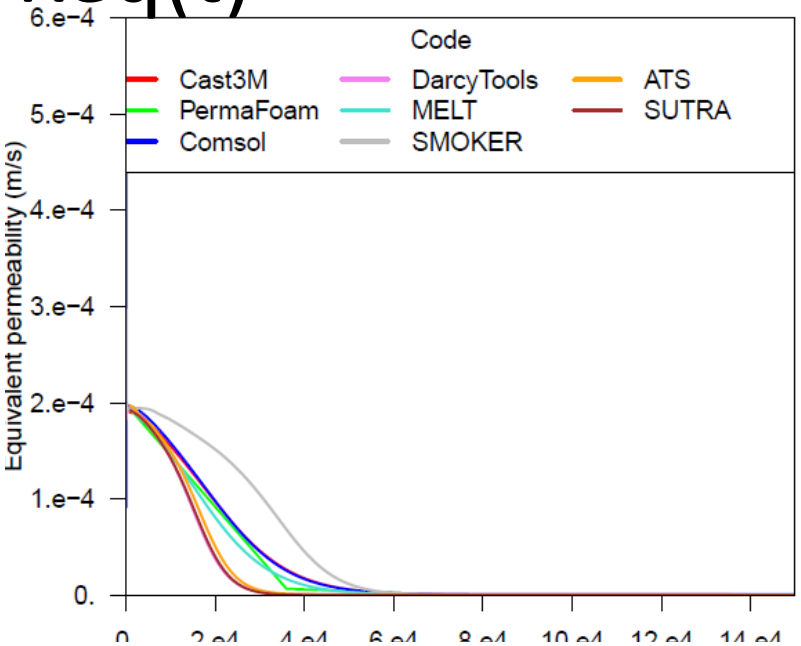


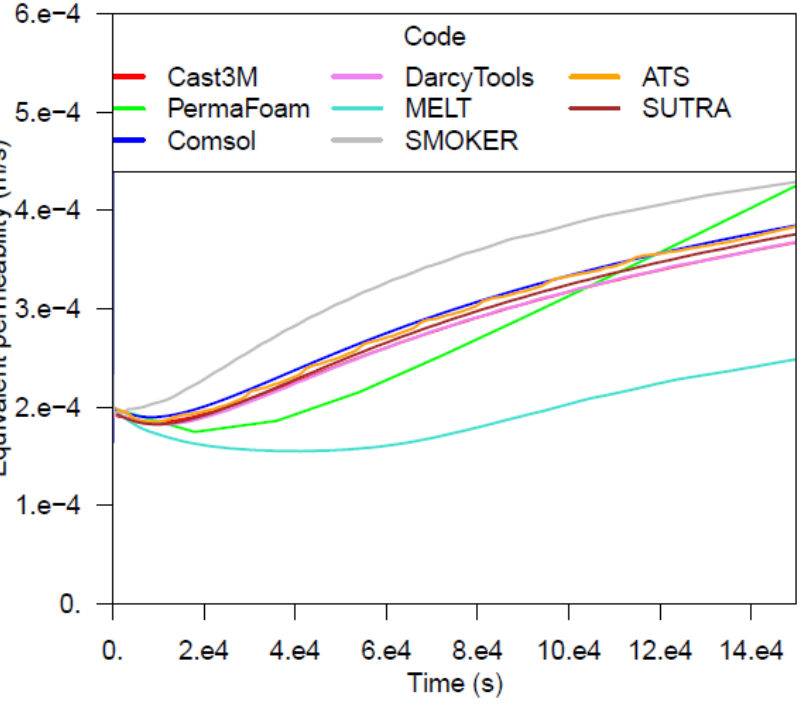


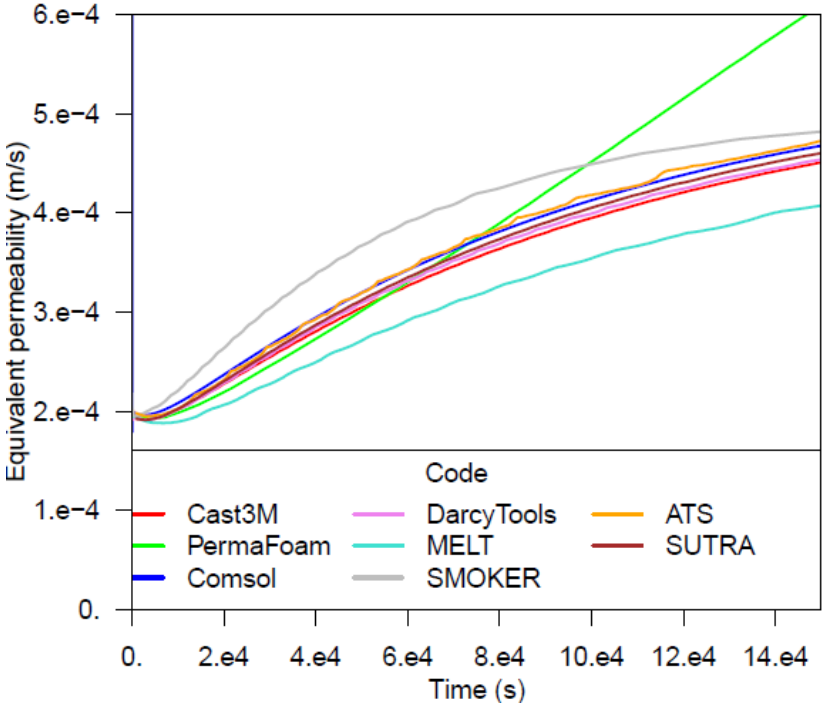


TH3_PM1 : Keq(t)

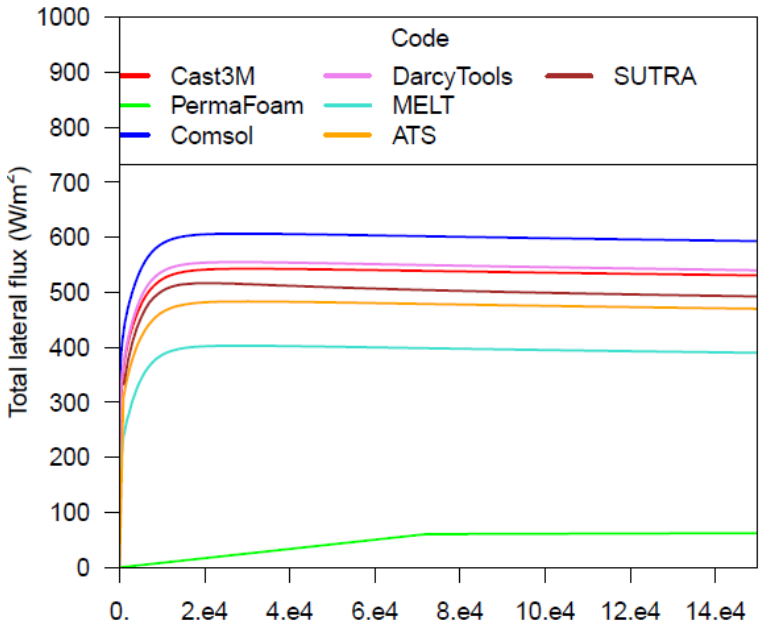

Code
Cast3M
PermaFoam
Equivalent permeability (m/s)
6.e−4
5.e−4
4.e−4
3.e−4
2.e−4
1.e−4
0.

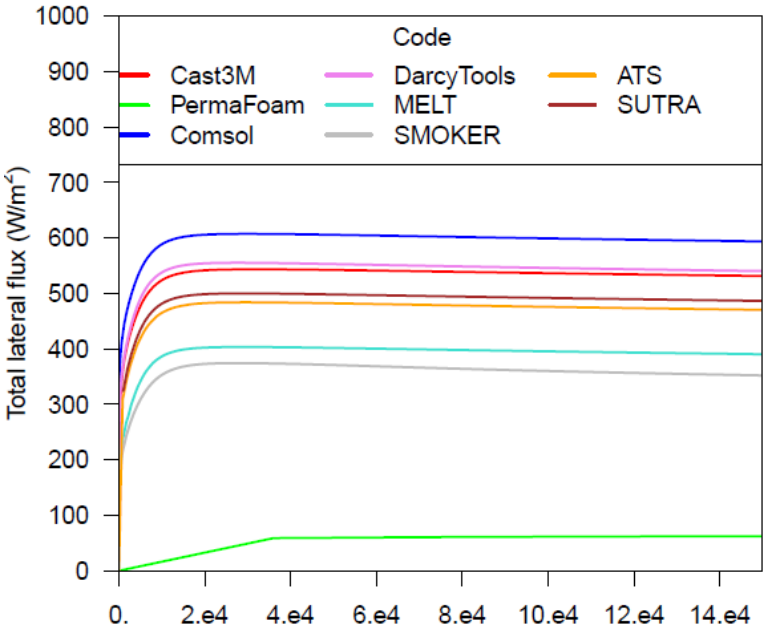

Code
Cast3M
PermaFoam
Comsol
DarcyTools
MELT
SMOKER
ATS
SUTRA
Equivalent permeability (m/s)
6.e−4
5.e−4
4.e−4
3.e−4
2.e−4
1.e−4
0.

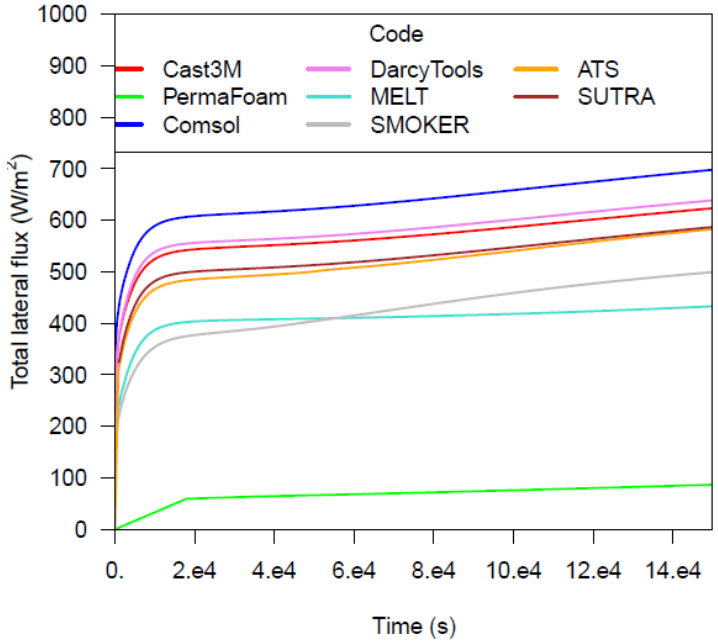

Code
Cast3M
PermaFoam
Comsol
DarcyTools
MELT
SMOKER
ATS
SUTRA
6.e−4
5.e−4
4.e−4
3.e−4
2.e−4
1.e−4
0.
0.
2.e4
4.e4
6.e4
8.e4
10.e4
12.e4
14.e4
Time (s)

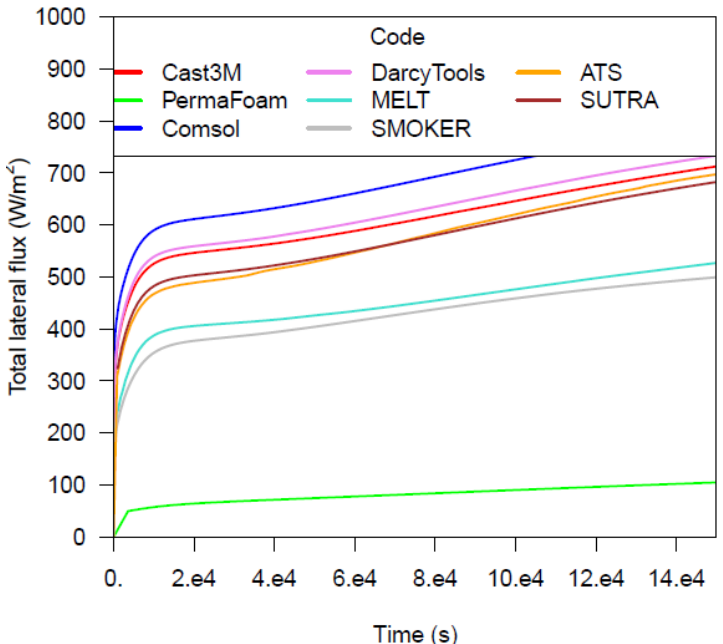

Code
Cast3M
PermaFoam
Comsol
DarcyTools
MELT
SMOKER
ATS
SUTRA
Equivalent permeability (m/s)
6.e−4
5.e−4
4.e−4
3.e−4
2.e−4
1.e−4
0.
0.
2.e4
4.e4
6.e4
8.e4
10.e4
12.e4
14.e4
Time (s)

TH3_PM2 : InFluxes(t)

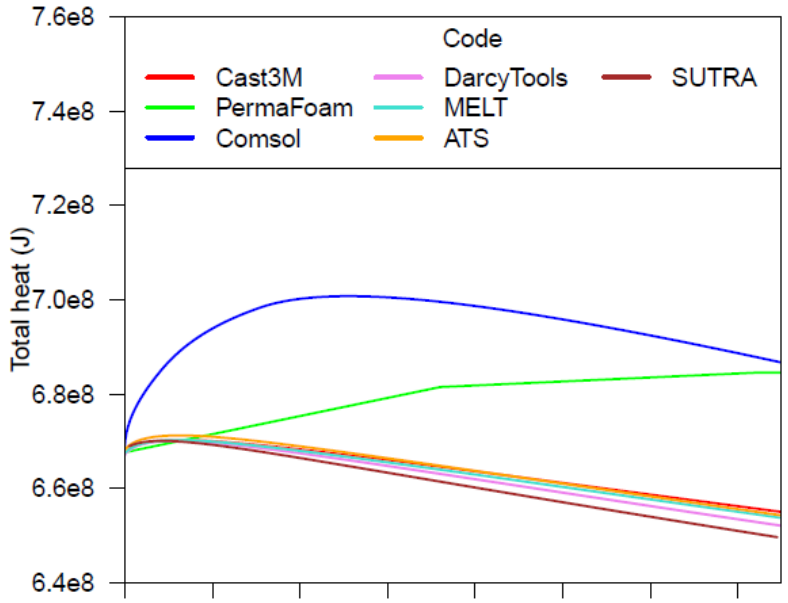


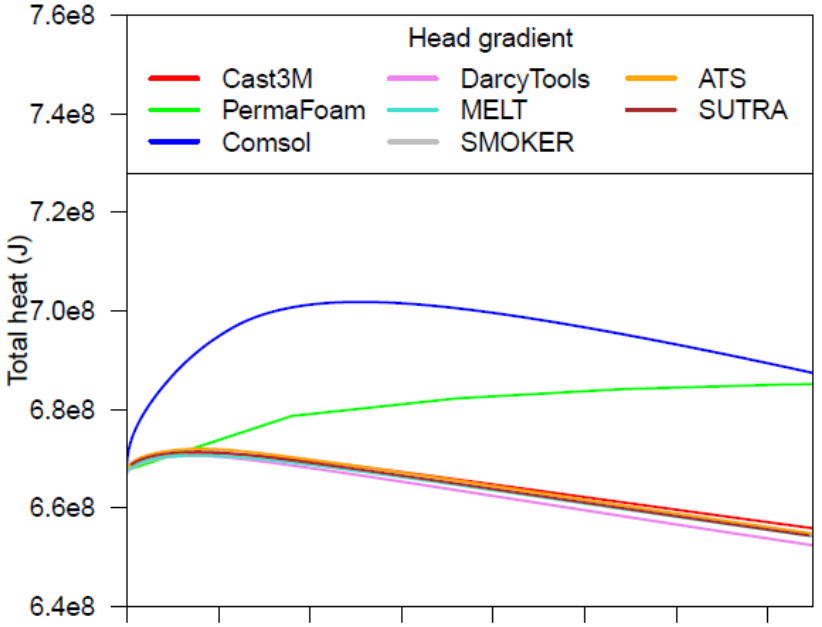


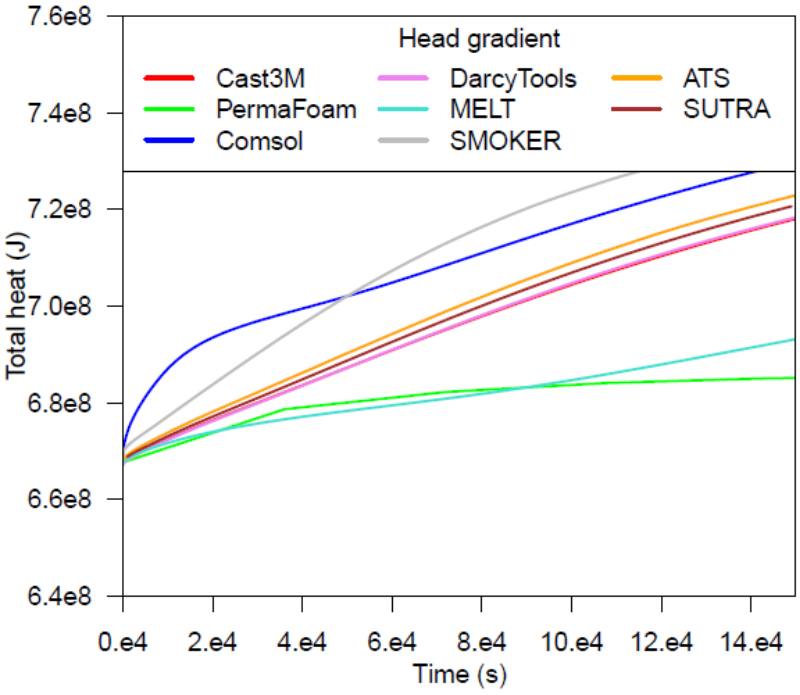


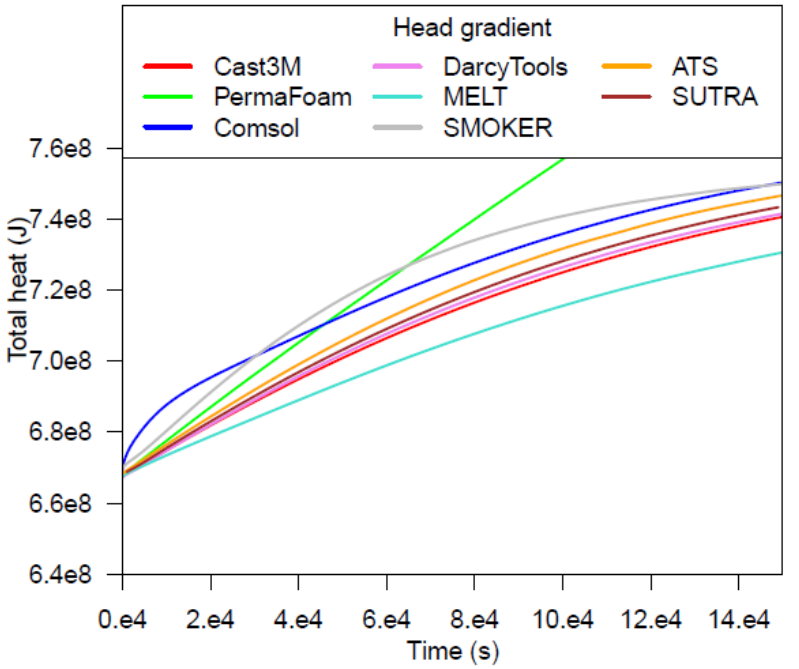


TH3_PM3 : Total Heat(t)









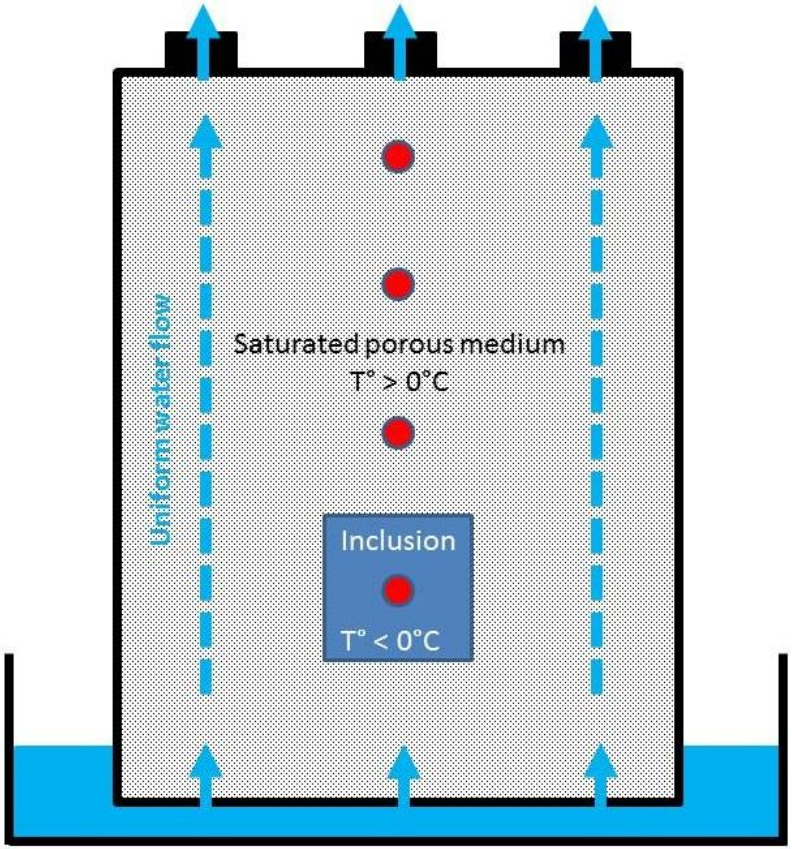
Lab. experiments

1. Associated with TH2, frozen inclusion
2. Pressure increase with the freezing front (Nicolas Roux)

Lab. Experiment TH2 « Frozen Inclusion »

collaboration GEOPS (F. Costard, T. Ali)

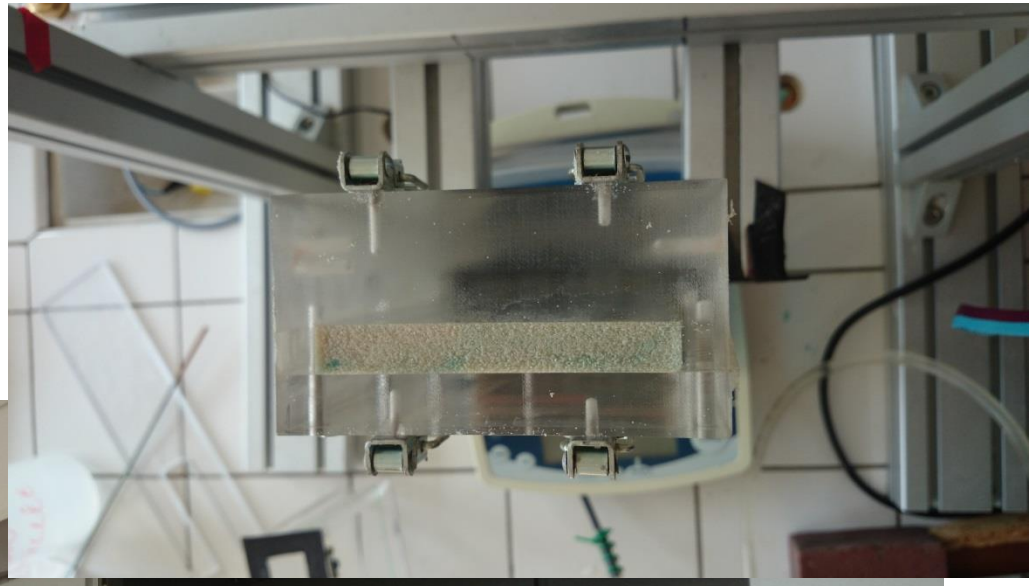
Monitoring of temperature (in the inclusion & downstream)
Monitoring of water flow rate
Measurement of transport velocity with tracer tests



« controlled conditions »?

Side heat losses (minimized with insulation & cold room conditions)
Initial conditions « smooth »
Control homogeneity of the porous medium (saturation & porosity)

Ongoing study …



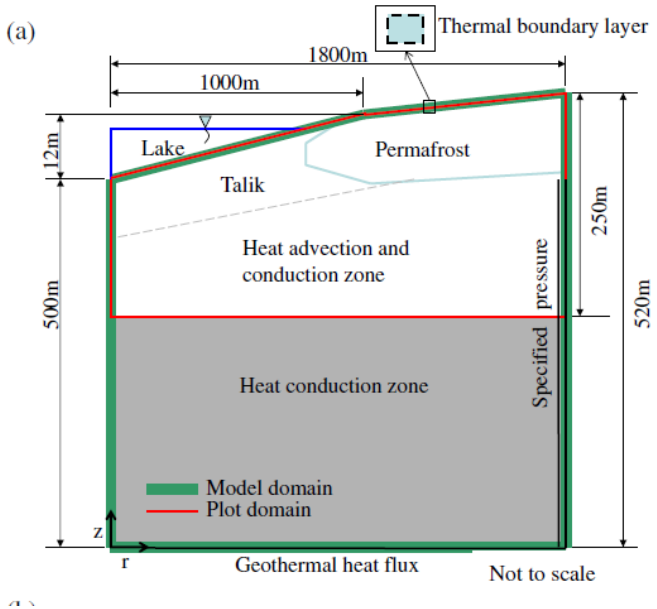
Funding

- InterFrost funded till end 2014 by French INSU EC2CO (kick off meeting supported)
- Lab experiments funded by IPSL till end 2015

- Funding is further required to organize meetings and for participants
  - Clic (for travel costs, formerly accepted but now restrained to purely « climate » issues)
  - IPA action groups (identify outcomes, 30 April 2015) « … these groups have limited terms and focus on clearly defined research outputs like maps, science plans or datablases … ».
    - Case of Guido Grosse (Research Coordination Network on Vulnerability of Permafrost Carbon – Thermokarst Working Group)
  - French « Chantier Arctique » project proposing to integrate the climate community with next step including Richards equations

Academic though « Practical » cases

- **Case of Guido Grosse (Research Coordination Network on Vulnerability of Permafrost Carbon – Thermokarst Working Group): database of cases of systems under climate change**
  - **Simple lake system (Rowland et al. 2011; Wellman et al 2013)**



- **Other cases possible: cut in a water catchment**

Next steps

- Paper about TH2 and TH3
- Non saturated media
  - Revisited by Painter recently for experiments (esp. Mizogushi)
  - Paper by Barret Kurylyk
- Experiments (running ones, others)
- Field data ?
  - System in North Quebec with John
  - System in Siberia with Christophe

Schedule?

- Paper about TH2 and TH3
- Non saturated media
  - Revisited by Painter recently for experiments (esp. Mizogushi)
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Actions for TH2&3 (1)

- Provide a mathematical expression for all performance measures, revisit their names, remove the TH3_PM1 0% case
- Please revisit your results considering a spatial and temporal convergence analysis. Maybe the mesh size / time steps are not sufficiently small
- PM corresponding with Threshold times with estimation bounds/range
- Provide your mesh size, time steps … to fill a big table
- Clarify the situation in TH3_PM1 by adding a new PM: point temperature evolution within the talik zone (precise!)
  - Needs a pre study ? Devoted to a sub-group ? Chris & Jeff
  - Other issue with oscillations (see T1 or TH1 rather?)
  - Two points depending on the regime
  - Plot profiles time=threshold/2. for all
- Push codes further? Increase velocities ? Steeper freezing & permeab. curves? Variable boundaries inside the domain? Limit in term of computational time? Limit in terms of minimum time step? Directions of limits (steeper when w smaller)
- Include dependence study on w? Yes (-4°C, base, the smaller we can make)
- Provide the curves threshold as a function of gradH?
- Add a 6% gradient ? Value at the threshold like 6.4%

Actions for TH2&3 (2) & schedule

- Provide all results by end of June (all)
- Send a paper structure (now, finalized CG, beginning July)
- Send compilation with first line of thoughts shared (CG, soon)
  - About the need for converged results
  - What have we learnt
    - Approaches/discretization/limits …
    - Make convergence studies !!!!!
  - The ways to obtain it (Fouriers, CFL and spatial and temporal convergence tests)
  - Include Peclets numbers … understand TH3 … Barret.
  - Local refinements, massively parallel methods …
  - About discrepancies in the physics implemented in the codes
  - About the different types of PM (various spatial integration levels)
  - …

- Watch that all questionaires are filled and made available

Next meetings?

- First have draft paper and experiments (end of June) sufficiently advanced
- Prepare an overview of future tasks
- Meet then

IPA action group call

- Submit as existing with production of validation test cases
- Provide guidance, experience on numerics and processes reassessment
- When is advection important ? Guidelines …
- Help from Jennifer … & Barret

Future tasks

- Experiments in cold room
- Field data (monitoring, sites, …)
- Impact of climate change on a typical unit of the landscape (a lake system)
- Large scale systems
- Revisit T2?
- Non-saturated issues

Cold room experiments

- TP case (pressure increase) … as a first step towards mechanical issues
- TH2 case and what is proved by an experiment?
- Others ?

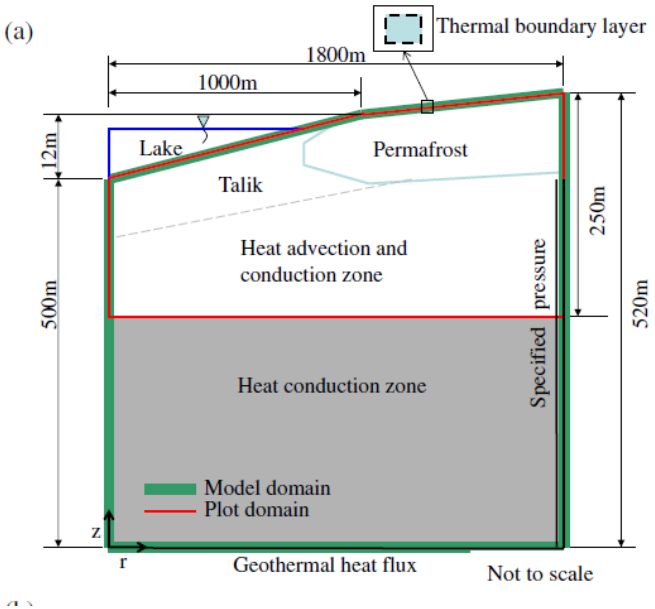
Field cases studies

- John’s case in North Québec
- Christophe’s case in Siberia
- Western Ontarion (Biotron) … Jeff & Barret

  - Compile the information for an oral presentation or one page to send to the group. Schedule : send one page of summary for summer (end of june)

Impact of climate change on a typical unit of the landscape (a lake system)

- … Johanna, Jennifer, Cliff, John, … side preparation



Large scale systems

- … what do you mean ?
- How can we improve our large scales simulations knowing what we have learnt here at the small scale?
- Information loss across spatial and temporal scales … link with T2?
- Extend Talik issue of TH3 to a larger scale « real » case?
- French-swedish case discussed (Johann, Patrik)

Revisit T2?

- Long term simulation of Permafrost depths (1D approaches at geological times)
- Heterogenity (moisture content, include salinity affecting soil freezing properties, characteristic curves …)
- Discuss with Johanna test cases …

Non-saturated issues

- Scott Painter recently revisited the experiments (es. Mizogushi)
- Barret the physics behind … review of experiments (Mizoguchi, Jame and Norum)
- What are the challenges and our added value in considering these issues?
- Differences in saturation winter/summer, Agnès post doc
- Include climate community