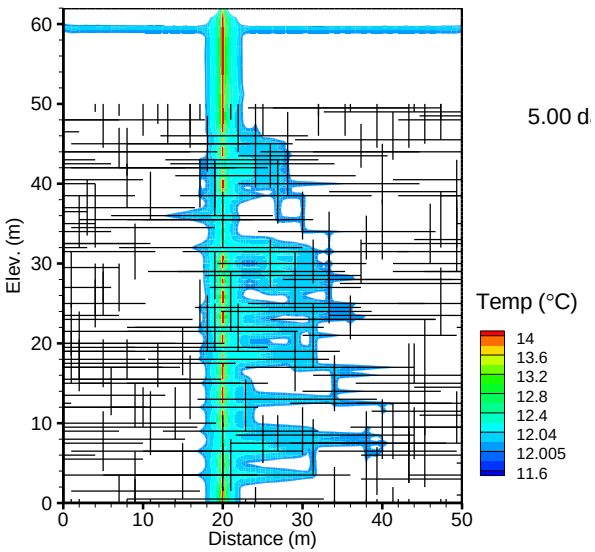
Heat Transport Benchmark Modelling

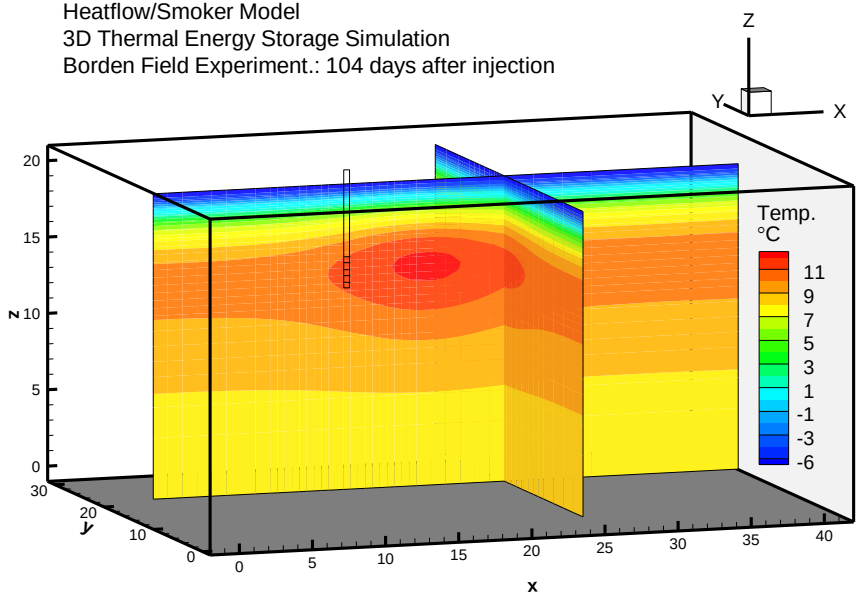
Thermal tracers D FN
Pehme et al., J. Hydrol., (2013)

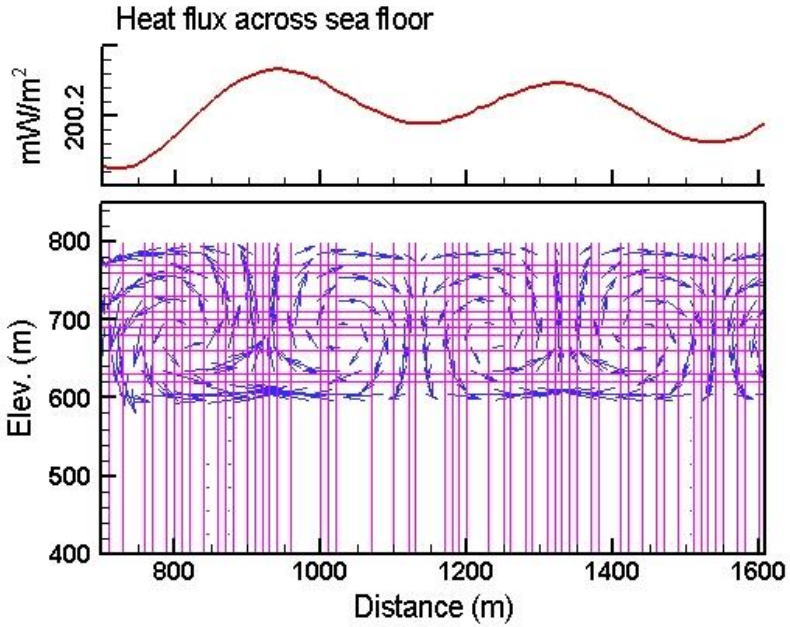


HEATFLOW/SMOKER Model

ATES, Molson et al. WRR, (1992)

Heatflow/Smoker Model
3D Thermal Energy Storage Simulation
Borden Field Experiment.: 104 days after injection





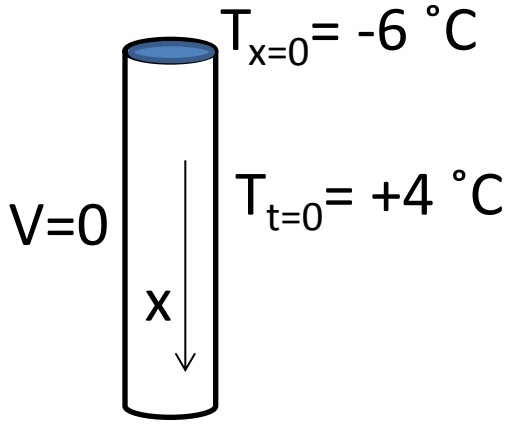
'Black Smoker'
Hydrothermal systems

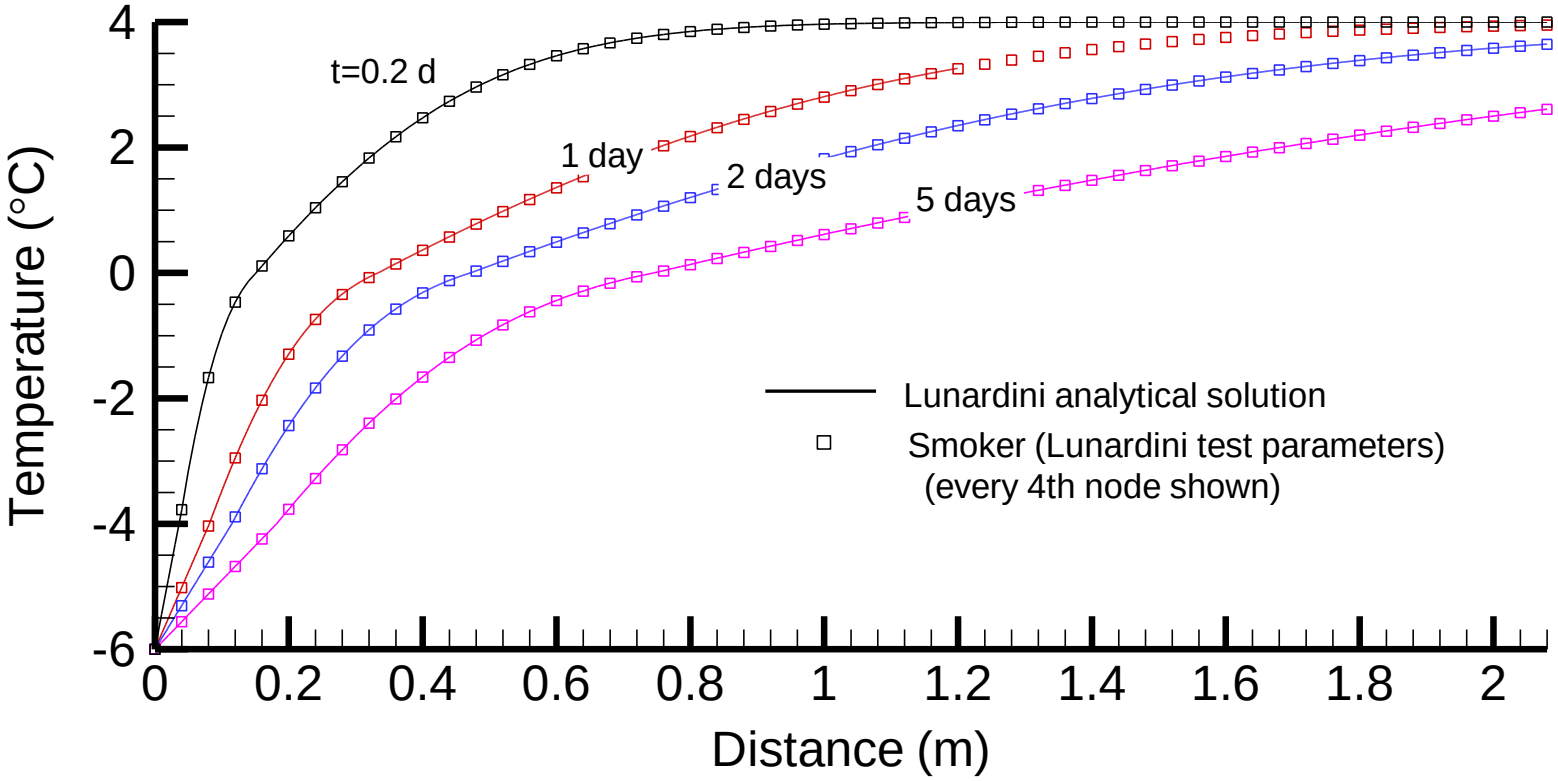
Yang et al, GRL, (1996)

Model Benchmarks:

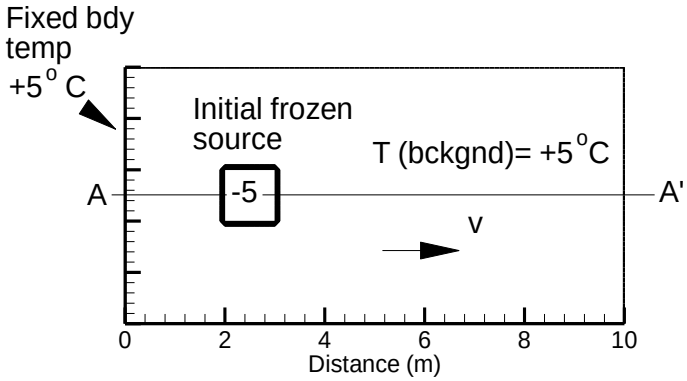
HEATFLOW/SMOKER Model

Validation:
Lunardini (1985) 3-zone solution
programmed by M. Ghias, U. Laval



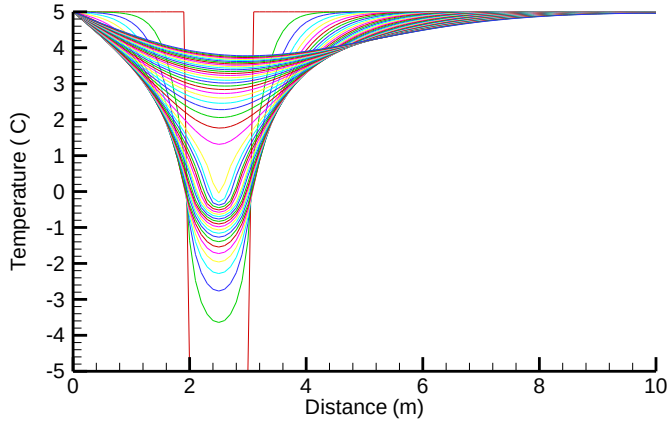


Benchmark TH2
SMOKER Model (Molson & Frind, 2014)



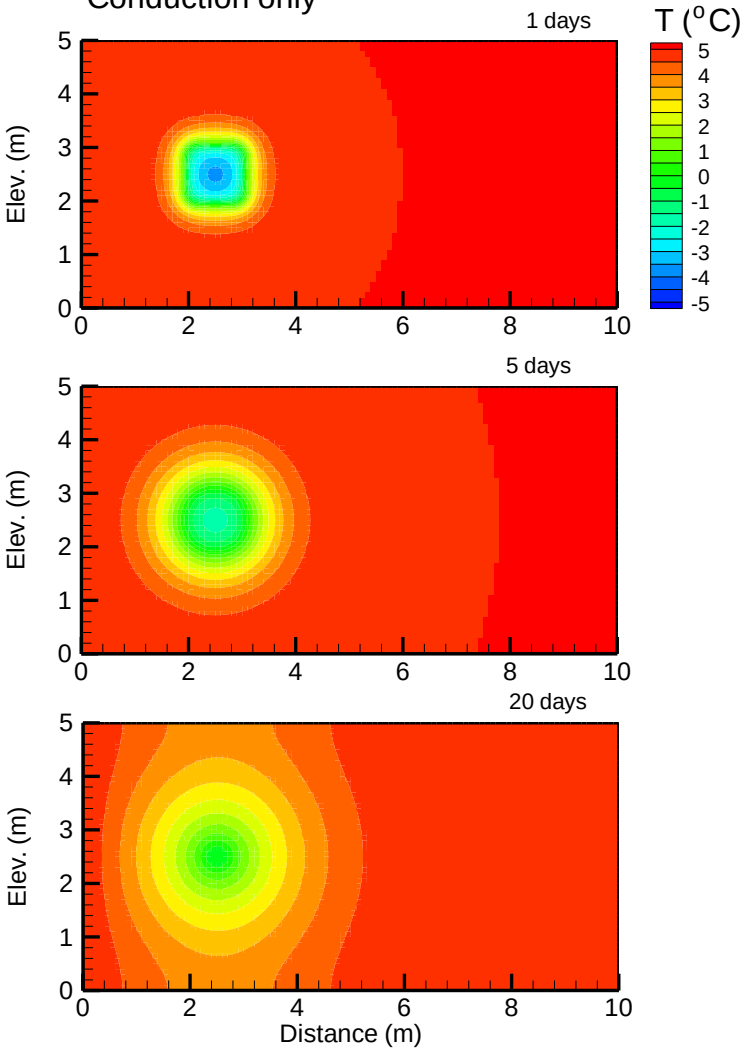
Benchmark TH2
SMOKER Model (Molson & Frind (2014)

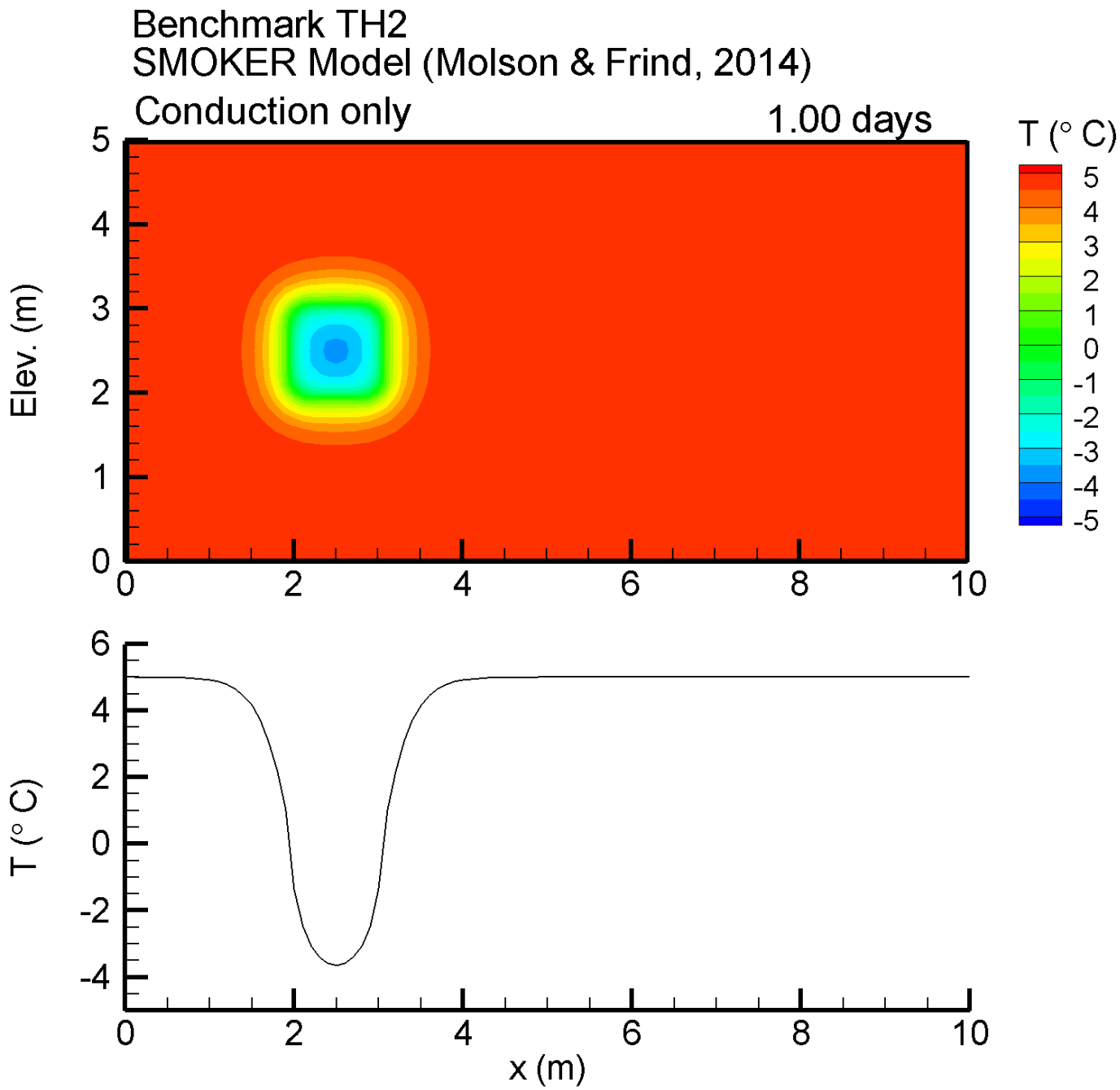
Conduction only



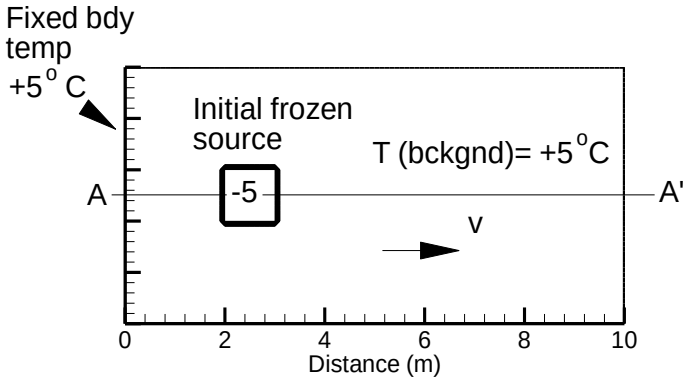
Benchmark TH2
SMOKER Model (Molson & Frind, 2014)

Conduction only



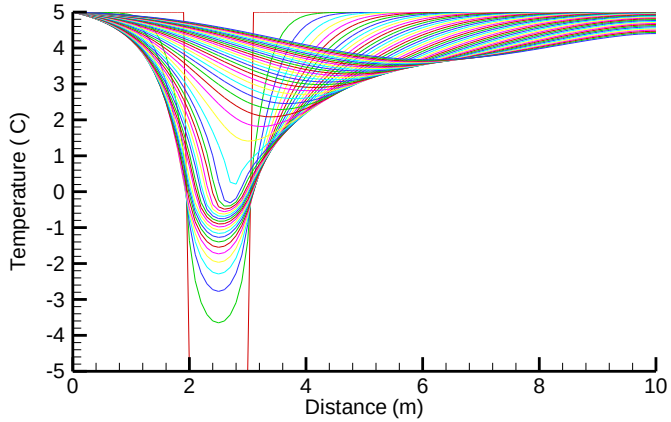

Benchmark TH2
SMOKER Model (Molson & Frind, 2014)
Conduction only
1.00 days
T (° C)
5
4
3
2
1
0
-1
-2
-3
-4
-5
Elev. (m)
0
2
4
6
8
10
T (° C)
6
4
2
0
-2
-4
x (m)

Benchmark TH2
SMOKER Model (Molson & Frind, 2014)



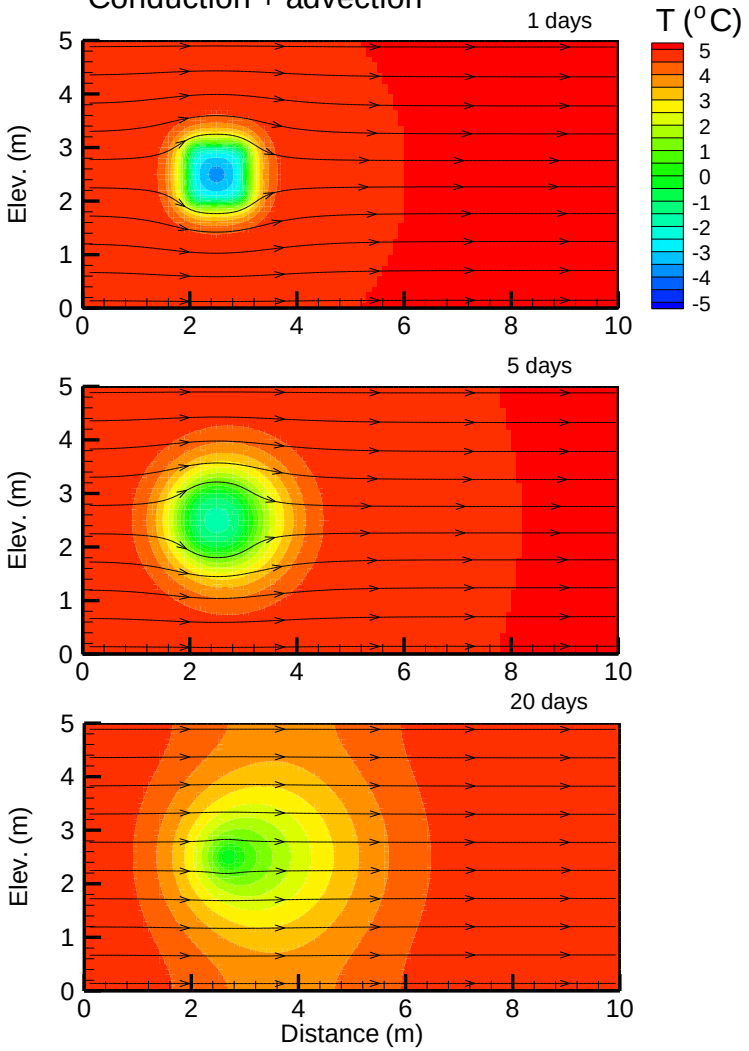
Benchmark TH2
SMOKER Model (Molson & Frind (2014)

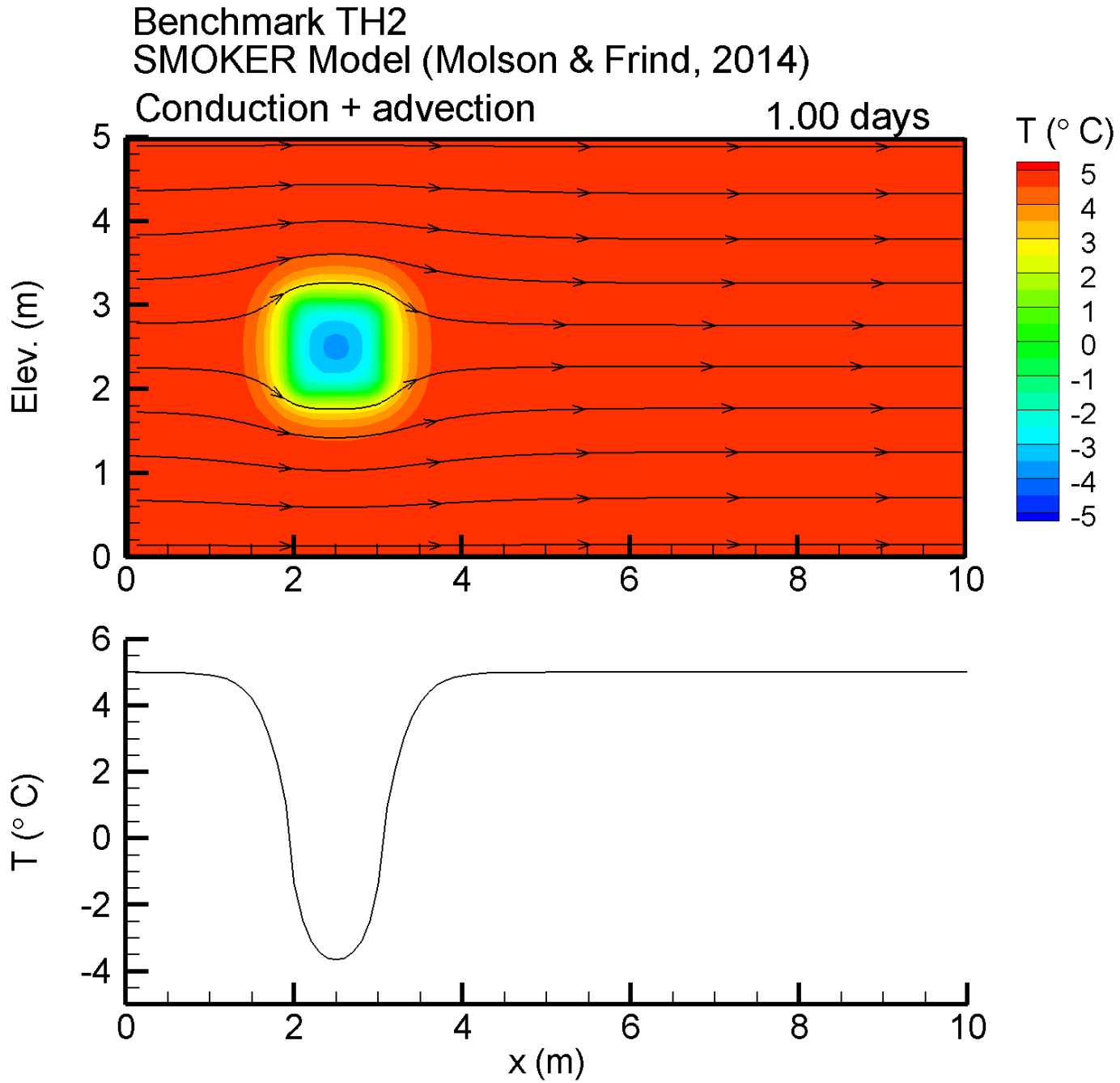
Conduction + advection

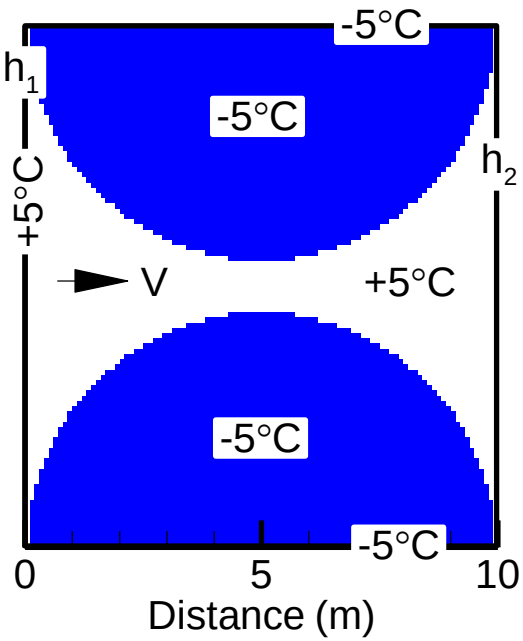


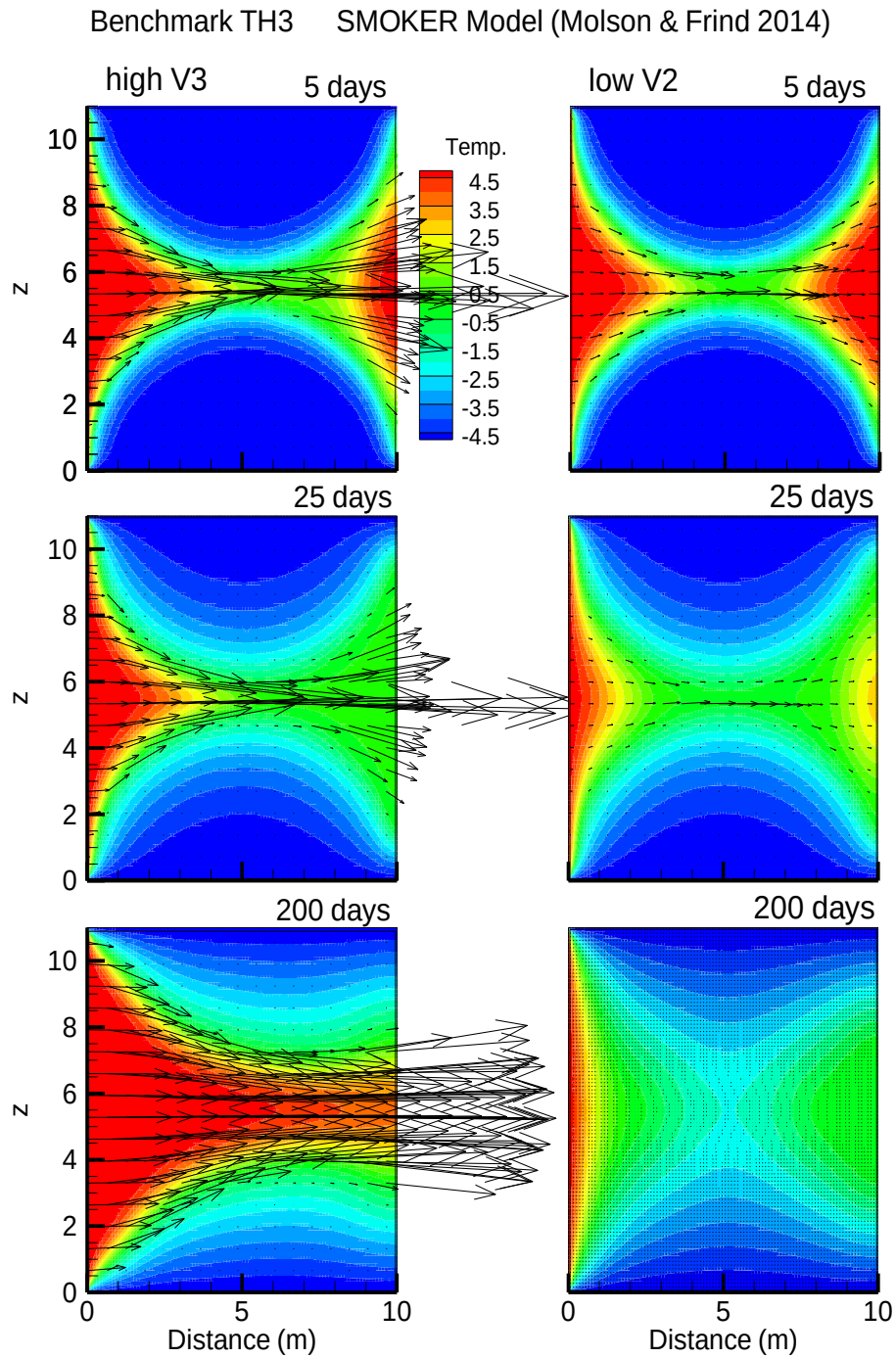
Benchmark TH2
SMOKER Model (Molson & Frind, 2014)

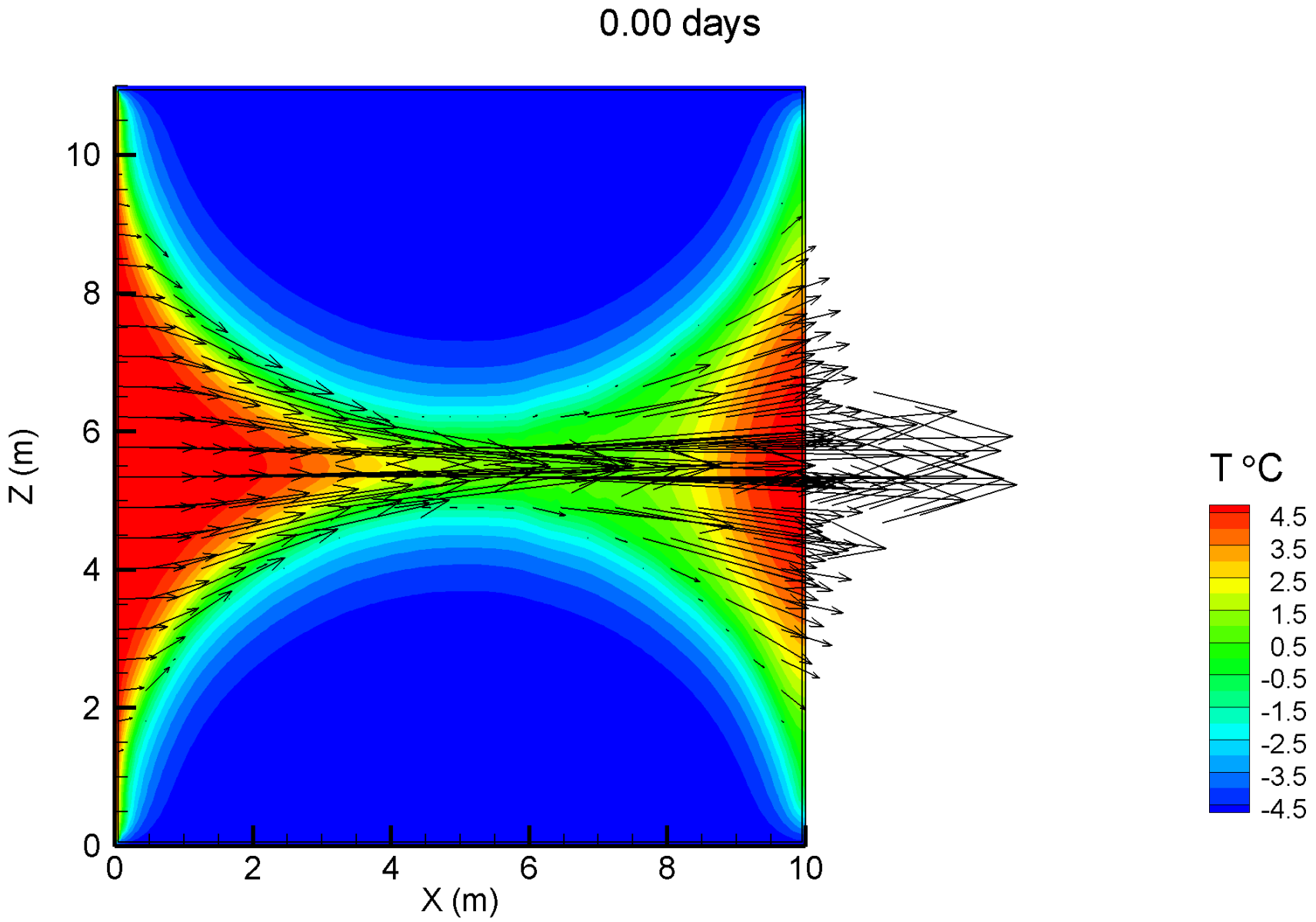
Conduction + advection

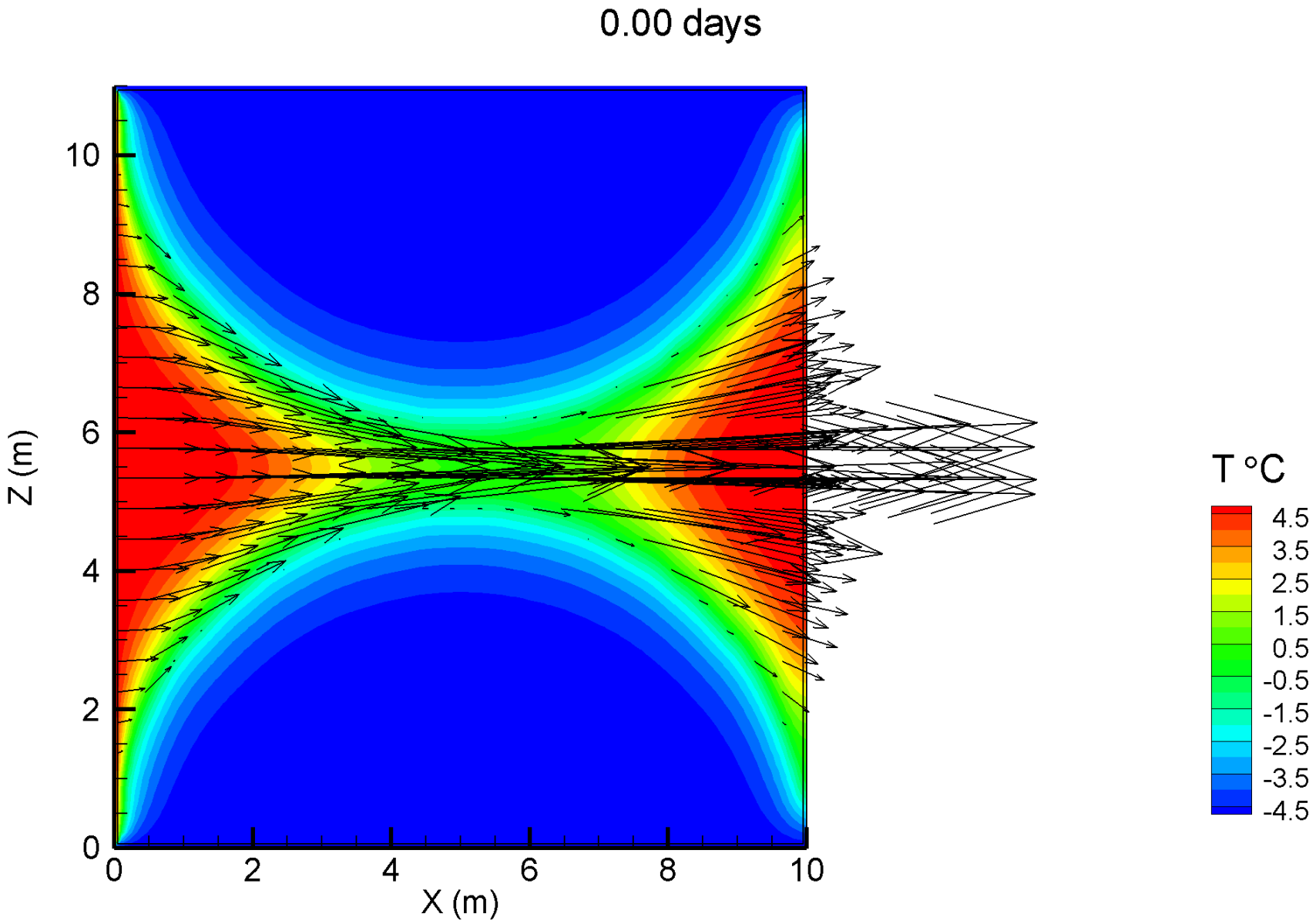


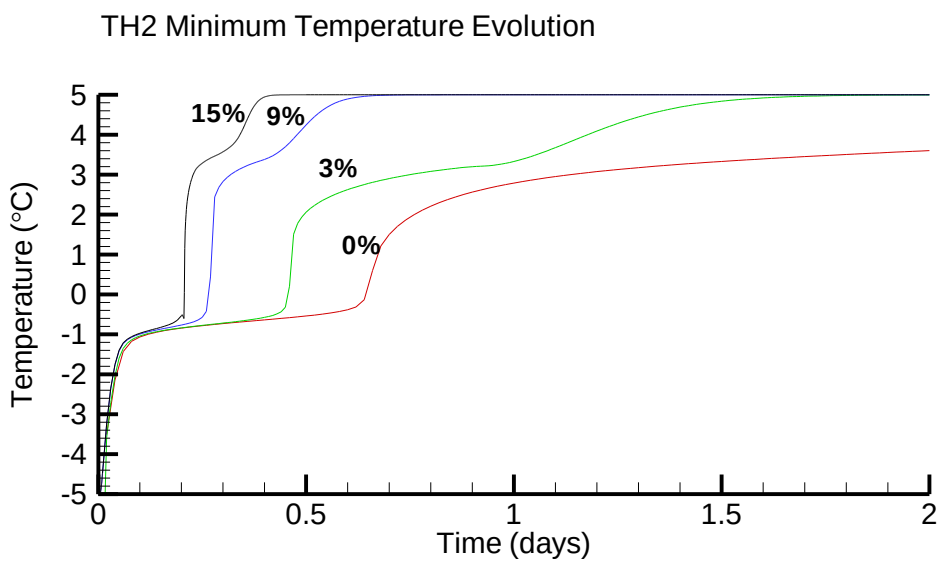

Benchmark TH2
SMOKER Model (Molson & Frind, 2014)
Conduction + advection
1.00 days
T (° C)
5
4
3
2
1
0
-1
-2
-3
-4
-5
Elev. (m)
0
2
4
6
8
10
T (° C)
6
4
2
0
-2
-4
x (m)

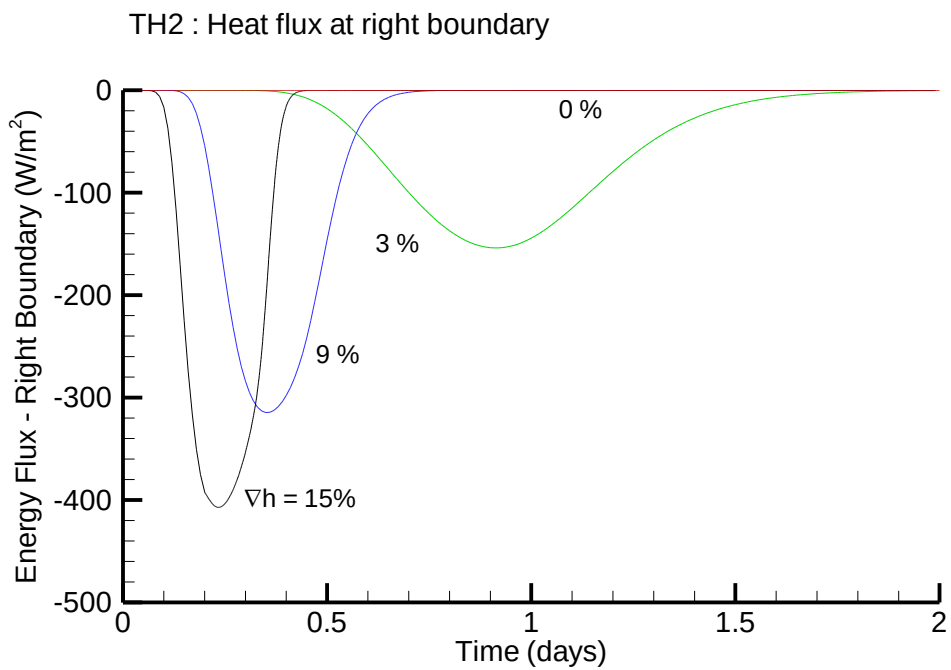

-5°C
h1
-5°C
h2
+5°C
V
+5°C
-5°C
-5°C
0
5
10
Distance (m)

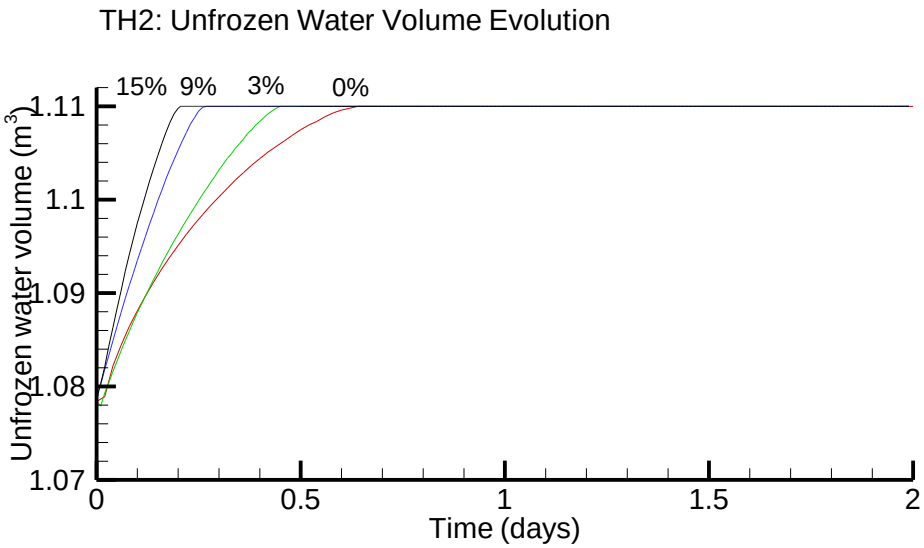

Benchmark TH3 SMOKER Model (Molson & Frind 2014)
high V3
5 days
low V2
5 days
Temp.
4.5
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
-4.5
25 days
25 days
200 days
200 days
z
0
2
4
6
8
10
0
5
10
Distance (m)
Distance (m)

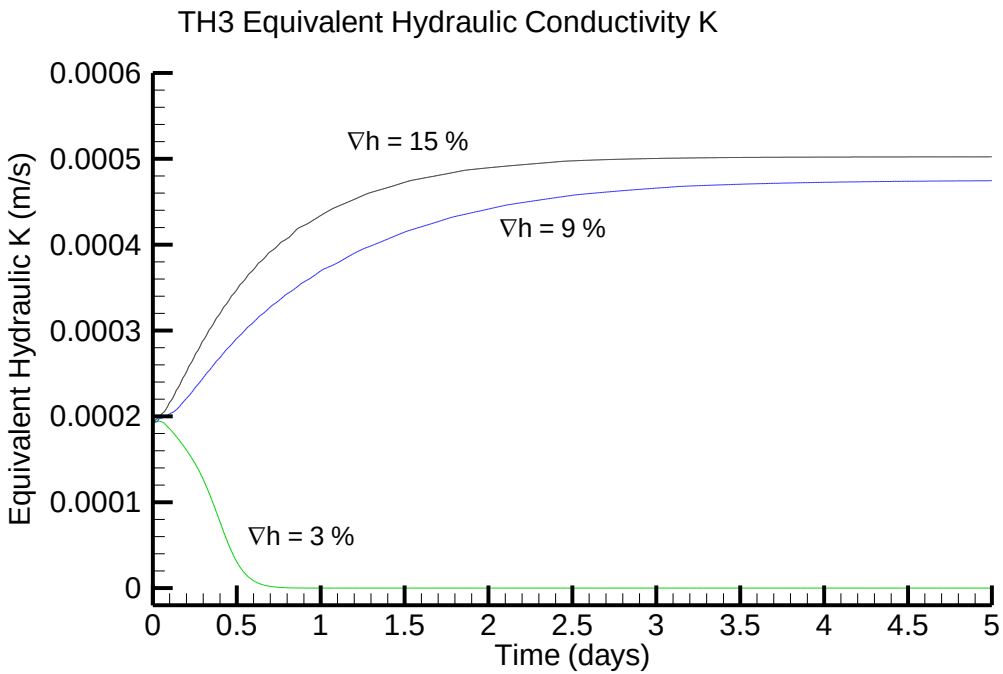

0.00 days
Z (m)
X (m)
0
2
4
6
8
10
T °C
4.5
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
-4.5

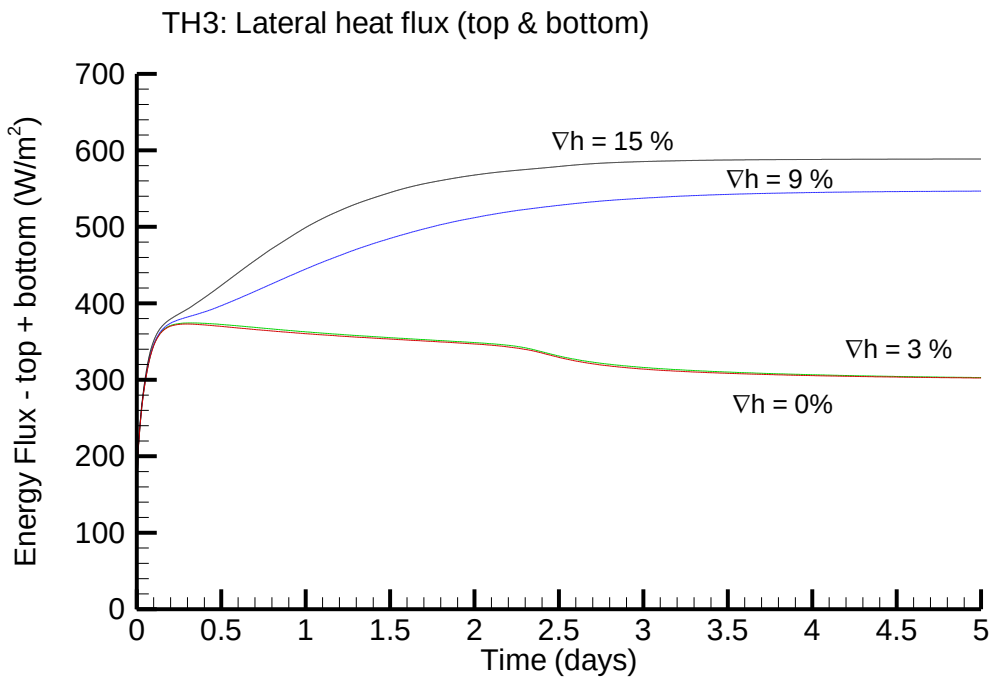

0.00 days
Z (m)
X (m)
0
2
4
6
8
10
T °C
4.5
3.5
2.5
1.5
0.5
-0.5
-1.5
-2.5
-3.5
-4.5

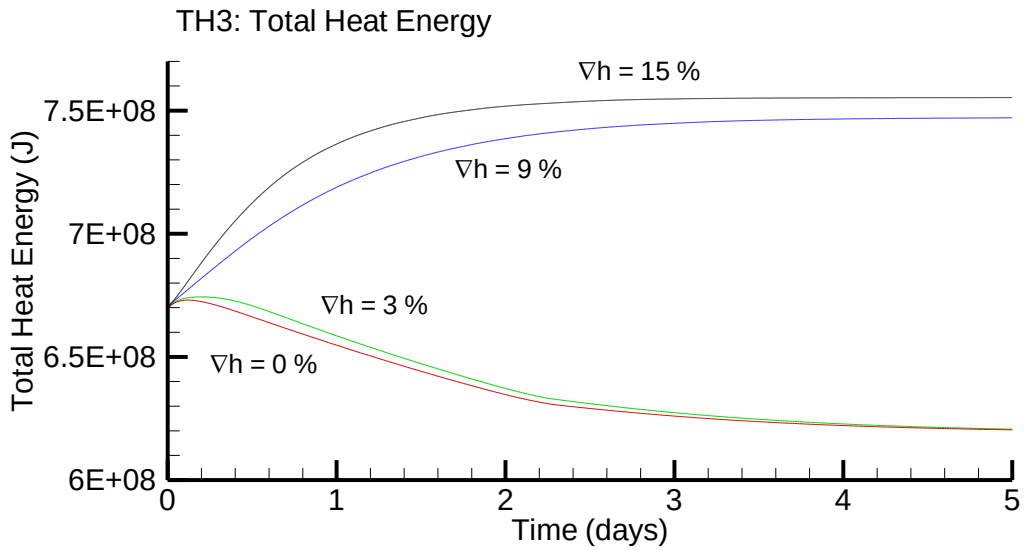

TH2 Minimum Temperature Evolution
Temperature (°C)
Time (days)
15%
9%
3%
0%
5
4
3
2
1
0
-1
-2
-3
-4
-5
0
0.5
1
1.5
2

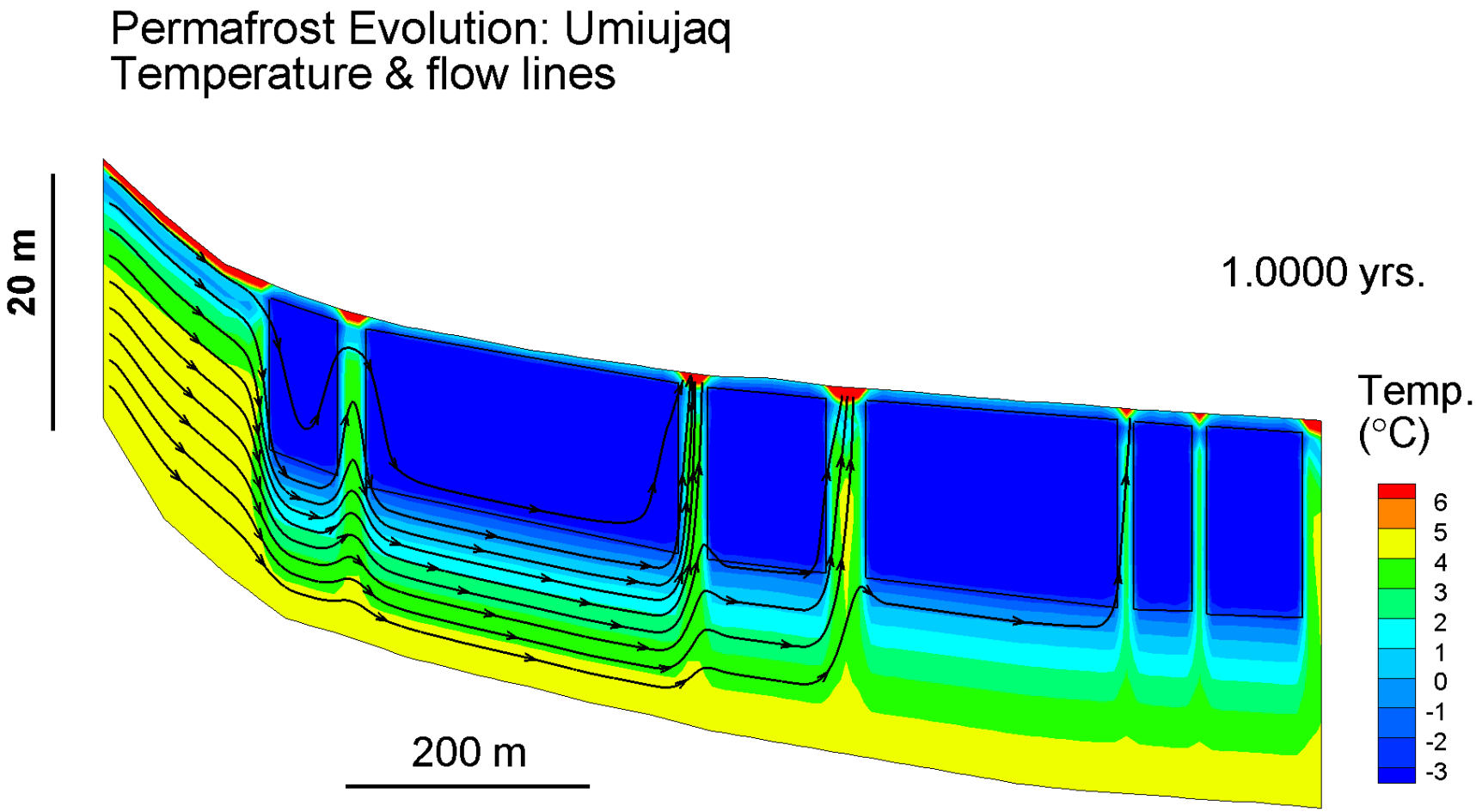

TH2 : Heat flux at right boundary
Energy Flux - Right Boundary (W/m2)
Time (days)
0 %
3 %
9 %
∇h = 15%
0
-100
-200
-300
-400
-500
0
0.5
1
1.5
2


TH2: Unfrozen Water Volume Evolution
15%
9%
3%
0%
Unfrozen water volume (m3)
1.11
1.1
1.09
1.08
1.07
0
0.5
1
1.5
2
Time (days)


TH3 Equivalent Hydraulic Conductivity K
Equivalent Hydraulic K (m/s)
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
∇h = 15 %
∇h = 9 %
∇h = 3 %
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (days)


TH3: Lateral heat flux (top & bottom)
Energy Flux - top + bottom (W/m2)
700
600
500
400
300
200
100
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
Time (days)
∇h = 15 %
∇h = 9 %
∇h = 3 %
∇h = 0%


TH3: Total Heat Energy
Total Heat Energy (J)
7.5E+08
7E+08
6.5E+08
6E+08
0
1
2
3
4
5
Time (days)
∇h = 15 %
∇h = 9 %
∇h = 3 %
∇h = 0 %


Permafrost Evolution: Umiujaq
Temperature & flow lines
20 m
1.0000 yrs.
Temp.
(°C)
6
5
4
3
2
1
0
-1
-2
-3
200 m

Acknowledgements

Développement durable, Environnement et Lutte contre les changements climatiques

Québec

Fonds de recherche Nature et technologies

Québec

NSERC CRSNG

Canada Foundation for Innovation

Fondation canadienne pour l'innovation

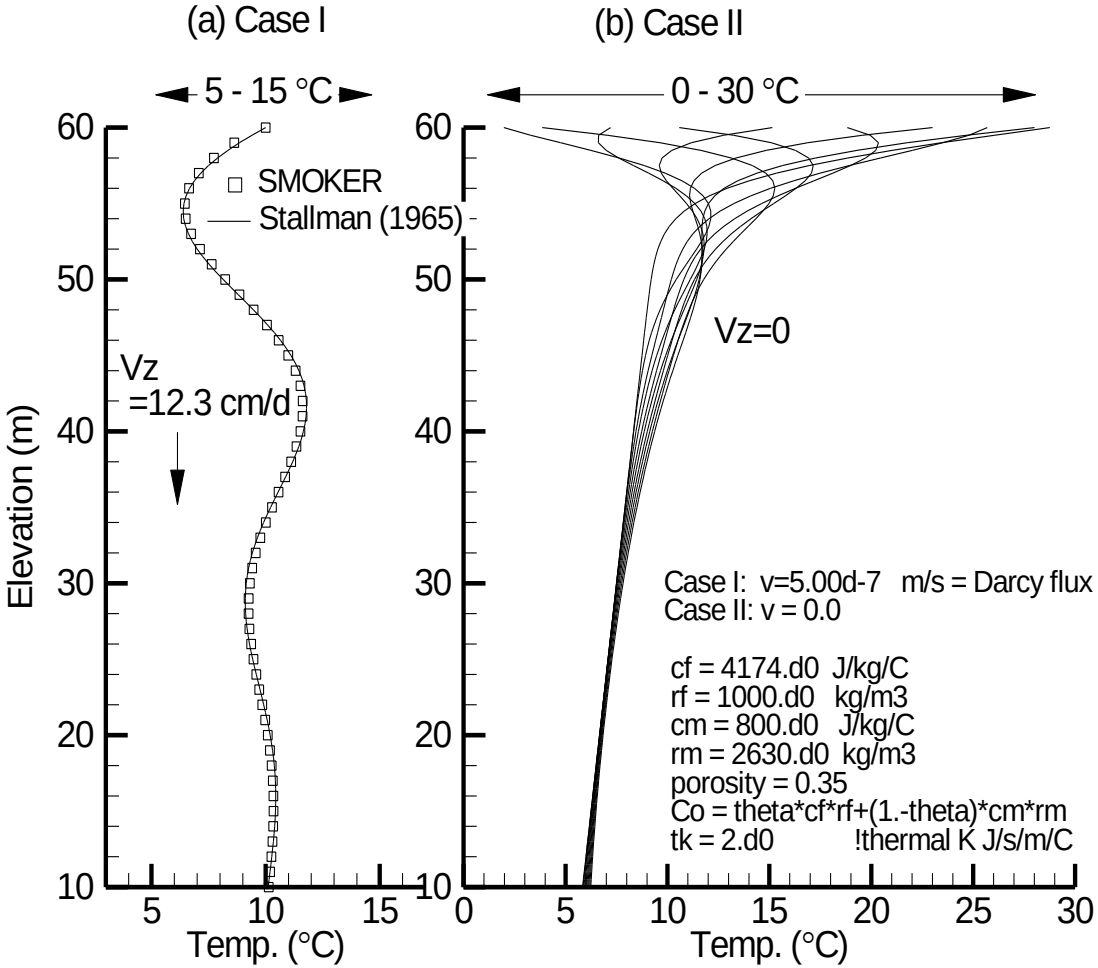
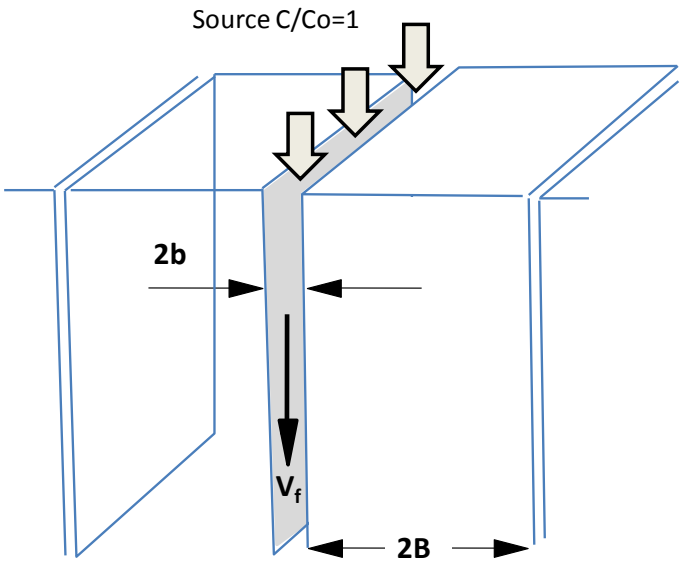
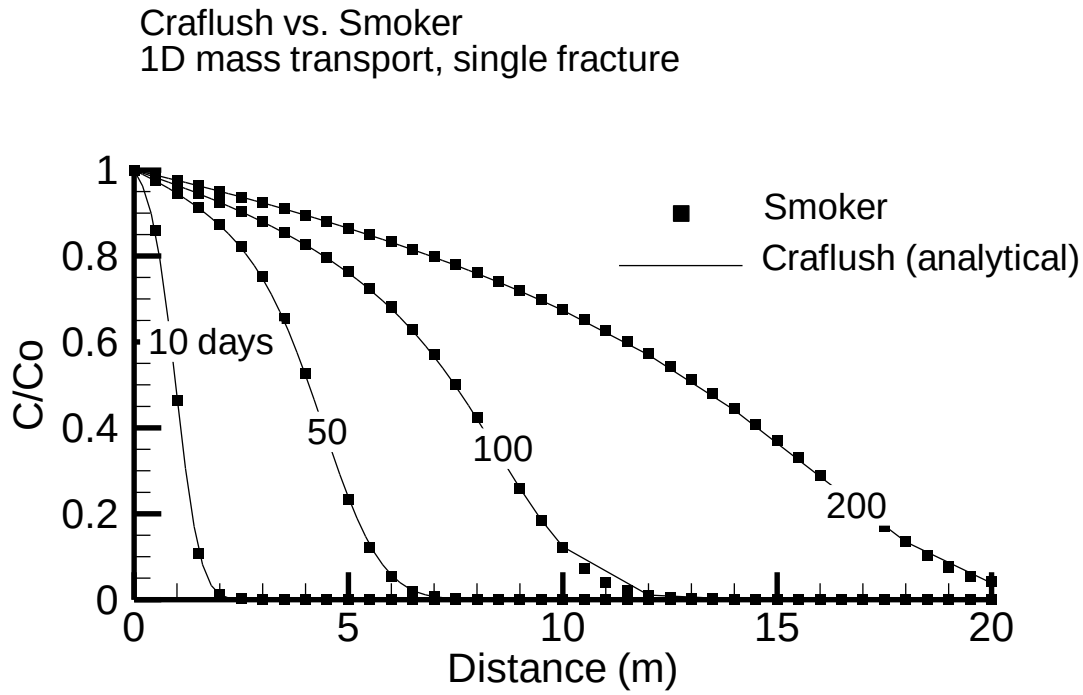
Centre d'études nordiques

UNIVERSITÉ LAVAL

Program of Energy Research and Development (PERD)

Indian & Northern Affairs Canada (INAC)

Validation: Stallman (1965) Solution



Validation: Discrete Fractures