Presented at the COMSOL Conference 2009 Milan

COMSOL2009 Conference, Milano, 14-16 October 2009

Variation of the Frost boundary below Road and Railway Embankments in Permafrost Regions in Response to Solar Irradiation and Winds

Norbert Kömle
Space Research Institute
Austrian Academy of Sciences
Graz, Austria

Email: norbert .koemle@oeaw.ac.at

Wenjie Feng
State Key Laboratory of Frozen Soil Engineering, CAREERI
Lanzhou, China

Frost damage of highland roads

Awnings and other protection measures for the permafrost

Figure 32. Scenery of sunshine shield railway emba

Awnings along the new Qinghai-Tibet railway route

Shielding of heat flow from the ground by isolation material

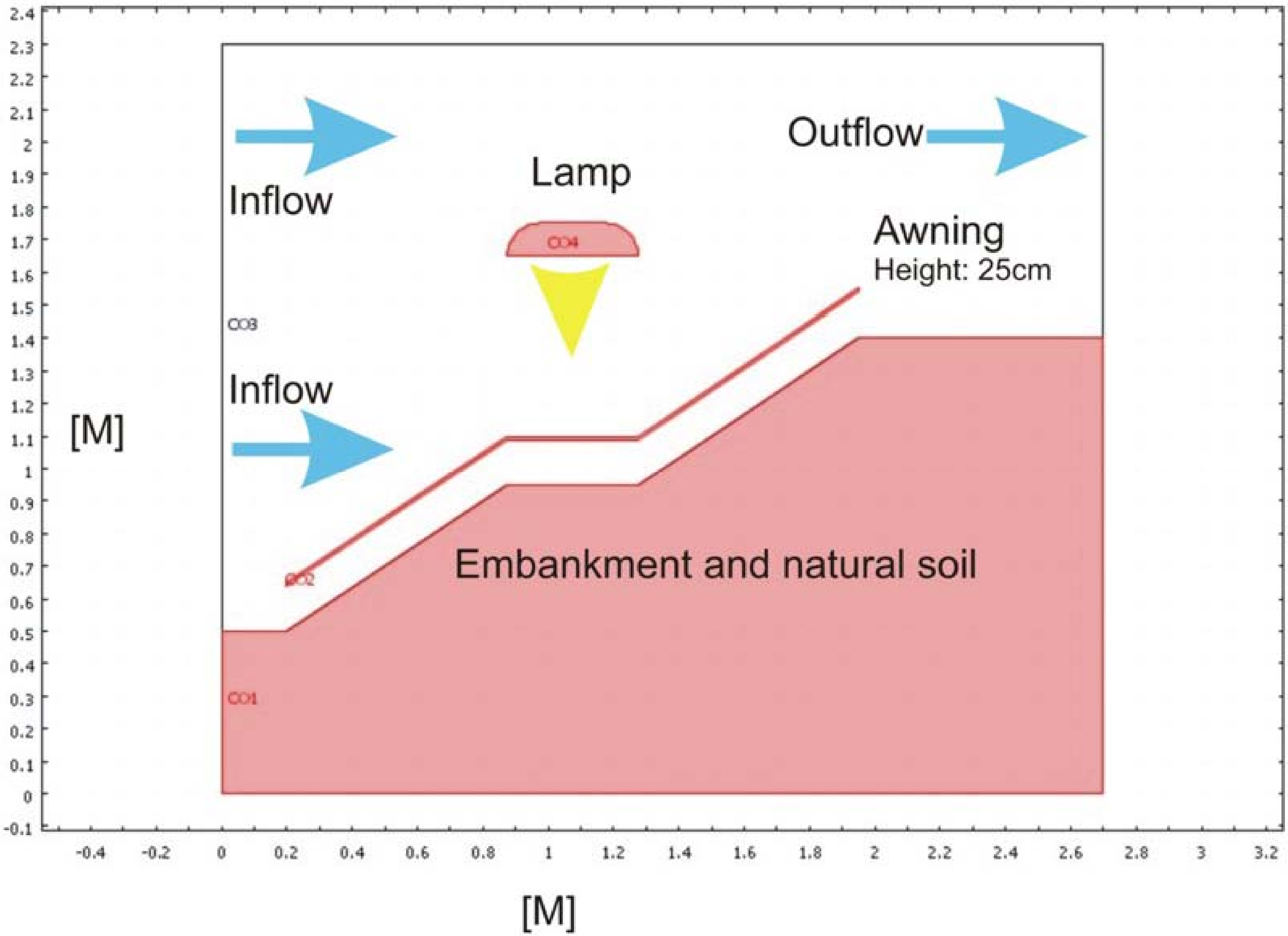
Figure 24. Scenery of thermal insulation embankment construction

Figure 30. Scenery of air convetion railway embankment

Big gravel to allow for air ventilation of the embankment

Indoor tests setup

Model geometry for lab setup



Equations I

Heat transfer:

$$\rho C\frac{\partial T}{\partial t}+\nabla\cdot\left(-k\nabla T\right)=Q-\rho Cu\cdot\nabla T$$

Gas flow (weakly compressible Navier-Stokes):

$$\rho u\cdot\nabla u=\left[-pI+\eta\left(\nabla u+(\nabla u)^{T}\right)-\left(\frac{2\eta}{3}-\kappa\right)(\nabla u)I\right]$$

$$\nabla\cdot\left(\rho u\right)=0$$

Equations II

Heat capacity with melting:

$$C = C_{clay} + D_m Q_m$$

Implementation of phase change:

$$D_m = \frac{e^{-(T-T_m)^2/\sigma^2}}{\sqrt{\pi\sigma^2}}$$

Equations III

Thermal parameters variation frozen/unfrozen:

$$\rho_{clay} = \frac{1}{2}\left(\rho_{clayf} + \rho_{clayu}\right) + \left(\rho_{clayu} - \rho_{clayf}\right)\frac{1}{\pi} \cdot \arctan\left[b_m\left(T - T_m\right)\right]$$

$$C_{clay} = \frac{1}{2}\left(C_{clayf} + C_{clayu}\right) + \left(C_{clayu} - C_{clayf}\right)\frac{1}{\pi} \cdot \arctan\left[b_m\left(T - T_m\right)\right]$$

$$k_{clay} = \frac{1}{2}\left(k_{clayf} + k_{clayu}\right) + \left(k_{clayu} - k_{clayf}\right)\frac{1}{\pi} \cdot \arctan\left[b_m\left(T - T_m\right)\right]$$

Model parameters

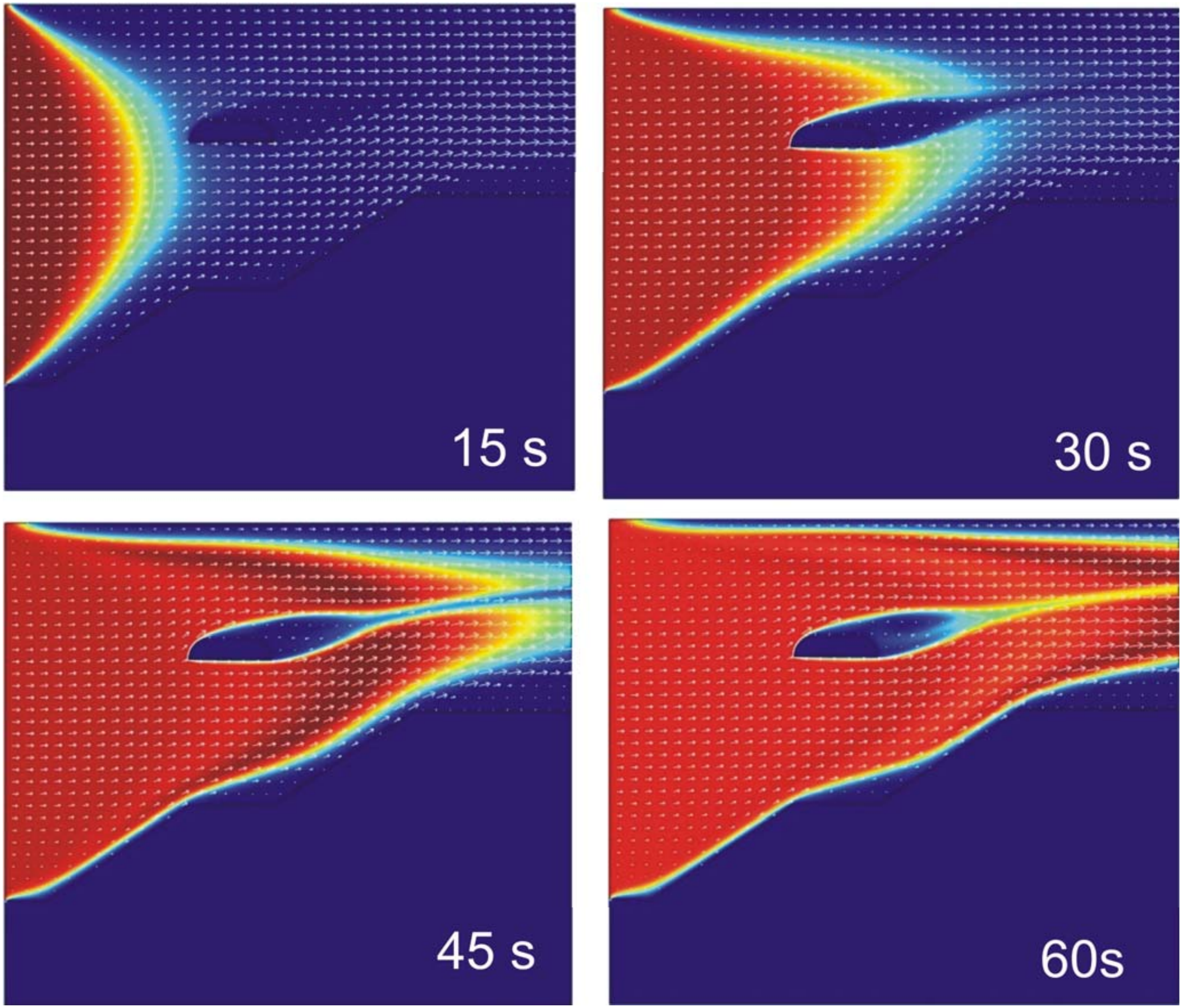
Parameter	Value	Description
k_{clayu}	1.60 [W/m/K]	soil heat conductivity (unfrozen)
k_{clayf}	1.98[W/m/K]	soil heat conductivity (frozen)
ρ_{clayu}	1800 [kg/m^3]	soil density (unfrozen)
ρ_{clayf}	1800 [kg/m^3]	soil density (frozen)
C_{clayu}	1266 [J/kg/K]	soil heat capacity (unfrozen)
C_{clayf}	977.2 [J/kg/K]	soil heat capacity (frozen)
k_{air}	0.024[W/m/K]	air heat conductivity
varrho _{air}	1.169[kg/m^3]	air density
C_{air}	1005[J/kg/K]	air heat capacity
η	17.2e-6[Pa s]	air viscosity
T_{init}	273.15 [K]-5[K]	initial temperature
p_0	1e5[Pa]	air pressure
T_m	273.15[K]	ice melting temperature
b_m	10[1/K]	sharpness parameter for phase change
σ	0.1[K]	Gauss parameter for phase change
b_1	10[1/s]	sharpness parameter for lamp on
b_2	10[1/s]	sharpness parameter for lamp off
ΔT	± 10[K]	air temperature change
watercontent	0.12	water content of soil
Q_{mH2O}	333e3[J/kg]	ice melting heat
Q_m	watercontent* Q_{mH2O}	soil melting heat
k_{awning}	238[W/m/K]	awning thermal conductivity
ρ_{awning}	2700[kg/m^3]	awning density
C_{awning}	945[J/kg/K]	awning heat capacity
k_{lamp}	238[W/m/K]	lamp heat conductivity
ρ_{lamp}	2700[kg/m^3]	lamp density
C_{lamp}	945[J/kg/K]	lamp heat capacity
ε_{lamp}	1.00	lamp emissivity
ε_{clay}	0.75	soil emissivity
$\varepsilon_{awningt}$	0.80	awning top emissivity
$\varepsilon_{awningb}$	0.30	awning bottom emissivity

Inflow velocity profile

$$u(y) = u_{\max}\left[1 - \left(\frac{y - y_m}{y_{top} - y_m}\right)^2\right]$$

$$y_m = \frac{1}{2}\left(y_{bottom} + y_{top}\right)$$

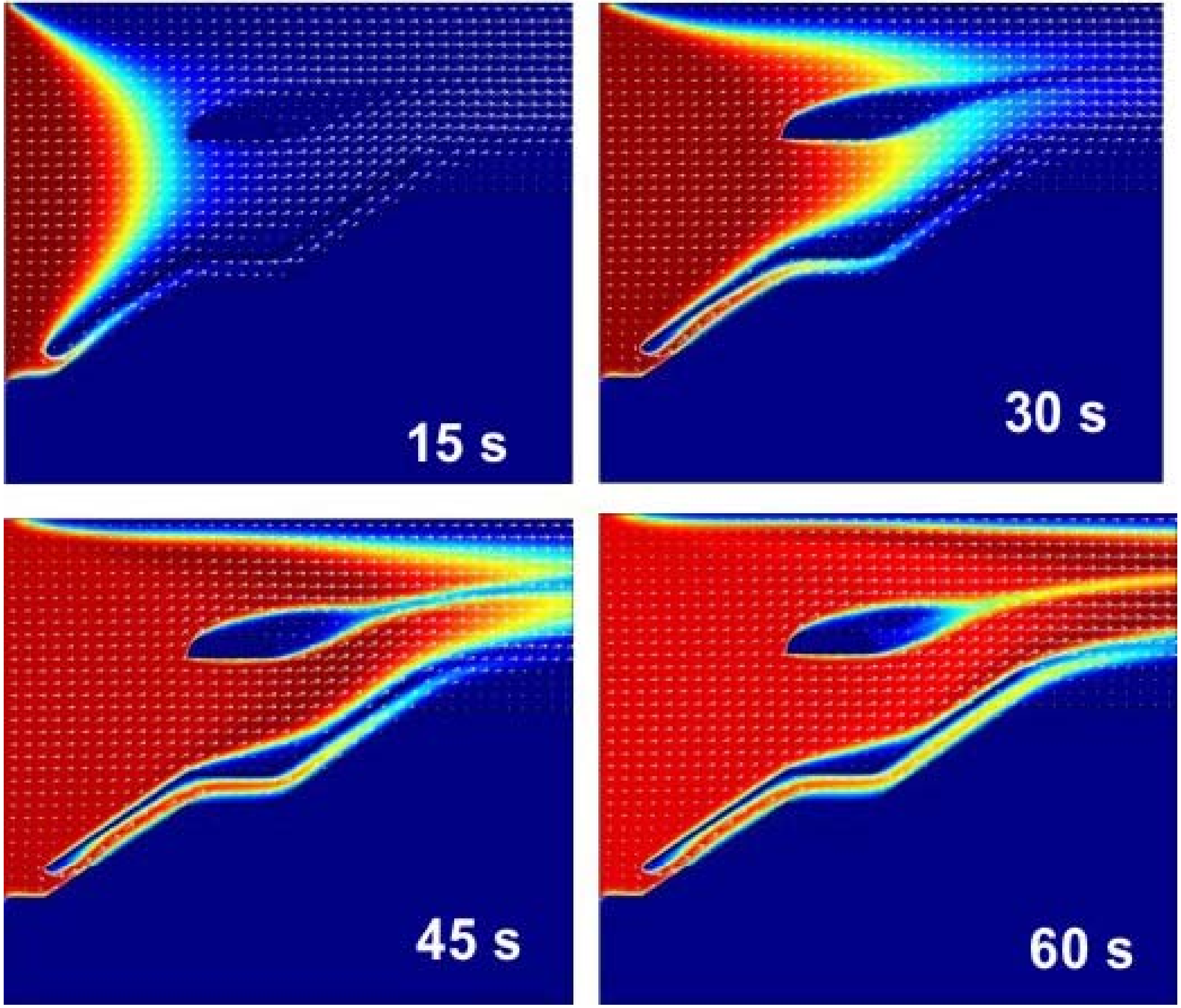
No awning – heated air



$\Delta T = +10K$

$u_{max}=5cm/s$

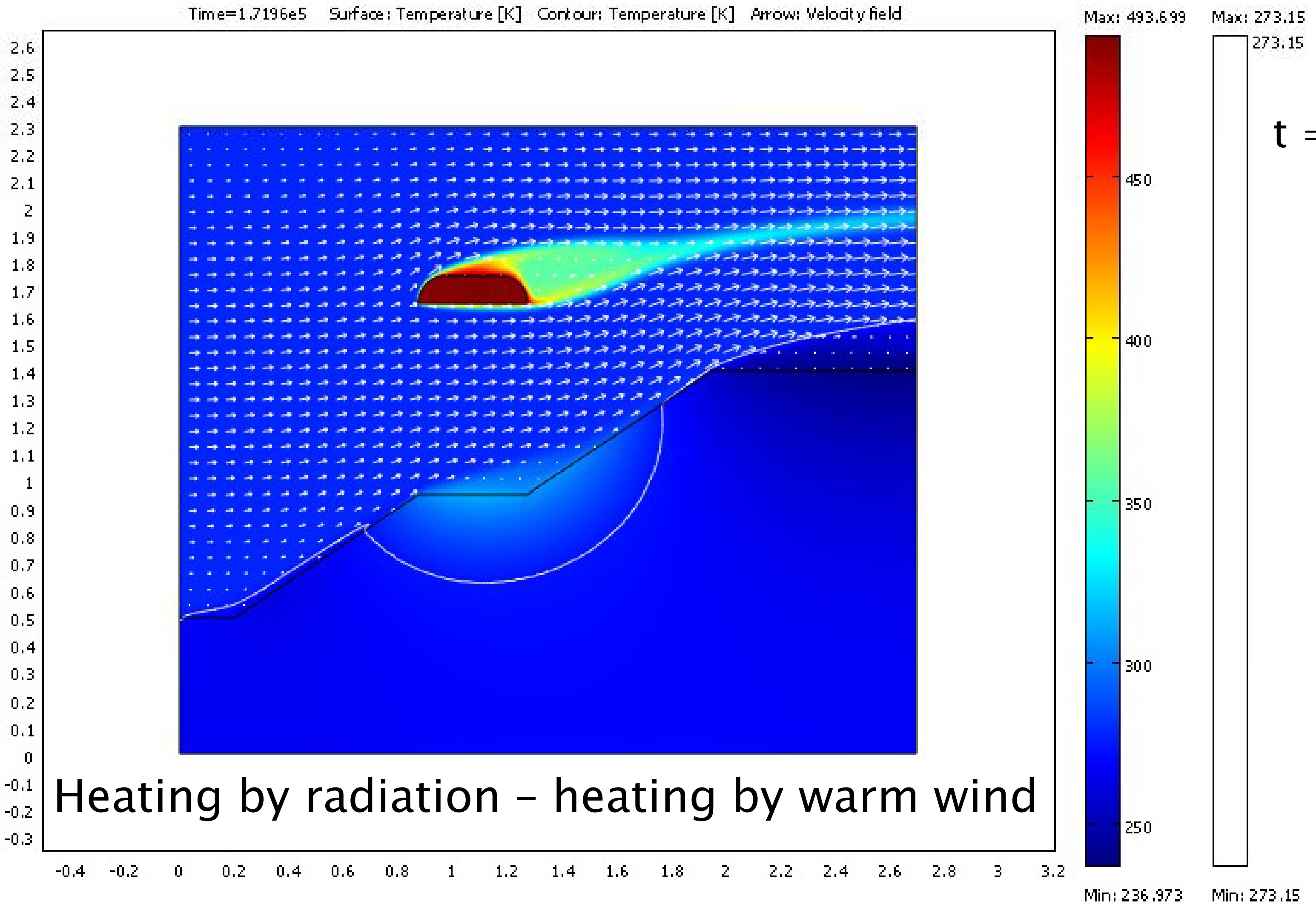
Awning – heated air



$\Delta T = +10K$

u_{max}=5cm/s

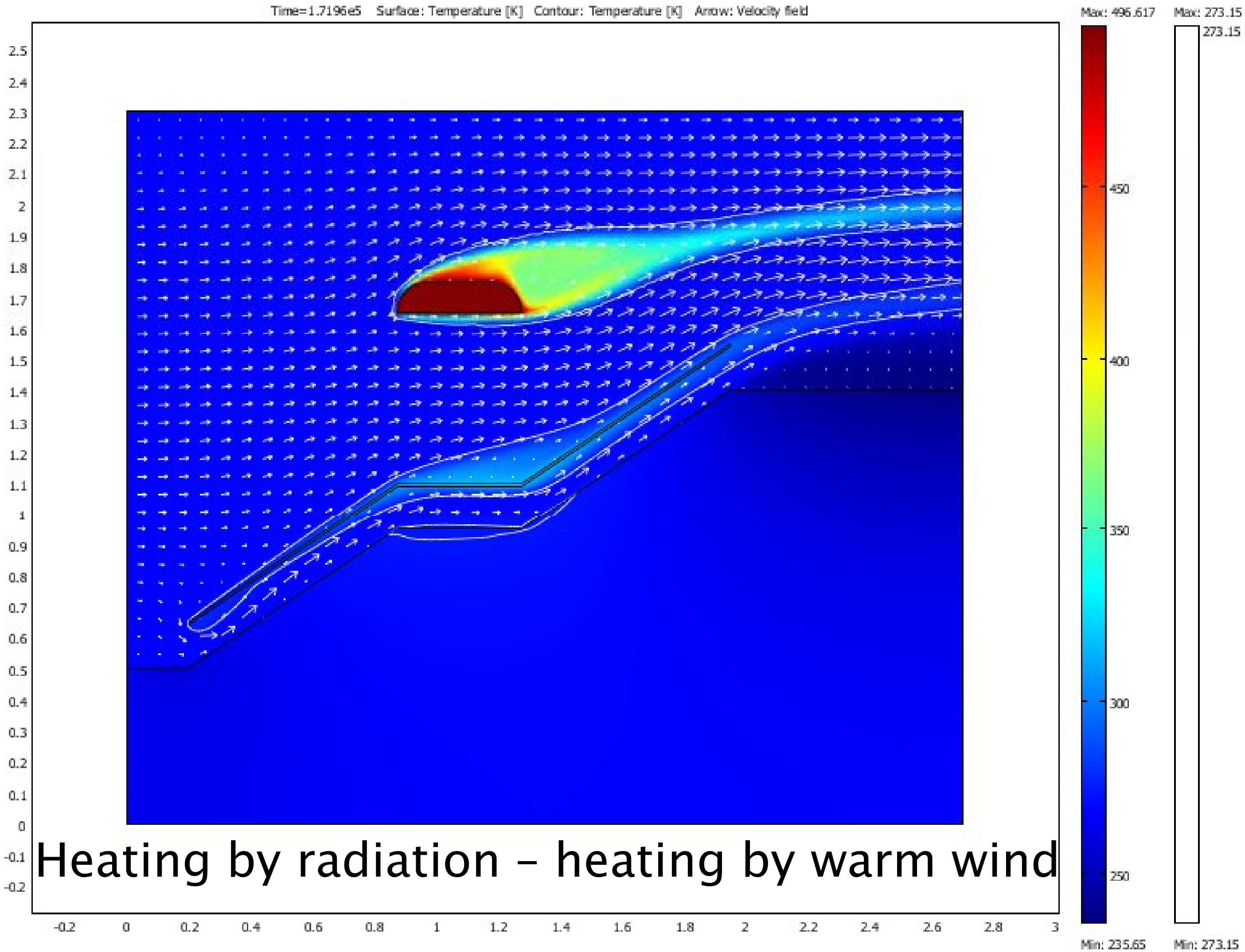
Long term calculation: no awning



t = 48h

Heating by radiation – heating by warm wind

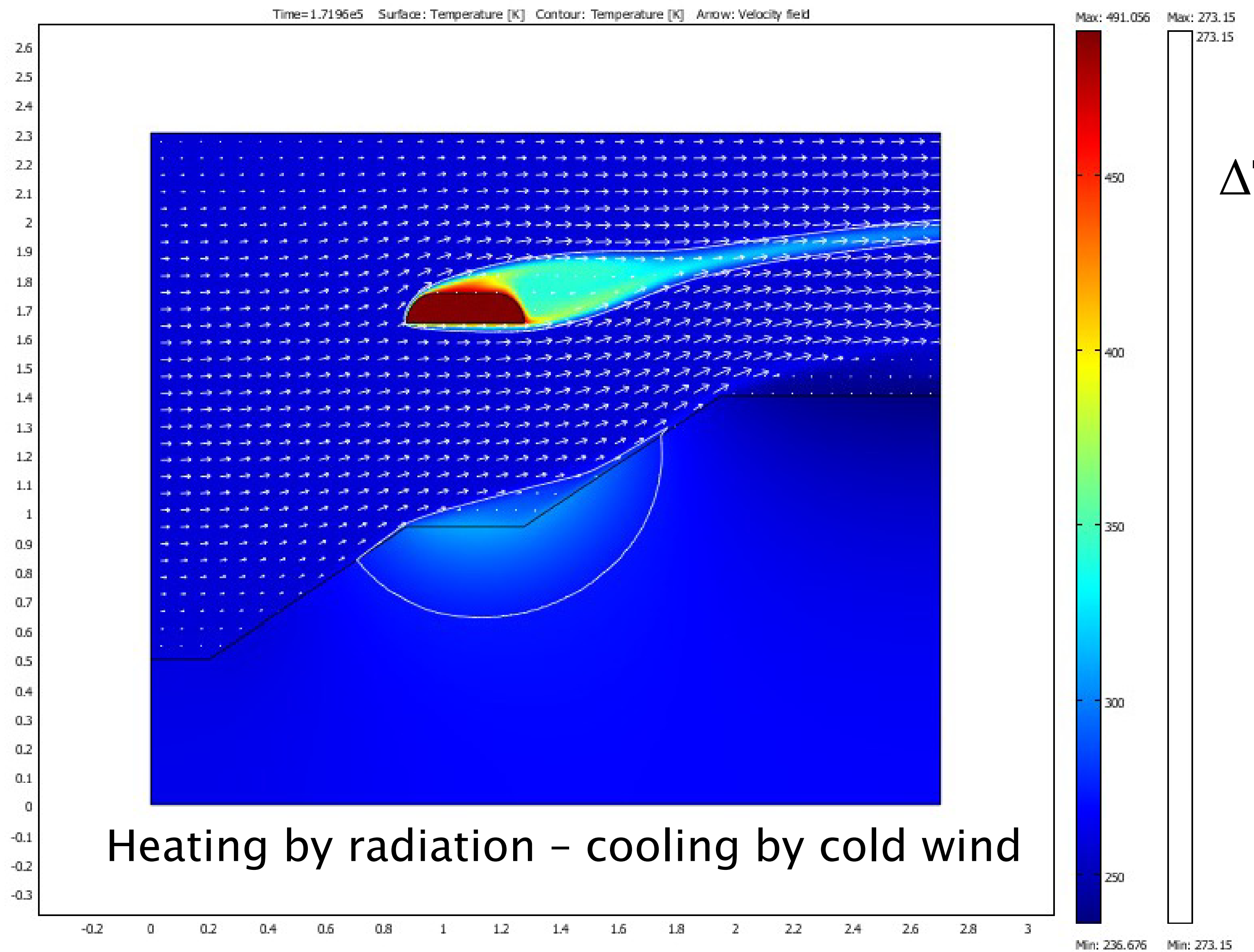
Long term calculation: with awning



t = 48h

Heating by radiation – heating by warm wind

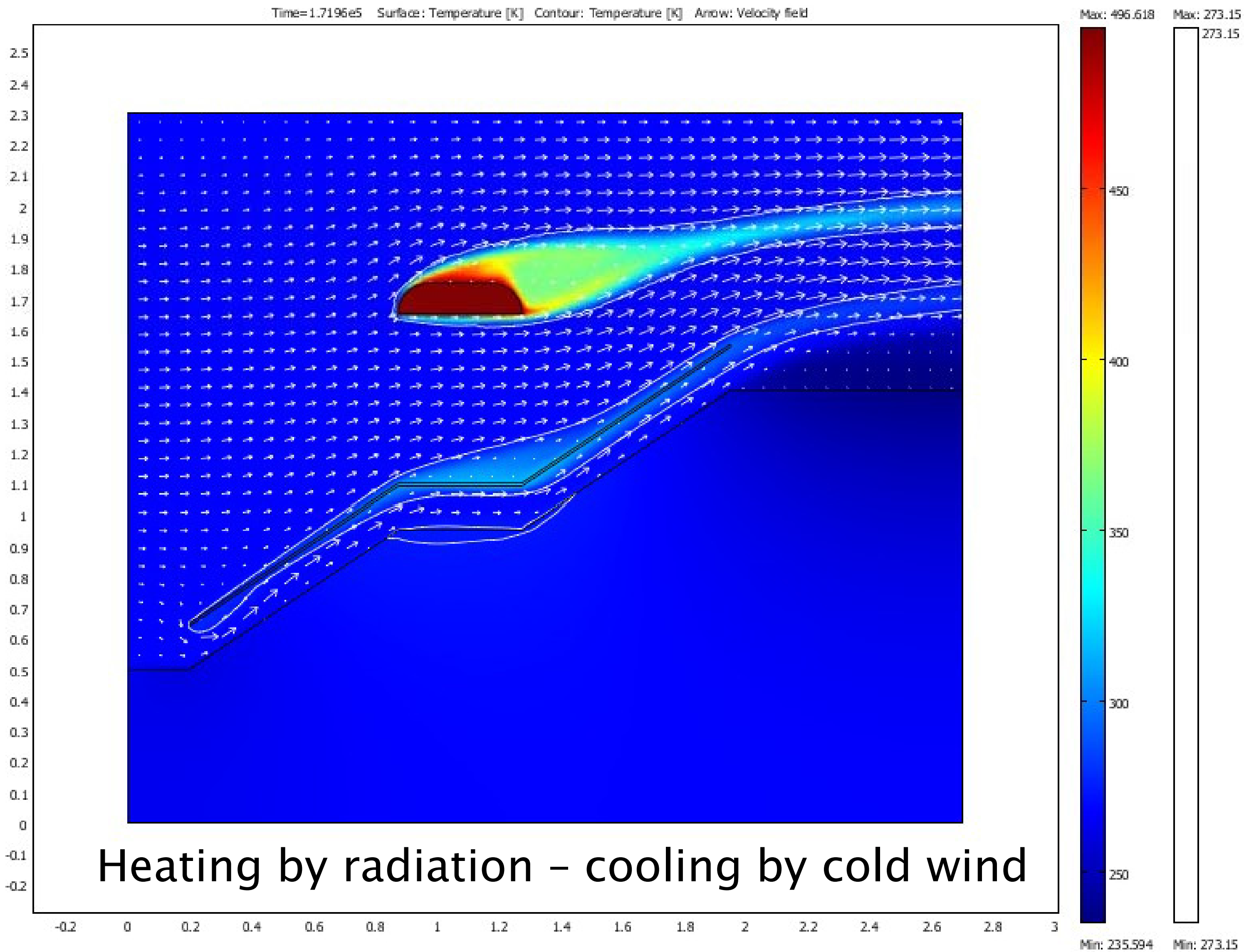
Long term calculation – no awning



$\Delta T = -10K$

Heating by radiation – cooling by cold wind

Long term calculation – with awning



t = 48h

Results and conclusions

- Awnings along embankments have a strong protection effect for the permafrost, keeping round temperatures low.

- For the slow wind velocities used in our calculations and laminar flow, there is very little influence of changing air temperature on the depth of the frost boundary.

- However this may may change when higher wind velocities and turbulent flow occur. – till now we did not succeed to calculate these cases because of unresolved convergence problems!