Modeling coupled heat and moisture transfer in soil
Use flexPde for simulation

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Abstract

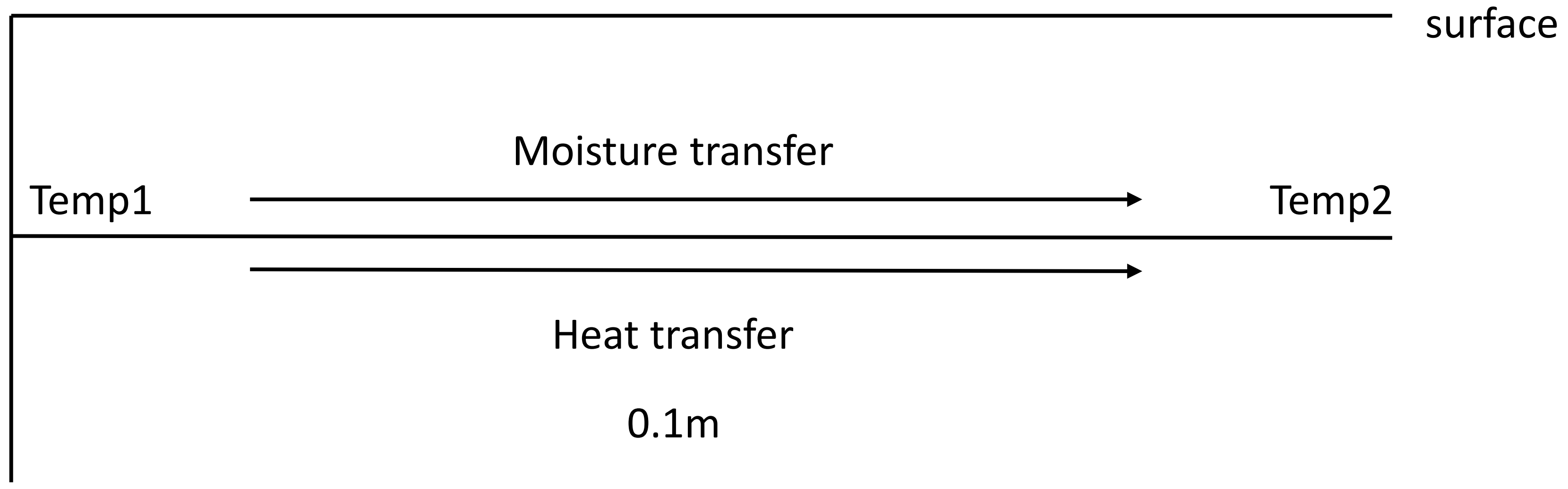
- Ground-heat transfer is tightly coupled with soil-moisture transfer. The coupling is threefold: heat is transferred by thermal conduction and by moisture transfer; the thermal properties of soil are strong functions of the moisture content; and moisture phase change includes latent heat effects and changes in thermal and hydraulic properties.

Materials and methods

- The heat and mass transfer equations developed in this work follow an approach based on physical models of the processes that occur in the unsaturated soil. We choose a horizon in the underground and set different temperature of each end, and simulated the temperature, conductivity and other characteristics along this line.

Description of the model

Basic model



Moisture transfer equation

- Moisture transfer is evaluated by considering two mechanisms for water migration: liquid movement under potential (ψ) gradients (Darcy's law), diffusion of vapor in the air contained in the pores under concentration (C_v) gradients (Fick's law)

Water movement

- This water movement influences the volumetric water content (or wetness), q (m3 w/m3), of a soil region. Water content (q) and vapor concentration (C_v) can be related to potential (ψ) and temperature (T) for specific soils. So application of the continuity principle on the water flux, F_w (kg/m2s), from these mechanisms and grouping of the resulting terms in capacity and diffusion coefficients yield an equation of the form:
- $\rho_w \frac{\partial \theta}{\partial t}$=$C_{Tw} \frac{\partial T}{\partial t}$+$C_{\psi w} \frac{\partial \psi}{\partial t}$=-$\nabla.F_w$=$\nabla.[D_{\psi w}\nabla\psi + D_{Tw}\nabla T]$

Vapor movement

- Another potentially important quantity for coupling soil models is the vapor content of the air contained in the pores. Since the vapor and liquid phases of water in the pores should be in equilibrium, the relative humidity (RH) of this pore air is:
- **RH=**$\boldsymbol{\frac{P_v}{P_{vs}}}$**=**$\boldsymbol{\frac{C_v}{C_{vs}}}$**= exp (**$\boldsymbol{\frac{\psi}{\mathrm{R}T}}$)
- $C_{Tv}\,\frac{\partial T}{\partial t}+C_{\psi v}\,\frac{\partial \psi}{\partial t}=\nabla.[D_{\psi v}\nabla\psi + D_{Tv}\nabla T]$

Heat transfer equation

- Analysis of soil physics generally considers only thermal energy.
- $C_{T\psi}\frac{\partial\psi}{\partial t}+C_{TT}\frac{\partial T}{\partial t}=\frac{\partial}{\partial z}\left(K_{T\psi}\frac{\partial\psi}{\partial z}\right)+\frac{\partial}{\partial z}\left(K_{TT}\frac{\partial T}{\partial z}\right)$

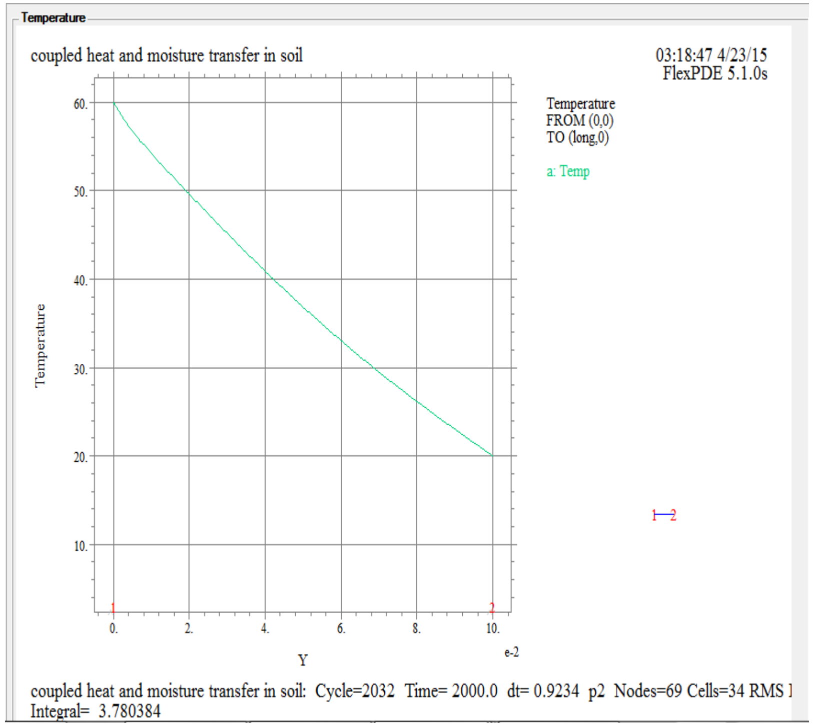
Governing equations

- $C_{\psi\psi}\frac{\partial\psi}{\partial t} + C_{\psi T}\frac{\partial T}{\partial t} = \nabla.[D_{\psi m}\nabla\psi + D_{Tm}\nabla T]$
- $C_{T\psi}\frac{\partial\psi}{\partial t} + C_{TT}\frac{\partial T}{\partial t} = \frac{\partial}{\partial z}\left(K_{T\psi}\frac{\partial\psi}{\partial z}\right) + \frac{\partial}{\partial z}\left(K_{TT}\frac{\partial T}{\partial z}\right)$

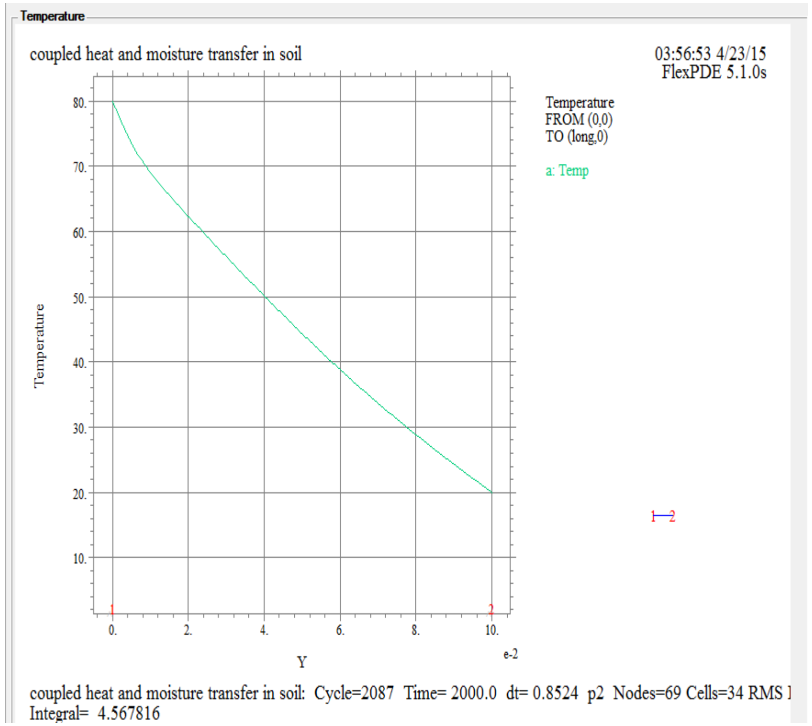
Description of the experiment

- Measured with different parameter
- The initial condition is that the matric potential is -0.28, the temperature of the left end is 60 degree and the right end is 20 degree. The length of the horizon is 0.1m, the porosity is 0.4. Measured the first 2000 seconds and change the temperature of the left end to 80 degree and repeat the works above, the results is in the follows:

Temperature distribution on the horizon

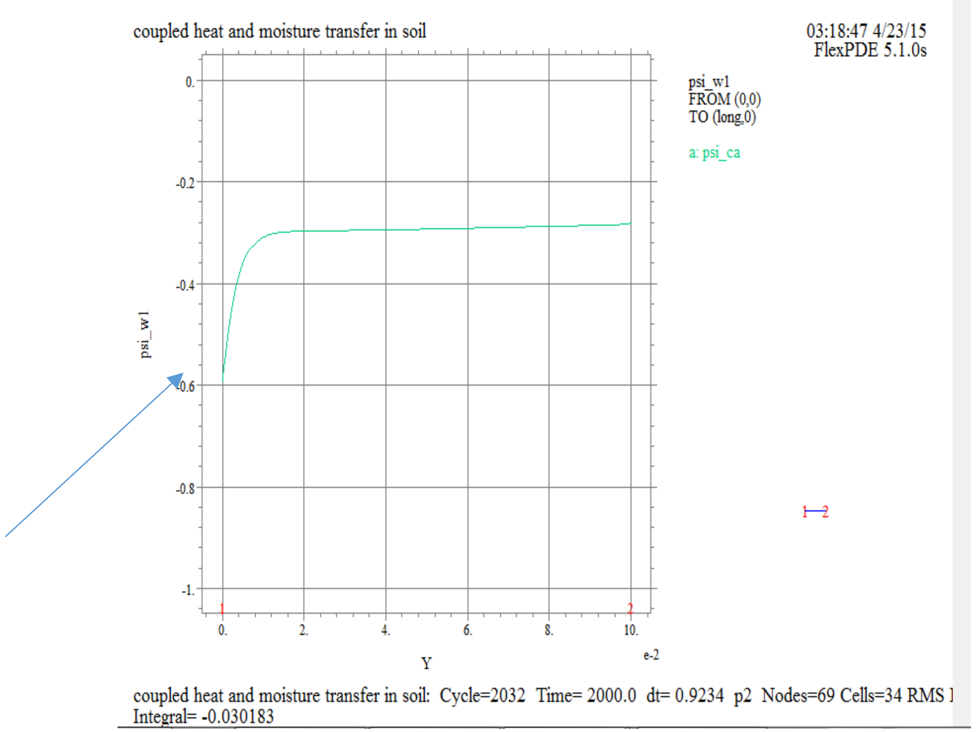


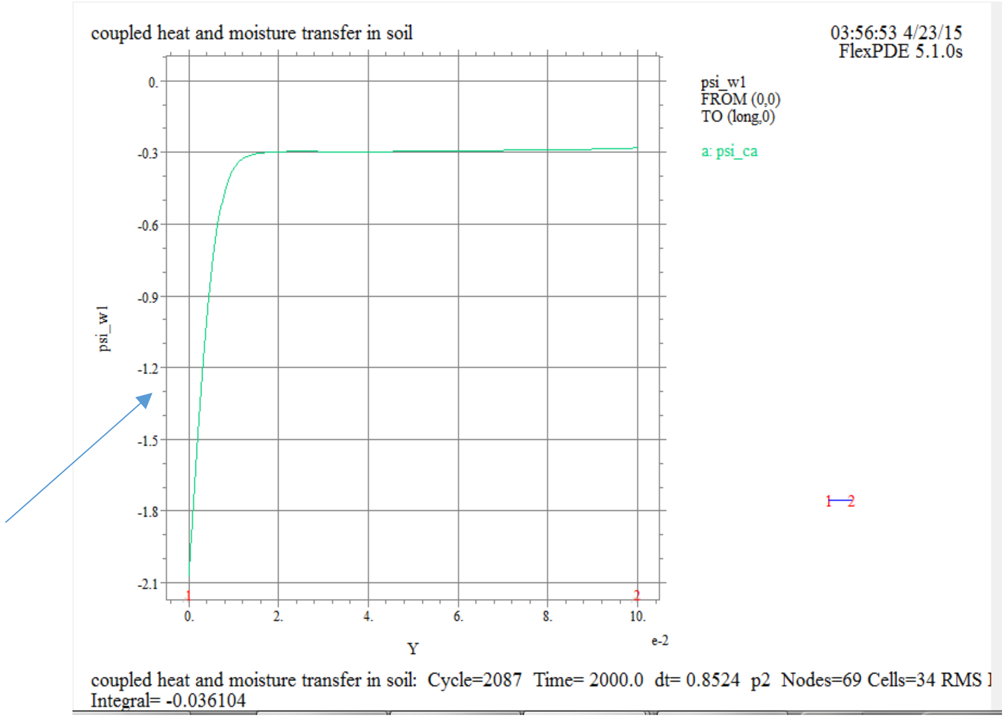
60 degree



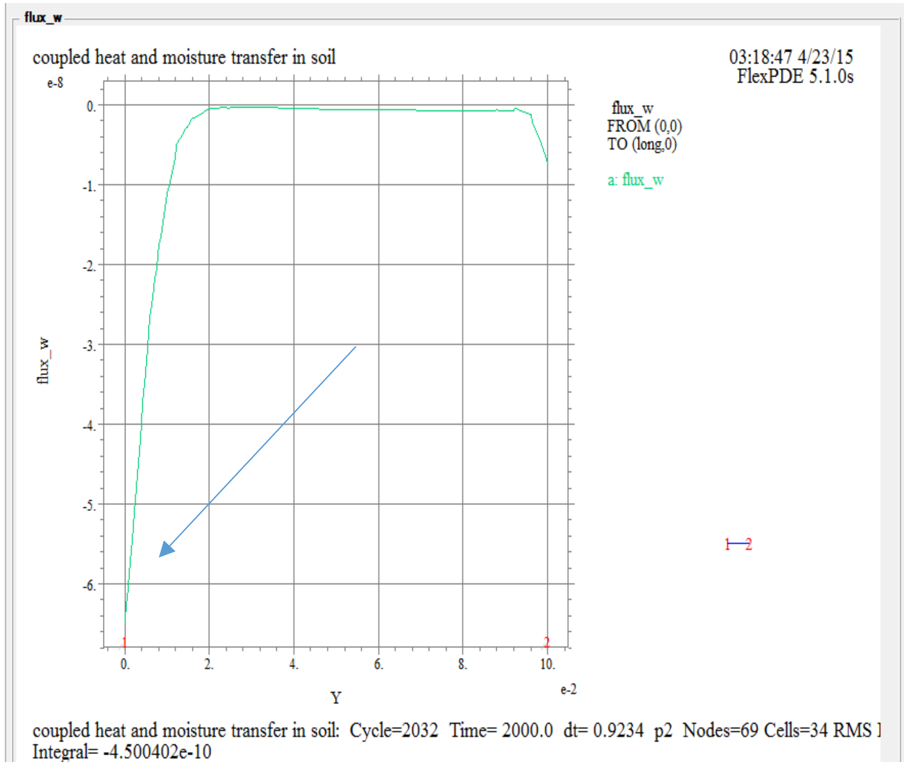
80 degree

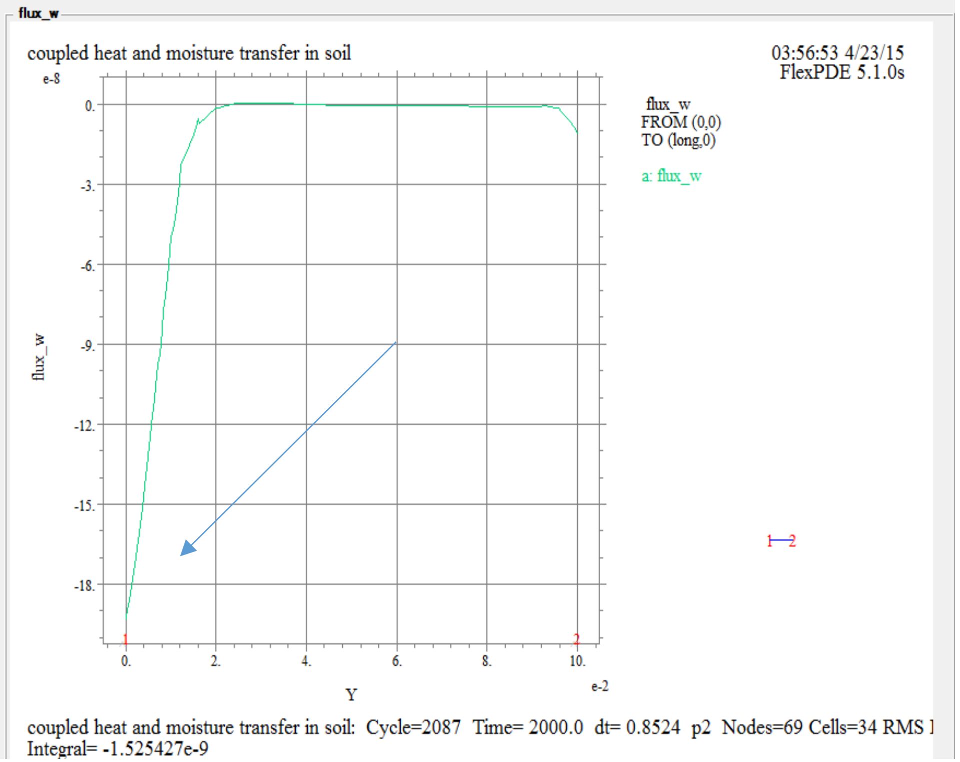
capillary pressure distribution of the horizon



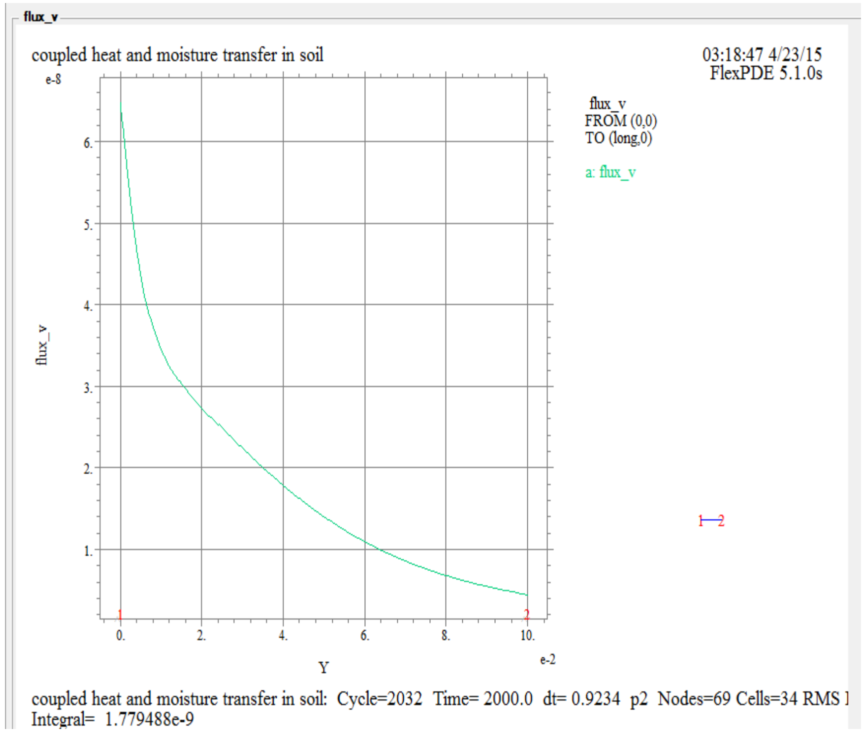


Water flux


flux_w
coupled heat and moisture transfer in soil
03:18:47 4/23/15
FlexPDE 5.1.0s
e-8
0.
-1.
-2.
-3.
-4.
-5.
-6.
flux_w
0.
2.
4.
6.
8.
10.
e-2
Y
flux_w
FROM (0,0)
TO (long,0)
a: flux_w
coupled heat and moisture transfer in soil: Cycle=2032 Time= 2000.0 dt= 0.9234 p2 Nodes=69 Cells=34 RMS I
Integral= -4.500402e-10


flux_w
coupled heat and moisture transfer in soil
03:56:53 4/23/15
FlexPDE 5.1.0s
e-8
0.
-3.
-6.
-9.
-12.
-15.
-18.
flux_w
0.
2.
4.
6.
8.
10.
e-2
Y
flux_w
FROM (0,0)
TO (long,0)
a: flux_w
coupled heat and moisture transfer in soil: Cycle=2087 Time= 2000.0 dt= 0.8524 p2 Nodes=69 Cells=34 RMS I
Integral= -1.525427e-9

Vapor flux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coupled heat and moisture transfer in soil
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FlexPDE 5.1.0s
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flux_v
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Y
flux_v
FROM (0,0)
TO (long,0)
a: flux_v
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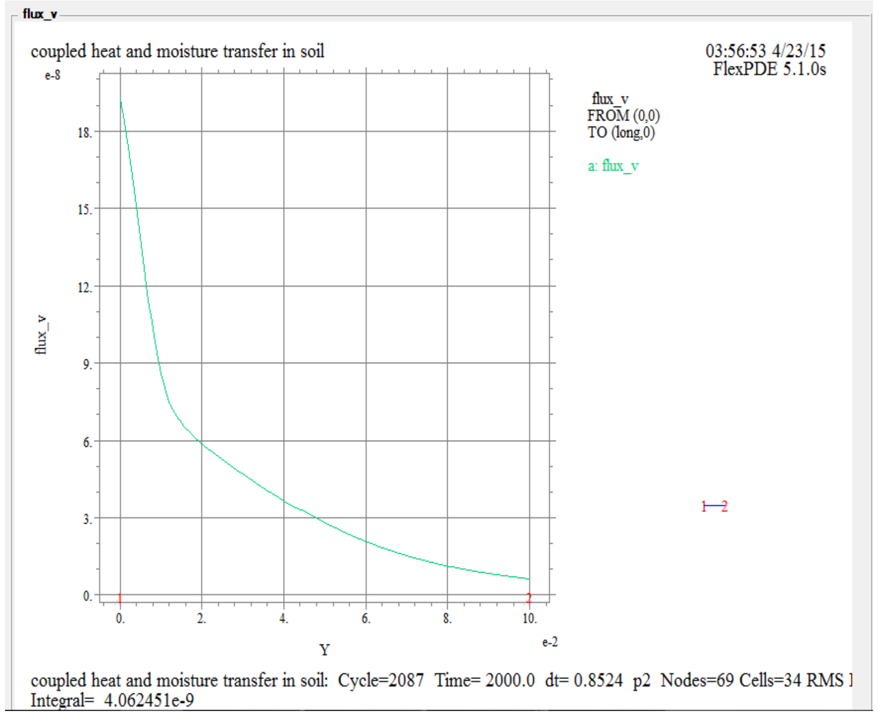
Integral= 1.779488e-9


flux_v
coupled heat and moisture transfer in soil
03:56:53 4/23/15
FlexPDE 5.1.0s
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flux_v
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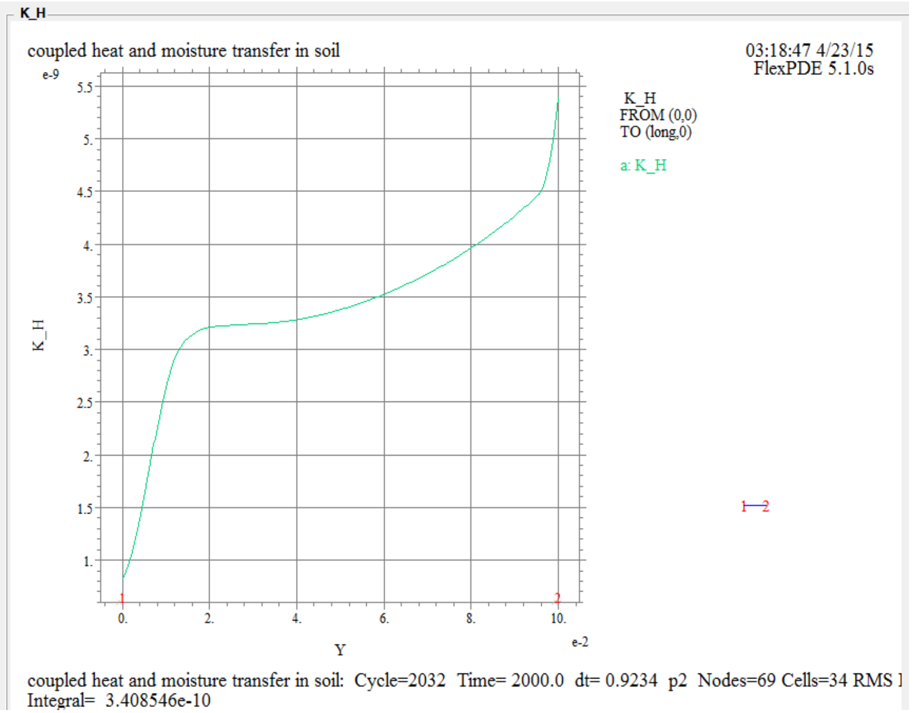
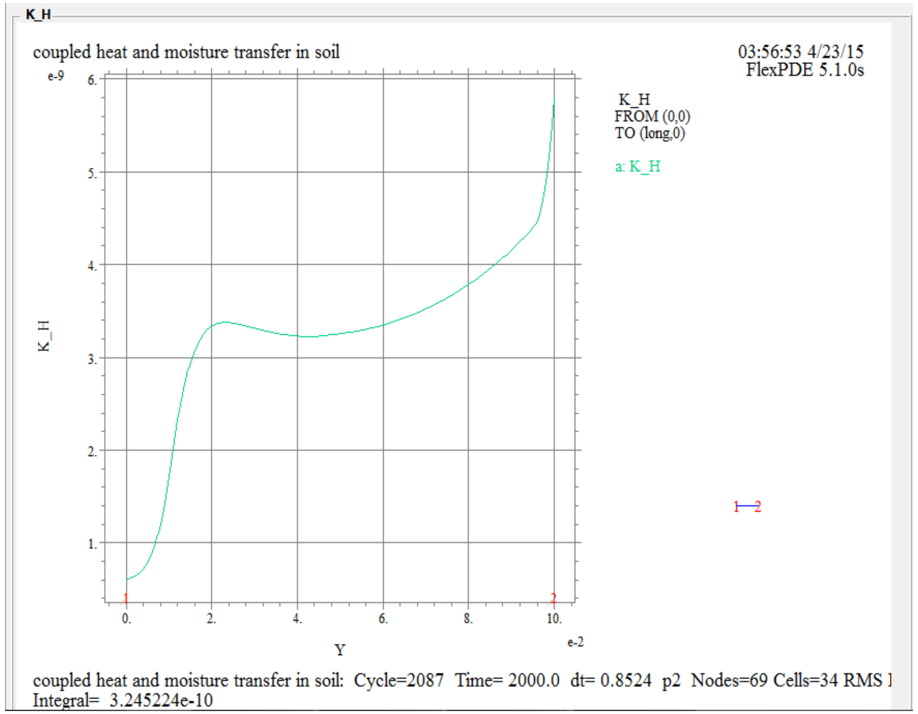
e-2
Y
flux_v
FROM (0,0)
TO (long,0)
a: flux_v
coupled heat and moisture transfer in soil: Cycle=2087 Time= 2000.0 dt= 0.8524 p2 Nodes=69 Cells=34 RMS
Integral= 4.062451e-9

hydraulic conductivity distribution





Conclusion

- In this paper, a coupled water and heat transport model is developed to represent physical processes in unsaturated soil. Different parameters are concerned with this model. Therefore, a sensitivity analysis would help identifying the main processes responsible for the observed discrepancies. We have demonstrated the importance of the different temperature to the moisture transfer and the change of capillary potential. The bigger difference of temperature between the two ends, the moisture transfer will be more active.

- Question?