Evaporation and Soil Salinization

International Research Training Group nupus

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Motivation

- Focus: model atmospheric processes and evaporative salinization
- State-of-the-art: coupled REV-scale model concept for evaporative
- Goal: Determine the limits of the model and improve the predictability

Figure: Irrigated agricultural lands

Figure: Salinized Abandoned land

Model concept

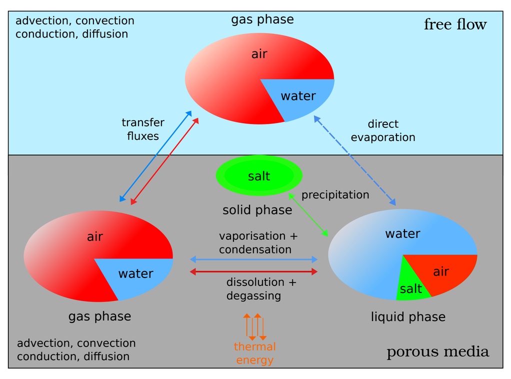


Figure: Overview of the model concept

- Non-isothermal porous-medium flow (salt transport)
- Non-isothermal laminar (Stokes) free-flow
- Implementation within the modeling framework of DuMu^x

Porous-media

For each component a mass balance equation is solved:

$$\sum_{\alpha\in\{l,g\}} \frac{\partial(\phi \varrho_{mol,\alpha} S_\alpha x_\alpha^\kappa)}{\partial t} - \sum_{\alpha\in\{l,g\}} \nabla \cdot \left\{ \frac{k_{r\alpha}}{\mu_\alpha} \varrho_{mol,\alpha} x_\alpha^\kappa \mathbf{K} (\nabla p_\alpha - \varrho_\alpha \mathbf{g}) \right\}$$
$$- \sum_{\alpha\in\{l,g\}} \nabla \cdot (D_{pm,\alpha}^\kappa \varrho_{mol,\alpha} \nabla x_\alpha^\kappa) - \sum_{\alpha\in\{l,g\}} q_\alpha^\kappa = 0 \qquad \forall\, \kappa \in \{w,a,s\}$$

$$q_\alpha^\kappa = \begin{cases} \frac{\partial(\phi \varrho_{mol,l} S_l (x_l^s - x_{l,max}^s))}{\partial t} & \text{for } \kappa = s,\ \alpha = l \\ 0 & \text{else} \end{cases}$$

One energy balance equation (Local thermal equilibrium):

$$\sum_{\alpha\in\{l,g\}} \frac{\partial(\phi \varrho_\alpha u_\alpha S_\alpha)}{\partial t} + \frac{\partial(\phi_S^s \varrho_S^s c_S^s T)}{\partial t} + (1-\phi_0)\frac{\partial(\varrho_S c_S T)}{\partial t}$$
$$+ \sum_{\alpha\in\{l,g\}} \nabla \cdot (\varrho_\alpha h_\alpha \mathbf{v}_\alpha) - \nabla \cdot (\lambda_{\mathrm{pm}} \nabla T) - q_T = 0$$

Conservation of the precipitated salt and porosity and permeability change [2] :

$$\frac{\partial(\phi_S^s \varrho_{mol,S}^s)}{\partial t} + q_l^s = 0$$

$$\phi = \phi_0 - \phi_S^s \qquad \frac{K}{K_0} = \left(\frac{\phi}{\phi_0}\right)^3 \left(\frac{1-\phi_0}{1-\phi}\right)^2$$

Free-flow

Component mass balance:

$$\frac{\partial(\varrho_{mol,g} x_g^\kappa)}{\partial t} + \nabla \cdot (\varrho_{mol,g} x_g^\kappa \mathbf{v}_g) - \nabla \cdot (D_g^\kappa \varrho_{mol,g} \nabla x_g^\kappa) - q_g^\kappa = 0 \qquad \forall\, \kappa \in \{w,a\}$$

Phase mass balance:

$$\frac{\partial \varrho_g}{\partial t} + \nabla \cdot (\varrho_g \mathbf{v}_g) - q_g = 0$$

Stokes equation for momentum balance [1]:

$$\frac{\partial(\varrho_g \mathbf{v}_g)}{\partial t} + \nabla \cdot [p_g \mathbf{I} - \mu_g (\nabla \mathbf{v}_g + \nabla \mathbf{v}_g^T)] - \varrho_g \mathbf{g} = 0$$

Energy balance:

$$\frac{\partial(\varrho_g u_g)}{\partial t} + \nabla \cdot (\varrho_g h_g \mathbf{v}_g) - \nabla \cdot (\lambda_g \nabla T) - q_T = 0$$

DFG Support of the German Research Foundation is gratefully acknowledged.

Interface

- Normal and tangential traction contribution [1]:

$$\mathbf{n} \cdot [(p_g \mathbf{I} - \tau)\mathbf{n}]^{ff} = [p_g]^{pm} \qquad \left[\left(\mathbf{v}_g + \frac{\sqrt{k_i}}{\alpha_{\mathrm{BJ}}\, \mu_g} \tau \mathbf{n} \right) \cdot \mathbf{t} \right]^{ff} = 0$$

- Continuity of fluxes:

$$[\mathbf{q} \cdot \mathbf{n}]^{ff} = [\mathbf{q} \cdot \mathbf{n}]^{pm}$$

- Local thermal equilibrium:

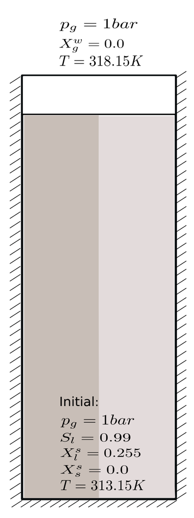
$$[T]^{ff} = [T]^{pm}$$

- Local chemical equilibrium:

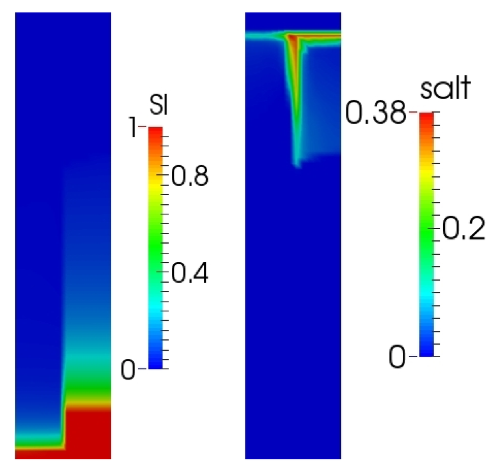
$$[x_g^k]^{ff} = [x_g^k]^{pm} \qquad \forall\, \kappa \in \{w,a\}$$

Results

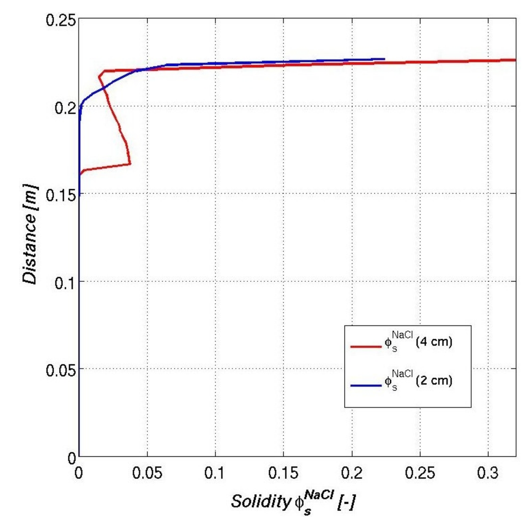
Decoupled model:



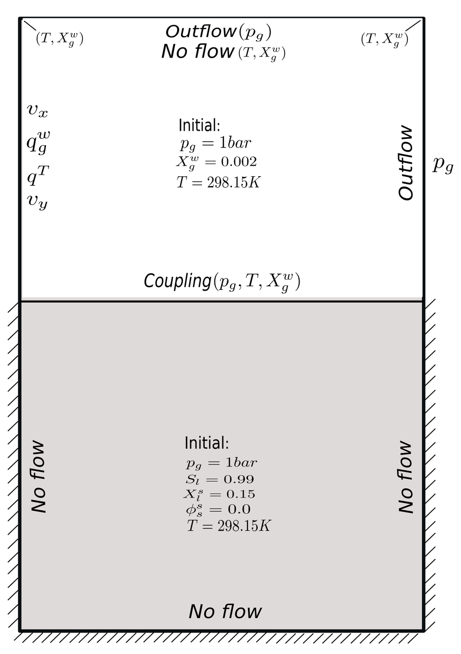
Problem



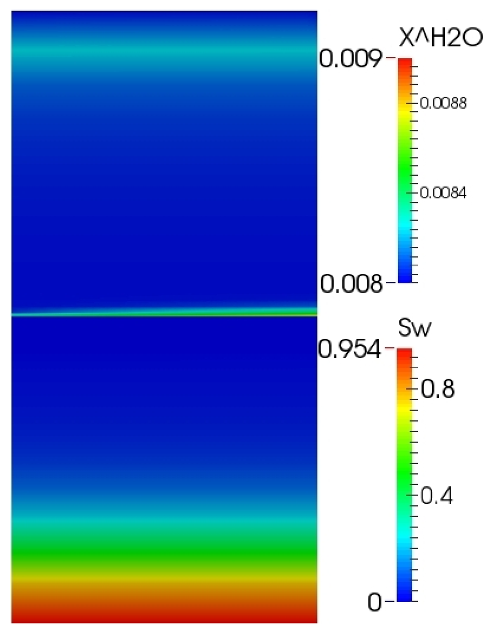
Salinization



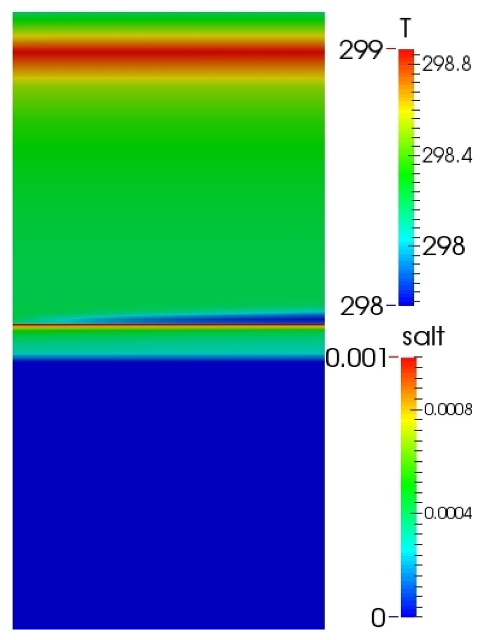
Coupled model:



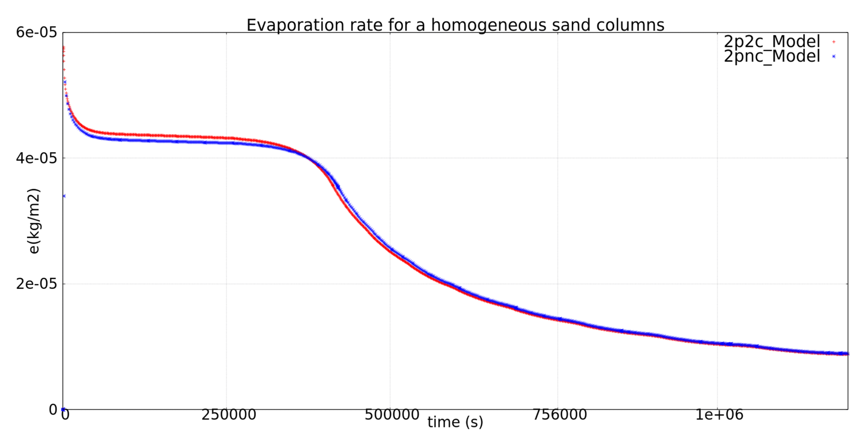
Problem



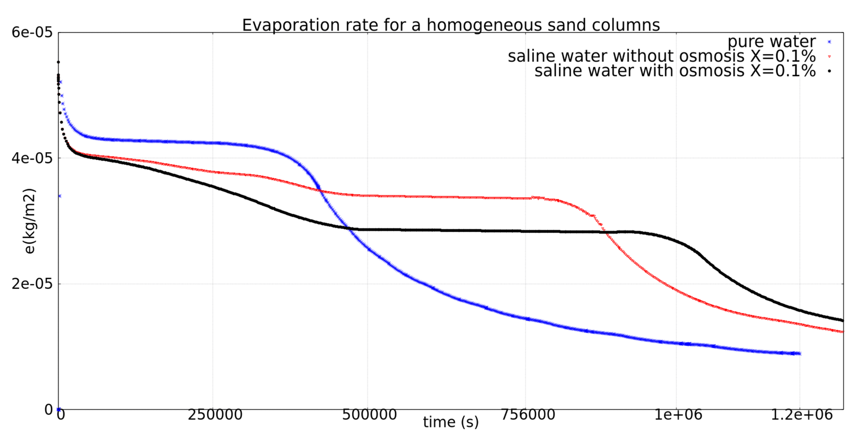
Drying



Salinization



Pure Water



Saline Water

Outlook

Ongoing work:

- Model concept for osmosis
- Test alternative models to describe change in porosity and permeability
- Transport for dissolved salt species (e.g. Na^+ and Cl^-) and precipitation

Future work:

- Validation against experimental data
- Effects of surface albedo and radiation

Literature

[1] K. Mosthaf, K. Baber, B. Flemisch, R. Helmig, A. Leijnse, I. Rybak, and B. Wohlmuth. A coupling concept for two-phase compositional porous-medium and single-phase compositional free flow. *Water Resources Research*, 47, 2011.

[2] M. Zeidouni, M. Pooladi-Darvish and D. Keith. Analytical solution to evaluate salt precipitation during CO2 injection in saline aquifers. *International Journal of Greenhouse Gas Control*, 3:600-611 (2009).