Drying of saline porous-media in contact with the free-flow

International Research Training Group nupus

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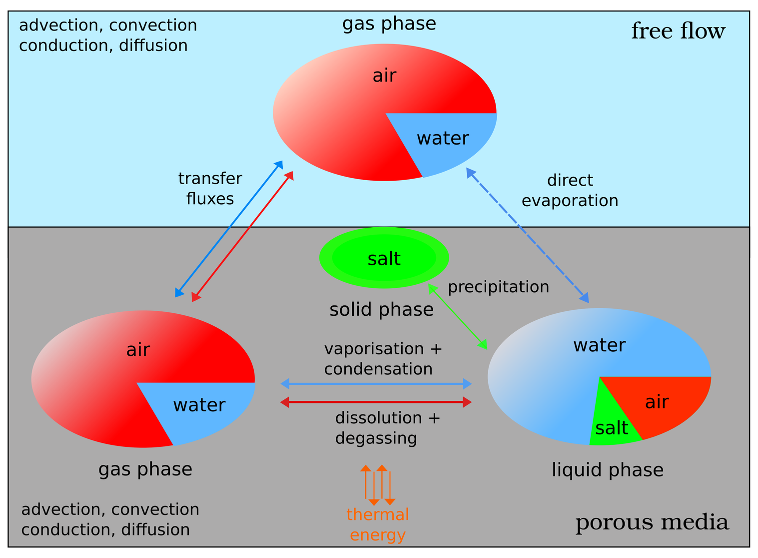
Motivation

- Focus: Modeling atmospheric processes for evaporative salinization
- State-of-the-art: Free-flow porous-media coupled REV-scale model concept

Figure: Irrigated agricultural lands

Figure: Salinized abandoned land

Model concept



- Non-isothermal porous-medium flow and transport (phases: solid, liquid and gas)
- Non-isothermal Stokes free-flow (gas phase)
- Implementation within the modeling framework of DuMu^x

Porous-media

For each component conservation equation is solved:

$$\sum_{\alpha\in\{l,g\}} \frac{\partial(\phi \varrho_{mol,\alpha} S_\alpha x_\alpha^\kappa)}{\partial t} - \sum_{\alpha\in\{l,g\}} \nabla\cdot\left\{\frac{k_{r\alpha}}{\mu_\alpha}\varrho_{mol,\alpha} x_\alpha^\kappa \mathbf{K}(\nabla p_\alpha - \varrho_\alpha \mathbf{g})\right\}$$

$$- \sum_{\alpha\in\{l,g\}} \nabla\cdot(D^\kappa_{pm,\alpha}\varrho_{mol,\alpha}\nabla x^\kappa_\alpha) - \sum_{\alpha\in\{l,g\}} = q^\kappa \;\forall \kappa \in \{w,a,s\}$$

$$q^\kappa = \begin{cases} k_p \phi \varrho_{mol,l} S_l (x_l^s - x^s_{l,max}) & \forall \kappa = s \\ 0 & \text{else} \end{cases} \qquad q^\kappa = k_p A_p(S_w) \mid 1-\Omega_n^\theta \mid^\eta$$

One energy balance equation (Local thermal equilibrium)

Conservation of the precipitated salt and porosity and permeability change [1] :

$$\frac{\partial(\phi_S^s \varrho^s_{mol,S})}{\partial t} = q^s \quad \left(\phi = \phi_0 - \phi_S^s,\; \frac{K}{K_0} = \left(\frac{\phi}{\phi_0}\right)^3 \left(\frac{1-\phi_0}{1-\phi}\right)^2,\; \frac{p_c}{p_{c0}} = \sqrt{\frac{K}{K_0}}\right)$$

Free-flow

Stokes equation for momentum balance [1]:

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

Interface

- Normal and tangential traction contribution [1]:

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

- Continuity of fluxes:

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

- Local thermal equilibrium:

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

- Local chemical equilibrium:

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

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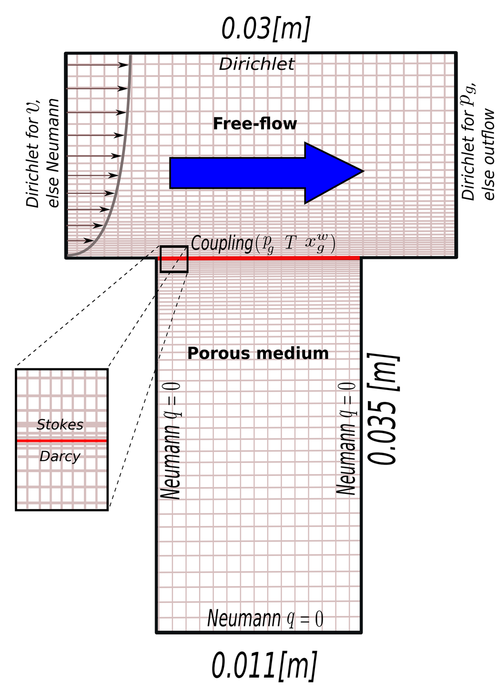
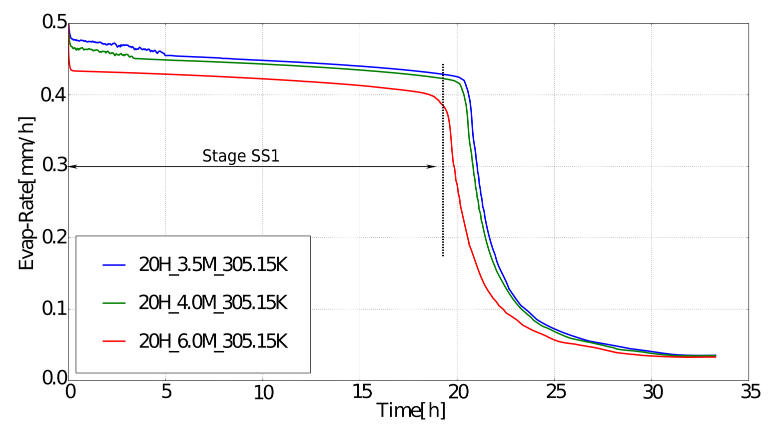
Numerical experiments

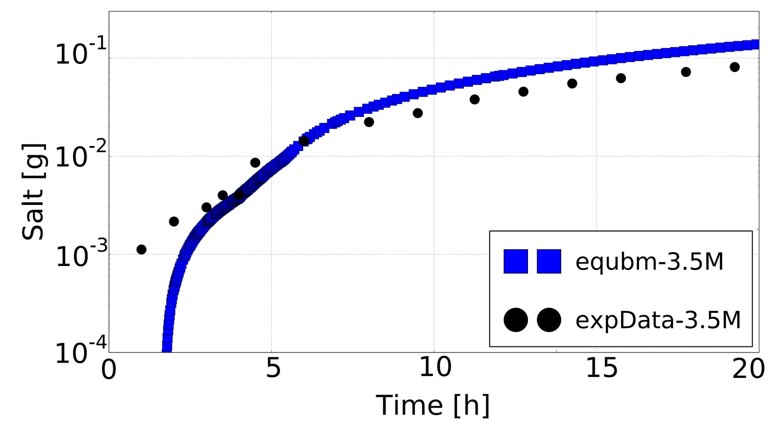
Validation (Homogeneous case) [1]:



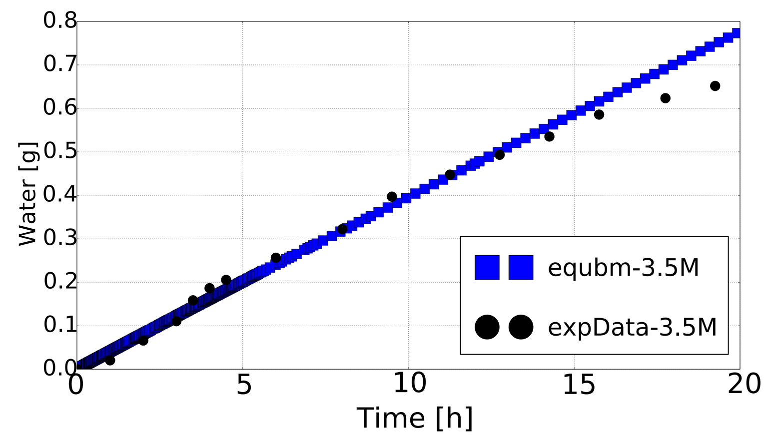
Numerical setup



Drying rate

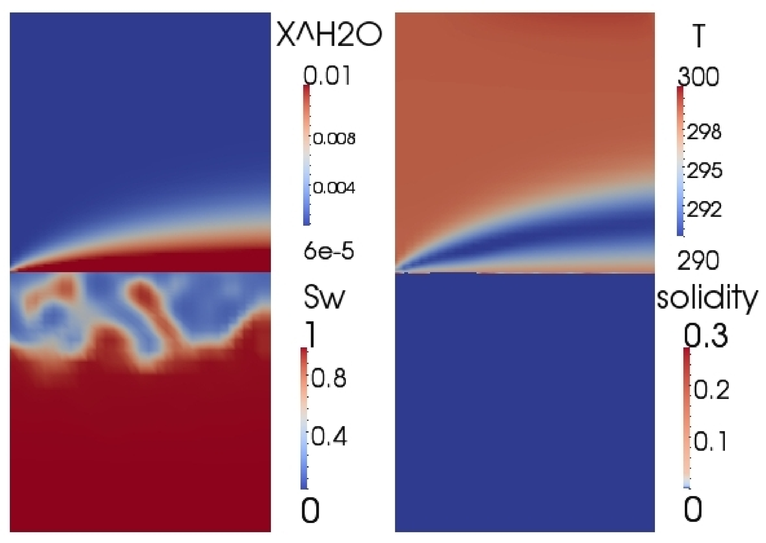


Salt precipitation

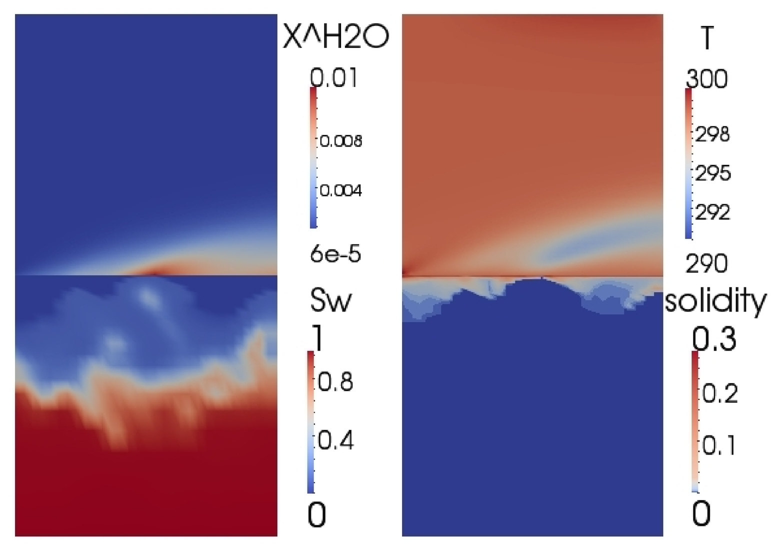


Water loss

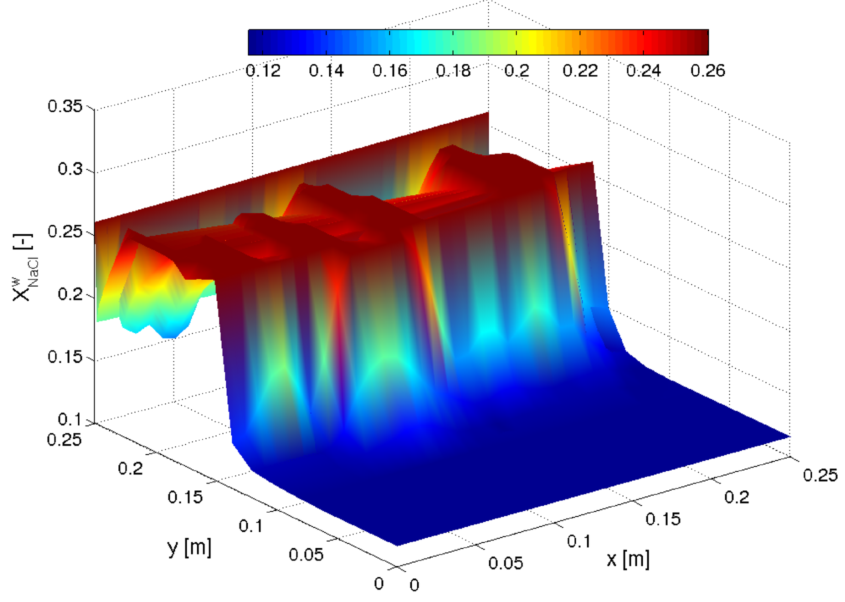
Heterogeneous case:



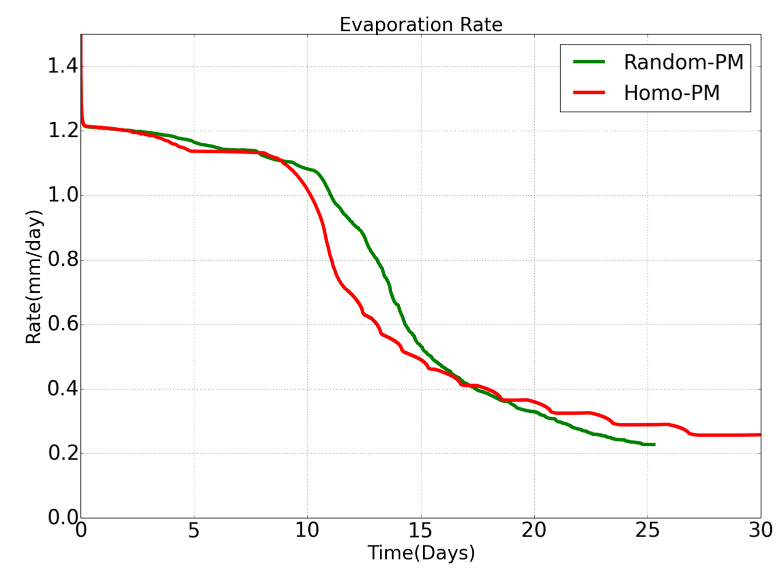
Drying after 5 days



Drying after 20 Days



Salinity after 15 Days



Evaporation rate

Additional work

- Reactive precipitation approach for mixed salts (e.g. Na^+, Cl^- and I^-)
- Formation of hydrates
- Consequence of variation in porous-media and free-flow properties
- Influence of surface saturation, flow velocity and radiation on salinization

Literature

[1] V. Jambhekar, N. Schröder, R. Helmig, N. Shokri.
Free-Flow-Porous-Media Coupling for Evaporation-Driven Transport and Precipitation of Salt in Soil, *Transport in porous media* (June, 2015).

[2] M. Rad, M. Dyonisius and N. Shokri.
Nonlinear Effects of Dissolved NaCl Concentrations on Water Evaporation From Porous Media. *General Soil Physics: II*, 117-38 (October 17, 2011).

[3] 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).

DuMu^x The simulations are preformed using DuMu^x.