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Preferential upward flow in soils: A 3D comparison of modeled and ERT-derived data from a salt tracer experiment under evaporation conditions

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Upward water flow induced by evaporation or groundwater level rise can cause soil salinization and transport of contaminants to the soil surface. A limitation for the prediction of upward transport using numerical models might be an incomplete process description of this transport within the models, especially under consideration of heterogeneous structures. In contrast to infiltration conditions, few experimental datasets of transport under upward flow conditions that can be used to test existing models exist. Therefore, we studied upward transport at the pedon-scale in a laboratory soil with a defined heterogeneity and controlled upper and lower boundary conditions. A second aim was the assessment of the potential of Electrical Resistivity Tomography (ERT) to image and characterize upward transport and to use these temporal and spatial highly resolved experimental data to validate current model approaches.

Using stochastic simulation, we designed a laboratory soil composed of three materials, which represent a correlated indicator field with horizontal and vertical heterogeneity. A salt tracer experiment was performed over 40 days with steady-state upward flow. Constant evaporation conditions were established using an air-conditioning chamber. A constant water level with the tracer solution was imposed at the lower boundary. ERT results showed solute mass flowing upwards along a few preferential pathways and accumulating heterogeneously at the soil surface. Three-dimensional numerical simulations based on Richards' and the convection-dispersion equation satisfactorily described solute transport in the lower part of the soil, whereas closer to the surface larger discrepancies occurred. On the experimental side, uncertainties in the petrophysical relationship and spatial smoothing inherent to the applied Occam-type smoothness constrained geophysical inversion contributed to observed deviations between ERT and model results. Comparing measured with modeled (using the geophysical forward model on the modeled solute concentration) ERT measurements, however, indicated that part of the discrepancies are caused on the modeling side. Here we identified three main contributors: i) an imperfect parameterization of the hydraulic properties of the individual materials, ii) neglect of water vapor fluxes iii) insufficient description of the upper boundary condition. In the latter case, we observed an actual evaporation rate (Ea) that was locally higher than a determined reference evaporation rate (Eref). This can be explained by thermal energy fluxes within the upper part of the soil from hotter dry to colder wet regions and changed air conditions in the chamber due to a lower global evaporation rate. To account for this in the widely-used "Eref/Ea" approach, Eref needs to be spatially variable at the scale of soil heterogeneity.