Geophysical Research Abstracts
Vol. 21, EGU2019-14955, 2019
EGU General Assembly 2019

Conceptual inconsistencies of the convection-dispersion equation used for modeling solute transport in variably-saturated soils

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Solute transport in porous media is typically simulated with the convection dispersion equation (CDE). Hydrodynamic dispersion is usually assumed to behave similarly as molecular diffusion and is therefore formulated using Fick's law. In this contribution, the application of the CDE for modeling solute transport in porous media is critically analyzed for situations in which the solute concentration changes locally while water is flowing. A local increase or decrease of concentration caused by root water uptake or evaporation (phase change) leads to concentration gradients in all spatial directions and induces diffusive as well as dispersive solute fluxes in all directions. These fluxes include a dispersive flux opposite to the direction of the water flux which is physically wrong. The aim of this study was to investigate the magnitude of the resulting error by means of numerical simulations. We simulated solute transport during steady-state evaporation from a groundwater table to a bare soil surface with the Hydrus-1D code. The solute was assumed to originate from the groundwater. The simulation lead to the correct result that the solute accumulates around the evaporation plane located close to the soil surface. However, because Fick's law is used to model the dispersive flux, both diffusive and dispersive solute fluxes were directed downward, i.e. opposed to the gradient in solute concentration. While this is physically correct for the diffusive flux, it is fundamentally wrong for the dispersive flux. We show that the erroneous dispersive flux can have the same order of magnitude as the convective solute flux. Under such conditions, application of the CDE is questionable.