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Modelling dynamic non-equilibrium water flow observed in experiments with controlled pressure head or flux boundary conditions

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Experimental observations have shown that the soil hydraulic properties estimated under static and dynamic flow conditions can differ considerably. This phenomenon is often named “dynamic non-equilibrium” or “dynamic effect” and it constitutes a very popular topic in recent years. In the case of experiments with controlled pressure head boundary conditions such as the Multistep Outflow (MSO) method, non-equilibrium effects appear as a relaxation in the cumulative outflow (resp. system-averaged water content) while the pressure head in the soil column indicates hydrostatic equilibrium. For experiments with flux boundary conditions like the Multistep Flux (MSF) method, non-equilibrium effects appear as a relaxation of the pressure head while the flux density and macroscopic water content distribution appear static.
A numerical model is proposed to quantitatively describe dynamic non-equilibrium effects during variably saturated flow. The model considers two continua at the macroscopic scale: one continuum is described by the Richards equation and the second, associated with non-equilibrium water flow, assumes a time dependent equilibration of the water content as described in the approach of Ross and Smettem (2000). In comparison to the Richards equation, our new model requires two additional parameters. The first accounts for the time-dependent equilibration of the water content in the non-equilibrium domain and the second quantifies the contribution of the two continua to the overall water flow. We fitted the new model to experimental data for the same soil column but for two different experimental types: MSO and MSF. The new model describes the observed dynamic non-equilibrium effects very well for both MSO and MSF experiments. Most importantly, the fitted values of the non-equilibrium parameters described above are very close to each other for the two different experiments indicating that the non-equilibrium parameters depend on the soil properties only and not on the applied boundary condition.