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

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1 Introduction
Dynamic non-equilibrium water flow or dynamic effects (DNE) refer to various phenomena which cannot be described by the classical theory (Richards equation). These phenomena are well-known since the 1960s and the pioneering work of Topp et al. (1969, SSSAJ). DNE occur mainly as (Hassanishadeh et al. 2002, V2j; Diamantopoulos and Durner, 2012, V2j):
1. flow-rate dependence of soil hydraulic properties (SHPs) (Topp et al., 1969, SSSAJ)
2. DNE in multiphase outflow (MSO) experiments (Schulze et al., 1999)
3. DNE in multiphase flux (MSF) experiments (Weller and Vogel, 2012, V2j)
In the first case, the SHPs differ under static and transient conditions. In the second case, DNE appear as a relaxation in the cumulative outflow while the pressure head in the soil column is at hydrostatic equilibrium. In the third case, MSF experiments, DNE effects appear as a relaxation of the pressure head while the flux density and macroscopic water content distribution appear static.

Scope
Diamantopoulos et al. (2012, WRR) presented a model for describing DNE effects in MSO experiments. In this work we present a sensitivity analysis for modelling the main DNE observations among different experimental setups.

2 Model description

- equilibrium domain
  Richards equation
  \[ \frac{\partial \psi}{\partial t} = \frac{K}{\theta_e} \left( \frac{\partial \psi}{\partial h} \right) \]
- non-equilibrium domain
  Ross and Smettem (2000, SSSAJ)
  \[ \frac{\partial \psi}{\partial t} = f(\theta_e, \theta_n) = \frac{\theta_e - \theta_n}{\tau} \]

proposed model (DNE, Diamantopoulos et al. 2012, WRR)
\[ (1 - f_n) \frac{\partial \theta_n}{\partial t} + f_n \frac{\partial \theta_n}{\partial t} = \frac{\partial}{\partial z} \left[ K \left( \frac{\partial h}{\partial z} \right) \right] - 1 \]

3 Flow rate dependence of SHPs

Fig 2a. The pressure head at the lower boundary was smoothly changed from 0 to -80 cm in 300 h. After an equilibration time of 24 h it changed from -80 cm to 0 cm again in 500 h.
• the results show that the in-situ measured water retention curves are identical for all models.

Fig 2b. The pressure head at the lower boundary was smoothly changed from 0 to -80 cm in 20 h, remained there for 60 h, and then it raised again to 0 within 20 h.
• Dual-NE predicts an apparent hysteresis in the water retention curve contrary to the prediction of the Richards equation.

4 DNE in MSO experiments

Fig 2a. Sensitivity analysis for the \( \tau \) parameter of the Dual-NE model
• Dual-NE predicts the major observation in the MSO/MSI experiments, the cumulative outflow data show a relaxation whereas the pressure head measured inside the soil column is at hydrostatic equilibrium.
• Richards equation can not describe this
• Fitting the data of MSO experiments with the Richards equation leads to potentially wrong SHPs.

5 DNE in MSF experiments

Fig 3a. Sensitivity analysis for the \( \tau \) parameter of the Dual-NE model
• Dual-NE predicts the major observation in the MSF/MSI experiments that the pressure head shows a relaxation towards a less negative value (drainage), even if apparent water content is constant.
• Richards equation can not describe this
• It predicts instantaneous equilibration between water content and pressure head.

7 Conclusions
• The Dual-NE model was able to describe the three major observations of DNE effects
  • In a future work, it is important to investigate if the Dual-NE can describe DNE effects for the same soil column with the same SHPs and the same pair of non-equilibrium parameters.

References