Comments on “Theory for Source-Responsive and Free-Surface Film Modeling of Unsaturated Flow”

The Nimmo (2010) source-responsive (SR) model has the very ambitious scope of determining the wetting front in a soil as caused by fast vertical water infiltration. This infiltration overcomes the shallow zone of the soil column and increases the water content at a certain depth from the top to a value that is higher than expected.

I agree with the comments of Germann (2010) and I believe that the Stokes principles and their applications to preferential flow have not yet been fully explored. Furthermore, innovative theories must be able to withstand very careful scrutiny. For this, Nimmo is to be commended for the presentation of this impressive work on the SR model.

The SR model uses an empirical approach based on numerous experiments and infiltration data collected in the laboratory and at different field sites. The main aspect of the SR model was based on Nimmo's numerous attempts to simulate infiltration data using the Richards equation. Following the Richards equation, Nimmo perceived that an increase in water content at a given depth in the soil is due to a prior increase in water content in immediately adjacent portions of the soil. In other words, during infiltration, the Richards approach requires a monotonically increasing water content with depth. In contrast, infiltration test data collected at depths around 1 m (and greater) show a major increase in water content, but this increase has a timing and magnitude that are not appropriately synchronized with the water content increases at all shallower depths. Thus, for this anomaly, Nimmo argued that some wetting behaviors are incompatible with the results of the Richards equation when homogenous soils are considered.

Some of the specific theoretical developments that lead to the governing flow equation for the SR model in the work of Nimmo (2010) must be improved, however, by incorporating further details.

An important aspect of the theory of unsaturated flow in heterogeneous porous media is the scale of representation of the filtration mechanisms; these allow us to write the governing equation. In the SR model, the vertical (one-dimensional) unsaturated water flow is defined in two different regions: (i) the diffusive (Darcy–Buckingham–Richards) domain D; and (ii) the source-responsive domain S, in which the water flows in films attached to the soil particle surfaces and is driven by gravity. Then, Nimmo defines some soil physical properties and sums their values in each single domain. These properties are the water content \( \vartheta \) (see Eq. [1] in Nimmo, 2010), the porosity, and the flux density (see Eq. [2] in Nimmo, 2010).

Conversely, we may suppose that the domains D and S have a different scale of representation, and thus it is necessary to convert the soil properties to the same scale before proceeding to sum the physical properties. Assuming that for the heterogeneous investigated soil there exists a representative elementary volume for the S model flow, REV_S, as well as a second elementary volume of a smaller size representative of diffusive flow, REV_D, the total soil water content at depth \( z \) and time \( t \) can be defined in the SR model as

\[
\vartheta(z,t) = \vartheta_S(z,t) + \int_{\text{REV}_S} \vartheta_D(z,t) \, dV
\]  

[1]