How modelling water transfer in stratified porous media ?

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Abstract :

The aim is to model water transfer in stratified porous media (hydrophilic and hydrophobic stratus).
We take into account the notion of **wettability** and **surface tension** to complete Darcy-Richards model.
A bifurcation analyse shows preferential flow : fingering instability, water trapping and intermittence flow.
That will allow to better understand water transfer in heterogenous soil with organic matter.

1) Introduction

Water transfer in unsaturated porous media displays phenomena that are still poorly understood such as the fingering instability of the wetting front, water trapping and intermittent flow in heterogeneous media.
Hydrophobicity is suspected to be the cause of preferential flow.

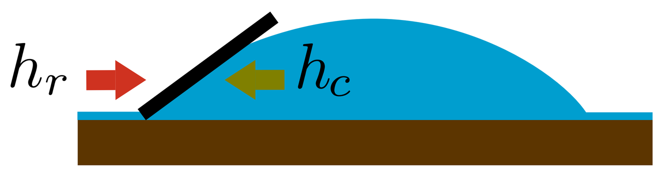
Tellam and Sililo experiment, which illustrate fingering in a stratified porous media

2) Modelling

Wettability

Wettability is the fluid capacity to be spread on/in a medium

Plan substrate



Partial wetting

Complete wetting

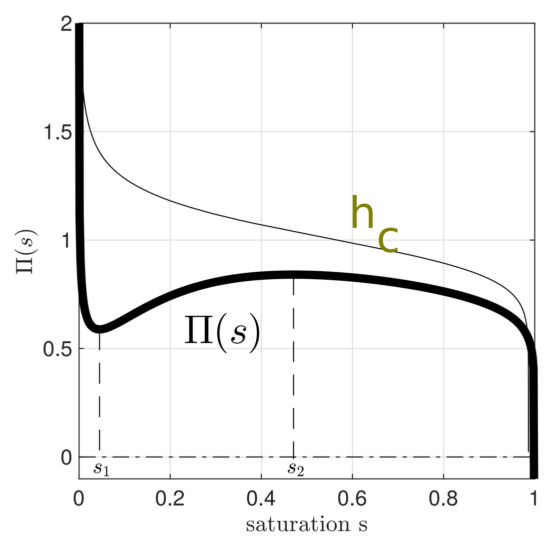
Partial wetting results from competition between h_c attractive and h_r repulsive interaction, modelled by con- and dis-jonction pressure

Porous media

Wettability modelled by effective disjonction pressure $\Pi(s)$

$$\Pi(s) = h_c(s) - h_r(s)$$

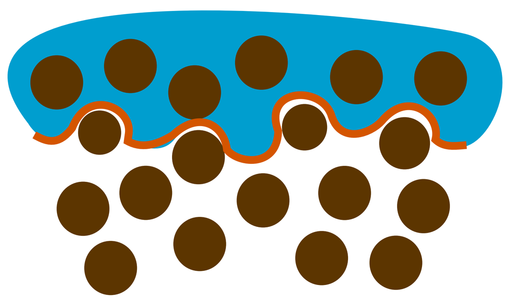
capillary pressure — repellency pressure



Surface Tension

Water free surface

Non local interaction $T\Delta s$
T : effective surface tension



Governing equation of saturation

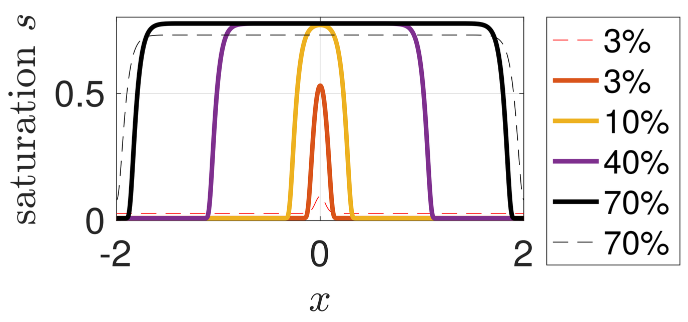
$$\frac{\partial s}{\partial t} = \nabla \cdot (K(s)\nabla[h_c(s) - h_r(s) + T\Delta s + g_r z])$$

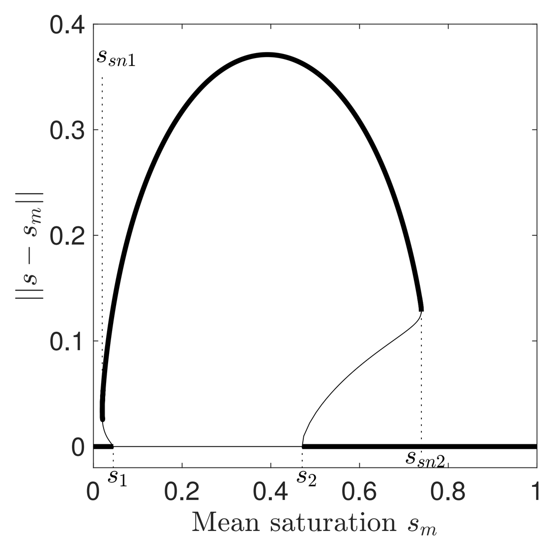
hydraulic conductivity — gravity coefficient

3) Modelling results

a) Homogeneous medium without gravity

Bifurcation graph show coexisting flow. We obtain a sort of precursor film that correspond to the residual water content in the soil.

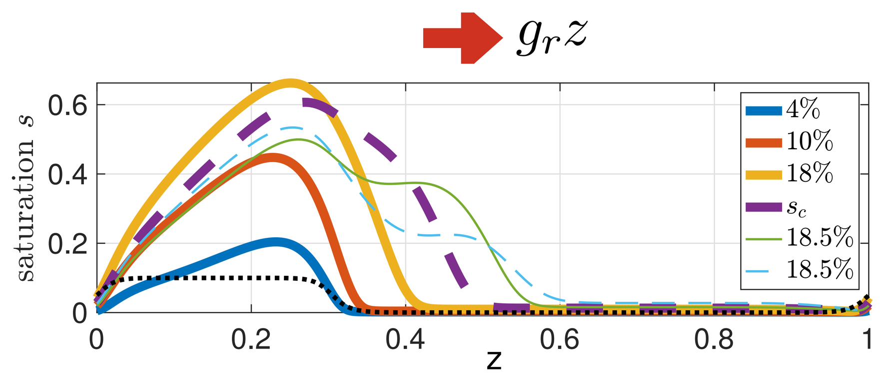




b) Stratified medium with gravity

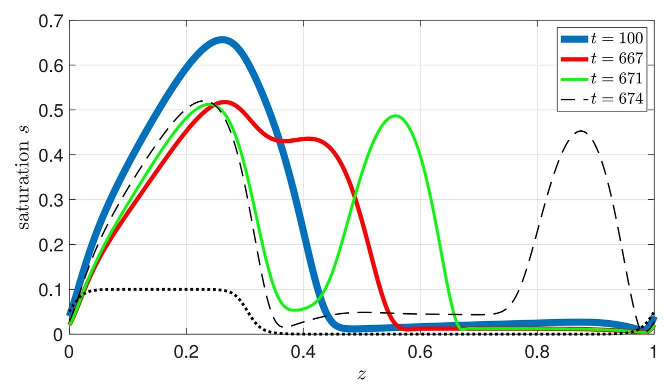
Water trapped

In 1D, we capture **water trapping** in hydrophilic layer.

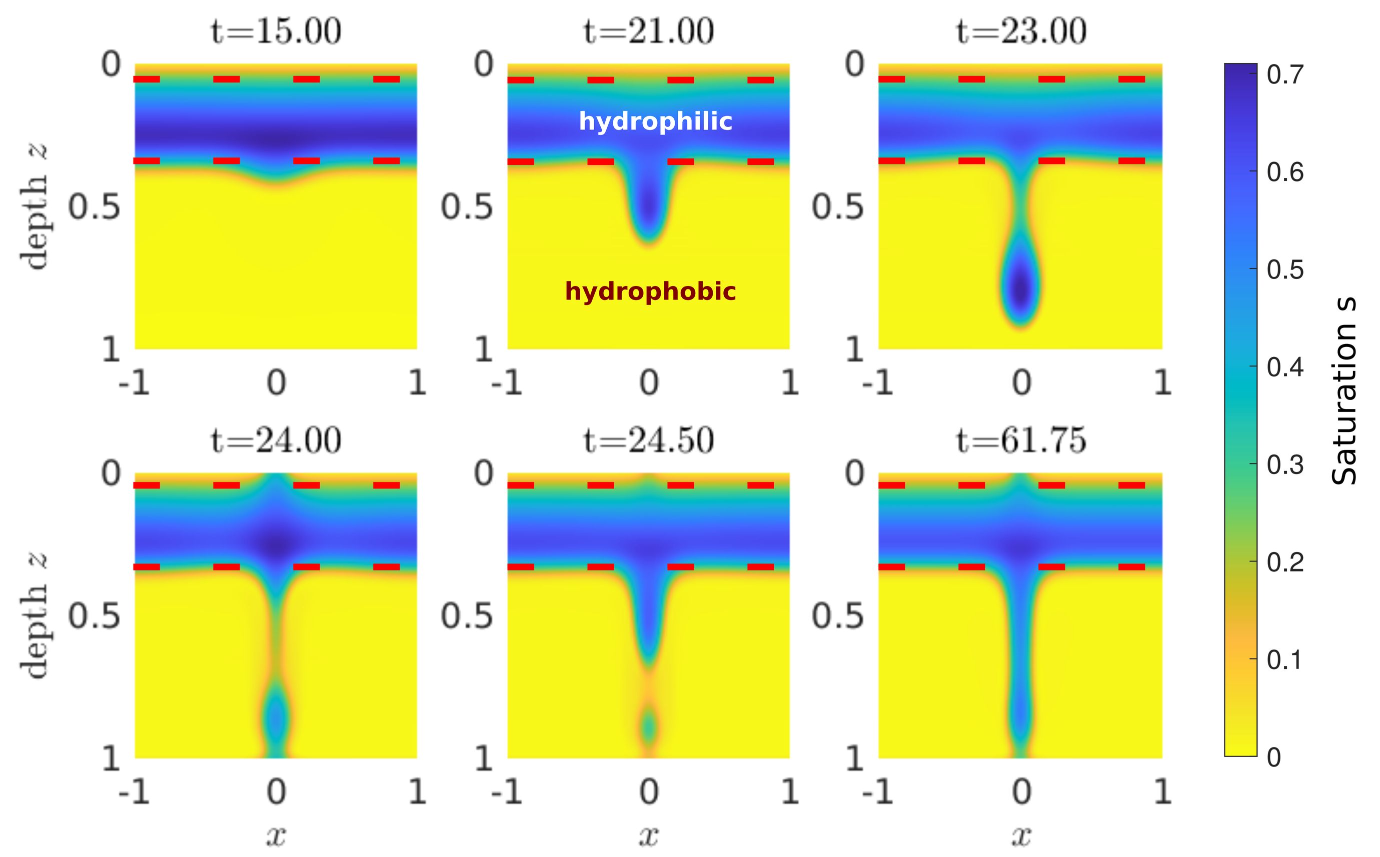


Water flow

In 1D, we observe **intermittent flow** when we are below a critical saturation.



In 2D, **fingering instability** appears in hydrophobic layer whereas hydrophobic layer conserves main part of the water.



4) Conclusion

This model allows to obtain preferential flow contratry to the Darcy Richards' model :

- Water trapping
- Intermittent flow
- Fingering instability

Outlook, the current work can be applied to soils containing organic matter such as the rhizosphere with amphiphilic molecules like exopolysaccharides.

References

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