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An OpenFOAM massively parallel solver for Richards Equation : towards mechanistical modelling of transfers at the watershed scale

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1 Introduction

Many applications both in engineering and in basic research involve transfers of water in variably saturated porous media, such as soils for example. From the point of view of water engineering, the direct infiltrations of rainwater into soils are the main recharge of the groundwaters, and transfers of contaminant solute through soils are one of the main source of pollution of groundwaters, e.g. through infiltration of nitrates and pesticides. An accurate modelling of water transfers in soils is thus an important stake for this kind of applications. From the stand point of basic research in geosciences, these phenomena are also of great interest, since for example the water content in a soil profile is one of the driven parameters of the weathering processes, which are key processes of the carbon cycle (e.g. [1]).

In order to predict the impact of global warming on weathering processes, mechanistical modelling of the water fluxes in soils are needed (e.g. [2]), since modelling in evolving climatic conditions (e.g. dry or wet warming) are needed. Large scale modelling are also needed, both from the spatial point of view (watershed scale must be considered to be able to make mass balances) and from the temporal point of view (modelling on the time scale of the observed global warming, i.e. century scale).

Numerical tools which allow accurate modellings of water transfers in soils are already available (e.g. [3], [4], [5], [6]), but they does not allow to use massively parallel computations with hundreds or thousands of processors (cores). However the use of such massively parallel computing techniques are required to handle modelling of water transfer processes on watersheds of the scale of several square kilometres on century time scale. More generally, the need of high performance computing in geosciences modelling has been point out in the literature (e.g. [7]).

In this work we present a framework of modelling which allow the resolution of the non-linear Richards equation on 3D cases by using massively parallel computation techniques. The numerical tool used is the open source CFD tool box OpenFOAM (e.g. [8]). Here we will present the model itself through a validation case and an example of application on field data, and then the parallel performance of the solver in order to show the capability of the develop modelling tool to handle mechanistical modelling of water transfers at the square kilometres spatial scale and on decade or century time scale.

2 The RichardsFOAM modelling tool : validation and example of application

If one assume a nil viscosity of the air phase, and an air phase fully and permanently connected to the atmosphere, a two-phase (water and air) flow in porous media problem may be reduce to a one equation problem. This leads to the well know Richards equation, shown below :

$$C(h) \frac{\partial h}{\partial t} = \nabla \cdot (\mathbf{K}(h) \cdot \nabla (h + z)) \quad (1)$$

In this equation, h is the pressure head expressed as length of water column [L], z is the vertical coordinate [L] (oriented upward), $\mathbf{K}(h)$ is the hydraulic conductivity of the unsaturated porous medium [L.T⁻¹] and $C(h)$ is the capillary capacity of the unsaturated porous medium [L⁻¹]. The non-linearities due to the dependency of the hydraulic conductivity and of the capillary capacity to pressure head in the soil are classically handled

with a Picard method (e.g. [3], [5]) implemented into a home-made OpenFOAM solver, the so-called RichardsFOAM solver. In order to validate this solver, we will present in the first part a code to code benchmark approach by comparing the results of RichardsFOAM with the well known software HYDRUS on a simple test case. Then, an application of RichardsFOAM on field data acquired in south west India, in a monsoon area, is proposed as an illustrative example. The main originality of RichardsFOAM is that it allows to use massively parallel computing, and the parallel performance of this solver will be investigated in the second part of this work.

3 Massively parallel computing performance of RichardsFOAM

In this part we will present the capability of RichardsFOAM to run longtime simulations at the watershed scale with a reasonable computation time. After a careful study of convergence, we build up strong scaling curves and weak scaling curves (computations made on the CALMIP (Toulouse University Computing Center) cluster, <http://www.calmip.cict.fr/spip/>) for a simple 3D case (infiltration on a 10 m thick loam slope with a river at the bottom). The strong scaling curves has been made for a slope of about 3 square kilometres of surface, with a mesh of about 36 millions of cells. One of these curves is presented in figure 1.

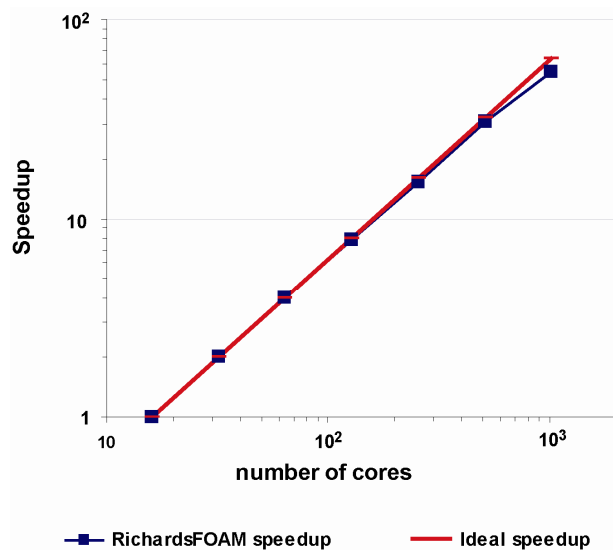


Figure 1: Strong scaling curve from 16 cores to 1024 cores, made for a test case of infiltration in a 3D slope .

One can see that RichardsFOAM exhibits good parallel computing performances (in this case, about 85% of parallel efficiency with 1024 cores). The scaling curves will be used to discuss the current limits of scales which one can deal with by using RichardsFOAM, and the associated perspectives in the field of basic research in geosciences.

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