Enhancements in Large-Scale Subsurface Flow Modeling

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Résumé

The general context of this work is the development of a numerical strategy to improve the modelling of the hydrological response of a catchment on a multi-decadal scale. At the spatial and temporal scales considered, surface runoff cannot be accurately described by surface processes alone, due to its active coupling with subsurface flow (the groundwater system) (Camporese et al. 2010). To successfully integrate these couplings, it is necessary to correctly describe the variables that will control the exchanges. That is the reason why it is crucial to simulate not only the groundwater system, but also the dynamics of the unsaturated zone.

However, modeling groundwater flow involves complex interactions between infiltration processes and aquifer dynamics. Richards' equation accurately models both unsaturated and saturated flow, including infiltration processes, but is computationally expensive when applied over large three-dimensional domains, particularly due to the strong non-linearity of the equations (Cockett, Heagy, and Haber 2018). Therefore, the objective of this work is to enhance the computational efficiency of subsurface water flow modeling at large temporal and spatial scales.

The core idea of this research is, through a set of reasonable assumptions, to divide the two dominant physical processes: the infiltration and the aquifer dynamic, where the first one is described by a one-dimensional congested Richards equation in the vertical direction (z-axis) (Brenner and Cancès 2017), and the second one by the Dupuit-Forchheimer type equation in the horizontal plane ((x, y)-axes). This decomposition assumes that flow in the unsaturated zone is predominantly vertical, while flow within the saturated aquifer is considered primarily horizontal, which is justified by a low shallowness number. These two models are then coupled through a source term that ensures mass conservation. It has to be kept in mind that this approach may lead to some limitations in accurately representing few complex hydrogeological configurations, but this approach approximates well the three-dimensional groundwater flow using a multi-directional framework, which is computationally very efficient.

Mots-Clés: Bassin versant, Hydrologie, Aquifère, Modélisation, Schéma Numérique

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