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Flow and heat transfer in porous media under freeze-thaw cycles

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Coupled processes of flow and heat transfer in porous media are long-standing challenges for numerical simulations, which become more complicated under freeze-thaw cycles (FTCs). Fundamental understanding of the multi-scale (e.g. pore-, column- to watershed-scale), multi-phase (i.e. ice, water and soil), and multi-processes (i.e. flow, heat transfer and phase change) system is of great interest in a wide range of scientific and engineering applications, such as frozen soil physics, concrete engineering practice and material science. In this study, we develop a Darcy-scale numerical model for simulating thermo-hydro (TH) processes in porous media under FTCs, which is formulated by mass conservation, Darcy's law, and energy conservation and solved using OpenFOAM. As validations, two benchmark cases (under thawing) using synthetic porous media samples are simulated to demonstrate the accuracy of the current model. Considering realistic scenarios, the proposed model is further applied to simulate flow and heat transfer in a 2D transect sampled from the upper reaches of the Heihe River Basin (uHRB). On-site hydrogeological properties are adopted to configure the numerical model. Interface between the unfrozen and frozen zones is delineated by different temperature gradients. Soil moisture and temperature profiles are collected from field observations and utilized for cross-comparisons. Simulated results are in general agreement with the observation data, which shows that the model is capable of capturing the strong coupling between TH processes occurring under FTCs.