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Adaptive hybrid multilayer model coupling vertically-integrated and full multi-dimensional models for geological CO2 storage

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CO_2 injection into a saline aquifer leads to a two-phase flow system (supercritical CO_2 and brine), which often involves large spatial and temporal scales that require high computational cost. To address the computational challenge, in the past decade, a series of simplified models based on vertical integration of the full multi-dimensional governing equations have been developed. These vertically integrated models either assume a rapid segregation between CO_2 and brine due to strong buoyancy (i.e., vertical equilibrium assumption) or solve the one-dimensional vertical two-phase flow dynamics as fine-scale problems on top of the (coarse-scale) vertically integrated equations. The former is ofen referred to as vertical equilibrium (VE) model, while the latter relaxes the VE assumption and is called dynamic reconstruction (DR) model [1,2]. The major computational cost of the VE and DR models comes from solving the coarse-scale vertically integrated equations while the computation associated with the vertical reconstructions (either VE or DR) is minor. As such, they are much more computationally efficient than full multi-dimensional models and have been used to answer many important engineering questions. However, the vertically integrated VE or DR models are often limited to aquifers with homogeneous or layered heterogeneous properties. Thus, for aquifers with strong 3D heterogeneity, the computationally expensive 3D models are to date the only robust option.
In this talk, we present a hybrid multilayer framework to couple full multi-dimensional models with the various vertically integrated models. Such a framework allows us to use full multi-dimensional models in highly heterogeneous layers of an aquifer where full multi-dimensional model is the only robust option, while applying simplified vertically integrated models in layers with homogeneous or layered heterogeneous properties. We develop algorithms to couple the full multi-dimensional model with vertically integrated models (VE or DR), as well as algorithms for the coupling between the VE and DR models. In addition, we develop a local criterion to adaptively switch between VE and DR reconstructors [3], i.e., use VE reconstructor when the two fluid phases are in equilibrium while use DR reconstructor to capture vertical dynamics when the fluids deviate from vertical equilibrium. Comparisons with full multi-dimensional models (MRST [4] is used in our work) show that our adaptive hybrid multilayer model is much more computationally efficient than full multi-dimensional models while providing results with similar accurary, making this hybrid model an attractive tool for modeling of CO_2 injection and migration in highly heterogeneous saline aquifers.

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