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Rigorous Upscaling of the Navier-Stokes Equations in Heterogeneous Porous Media

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Fluid flow through heterogeneous porous media is ubiquitous in a variety of subsurface engineering applications, including hydrology, geothermal energy production, hydrogen storage, and carbon dioxide sequestration. To efficiently study macroscopic fluid flow—as well as other macroscopic phenomena—in these systems, rigorous upscaling techniques can be employed to derive coarse-grained models with *a priori* error estimates and *applicability conditions* (i.e., physical conditions under which a model will meet its *a priori* error estimates). No fitting parameters are required in the formulation of such models, as the coarse-grained descriptions are derived using fine-scale information (e.g., the microstructure geometry and equations describing the fine-scale physics) to accurately account for multiscale behaviors. Despite their benefits in accuracy and efficiency, a majority of upscaling techniques depend on a strict set of methodological assumptions (e.g., diffusion- or viscous-dominated physics, periodic geometries at finer scales, scale separation, and negligible effects from the boundaries of a system) that hinder their ability to be rigorously applied in practice. To overcome these limitations, we previously developed a novel upscaling methodology, the Method of Finite Averages (MoFA), that avoids the aforementioned assumptions and provides a unique combination of *rigor* and *generality* while modeling physical phenomena in heterogeneous porous media. In this work, we apply MoFA to rigorously upscale the Navier-Stokes equations and develop a model for fluid flow in heterogeneous porous media. The resulting upscaled model rigorously accommodates temporally-varying, system-scale boundary conditions and low-Reynolds-number flows (i.e., Re $\sim$ 1). We demonstrate these capabilities and discuss the computational efficiency achieved with the MoFA model through numerical validation experiments.

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References

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