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Effective Block-Scale Dispersion and Its Self-Averaging Behavior in Heterogeneous Porous Media

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Upscaled (effective) dispersion coefficients in spatially heterogeneous flow fields must (1) account for the sub-scale variability that is filtered out by homogenization and (2) be modeled as a random function to incorporate the uncertainty associated with non-ergodic solute bodies. In this study, we use the framework developed in de Barros and Rubin (2011) [de Barros F.P.J. and Rubin Y., Modelling of block-scale macrodispersion as a random function. Journal of Fluid Mechanics 676 (2011): 514-545] to develop novel semi-analytical expressions for the first two statistical moments of the block-effective dispersion coefficients in three-dimensional spatially random flow fields as a function of the key characteristic length scales defining the transport problem. The derived expressions are based on perturbation theory and limited to weak-to-mild heterogeneity and uniform-in-the-mean steady state flow fields. The semi-analytical solutions provide physical insights of the main controlling factors influencing the temporal scaling of the dispersion coefficient of the solute body and its self-averaging dispersion behavior. Our results illustrate the relevance of the joint influence of the block-scale and local-scale dispersion in diminishing the macrodispersion variance under non-ergodic conditions. The impact of the statistical anisotropy ratio in the block-effective macrodispersion self-averaging behavior is also investigated. The analysis performed in this work has implications in numerical modeling and grid design.