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# Three-dimensional Scalar Mixing in Porous Media - Flow Heterogeneity and Mixing Enhancement

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This work addresses the dissipation of gradients, dilution and mixing of passive scalars in three-dimensional heterogeneous porous media. It is well known that spatial heterogeneity of hydraulic conductivity causes a significant increase of mixing and dilution. Irregular flow patterns force spreading of the contaminant plume, leading to erratic spatial distributions of concentrations. Contrasts in the medium permeability may cause flow focusing, which distorts the shape of a solute cloud and increases contact surface with the surrounding fluid. For two-dimensional problems, this has been studied and analyzed extensively.

In recent work, we showed how specific hydrodynamic features of a two dimensional Darcian flow, e.g. shear and normal strain stresses, can be linked directly to the increase of mixing and dilution of a passive scalar. The flow topology in three-dimensional domains, however, may differ from that in two-dimensional flows. In three-dimensional domains, flow trajectories may twist and wrap. This might re-shuffle the initial spatial structure and thus generate even more contact surface with the surrounding fluid. In general, kinematical mechanisms such as shear and normal strain deformations gain an additional dimension to work on.

Through numerical simulations, we illustrate how these mechanisms are also among the key drivers for enhanced mixing in three-dimensional porous media. We raise the question under what circumstances and to which extents the additional degrees of freedom in the hydrodynamic mechanisms can further enhance mixing and dilution in spatially heterogeneous problems. In this numerical study, we quantify metrics of the mixing behavior for a scalar plume emitted from a continuous source. Within a stochastic framework, we show how several hydrodynamic features impact the pre-defined mixing metrics.