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Non-Fickian mixing in heterogeneous porous media

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Mixing is a fundamental process that drives chemical reactions in fluids. It also plays a central role in governing the spatial organization of passive scalar fields in natural flows, such as oceanic, atmospheric or hydrologic flows. Mixing is greatly enhanced in fluctuating velocity fields, which may arise from turbulent conditions, chaotic temporal fluctuations or from the heterogeneity of the media through which the fluid flows. On the one hand, the multiscale heterogeneity of these velocity fields yields an anomalous growth of the mixing zone. On the other hand, it leads to a complex concentration distribution inside the mixing zone. We show that these two processes can be quantified by temporal and spatial scaling exponents. Using numerical simulations of flow and transport in highly heterogeneous permeability fields, we demonstrate the effect of superdiffusive spreading on the global mixing rate and discuss the consequences for upscaling reactive transport in heterogeneous flows.