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Evaluating the assumption of power-law late time scaling of breakthrough curves in highly heterogeneous media

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Power-law (PL) distributions are widely adopted to define the late-time scaling of solute breakthrough curves (BTCs) during transport experiments in highly heterogeneous media. However, from a statistical perspective, distinguishing between a PL distribution and another tailed distribution is difficult, particularly when a qualitative assessment based on visual analysis of double-logarithmic plotting is used.

This presentation aims to discuss the results from a recent analysis where a suite of statistical tools was applied to evaluate rigorously the scaling of BTCs from experiments that generate tailed distributions typically described as PL at late time.

To this end, a set of BTCs from numerical simulations in highly heterogeneous media were generated using a transition probability approach (T-PROGS) coupled to a finite different numerical solver of the flow equation (MODFLOW) and a random walk particle tracking approach for Lagrangian transport (RW3D). The T-PROGS fields assumed randomly distributed hydraulic heterogeneities with long correlation scales creating solute channeling and anomalous transport. For simplicity, transport was simulated as purely advective.

This combination of tools generates strongly non-symmetric BTCs visually resembling PL distributions at late time when plotted in double log scales. Unlike other combination of modeling parameters and boundary conditions (e.g. matrix diffusion in fractures), at late time no direct link exists between the mathematical functions describing scaling of these curves and physical parameters controlling transport.

The results suggest that the statistical tests fail to describe the majority of curves as PL distributed. Moreover, they suggest that PL or lognormal distributions have the same likelihood to represent parametrically the shape of the tails. It is noticeable that forcing a model to reproduce the tail as PL functions results in a distribution of PL slopes comprised between 1.2 and 4, which are the typical values observed during field experiments.

We conclude that care must be taken when defining a BTC late time distribution as a power law function. Even though the estimated scaling factors are found to fall in traditional ranges, the actual distribution controlling the scaling of concentration may different from a power-law function, with direct consequences for instance for the selection of effective parameters in upscaling modeling solutions.