Evolution of Lagrangian velocities in steady Darcy flow fields and impact on solute dispersion

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Abstract

Understanding transport mechanisms in heterogeneous porous media is challenging, because the spatial organization of the flow field and velocity fluctuations are intertwined. As a result, transport behaviors are complex and cannot be predicted by advective-dispersive models for equivalent homogeneous media. Perturbation theory predictions remain limited to log hydraulic conductivity fields, with variances smaller than 1. Here, we elucidate how structural properties and velocity fluctuations impact transport processes in heterogeneous porous media. We study purely advective transport in steady Darcian flow fields with heterogeneous hydraulic conductivity fields described by two point distributions: a log-normal and a truncated gamma. The latter allows relaxing the assumption of independent mean and variance, a singular property of the lognormal distribution. We analyze the statistical properties of particle velocity series sampled along streamlines isochronically and equidistantly. Isochrone series of Lagrangian velocities show intermittency: short stays with high velocities and long stays at low velocities. We find that this property is less pronounced with equidistant sampling, suggesting that correlation between subsequent space steps is low. Analyzing this correlation of Lagrangian velocities for different degree of heterogeneity, we identify and quantify a characteristic length scale over which particle velocities persist. This length can be related to the Eulerian velocity and to the hydraulic conductivity statistics. In addition, we show that Lagrangian velocity statistics can be non-stationary, depending on the injection mode. This statistical property highlights the importance of conditioning on initial velocities to perform accurate predictions. To predict solute transport, accounting for the evolution of Lagrangian velocity distribution, we present two models – a relaxation [1] and a mean reverting. These models are parameterized in terms of the Eulerian velocity statistics and the conductivity distribution. The difference between these models lies in the fact that the relaxation model accounts for a velocity dependent rate of change in the velocity distribution whereas this rate is constant in the relaxation model. We compare and discuss these models with results from direct numerical simulations. It shows that the predictions are in good agreement for the evolution of the mean and variance of the Lagrangian velocity, and that the relaxation model reproduces more closely the evolution of the complete Lagrangian distributions.

References

[1] M. Dentz, P. K. Kang, A. Comolli, T. Le Borgne and D. R. Lester. Continuous time random walks for the evolution of Lagrangian velocities, *Phys. Rev. Fluids*, Vol. I., 7, (2016).