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An Eulerian joint velocity-concentration PDF method for solute dispersion in highly heterogeneous porous media

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In risk analysis applications involving heterogeneous formations, the knowledge of the solute concentration probability density function (PDF) at different spatial locations and times is crucial. We propose a new joint velocity-concentration PDF method applicable for highly heterogeneous porous media that accounts for advective transport, pore-scale dispersion and molecular diffusion. Unlike in low order approximation (LOA) methods that are valid for low conductivity variances σ_Y^2 and where the one-point velocity PDF is typically assumed to be a Gaussian, the proposed joint PDF method honors the increasingly non-Gaussian velocity one-point PDF and the long-term velocity correlations that were reported in different Monte Carlo (MC) studies for $\sigma_Y^2 > 0.5$ [e.g., Salandin, P. and V. Fiorotto, WRR, 1998. 34(5) and Trefry, M.G., F.P. Ruan, and D. McLaughlin, WRR, 2003. 39(3)]. Furthermore, the new joint PDF method does not involve any a-priori assumption about the shape of the resulting marginal concentration PDF. LOA methods that provide information on the concentration mean and variance [Fiori, A. and G. Dagan, Journal of Contaminant Hydrology, 2000. 45(1-2)] on the other hand are typically complemented by assuming that the concentration PDF has a β-PDF shape [Bellin, A. and D. Tonina, Journal of Contaminant Hydrology, 2007. 94(1-2)]. The Eulerian joint velocity-concentration PDF transport equation in our model is numerically solved with a computationally efficient particle method. The suggested joint PDF method is validated by comparison with MC data reported by Caroni and Fiorotto for Péclet numbers ranging from 10 to 10^4 and $\sigma_Y^2 = 1$ and 2 [Caroni, E. and V. Fiorotto, Transport in Porous Media, 2005. 59(1)].