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A numerical lamellae method based on flow maps

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A hyperbolic description of the problem of solute transport using a deterministic and Lagrangian formulation that combines characteristics of the classical formulations based on the Fokker-Planck (FP) and Langevin equations is developed. This formulation is based on a Liouville master equation, whose hyperbolicity allows for tracing the concentrations along characteristic lines in the augmented phase space composed by solute particle locations and a set of (time-independent) random coefficients used to define a source term that introduces the noise added to the system, in lieu of (time-dependent) stochastic processes. This circumvents the use of stochastic calculus and eliminates the diffusive term of the master equation, at the expense of increasing the dimensionality of the joint probability density function (PDF) of solute particle locations. The characteristic lines define flow maps for the joint PDF and its support such that all one-point space-time statistical information to study mixing and dispersion respectively is contained in them. Therefore, diffusion is modeled with kinematics parametrically dependent on random coefficients. This approach can be combined with numerical algorithms to solve ordinary differential equations (ODEs), that are unaffected by the Courant-Friedrichs-Lewy (CFL) stability condition, do not suffer from Gibbs oscillations, do not require (order-reducing) filtering and regularization techniques, and do not rely on standard Monte Carlo sampling. Because of these reasons this formulation offers more accuracy and a lower computational cost in comparison to Eulerian grid-based and Lagrangian particle tracking solvers. To find the proper noise term to add, we impose that averaging the Liouville equation over the coefficients must lead to the FP equation, which leads to a classical closure problem for the moments of the joint PDF. However, assuming a local linearization in concordance with the Ranz transform used in the lamellae description, a simple closure based on truncated central moments becomes exact and so does this hyperbolic description, which accounts for diffusion in all directions. In this talk, I will discuss the methodological advantages of using a hyperbolic description of mixing, and show how it can be used to construct a numerical lamellae method for arbitrarily shaped initial concentration profiles.

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References

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