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Memory effects induced by dependence on initial conditions of transport in heterogeneous media

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Memory effects in the pre-asymptotic regime of transport in heterogeneous media, indicated by reliable numerical experiments, are explained by a dependence on initial conditions which is specific for systems with space variable properties. Using the Itô formalism, we obtain a decomposition of the second spatial moment of the concentration in terms of the factors which govern non-reactive transport in heterogeneous media such as aquifers, turbulent atmosphere or ionized plasmas. We show that, for transport in statistically homogeneous velocity fields, a "memory-free" moment (i.e. independent of the initial state) can be defined by summing up the local dispersion and a contribution of the velocity correlation sampled along the trajectories of the solute molecules. In a consistent first-order approximation in velocity fluctuations, the latter reduces to the one-particle displacement variance governed by the Eulerian velocity correlation, as derived in Lagrangian theory of advective transport [1]. Further we define a "memory term", describing the persistent influence of the initial conditions, caused by correlations between initial positions and velocity fluctuations along the trajectories of the solute particles. For deterministic advective transport, the memory term introduced here particularizes to the supplementary term of the second moment found by Sposito and Dagan [2]. The ensemble average of the memory term measures the difference between the second moment of the ensemble averaged concentration and the memory-free moment [3]. New numerical simulations presented here indicate that the memory terms are responsible for non-ergodic behavior of the second moments in the case of large initial plumes, for which one usually assumes that ergodicity conditions are ensured.

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