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Spatial Markov processes for modeling Lagrangian particle dynamics in natural flow fields

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Natural flow fields generally display a complex spatiotemporal organization due to heterogeneous geological structures or coherent turbulent structures at different scales, for example, which leads to non-Fickian transport properties. We present recent findings based on a Lagrangian analysis of solute particle velocities (Le Borgne et al., PRL 2008, Le Borgne et al., PRE 2008). While descriptions of transport in turbulent flow fields often assume Lagrangian velocities to be markovian in time, we demonstrate numerically that Lagrangian velocities in heterogeneous porous media describe a Markov process at fixed distances along particle trajectories, (i.e., a spatial Markov process). This description turns out to be a correlated CTRW formulation that generalizes the continuous time random walk model to transport in correlated velocity fields. This finding is remarkable given the broad use of CTRWs in the description of anomalous transport. Note that the CTRW representation is often based on a phenomenological understanding of the small scale behavior. Here, it results directly from the spatial markovianity of the Lagrangian velocity description. As such, it provides an explicit link between small scale understanding (as represented by the Lagrangian velocity statistics) and large scale dynamics. The proposed Lagrangian statistical model is shown to provide accurate predictions for transport in the preasymptotic non-Fickian transport regime for different velocity field organizations, at pore scale and at Darcy scale.