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Lattice Boltzmann methods in Geosciences

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Numerical models often offer the only possible approach to study the complex non-linear dynamics of geodynamical processes that are difficult or impossible to scale for laboratory experiments. The development of improved computer resources has allowed the emergence of large-scale parallel computations in Earth Sciences. These resources have lead to an increasing complexity in models where a greater number of adjustable parameters arise. Although the increasing number of free parameters offers a greater flexibility to fit satisfyingly the set of available constraints (e.g. geochemical, structural) it also provides new challenges in terms of the size of the parameter space and non-uniqueness of model solutions. Another significant challenge associated with state-of-the-art models is that their complexity is in general associated with the addition of parameterizations of the unresolved (small) scale processes. This trend calls for the development of complementary high-performance models to constrain the physics at small-scales where mass, momentum and energy exchanges at interfaces between different phases control the dynamics in heterogeneous media. We argue that more attention should be devoted to the development of multiphase numerical modeling at the granular (pore) scale to investigate the dynamical behavior of heterogeneous media and the emergence of feedbacks that influence the response of these media at much greater scales. The lattice Boltzmann method is a paradigm that emerged almost three decades ago. It is based on kinetic theory and follows a bottom-up approach that contrast the top-down strategy of standard methods such as Finite Volumes, FEM and Finite Differences. Lattice Boltzmann is ideally suited to handle the complex dynamics of multiphase systems at small spatial scales and is very efficient for parallel programing. In this presentation, we discuss the development of different lattice Boltzmann models developed in our group over the last years through different applications in Earth Sciences (magma dynamics, melt extraction in the upper mantle, reactive transport in porous media, stress propagation in porous media). The focus of this presentation is (1) to introduce and discuss some advantages and shortcomings of the lattice Boltzmann method and, (2), to highlight the importance of an accurate description of small-scale processes to build consistent parameterization for large-scale simulations in geodynamics.