Embedding lattice-Boltzmann based resolved fluid-particle simulations (LB-DEM) into classical finite volume simulation of river flow

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ABSTRACT

Sediment transport in rivers is a multi-scale process that comprises of local phenomena on particle scale (e.g. bed morphology, particle shape) as well as global phenomena on the scale of the river depth and width (e.g. large scale turbulent vortices). In classical numerical simulations these scales are clearly separated. In macroscopic simulations of river flow, the onset of sediment transport is evaluated based on semi-empirical correlations of e.g. critical wall shear, without resolving detailed fluid-particle interactions. In small-scale simulations of particle motion, simulation domains are commonly limited to periodic boxes, without considering the influence of incoming macroscopic turbulent structures.

In our study we account for both scales by embedding a resolved lattice Boltzmann based Discrete Element Method (LB-DEM) co-simulation into a macroscopic finite volume based CFD simulation. In this setting, the small scale simulation receives its boundary conditions directly from the macroscopic simulation of river flow, accounting for the effect of large scale vortices on local sedimentation events. This combination between finite volume simulation, lattice Boltzmann simulation and discrete element method has been realised within an open source environment by combining the open-source software packages OpenFOAM, Palabos and LIGGGHTS.

The coupled methodology is applied to a generic confluent river junction found in literature[1]. In this flow configuration periodically detaching vertical vortices are formed at the free boundary layer between the two merging rivers. By embedding a local LB-DEM simulation into the finite volume river flow simulation, we can study the effect of macroscopic turbulence on local sediment transport.

These combined simulations are numerically stable and computationally very efficient with nearly linear parallel scalability up to 256 cores (on the LB-DEM side). Furthermore, simulation results agree well with semi-empirical predictions for the onset of sediment transport as well as with additional experimental observations.

REFERENCES

1. Keylock, C.J., Constantinescu, G., and Hardy, R.J. (2012). The application of computational fluid dynamics to natural river channels: Eddy resolving versus mean flow approaches. Geomorphology 179, 1-20.