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Application of lattice Boltzmann simulations and multifractal analysis to describe the simulated flow velocity in idealised porous media

Francisco Jose Jimenez-Hornero (1), Eduardo Gutierrez de Rave (2), Juan V. Giraldez (3), and Jorge E. Jimenez-Hornero (4)

(1) Dept. of Graphic Engineering and Geomatics, University of Cordoba, Spain (ir2jihof@uco.es), (2) Dept. of Graphic Engineering and Geomatics, University of Cordoba, Spain (eduardo@uco.es), (3) Dept. of Agronomy, University of Cordoba and IAS CSIC, Spain (ag1gicej@uco.es), (4) Dept. of Computing and Numerical Analisys, University of Cordoba, Spain (jjimenez@uco.es)

The combination of the lattice Boltzmann numerical simulations with multifractal analysis is used here to study the water flow in idealised porous media, phenomenon of interest for agricultural soils and water conservation. Thus, the description of simulated flow velocities in idealized porous media has been carried out by using the multifractal method known as sandbox. Standard multifractal analysis based on the box-counting fixed-size method gives emphasis to domain regions containing few data points that sparks the biased assessment of the generalized fractal dimensions for negative moment orders. This circumstance is relevant when describing the flow velocity field in idealised three-dimensional porous media. The application of the sandbox method was explored as an alternative to the box-counting procedure to analyze the flow velocity magnitude simulated with the lattice model approach at the pore scale for six different media. The results obtained from the generalized fractal dimensions spectra showed the multifractal nature of the flow velocity. In all the cases, the fractal dimension of the set over which the measure was carried out was lower than 3, which is the capacity dimension of the support. This circumstance demonstrates the influence of the pore phase geometry on the flows that cannot fill the 3D domain. The sandbox method improved the performances of the multifractal analysis carried out with the box-counting procedure because of reducing the undesired effect of anomalous contribution of regions containing few data points (e.g. the case of low porosity) in the calculation of the generalized fractal dimensions. In addition, the multifractal spectra estimated with the sandbox method indicated the influence of the porous media structure on the simulated flows in a clearer way. As the porosity decreases, the multifractal spectra revealed more heterogeneity as well as the presence of extreme values in the distribution of the high flow velocity magnitudes. Significant correlations were found between some parameters that control the shapes of the generalized fractal dimensions and multifractal spectra and the coefficients of variation, skewness and kurtosis when the sandbox method was applied.

Highly heterogeneous transport phenomena have been observed from field experiments and the flow heterogeneity increases with the measurement scale. For this reason, it is desirable to describe flow and transport phenomena in large scales from observations at smaller scales. The combination of the lattice BGK model simulations with the multifractal analysis introduced in this work is a suitable approach to solve this challenge by determining the scale-dependent variability of the considered flows.