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Turbulent transport across the sediment-water interface: Pore-resolved direct simulations and upscaled modeling

Monday, 22 May 2023 15:00 (15 minutes)

Pore-resolved direct numerical simulations (DNS) are performed for turbulent open channel flow over a randomly packed porous sediment bed over a range of permeability Reynolds numbers of $Re_K = \mathcal{O}$(1-10) representative of aquatic systems. A fractional time-stepping based fictitious domain method (Apte et al. 2008) is used to simulate flow over spherical sediment particles on Cartesan grids by enforcing the rigidity and no-slip condition on the particle boundaries. The DNS predictions are compared with the experimental data of Voermans et al. (2017) to show excellent agreement of mean and turbulent flow quantities. A space-time averaging methodology is used to compute the Reynolds stresses, form-induced stresses, and pressure fluctuations. Shear layer and turbulent shear stress as well as Reynolds and form-induced bed-normal stresses increase with Re_K. The peak values of the form-induced stresses were found to occur within the top layer of the sediment bed for the Reynolds numbers studied. The sum of turbulent and form-induced pressure fluctuations at the zero-displacement planes are statistically similar and can be well approximated by a $t-$location-scale distribution fit based on high-order statistics, providing with a model that could potentially be used to impose boundary conditions at the SWI in reach scale simulations. A continuum model based on the volume-averaged Navier-Stokes (VANS) equations is developed by defining smoothly varying porosity across the bed interface and modeling the drag force in the porous bed using a modified Ergun equation with Forchheimer corrections for inertial terms (Wood et al., Annual Review of Fluid Mechanics, 2020). A spatially varying porosity profile generated from the pore-resolved DNS is used in the continuum approach. Mean flow and Reynolds stress statistics and net momentum exchange between the free-stream and the porous bed are compared to show very good agreement. The continuum VANS approach allows for significant reduction in computational costs, thereby allowing to study hyporheic exchange of mass and momentum in large scale aquatic domains with combined influence of bedform and bed roughness.

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Participation

In-Person

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Primary authors: Mr KARRA, Shashank (Oregon State University); APTE, Sourabh (Oregon State University)

Presenter: APTE, Sourabh (Oregon State University)

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