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Upscaling of bottom-generated turbulence in large-scale 3D models for sediment transport in estuaries and coastal zones

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Currently used 3D numerical sediment transport models still fail to make good quantitative predictions. To a great extent, this can be attributed to the inadequate description of physical processes which occur at the subgrid scale level. From flume experiments it is known that particle-turbulence interactions near the bed significantly change the effective roughness experienced by the overlying water column. This results in different transport rates if not accounted for.

From a theoretical perspective, bed load transport, sheet flow and fluid mud flow are all occurrences of supersaturated suspension flow in the inner near-bed layer comprising the viscous sublayer and the transient layer. Its thickness increases with sediment load, since particle-particle interactions (four-way coupling effects) consume considerable amounts of the available stream power. In order to know how much energy is left over to compute the transport capacity of the outer, fully-developed layer, it is necessary to quantify the energy budget in the inner layer.

This is a difficult task. Every modelling approach has its draw-backs and limitations. Lagrangean particle tracking is hopeless, since the required number of particles to approach field conditions is much too high, and the volumes occupied by the particles cannot be neglected. Grain sizes are non-uniform in nature and concentrations near the bed very high, making it very difficult to give an accurate description of the momentum exchange between fluid and solid phase, which accounts for particle collisions. Therefore, in view of large-scale applications, a one-fluid approach is adopted. This implies that the momentum equation is solved for the suspension, together with a turbulence closure model and the sediment mass balance.

Since the thickness of the supersaturated inner layer mostly is very small relative to the water depth and the vertical discretization in large scale applications, it is not possible to resolve this layer with a traditional low-Reynolds model approach, which requires a very fine grid. A new approach is proposed, where a modified Prandtl-mixing length (PML) model is used for the bed layer, and a new low-Reynolds model is applied in the outer layers. In this way it is possible to obtain a correct behaviour for tidal oscillating flow in estuaries, where low-Re effects enter high in the water column during slack water.

The correction factor for the PML eddy viscosity and the damping functions for the low-Re k-epsilon turbulence model are constructed based on theoretical constraints, DNS and LES generated data, as well as experimental flume data.

In parallel, LES and improved two-layer low-Re models are developed to simulate flow over rough bottoms without and with sediment, in order to generate data very close to the bed surface, where no measurements can be made. These additional data are used to help interpret experimental flume data, which always show relatively high experimental errors, and to extend the new damping functions for the cases with bottom roughness and suspended sediment.

Preliminary results of the new coarse grid RANS model for open-channel flow with various roughness conditions without and with suspended sediment will be shown, compared to LES results for flow over a wavy bottom, low-Reynolds RANS results over rough bottom and experimental flume data.