Multi-layered Coupled Hydrodynamics and Morphodynamics in Recirculation Flows

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Abstract

Modelling coupled hydrodynamics and morphodynamics has been a very active research area during the past years. In general, modelling coupled hydrodynamics and morphodynamics requires solution of the three-dimensional Navier-Stokes equations with free-surface boundary conditions for the hydrodynamics and a nonlinear Exner equation for the morphodynamics. The coupling between these processes takes place at the interface between the water flow and the bed topography and it appears as a differential source term in the Navier-Stokes equations. There are three challenges to deal with this class of problems: (i) the pressure is hydrostatic in the hydrodynamics, (ii) the top and bottom boundary areas are deformable in the hydrodynamics due to the free-surface and bed movement, and (iii) the time scales for hydrodynamics and morphodynamics are very different to each others.

In the current study we propose a new model to overcome some of the above difficulties. Firstly, we consider a multi-layer shallow water system to avoid the costly three-dimensional Navier-Stokes equations and remeshing strategies to deal with moving boundaries. Secondly, we consider the Grass model for the bed-load using the near-bed velocity in its formulation which overcomes the fast bed transport when a mean velocity is used. Thirdly, we present numerical assessment of the proposed model with extensive comparisons between our model and the three-dimensional model along with the conventional single-layer shallow water equations. The focus in the current study is on recirculation flows as for this type of water flows the standard shallow water equations fail to recover the vertical velocity field needed to generate the recirculation within the computational domain. As a numerical solver we employ our FVC method recently proposed in [1] to solve multi-layer shallow water flows without morphodynamics. The method is a finite volume method, simple to implement and does not require Riemann solvers in its formulation.

References

1. E Audusse and F Benkhaldoun and S Sari and M Seaid and P Tassi. A fast finite volume solver for multi-layered shallow water flows with mass exchange. Journal of Computational Physics 272, (2014) 23-45.