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Combined characteristics and finite volume methods for sediment transport and bed morphology in surface water flows

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Abstract

We propose a new numerical method for solving the equations of coupled sediment transport and bed morphology by free-surface water flows. The mathematical formulation of these models consists of the shallow water equations for the hydraulics, an advection equation for the transport of sediment species, and an Exner equation for the bedload transport. The coupled problem forms a one-dimensional hyperbolic system of conservation laws with geometric source terms. The proposed numerical method combines the method of characteristics with a finite volume discretization of the system. The combined method is simple to implement and accurately resolves the governing equations without relying on Riemann problem solvers. Numerical results are presented for several test examples on sediment transport and bed morphology by free-surface water flows.
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Keywords: Shallow water equations; Sediment transport; Bed morphology; Finite volume scheme; Method of characteristics

1. Introduction

The main concern of morphodynamics is to determine the evolution of bed levels for hydrodynamic systems such as rivers, estuaries, bays and other nearshore regions where water flows interact with the bedload geometry. Examples of applications include among others, beach profile changes due to severe wave climates, seabed response to dredging procedures or imposed structures, and harbour siltation. The ability to design numerical methods able to predict the morphodynamic evolution of the coastal seabed has a clear mathematical and engineering relevances, compare [13,15,14,3] among others. In practice, morphodynamic problems involve coupling between a hydrodynamic model, which provides a description of the flow field leading to a specification of local sediment transport rates, and an equation for bed level change which expresses the conservative balance of sediment volume and its continual redistribution with time. In the current study, the hydrodynamic model is described by the shallow water equations, the suspended sediment is modelled using an advection equation accounting for deposition and erosion effects, and the transport of the bedload is modelled by the Exner equation. The coupled models form a hyperbolic system of conservation laws with source terms. It is well known that the solutions of these systems may present steep fronts and even shock discontinuities, which need to be resolved accurately in applications and often cause severe numerical difficulties, see for example [5,3].

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