Sediments and Subgrid
A Great Combination

Volp, Nicolette; van Prooijen, Bram; Pietrzak, Julie; Stelling, Guus

Publication date
2016

Document Version
Final published version

Citation (APA)
Volp, N., van Prooijen, B., Pietrzak, J., & Stelling, G. (2016). Sediments and Subgrid: A Great Combination . Abstract from 18th Physics of Estuaries and Coastal Seas Conference, 2016, The Haque, Netherlands.

Abstract for the 18th Physics of Estuaries and Coastal Seas Conference, 2016

Sediments and Subgrid: A Great Combination

Nicolette D. Volp , Bram C. van Prooijen , Julie D. Pietrzak and Guus S. Stelling [1]

Keywords: coastal seas, subgrid, morphodynamics

Abstract Long term morphodynamic simulations are used for predicting the impact of climate change and human interventions in our estuarine and coastal regions. The accuracy of this type of simulations suffers generally from low resolution grids. Eventhough high resolution bathymetry data is increasingly more available thanks to new measurement techniques. However, the computational effort for such high resolution simulations is high. Even with increasing computer power and by using the various available techniques for speeding up simulations [Roelvink (2006)], the computational effort remains high. By introducing a subgrid based method for morphodynamics, we aim at increasing the accuracy of coarse grid based morphodynamic simulations, without significantly increasing the computational effort.

Over the last years, we have gained experience in hydrodynamic modelling using subgrid based methods [i.e. Defina (2003), Casulli (2009), Volp et al (2013)]. These methods combine coarse computational grids with high resolution information. In Volp et al (2013) we presented a subgrid based, two-dimensional, depth averaged hydrodynamic model, that is inspired by the method presented by Casulli (2009). The model makes use of two grids: a (coarse) computational grid and a high resolution subgrid, see Figure 1. The system of equations is solved at the coarse grid, but high resolution information is taken into account. The water level is assumed to be uniform within a computational cell, but the bed and the roughness are allowed to vary within a cell. Therefore, high resolution effects can be taken into account for the computation of cross-sectional areas, cell volumes, advection and friction. This also implies that cells can be wet, partly wet or dry. The solution based on a coarse computational grid improved significantly, when high resolution effects are taken into account. This result is obtained without a significant increase in computational cost.

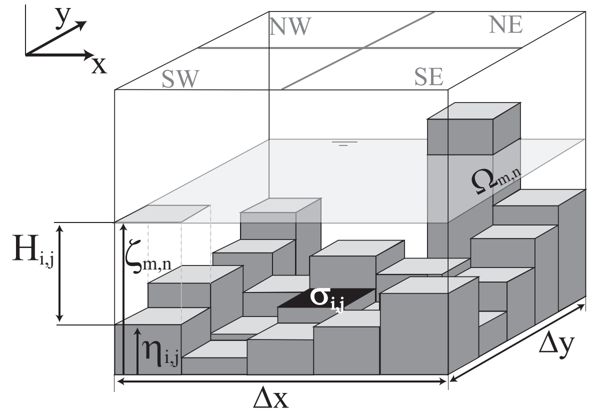

Figure 1: An overview of the computational grid with the underlying subgrid. Reprint from Volp et al (2015)

Long term morphodynamic simulations could benefit strongly from a fast and accurate hydrodynamic model. Moreover, they would profit as well from a more accurate description of the bed. Therefore, we developed a method to combine a subgrid based hydrodynamic model with a subgrid based method for morphodynamics. In order to preserve the high resolution information of the bathymetry, the bed is to be updated at high resolution. Therefore, a coupling is required between the coarse hydrodynamic variables, and those variables defined on the high resolution subgrid. High resolution water levels and water depths could be defined by interpolation, based on the bathymetry and the coarse grid water levels. More difficult is the interpolation of the velocity field. An algebraic expression for the velocity on high resolution is formulated, based on the coarse grid velocity, the coarse grid water level, the high resolution bathymetry and friction coefficient. The proposed formulation is based on the continuity equation and a simplified momentum equation: a local balance between pressure gradient and friction. This resulted in a high resolution velocity field, that could be used to compute bed shear stresses.

---

[1] Delft University of Technology, n.d.volp@tudelft.nl, b.c.vanprooijen@tudelft.nl, j.d.pietrzak@tudelft.nl, g.s.stelling@tudelft.nl

Sediment fluxes can be computed based on the high resolution shear stresses, which allows to resolve the sediment mass balance when lag effects are neglected. These computations are fully performed fully at the high resolution grid. However, for applications where these lag effects are important, the exchange terms can be added to the sediment mass balance. The net erosion or deposition depends on the capacity to keep sediment into suspension. Therefore, a sediment transport equation is included in the system of equations. The transport equation for suspended sediment is resolved on the coarse grid, to ensure no extra time step restrictions. However, the exchange terms need to be defined on high resolution. This is to ensure that the bed evolution equation is still fully solved at high resolution. Based on high resolution input and computed variables, the equilibrium concentration, the adaptation time scale and the sediment fall velocity can be defined at that resolution. We were able to include the high resolution sediment information in the coarse grid based computations of the concentration. We assumed that the concentration within a computational cell can be non-uniform. An estimate of the variation is made based on the assumption that the ratio of the erosion and deposition rates is uniform within a computational cell.

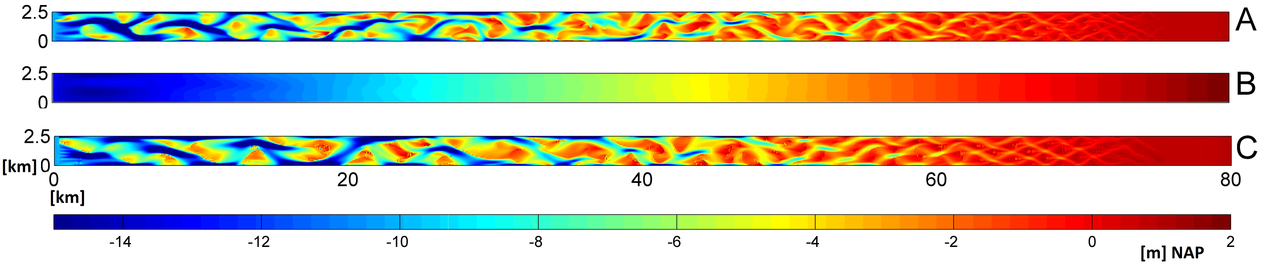

Figure 2: The bathymetry results of 3 simulations of the evolution of a schematic tidal estuary. Panel A; high resolution simulation. Panel B; coarse grid simulation, Panel C; subgrid based simulation. Modified from Volp et al (2016; submitted)

To illustrate the effect of taking high resolution information into account, the results of 3 simulations for the bed evolution in a tidal basin are shown in Figure 2. These are the bathymetry results after 80 years of evolution under tidal forcings. This numerical experiment is similar to Hibma (2004) and Wegen Roelvink (2008). Initially, the bed was uniformly sloping with some small perturbations imposed. In time, channels and shoals developed. The simulations were performed under exactly similar forcing conditions, but with different grid resolutions. Simulation A is computed using a high resolution grid, while Simulation B is computed on a coarse grid. Simulation C is a subgrid based simulation, where the computational grid is the same as the grid of Simulation B, whereas the subgrid resolution is equal to the one of Simulation A. There is a clear improvement of the results when a subgrid is taken into account. The CPU time needed to compute the result of simulation C is more than ten times shorter than the time needed for simulation A.

A subgrid based model for morphodynamics improves its solution in two ways. Firstly, when the model is able to compute at high resolution the bed update, the bed and its derivatives (for example slope effects) are better captured. Secondly, the high resolution of the original bed is preserved and updated, which will allow for a better hydrodynamic solution, so for an improved description of the forcing.

References

J. A. Roelvink (2006) Coastal morphodynamic evolution techniques. Coastal Engineering, 53, 277-287.

A. Defina (2000) Two-dimensional shallow flow equations for partially dry areas. Water Resources Research 36, 3251-3264

V. Casulli (2009) A high-resolution wetting and drying algorithm for free-surface hydrodynamics. International Journal for Numerical Methods in Fluids, 2009, 60, 391-408

N.D. Volp; B. C. van Prooijen and G.S. Stelling (2013) A finite volume approach for shallow water flow accounting for high-resolution bathymetry and roughness data. Water Resources Research, 2013, 49, 4126-4135

N.D. Volp; B. C. van Prooijen;J. D. Pietrzak and G.S. Stelling (2015) A subgrid based approach for morphodynamic modelling. Advances in Water Resources, doi: 10.1016/j.advwatres.2015.07.013

A. Hibma; M. J. F. Stive and Z. B. Wang (2004) Estuarine morphodynamics. Coastal Engineering, 51, 765-778

M. van der Wegen and J. A. Roelvink (2008) Long-term morphodynamic evolution of a tidal embayment using a two-dimensional, process-based model. Journal of geophysical research: Oceans (1978–2012), 113, 1-23