A parameter model for dredge plume sediment source terms

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Introduction

The work presented in this paper aims at the development of a stochastic model for the fast prediction of the distribution of dredging-induced sediment suspensions in the water column. In recent times, environmental impact assessments of dredging works have been subject to extensive regulation. Methods for the prediction of adverse effects of marine works are permanently being improved. Dredging using Trailer Suction Hopper Dredgers (TSHD) requires discharging of excess water from the vessel's hopper into the sea for optimal efficiency of the operation. The return flow is discharged through a vertical shaft through the dredger's hull, called the overflow. The released material usually contains a fraction of fine sediments for which the residence time in the hopper was insufficient to settle and thus stays in suspension until the overflow shaft is reached. Part of the released material might descend to the sea bed as a density current, another part might be dispersed to form a surface plume. The latter part is bound to stay in the water column for a longer period in case the sediment concentration is too low for a buoyancy-driven descent to the sea bed. The turbidity plume generated in this way can be advected by the sea currents and potentially reaches environmentally sensitive areas.

In the feasibility phases, the fate of these fine sediment plumes needs to be predicted in order to assess the need for mitigation measures. In the operational project phase, plume predictions are needed to assess the timing and location of the works planned for the coming days. The large-scale simulation of the plumes is generally executed with a shallow-water hydrodynamic flow model fitted with a source term for the overflow mixture. The source term which has to be supplied to the large-scale model is the fraction of the released sediments that ends up in the water column. The determination of this source term can be done using time-consuming process-based models, or by means of a parameterised prediction model. The development of the model structure and the fitting of its parameter by means of a large dataset of process-based model output are presented in this paper.

Process-based model

In order to design and fit the coefficients of a stochastic model, a dataset is needed. The dataset in this case has to consist of sediment flux profiles in the vicinity of a TSHD while dredging aggregates containing fine sediment, using the overflow. Decrop *et al.,* (2014a, 2014b) set up a Computational Fluid Dynamics (CFD) framework for the simulation of flow around a TSHD and the detailed turbulent dispersion of the near-field sediment plume, which is actually a buoyant jet-in-crossflow. The CFD model takes into account the effect of mixture bulk density, propeller action and air bubbles. An example of the result of a calculation for relatively shallow water can be seen in Fig. 1. Due to the shallow water in this case, a density current is formed near the sea bed (brown isosurface at sediment volume concentration C=10^{-5}) while higher in the water column a surface plume is generated (coloured contours at the water surface).

The liquid discharge and sediment concentration of the overflow discharge can be calculated by means of a hopper model such as by e.g. van Rhee (2002) or Jensen and Saremi (2014). The CFD model is validated using *in situ* measurements of different monitoring campaigns in the field. CFD model output at a fixed distance behind the dredger is transformed to vertical profiles of sediment mass flow rate q_s, which are then stored to serve as a dataset for fitting of the parameter model.

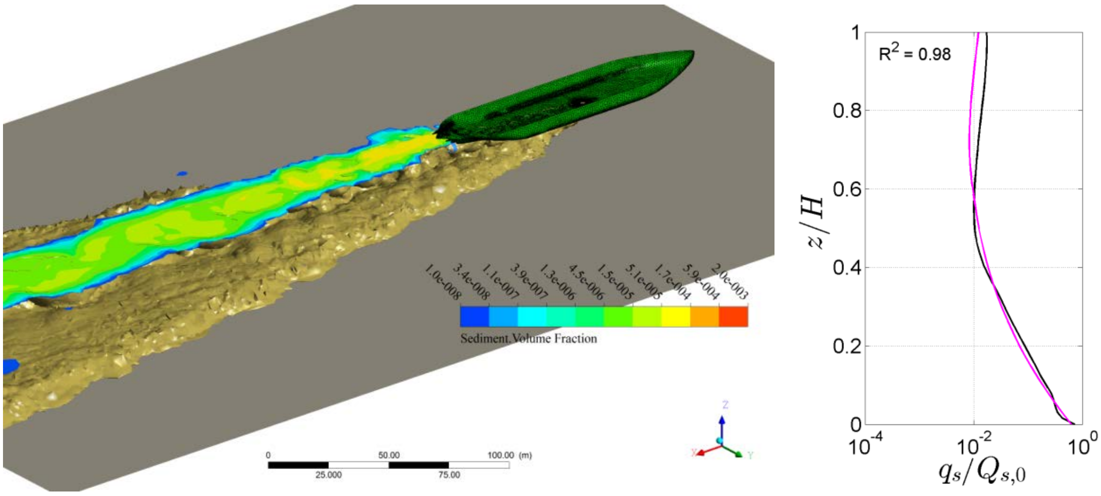

Fig. 1. Left panel: Example of CFD model output used for the fitting of a stochastic model for dredge plume source terms. Right panel: Example of vertical profiles of sediment mass flow rate q_s: a parameter model validation result in magenta and the corresponding CFD output in black line.

Parameter model

Overflow plume profiles extracted from a large number of different CFD simulations were analysed and a parameterisation of the vertical profile of q_s was defined. The different coefficients in the profile shape model were then fitted to the CFD model output dataset using a multivariate general regression model. Subsequently, the CFD model dataset was divided in a training dataset used for the fitting of the coefficients, and a validation dataset. The model includes a predictor step using the parameterisation, and a corrector step to assure the full sediment flux is accounted for. The parameter model provides a vertical profile of q_s in the plume at a given distance behind the ship, which can be directly applied as a source term in a large-scale hydrodynamic/sediment transport model. The result of a validation case for the parameter model is shown in Fig. 1 (right panel). Here, z/H is the distance above the bed divided by the water depth, q_s is the sediment mass flow rate in the plume (in kg/s per meter water depth) and $Q_{s,0}$ is the total solid discharge through the overflow (kg/s). The profile of q_s (normalised by $Q_{s,0}$) from the CFD model is shown in black, the parameter model output in magenta. Error statistics shows that for 75% of the set of validation runs, a coefficient of determination higher than 0.7 is obtained.

The resulting model can thus be implemented in large-scale hydrodynamic model codes, for the online determination of the overflow sediment source term.

References

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