Multi-class floc size distributions of cohesive sediments in the turbidity maximum of Changjiang River mouth

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Introduction

To manage coastal and estuarine waters, it is critical to accurately predict the movements of cohesive and non-cohesive sediments. There are well-established methods to estimate the behavior of non-cohesive sediments; however, without extensive knowledge on flocculation processes it remains difficult to predict the behavior of cohesive sediments. Flocculation is one of the main processes (e.g., erosion, deposition, settling, consolidation and flocculation) in cohesive sediment dynamics. The study of flocculation is an interdisciplinary work since it relates to various physical (e.g., transport, settling and deposition), chemical (e.g., contaminant uptake and transformation) and biological (e.g., community structure activities and metabolism) activities. Nevertheless, a widely-accepted flocculation model that can quantitative simulating the Floc Size Distributions (FSDs) for a relatively large study domain has not yet been fully developed. Recently, Lee et al. (2012) have pointed out that an observed FSD by LISST (Laser In Situ Scattering and Transmissometry) instrument can be decomposed into subordinate lognormal distributions for microflocs, macroflocs and megaflocs. With this three-class FSD decomposition, the accuracies of predicted settling velocities are largely enhanced compared with single-class approach. This method has been used in the well-mixed Belgian coast (Shen et al., 2018). Nevertheless, it is not clear if the FSDs in other regions, especially stratified estuaries, can be analyzed and simulated in the same way for a broader application. Therefore, the study aims to implement an improved quadrature-based Population Balance Equation (PBE), based on that given by Shen and Maa (2015), on a 1-D vertical hydrodynamic model (Shao et al., 2017), to simulate the floc sub-populations in the turbidity maximum of Changjiang River Estuary (Guo et al., 2017). The long term target is to better investigate the FSDs and the particle dynamics in 3-D estuarine models.

Field measurements

Field work was carried out in the North Passage of Changjiang River Estuary, in the wet season of the year 2016. In this study, navigation data of two typical tidal cycles that represents spring and neap tidal conditions respectively are highlighted to investigate the water levels, flow velocities, turbulences, salinities, suspended sediment concentrations (SSCs) and FSDs. Velocity profiles were collected by a shipboard downward-looking ADCP (Acoustic Doppler Current Profiler), the in-situ flocculated FSDs were measured with the LISST-100 (type C), and samples from different water levels were analyzed to determine the salinities, SSCs and primary particle size distributions. Notably, the measured FSDs were automatically decomposed into microflocs, macroflocs and megaflocs using the software DistFit (Lee et al., 2012).

Flocculation Model

The general transport equation (i.e., the PBE) that includes the kinetics of aggregation and breakage of flocs with size *L* can be expressed by:

$$\frac{\partial n(L,z,t)}{\partial t}+(w-w_s)\frac{\partial n(L,z,t)}{\partial z}-\frac{\partial}{\partial z}\left(\frac{\nu_t}{\sigma_t}\frac{\partial n(L,z,t)}{\partial z}\right)$$
$$=\frac{L^2}{2}\int_0^L\left[\frac{\beta\left((L^3-\lambda^3)^{1/3},\lambda\right)\cdot\alpha}{\left(L^3-\lambda^3\right)^{2/3}}\cdot n\left((L^3-\lambda^3)^{1/3},z,t\right)\cdot n\left(\lambda,z,t\right)\right]d\lambda$$

$$
- n(L,z,t)\int_0^{\infty} \beta(L,\lambda)\alpha(L,\lambda)n(\lambda,z,t)d\lambda
$$

$$
+\int_L^{\infty} a(\lambda)\cdot b(L\mid\lambda)\cdot n(\lambda,z,t)d\lambda - a(L)\cdot n(L,z,t) \quad (1)
$$

where n (L, z, t) is the number density function defined on the basis of floc size L at any location z at time t with

$$
n(z,L,t)=\sum_{i=1}^{3} w_i(z,t)\cdot\delta(L-L_i(z,t)) \quad (2)
$$

in which L_i and w_j (i = 1, 2, 3) are the representative sizes and weights of microflocs, macroflocs and macroflocs. Additionally, w is the vertical velocity along, w_s is the settling velocity, v_t is the eddy viscosity, σ_t is the turbulent Prandtl-Schmidt number, β is the collision frequency function, α is collision efficiency function, a is breakup frequency function and b is fragmentation distribution function. The right hand side of Eq. 1 include: (i) the birth of flocs with size L due to aggregation of smaller particles, (ii) the death of flocs with size L due to aggregation with other particles, (iii) the birth of flocs with size L due to fragmentation of bigger particles and (iv) the death of flocs with size L due to breakup into smaller particles. The left hand side terms include, from left-to-right, an unsteady term, an advection & settling term and a diffusion term, respectively.

Results

The results at a well-mixed estuary show that the 1-D vertical model in this study can reasonably reproduce the velocity profiles (Fig. 1). The model predicted sizes L_1, L_2 and L_{3_3} also match the sizes of microflocs, macroflocs and megaflocs of the observed FSD. Additional validations of subpopulations of FSDs in Changjiang River Estuary will be represented.

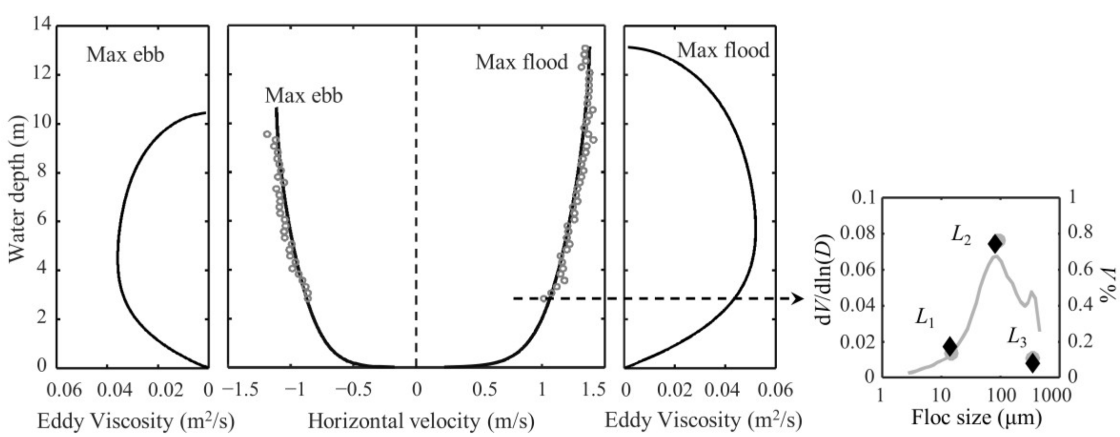

Fig. 1 An example of predicted velocity and eddy viscosity profiles at the maximum flood and the maximum ebb at a well-mixed estuary (modified from that given by Shen et al., 2018). The FSD at a selected location is presented by subpopulations of microflocs (L_1), macroflocs (L_2) and megaflocs (L_3). Symbols and lines in grey color are measurements and that in dark color are model predictions.

Conclusions

In summary, a framework is proposed based on implementing a quadrature-based PBE in a hydrodynamic model to mimic the representative sizes and their volume fractions of microflocs, macroflocs and megaflocs in the turbidity maximum of partially-stratified Changjiang River Estuary. This study, an integrated flow-turbulence-sediment model, although only validated in a 1-D vertical application at current stage, is a preliminary work to contribute to large scale simulations with comprehensive wave, suspended particles and water quality modules in the future.

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