TURBULENCE-RESOLVING NUMERICAL SIMULATION OF FINE SEDIMENT TRANSPORT OVER BEDFORMS

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INTRODUCTION

Wave-supported gravity currents in turbulent wave bottom boundary layer (WBBL) are one of the most important processes causing cross-continental shelf sediment transport. The high numerical accuracy 3D numerical model has been used to investigate the fine sediment transport in the WBBL and several different transport modes have been found due to sediment-induced density stratification (Ozdemir et al., 2010; Cheng et al., 2015). However, laboratory experiments suggest the presence of a small amount of sand fraction and the formation of ripple bed alter the structure of WBBL significantly (Hooshmand, et al., 2015). The purpose of this study is to understand the interplay of fine sand, bedforms, and sediment-induced density stratification in determining the transport modes of fine sediments in WBBL through turbulence-resolving numerical simulations.

MODELING METHODOLOGY

We extend the previous turbulence-resolving fine sediment numerical study (Cheng et al. 2015) for flow over complex bathymetry, multi-class sediments and flocculation (fine fraction). With the application of algebraic mapping (Yang and Shen, 2011), the transformed governing equations are solved in a regular domain with a standard projection method and the pseudo-spectral scheme. A third-order low-storage Runge-Kutta scheme is used for time-integration, and the resulting equations are approximated using discrete Fourier expansion in streamwise and spanwise direction, enforcing the periodic boundary condition in both directions. Instead of using the finite difference method (Yang and Shen, 2011), the Chebyshev expansion on Chebyshev-Gauss-Lobatto points is used in the vertical direction with no-slip on both top and bottom walls. Parallelized with the Message Passing Interface technique, the model is computationally efficient for event-scale study. We adopt the equilibrium Eulerian approach (Balachandar and Eaton, 2010) to simulate fine sediment transport with a multi-process-based model of Hir et al., (2011) for sand-mud mixture, which accounts for the dynamic bed armoring process. Settling velocity of the fine fraction is parameterized by flocculation process suggested by Soulsby et al., (2013), which requires information of sediment concentration and resolved turbulence statistics.

MODEL RESULTS

The numerical model is validated with laboratory experiment of fully turbulent flow over sinusoidal ripples reported by Hudson et al., (1996). In the experiment, the bed is covered by ripples with a length of $\lambda = 50.8$ mm and a steepness of 0.05, and the mean channel height is the same as the ripple length. Taking the half ripple length $H = \lambda/2$ as length scale and the bulk velocity as velocity scale, the resulting Reynolds number is 3460.

The numerical simulation is carried out with a domain size of $4\lambda\times2\lambda\times\lambda$ (streamwise, spanwise and vertical direction respectively), which is discretized by $160\times128\times129$ grid points. The predicted averaged streamwise velocity (see Figure 1a) agrees very well with measured data. Figure 1b shows a snapshot of resolved normalized turbulent kinetic energy. Compared with the flat top wall, significantly higher turbulence is observed near ripple region. In full paper, detailed result and analysis on sediment transport will be presented.

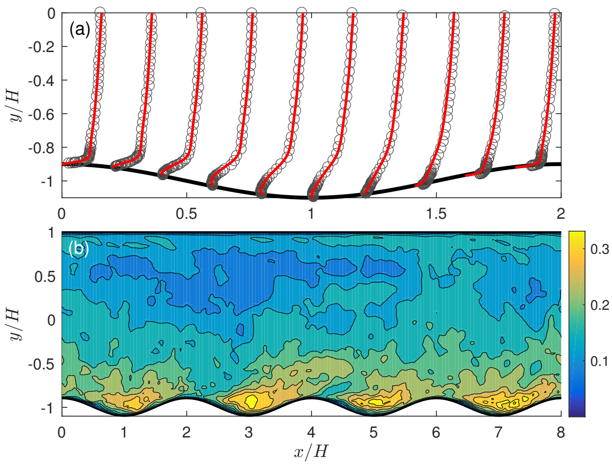

Figure 1 - (a) Comparison of mean streamwise velocity profiles between simulation results (red lines) and measured data (symbol). (b) A snapshot of dimensionless turbulent kinetic energy averaged in spanwise direction.

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