SEDIMENT ADVECTION AND DIFFUSION BY OBLIQUELY DESCENDING EDDIES

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INTRODUCTION

Three-dimensional vortex structures involving obliquely descending eddies (ODE), produced by depth-induced breaking-waves, has been proved to be associated with local sediment suspension in the surf zone (Zhou et al., 2017); vertical velocity fluctuations around the ODEs induces sediment suspension near the bed. Otsuka et al. (2017) explained the mechanical contributions of the ODEs to enhance local sediment suspension under the breaking waves and modeled the vortex-induced suspension to predict the profile of the equilibrium sediment concentration in the surf zone. In order to predict local behaviors of sediment, however, sediment-turbulence interactions in the transitional turbulence under breaking waves need to be understood. The interaction may be described in terms of Schmidt number (Sc). Sc has been empirically determined for trivial steady flows such as open channel or pipe flows. In the surf zone where organized flows evolve into a turbulent bore, the interaction may vary with the transitional feature of turbulence during a wave-breaking process, and thus Sc may be variable in time and space. No appropriate Sc model has been proposed for the surf zone flow. A parametric study on the sediment motion with respect to the variation of Sc is required for better prediction of sediment transport in the surf zone.

In this study, contributions of the sediment advection and diffusion in the vortex structure to the concentration are computationally investigated. Effects of Sc to the sediment suspension and diffusion process will be also discussed in this work.

COMPUTATIONAL METHOD

Three-dimensional Large Eddy Simulation was used to compute the turbulent flow under plunging wave-breaking over a uniformly sloping beach in the same manner as Otsuka (2017). We confirmed major features of the computed velocity and turbulent kinetic energy were in reasonably good agreement with the experimental ones.

Advection of numerical dye was computed as a simple model of the sediment transport, which approximately describes a dilute particle-laden flow containing very fine sediment without contact stress. The dye transport, defined as a deviation from an equilibrium state, was investigated during a wave-breaking process.

RESULTS AND DISCUSSIONS

Breaking waves produce organized vortex structures comprising horizontal roller vortices and multiple pairs of ODEs with streamwise counter-rotating vorticity aligned to the transverse direction, which approaches toward seabed after the wave has passed (Fig. 1, top). We found the organized vortices have important contributions to induce sediment suspension. Figure 1 (bottom) shows the cross-sectional distribution of dye concentration and streamwise vorticity at the wave plunging location. We find regular patterns of dye concentration in the transverse (y-) direction, indicating local suspension occurs at a certain interval aligned to y-axis. The formation of this coherent pattern is caused by the vortex-induced vertical flow as interpreted below.

When pairs of ODEs approach to the bed, transverse convergent flow is induced beneath the vortex pair, which carries the near-bed sediment to the central location between the vortices for forming sediment deposition. As the next vortex pair also induces near-bed convergent flow for creating the deposition, the wavy distribution of sediment concentration is formed under multiple vortex pairs. Since the upward flow is also induced between the counter rotating vortices, the deposited sediment is vertically carried through between the vortices and ejected toward the free-surface, resulting in the regular pattern of sediment concentration shown in Fig 1 (bottom). The turbulent diffusion may enhance the sediment mixture, depending on Sc, and maintain suspension for longer time against setting, causing modification of the mean concentration. Sc dependencies of the concentration will be discussed in this study.

REFERENCES

Zhou, Hsu, Cox, Liu (2017): Large-eddy simulation of wave-breaking induced turbulent coherent structures and suspended sediment transport on a barred beach, J. Geophys. Res. Oceans, vol. 122, pp. 207-235.
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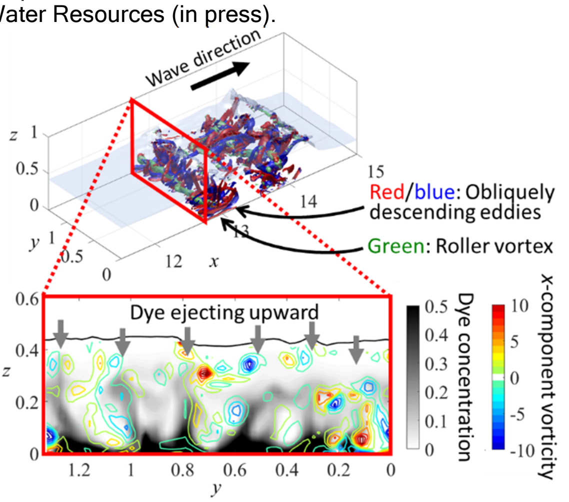

Figure 1 - Vorticity distribution in the vortex structure after wave plunging (top), and cross-sectional distribution of numerical dye (sediment) concentration and streamwise vorticity at the plunging point (in red square).