Large-eddy simulation of liquid-bubble interaction under surf zone breaking waves

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Wave breaking is a highly dissipative process, representing an important source of turbulence in the ocean surface layer. Air is entrained and rapidly evolves into a distribution of bubble sizes which interact with liquid turbulence and organized motions. Liquid-bubble interaction, especially in complex two-phase bubbly flow under breaking waves, is still poorly understood. This interaction, especially during active breaking, enhances liquid velocity fluctuations, reduces the energy in large scale motions, increases the energy of small scale motions, enhances dissipation, and may alter wave-induced vortex structures.

Derakhti and Kirby (2014a,b) have recently studied bubble entrainment and turbulence modulation by dispersed bubbles under isolated unsteady breaking waves along with extensive model verifications and convergence tests. In this presentation, we continue this examination with attention turned to the simulation of periodic surf zone breaking waves. In addition, the relative importance of preferential accumulation of dispersed bubbles in coherent vortex cores is investigated. Heavier-than-liquid particles, i.e. sediment, tend to accumulate in regions of high strain rate and avoid regions of intense vorticity. In contrast, lighter-than-liquid particles such as bubbles tend to congregate in vortical regions. We use a three-dimensional (3D) Navier-Stokes solver extended to incorporate entrained bubble populations, using an Eulerian-Eulerian formulation for a poly-disperse bubble phase. Turbulence is simulated using a large-eddy simulation (LES) approach with Germano/Lilly dynamic Smagorinsky subgrid formulation. SGS bubble-induced turbulence is modeled using a well-known formulation of Sato and Sekoguchi. The volume of fluid method is used for free surface tracking. The model accounts for momentum exchange between dispersed bubbles and liquid phase as well as bubble-induced dissipation.

We investigate the formation and evolution of breaking-induced turbulent coherent structures (BTCS) under both plunging and spilling periodic breaking waves (figure 1) as well as BTCS's role on the intermittent 3D distributions of bubble void fraction in the surf zone (figure 2). All of the simulations are also repeated without the inclusion of a dispersed bubble phase, to examine the effects of the dispersed bubbles on the intensity of the BTCS near the bottom. Bubble-BTCS interaction is important for understanding the BTCS's role on the sediment suspension in the surf zone, where the entrained bubbles are typically ignored in most of the current LES simulations of surf zone breaking waves.

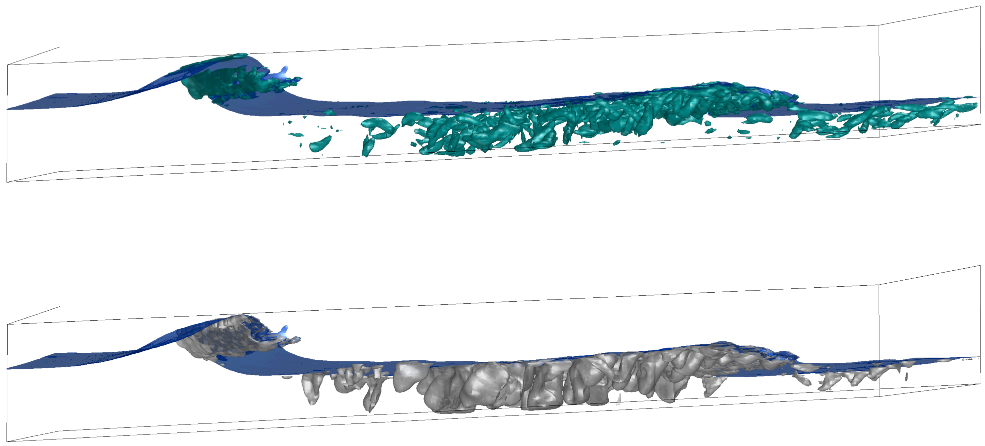

Figure 1. Snapshot of (top) BTCS identified using Q-criterion, iso-surface of $Q = 30$ and (bottom) 3D bubble plume distribution, iso-surface of $\alpha_b = 0.1\%$ under periodic surf zone breaking waves at t=t+T/8.

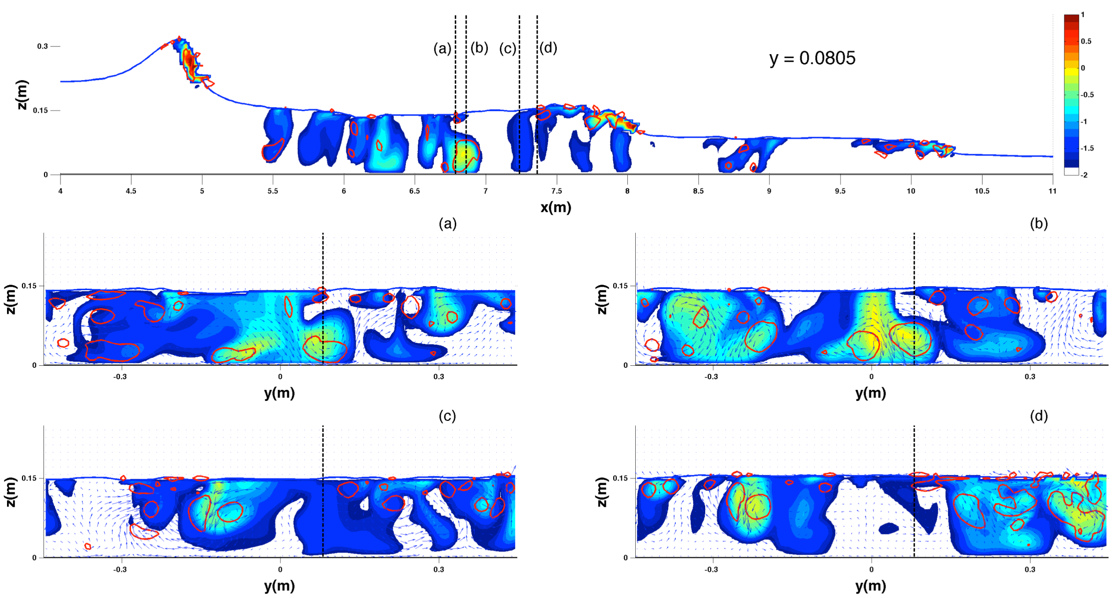

Figure 2. Snapshot of dispersed bubbles distributions in the surf zone at t=t+T/8. (top) cross-shore and (bottom) long-shore sections of the 3D bubble plume shown in figure 1. Red contours shown $Q = 30$. Colors shown bubble void fraction (%) in log-scale.