Direct numerical simulation of the interaction between collinear gravity waves and turbulence in open-channel flows

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The propagation of surface gravity waves over shallow water currents is a common occurrence in many coastal and fluvial environments. It is important to understand the mechanisms behind the nonlinear wave-current interaction since the wave-induced orbital motion strongly modifies the underlying turbulent flow and thereby influences aspects such as sediment transport and microplastics dispersion. The present contribution is concerned with non-breaking collinear gravity waves progressing over a moderately turbulent open-channel flow. We have performed direct numerical simulation of the phenomenon considering waves that are travelling in the direction of the mean flow and are characterised by period up to $T = 8.6\sqrt{h/g}$, length up to $L = 8h$ and crest-to-trough height up to $H = 0.2h$, h and g being the mean flow depth and magnitude of gravitational acceleration respectively. For performing the simulations, we have utilised a hybrid spectral/finite-difference code that solves the strong-conservation form of the Navier-Stokes equations in free-surface conforming curvilinear domains. The full nonlinear free-surface dynamics is accounted for by imposing the kinematic and dynamic boundary conditions therein. The waves are maintained in the simulations by prescribing a surface-normal pressure forcing that is computed from the inviscid progressive periodic wave solution proposed by Rienecker and Fenton[1]. As shown in figure 1, the waves modify the flow characteristics across the entire depth of the channel. In this contribution, we investigate the mechanism of the wave-turbulence interaction and evaluate the effect of the superimposed wave orbital motion on the mean flow and near-wall turbulent statistics.

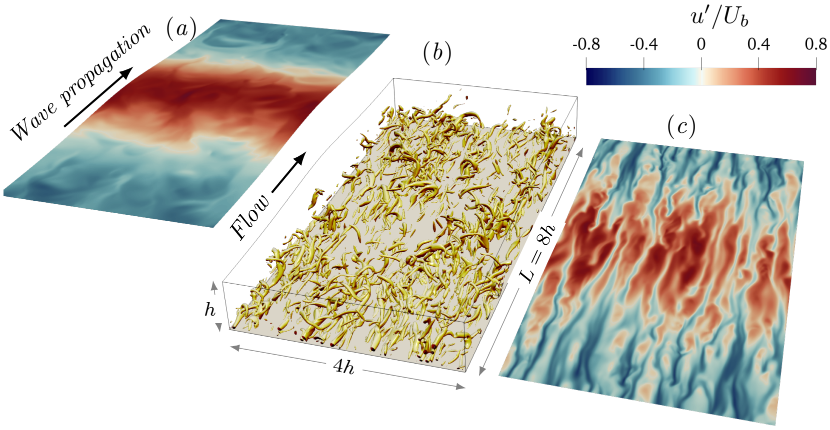

Figure 1: Visualisation of a turbulent open-channel flow under a progressive wave. (a) Streamwise velocity fluctuation at the free-surface; (b) Near-wall turbulent vortical structures; (c) Streamwise velocity fluctuation on a horizontal plane at $z^+ = 15$.

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[1]Rienecker, M. M. and Fenton, J. D., *J. Fluid Mech.* **104**, 119 (1981)