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Experimental study of flow structure in a shallow cavity using 3D-PTV

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Abstract

Understanding the flow field in a shallow cavity is important for quantifying mass transfer (nutrients, sediments or pollution) between the main flow and groyne fields in rivers. Most previous research has focused on two-dimensional flow structures in cavities. Also, the rigid-lid assumption was often employed neglecting the effects of surface gravity waves. In this work three-dimensional flow field and gravity waves were investigated in a laboratory setting using three-dimensional particle tracking velocimetry (3D-PTV). Three cameras were mounted above an open channel with a square cavity on its side. Trajectories of neutrally-buoyant particles used as flow tracers were simultaneously recorded with the cameras. 3D instantaneous and time-averaged velocity and vorticity fields were calculated from the particle tracks and surface oscillations caused by gravity waves were approximated from the highest particle positions. The results show a regular quasi-two-dimensional recirculating gyre in the cavity. However, the exchange process between the cavity and the channel flow is fully three-dimensional. It exhibits a -5/3 slope of the frequency spectrum of velocity fluctuations and the exchange shows significant variation with elevation above the bed. A secondary circulation within the cavity gyre appears in the time-averaged flow. It consists of a radial inflow along the bed towards the gyre core, upwelling at the cavity centre and spiralling outwards closer to the surface. Grtler-like streamwise vortices were found in the boundary layer that curves along the three side walls of the cavity. All of these three-dimensional structures can have a significant effect on the exchange process, which therefore cannot be described by two-dimensional models. However, parameterizations based on stability arguments may be used in future to account for their feedback on the two-dimensional flow. Comparing cases with different intensities of gravity waves confirmed they increase the exchange between the cavity and the main channel. It is suggested that gravity waves are resonantly amplified at certain free-stream velocities due to resonant coupling with the most energetic frequency of the main gyre within the cavity, contrary to previous studies.