Scale-to-scale energy transfer in the turbulence near a free surface

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Free surfaces are present in a range of turbulent flows with environmental and industrial importance, but our understanding of their effect is incomplete. Here, we leverage two large-scale facilities in which free-surface turbulence is generated in different ways. In the first, turbulence is forced in a ~2 m^3 water tank by two arrays of opposing pumps emitting jets in a random pattern[1]. The resulting homogeneous turbulence has a Reynolds number adjustable between $Re_\lambda = 230$ and 590. A snapshot of the vertical velocity along the vertical plane is shown in Figure 1a. In the second setup, grid turbulence is generated in an open water channel with a 1-m wide and 6-m long test section. Particle image velocimetry is used to characterize the turbulence below the free surface, on which waves are negligibly small. Consistent with previous numerical and experimental studies, we find that the vertical velocity fluctuations decay to vanishingly small levels within approximately one integral length scale below the surface (Figure 1b). The spatial correlation of these vertical fluctuations similarly decreases near the free surface (Figure 1c). Analysis of the inter-scale energy transfer shows how this is associated to a hindering of the energy cascade. This is further investigated imaging horizontal planes, which illustrates the scales of the upwelling and downwelling motions close to the surface. The systematic variation of Re_λ highlights the conditions for the applicability of rapid distortion theory[2].

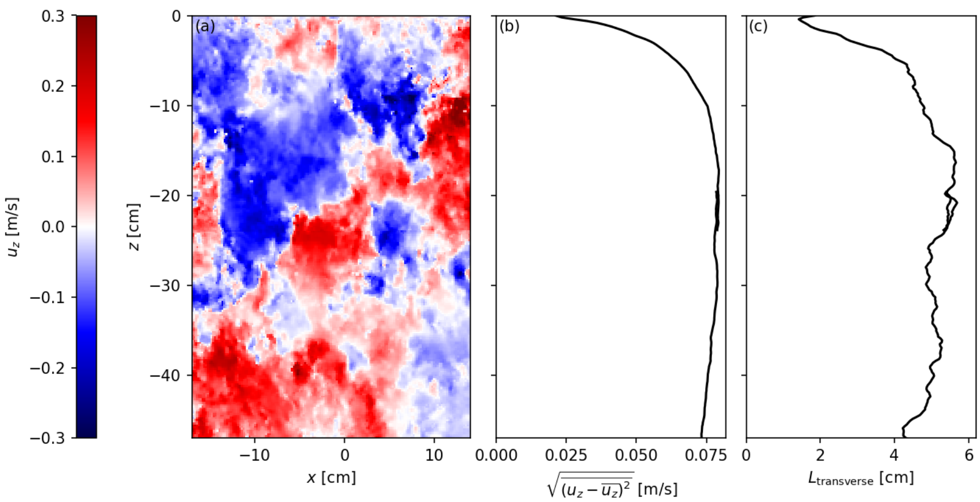

Figure 1. Statistics of vertical velocity in turbulence under a free surface (z=0). (a) A snapshot of an instantaneous vertical velocity field. (b) Root mean square of the vertical velocity fluctuation and (c) its correlation length as functions of depth.

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[1] Variano and Cowen, *J. Fluid Mech.* **604**, 1 (2008).

[2] Magnaudet, *J. Fluid Mech.* **484**, 167 (2003).