# Information depth of surface attached vortices in deformable free-surface turbulent flows

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Turbulence near deformable free surfaces plays a key role in a multitude of environmental, biological, and engineering processes, e.g., in gas and heat transfer across liquid-gas interfaces in rivers and oceans. Due to the difficulty of bulk flow measurements in the field, relating free-surface features to the sub-surface flow structures which cause them is of great practical importance.[1] In this paper, we take a step towards understanding the statistical relation between the imprints of surface-attached vortices and properties of the turbulent flow beneath. In line with other authors[2,3], we focus on the different regions near the free surface, denoted as the surface layer (the layer in immediate vicinity of the free surface where viscous near-surface effects are felt) and the deeper blockage layer (the layer below the surface layer where the kinematic restrictions due to the surface remain strong). Typical behavior of the flow in these layers can be seen by studying, e.g., the velocity derivatives of the flow field. These undergo large increase/damping in the surface layer, and converge towards linear variation in the blockage layer (see Fig. 1(a)[4]). By statistical analysis of DNS data for a deformable free surface with statistically steady homogeneous turbulence[5], the expected "information depth" of vortex structures attached to the surface is explored. We show that the vortices on the surface are strongly correlated to vortices below the surface in the surface layer and that this correlation falls off sharply throughout the blockage layer, a drop that is well approximated by a Gaussian fit (see Fig 1(b)). Combining these results with computer vision-aided techniques for surface structure detection[6] may open the way for a more detailed understanding of real-life free-surface flows by cheap image capturing and processing techniques.

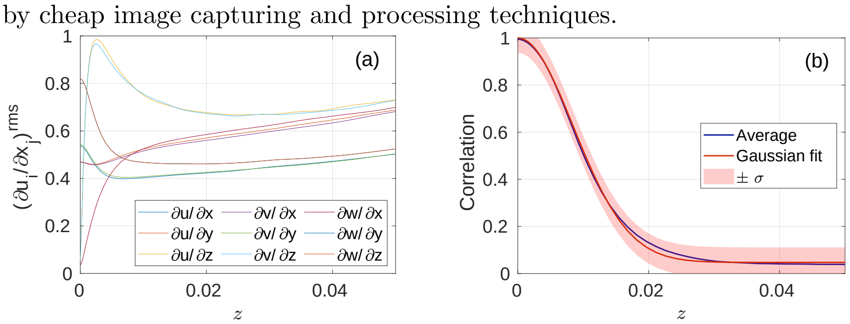


Figure 1: (a) Variation in velocity derivatives of fluid field at depth $z$ below the free surface. (b) Correlation of vortex centroids to vortex structures as a function of depth.

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[1]Muraro et al, J. Hydraul. Res., **59**, 1, (2021).

[2]Shen et al., *J. Fluid Mech.*, **386**, 167 (1999).

[3]Calmet and Magnaude, *J. Fluid Mech.*, **474**, 355 (2003).

[4]Cf. Fig. 7(b) in Shen et al.[2]

[5]DNS data is supplied by Anqing Xuan and Lian Shen. For details on the simulations, see Gao and Shen, *J. Fluid Mech.*, **658**, 33, (2010).

[6]Babiker et al. (forthcoming)