Local Thorpe length analysis of a gravity current

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Abstract

The Thorpe length L_T is an efficient quantity that measures the extent of overturning in stably stratified flows because it only requires a determination of the density field whereas other length scales require information about the velocity field. Thus, L_T is of great interest in oceanography where access to, for example, turbulent energy dissipation is challenging. We use experimental data from a wall-bounded shear flow, similar in nature to an oceanic overflow such as the Mediterranean outflow, to evaluate the stability and mixing characteristics of stably-stratified turbulent shear flows over a range of gradient Richardson number Ri_g from 0.1 to 1. The flow is confined from the top by a transparent horizontal boundary and a lighter fluid is injected into quiescent heavier fluid with relative density difference between 0.0026 and 0.0052. The flow near the boundary is turbulent with a Taylor Reynolds number $R_\lambda \approx 100$, and the density and velocity fields are measured simultaneously using planar laser-induced fluorescence (PLIF) and particle image velocimetry (PIV).

The Thorpe length L_T is the root-mean-square average of Thorpe displacements which are defined as the displacements parallel to gravity necessary to transform a non-monotonic (gravitationally unstable) profile into a monotonic (stable) profile. We evaluate L_T at different downstream positions along the interface between the turbulent current and the quiescent fluid. As Ri_g increases from 0.1 to 1, the interface fraction with non-vanishing L_T, i.e., overturning, varies from near 1 to near 0 and the character of the interfacial instability changes from Kelvin–Helmholtz to Holmboe type. Despite the different nature of the interfacial instability, the probability distribution of the normalized non-zero values of Thorpe length, $(L_T - \langle L_T \rangle)/\sigma(L_T)$ (non-zero average $\langle L_T \rangle$ and standard deviation $\sigma(L_T)$) has universal exponential tails. We also compare the characteristics of L_T with the Ozmidov length L_O and the Ellison length L_E and evaluate the buoyancy Reynolds number Re_b.

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