Local Thorpe length analysis of stratified turbulent shear flow

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Introduction

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 [1, 2]. Thus, L_T is of great interest in oceanography where access to, for example, turbulent energy dissipation is challenging. Here we use experimental data from a wall-bounded shear flow, similar in nature to an oceanic overflow such as the Mediterranean outflow [3], 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) [4].

Results

The Thorpe length L_T is the root-mean-square average of Thorpe displacements [1, 2] which are defined as the displacements parallel to gravity - the $\hat{z}$ direction - 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 for unstable cases with $Ri_g < 0.2$ where most of the interface is overturning, see Fig. 1 (a), and for comparatively stable situations with $Ri_g > 0.5$, Fig. 1 (b). In Fig. 1(c) we show a density profile with overturning, i.e., non-monotonic vertical density profile, the associated Thorpe reordered profile, and an inset of the density field with the vertical contour for the profile and the total vertical extent of the overturning region. As Ri_g increases from 0.1 to 1, the interface fraction with $L_T \neq 0$, i.e., overturning, varies from

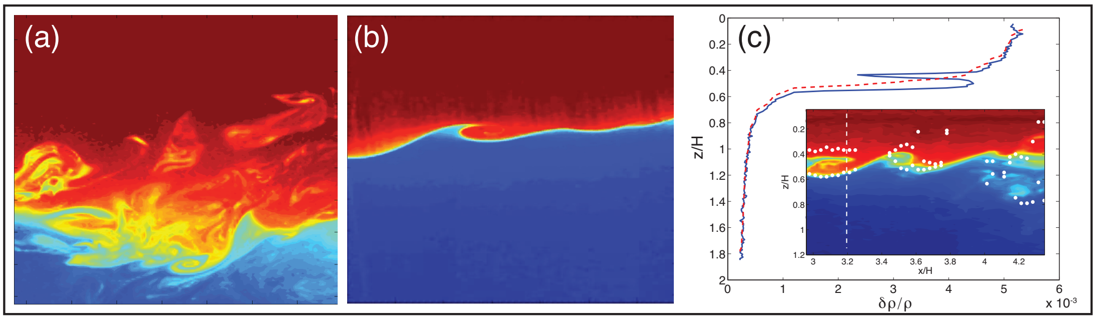

Fig. 1: Density fields - lower (red) and higher (blue) densities generally on top and bottom, respectively; (a) $Ri_g \approx 0.1$, (b) $Ri_g \approx 0.7$. (c) Density profile (for inset density image along white dashed line) without (solid) and with (dashed) Thorpe reordering. White circles denote overturning vertical extent.

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 $P(L_T^*)$ of the normalized non-zero values of Thorpe length $L_T^* = (L_T - \langle L_T \rangle)/\sigma_{L_T}$ (non-zero average $\langle L_T \rangle$ and standard deviation σ_{L_T}) has universal exponential tails. We 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. Our results are complementary to those in inclined layer [5] and Taylor-Couette geometries [6].

References

[1] S. A. Thorpe *Phil. Trans. Roy. Soc. London A* **286**:125-181, 1977.
[2] T. M. Dillon *J. Geophys. Res. Oceans* **87**:0148-0227, 1982.
[3] J. Price et al *Science* **259**:1278-1282, 1993.
[4] P. Odier, J. Chen, and R. E. Ecke *J. Fluid Mech.* **746**:498-535, 2014.
[5] C. Meyer and P. Linden *J. Fluid Mech.* **753**:242-253, 2014.
[6] A. W. Woods, C. P. Caulfield, J. R. Landel, and A. Kuesters *J. Fluid Mech.* **663**:347-357, 2010.

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