IRREVERSIBLE MIXING AND ENERGETIC ASPECTS OF TURBULENT STRATIFIED FLOW

Ernesto Horne[1] Alexandre Delache[2] , Louis Gostiaux[1] & Antoine Venaille[3]
[1] *LMFA UMR CNRS 5509, Ecole Centrale de Lyon, Université de Lyon, France*
[2] *Univ Lyon, UJM-Saint-Etienne, LMFA site de Saint Etienne UMR CNRS 5509, F-42023, Saint-Etienne, France*
[3] *Univ Lyon, Ens de Lyon, Univ Claude Bernard, CNRS, Laboratoire de Physique, F-69342 Lyon, France*

The global energy budget of the ocean depends on the local mixing produced by turbulence. Many processes produce mixing in the ocean, nevertheless, the details of the distribution of the injected energy is yet not fully understood. In this context, we performed a set of 3D Direct Numerical Simulations (DNS) of a turbulent stratified flow by solving the Navier-Stokes equation under Boussinesq approximation. A classical Fourier pseudo-spectral method is used with 1024^3 grid points. A porous penalization region is introduced to take into account a non-flux condition at the top and at the bottom of the box, and the horizontal plane presents periodicity. A turbulent velocity field imposed at $t = 0$ perturbs the initially stable buoyancy field. This allows to study decaying turbulence and to estimate the amount of irreversible mixing produced during the decay. The simulation is performed over ~ 48 initial overturning times $\tau_L = L/U$ (where L and U are respectively the integral lengthscale and the rms velocity of the initial turbulent flow).
A snapshot of a vertical cut of the buoyancy field is shown in figure 1(a) for the initial time $t = 0$ (top) and for the time $t = 29\tau_L$ (bottom). The parameters of the simulation are chosen to fix the Reynolds number, $Re = UL/\nu \simeq 1000$ and we varied over a large range of values the global Richardson number, $Ri_H = N^2\tau_L\tau_H = 1, 4, 16, 64, 256, 1024, 4096$ (where N is the Brunt-Väisälä frequency and $\tau_H = H/U$, with H the height of the domain). According to Winters et al. [1], we distinguish the kinetic energy E_k, the potential energy E_p associated with the full buoyancy field, the background potential energy E_b associated with the vertically sorted buoyancy field and the available potential energy $E_a = E_p - E_b$. We introduce the cumulative Richardson number Ri_c and the cumulative mixing efficiency η_c,

$$Ri_c = Ri_H . \frac{E_k(t=0)}{\int_0^{T_d} \varepsilon_k dt} \quad \& \quad \eta_c = \frac{\int_0^{T_d} \varepsilon_b dt}{\int_0^{T_d} \varepsilon_k dt + \int_0^{T_d} \varepsilon_b dt},$$

where ε_k is the kinetic dissipation rate, ε_b the variation of background potential energy produced by irreversible mixing, and T_d is the time where the conversion of internal energy to potential energy from boundaries becomes dominant respect to the kinetic dissipation rate. Recently, a statistical mechanics approach has been proposed to quantify the efficiency of mixing in decaying turbulent flows (Venaille et al. [2]). We obtain remarkably good agreement between DNS results and those theoretical predictions, as shown in figure 1(b). In addition, we describe quantitatively features of the energy transfers between Ek, Ep and Eb during the mixing process.

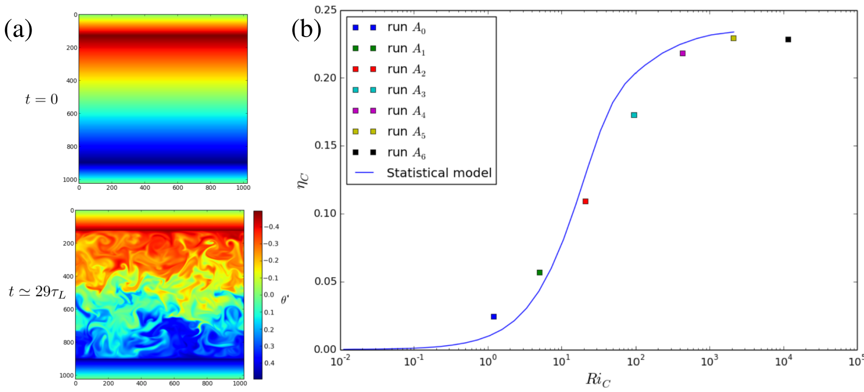

Figure 1. (a) Vertical cut of buoyancy field for the initial time $t = 0$ (top) and for the time $t = 29\tau_L$ (bottom). (b) Cumulative mixing efficiency as a function of the cumulative Richardson number for DNS (square dots) and model of statistical theory of Venaille et al. [2] (blue line).

References

[1] Winters, K. B., Loambard, P. N., Riley, J. J., & D'Asaro, E. A. *Journal of Fluid Mechanics*, **289**, 115-128, 1995.
[2] Venaille, A., Gostiaux, L. and Sommeria, J. *Journal of Fluid Mechanics*, **810**, pp. 554-583, 2017.