Direct Numerical Simulations of a turbulent stratified flow: energetics aspects and irreversible mixing

Ernesto Horne*[1], Alexandre Delache[1,2], and Louis Gostiaux[1]
[1]*LMFA UMR CNRS 5509, École 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*

The local mixing produced by turbulence in the ocean interior plays a crucial role in its global energy budget. This mixing drives large scale dynamics [1], as evidence in the meridional overturning circulation (MOC). The ciculation is produced thanks to the downward transport of energy from the surface to the deep bottom of the ocean, possible thanks to vertical mixing. In addition, vertical transport in the ocean is substantial for sequestering large quantities of dissolved greenhouse gases from the atmosphere to the deep ocean. Many processes produce mixing in the ocean. Nevertheless, the proportion of energy transferred from turbulent structures to effective mixing is very difficult to measure in the ocean [2], and the details of the distribution of the injected energy is yet not fully understood.

Run	n	Re	Ri
A_0	1024	1000	3.4
A_1	1024	1600	3.4
A_2	1024	2100	3.4
B_0	1024	1000	13.6

Table 1: Main parameters of the DNS: n is the number of grid points in each direction, Re the Reynolds number and Ri the Richardson number.

In order to answer these questions, a set of 3D Direct Numerical Simulations (DNS) of a turbulent stratified flow are performed by solving 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 non-flux conditions at the bottom and at the top of the box, and we assume periodicity in the horizontal plane. An turbulent velocity field is introduced at $t = 0$ which perturbs the initially stable buoyancy profile. The turbulent flow freely decays over 8 overturning times $\tau_L = L/U$, where L is the integral lengthscale and U is the rms of the initial turbulent velocity field. The main parameters of the DNS runs are shown in table 1 where $Re = UL/\nu$ and $Ri = N^2\tau_L\tau_H$, where N is the buoyancy frequency and $\tau_H = H/U$ with H the height of the domain. A snapshot of a vertical cut of the buoyancy field is shown in figure 1(a).

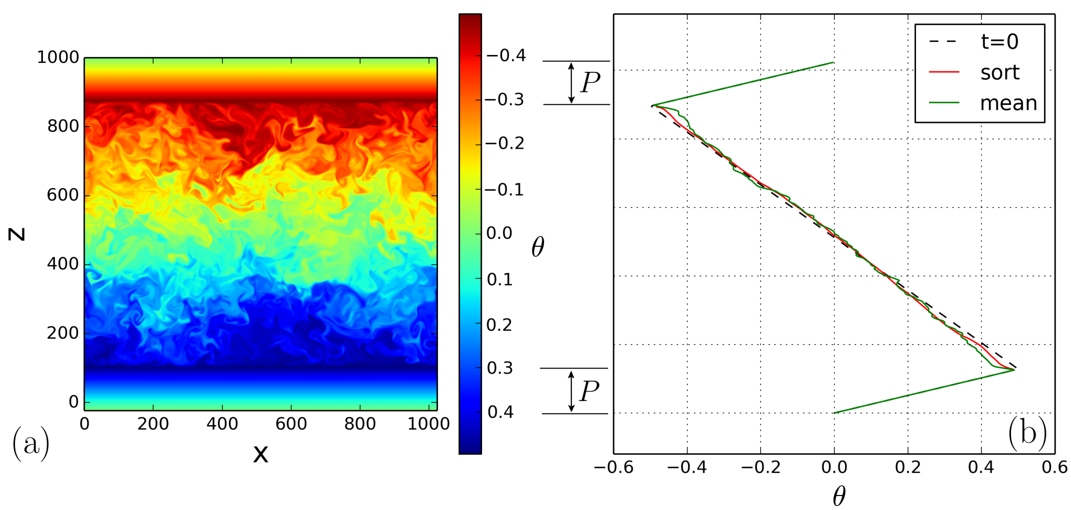

Figure 1: (a) Snapshot of a vertical cut of the buoyancy field θ at $t/N = 0.7$ corresponding to run A_0. (b) Vertical profile of the buoyancy field computed from the horizontal mean (red line) and the sorted buoyancy field (green line). The initial buoyancy profile is also indicated (dashed line). The penalization region is indicated by two arrows and the letter P between both figures.

*Email: ernesto.horne@ec-lyon.fr

One can distinguish the full buoyancy field associated with the potential energy Ep, and the sorted buoyancy field associated to the background potential energy Eb [3]. The horizontal average of the instantaneous buoyancy field can be used to compute Ep, while the horizontal average of the instantaneous 3D vertically sorted buoyancy field can be used to compute Eb. Both vertical profiles are shown in figure 1(b) for run A_0. Ep will contain the energy increase produced by the mixing within the flow in addition to the energy fluctuations associated to the reversible vertical buoyancy flux of waves and overturns. In contrast, the variation Eb is associated only to the irrevesible mixing produced in the flow, and it represents the minimum potential energy for the given buoyancy field.

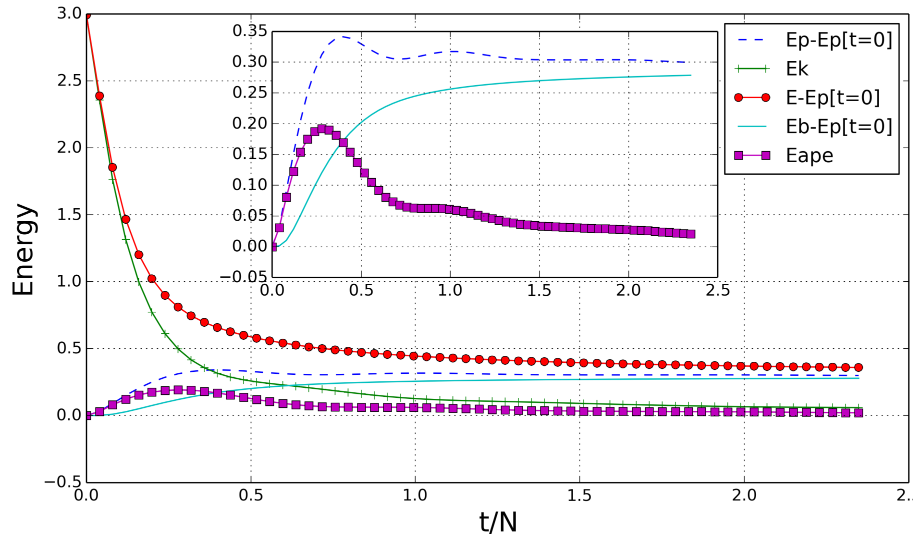

Figure 2: Evolution of the different energies of run A_0 as a function of t/N. $E = Ep + Ek$ is the total energy and $Eape = Ep - Eb$, is the available potential energy. The inset figure shows a zoom in the lowest values of energy to highlight the evolution of the potential energies.

The evolution of Ep, Eb and Ek the kinetic energy are shown in figure 2. The response of the buoyancy field to the initial forcing produces a maximum of $Eape = Ep - Eb$ at $t \approx \tau_L$, and this quantity further oscillates at the frequency close to N. In contrast, the background potential energy Eb monotonically increases reaching a final value which represents the amount of irreversible mixing that occurred during the run.

References

[1] Wunsch, C. & Ferrari, R.: Vertical mixing, energy, and the general circulation of the oceans. Annual Review of Fluid Mechanics 36, 281314. 2004.

[2] Ivey, G.N., Winters, K.B. & Koseff, J.R.: Density stratification, turbulence, but how much mixing? Annual Review of Fluid Mechanics 40 (1), 169. 2008.

[3] Winters, K. B., Loambard, P. N., Riley, J. J., & D'Asaro, E. A.: Available potential energy and mixing in density-stratified fluids. Journal of Fluid Mechanics, 1995.