Scale-by-scale anisotropy in freely decaying stably stratified turbulence

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Introduction

Stably stratified homogeneous turbulence is known to exhibit quasi-horizontal structures organized in vertically sheared layers. The thickness of these layers seem to scale according to a unit value of a related Froude number (see e.g. [1, 2]). However, at smaller scales, turbulent structures may recover an isotropic state. One therefore needs to study the dynamics of these structures as the result of a subtle interplay between linear wave and non-linear effects — that also depends on the context: forced or unforced turbulence, short or long times. The equilibrium between the inertial forces and buoyancy force suggests the introduction of the Ozmidov scale $l_o = (\varepsilon/N^3)^{1/2}$ [4], where N is the Brunt-Väisälä frequency and ε the dissipation. Structures larger than l_o are strongly influenced by stratification whereas structures smaller than l_o recover three-dimensional isotropy. The Ozmidov scale is widely used for the analysis of numerical simulations [5, 6] or experiments [7, 8]. Such a refined description is thus important for an accurate characterization of turbulent mixing in stratified flows. We propose here a parametric study of the scale-by-scale anisotropy using dedicated spectral statistics.

Detailed scale by scale analysis

In order to analyze further small-scale isotropisation, we present results from high resolution DNS (2048^3 points) of freely decaying turbulence at four different stratification rates. They confirm that the Ozmidov scale is a separating scale between anisotropic and isotropic ranges: for moderate stratification (fig. 1b), the large scales are preferentially horizontally oriented but the smaller scales recover a classical isotropic behaviour (as in fig. 1a). When stratification is increased, the small scales also become quasi horizontal (fig. 1c). We analyze this anisotropy scale by scale by considering the angle-dependent energy spectrum of velocity and density [3]. Moreover, we separate poloidal and toroidal contributions of velocity to the kinetic energy spectrum (this is also linked with the wave/vortex decomposition). The result of DNS show that for large scales, the toroidal part of kinetic energy E^T (linked to horizontal velocity) is larger than the poloidal part of energy E^P (linked to vertical velocity) : $E^T \gg E^P$, and the poloidal part of kinetic energy spectrum is of the order of the density spectrum $E^P \sim E^\rho$ (potential energy), as expected. At smaller scales close to the Ozmidov scale, DNS show that $E^T \sim E^P \sim E^\rho$ as a sign of restoration of isotropy. Nevertheless, at very small scales below the Ozmidov scale, DNS always show that $E^T \sim E^P$ but surprisingly, $E^\rho \gg E^T \sim E^P$. During the Colloquium, these observations will be further discussed along with additional aspects of the anisotropic dynamics and structure of stably stratified turbulence.

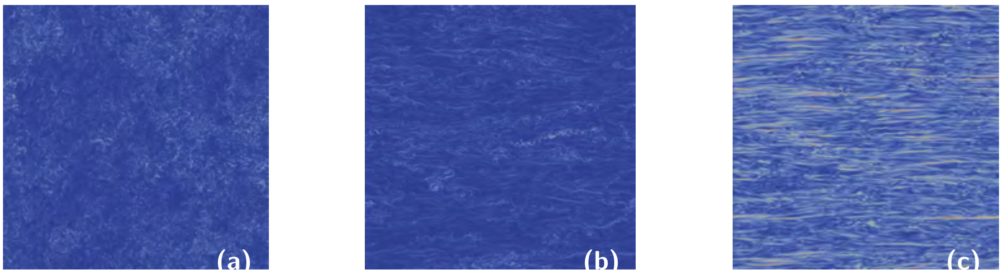

Fig. 1: Illustration of the layering through the enstrophy distribution in a vertical section: (a) reference isotropic case Reynolds number $Re \simeq 4271$; (b) weak stratification $Re \simeq 3748$, Froude number $Fr \simeq 0.45$; (c) strong stratification $Re \simeq 4198$, $Fr \simeq 0.13$.

References

[1] J. J. Riley and S. M. de Bruyn Kops. Phys. Fluids, 15 (7): 2047-2059, 2003.
[2] C. Staquet, F.S. Godeferd, J. Fluid Mech. 360, 295-340, 1998.
[3] F.S. Godeferd, C. Cambon, Phys. Fluids 6, 2084-2100, 1994.
[4] Ozmidov R.V. Izvestia Acad. Sci. USSR, Atmosphere and Ocean Physics, 1965,$N°8$
[5] Marino, R. and Mininni, P. D. and Rosenberg, D. L. and Pouquet, A., Phys. Rev. E, 90, 2, 2014.
[6] G. Brethouwer, P. Billant, E. Lindborg, J.M Chomaz, J. Fluid Mech. , vol. 585, pp. 343-368, 2007.
[7] J. J. Riley and E. Lindborg. J. Atmos. Sci., 65, 2416–2424, 2008.
[8] van Haren, H., and L. Gostiaux. Oceanography 25(2):124-131, 2012.

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