Numerical experiments on strongly stratified homogeneous shear turbulence

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Turbulence in strongly stable density stratification is a common phenomenon in atmosphere and in oceans and other large water bodies. Stably and strongly stratified turbulence have been studied in many experimental and numerical studies. A characteristic feature of strongly stratified turbulence observed in several studies is the formation of quasi-horizontal layers. During the last decade, the dynamics of the layered structure in absense of mean shear was revealed by Billant & Chomaz (Phys. Fluids 13, 1645-1651, 2001) and by Brethouwer et al. (J. Fluid Mech. 585, 343-368, 2007). They found that the layer thickness scales by U/N where U is the magnitude of the horizontal turbulent velocity and N is the Brunt-Väisälä frequency $N=(g/T_0\,\mathrm{d}T/\mathrm{d}z)^{1/2}$. Brethouwer et al. (2007) concluded in their DNS study that, in the absense of mean shear, strongly stratified turbulence has two very different regimes depending on the parameter $R=F_h^2 Re$ related to buoyant Reynolds number. Here F_h is the horizontal Froude number $F_h=\varepsilon/(U^2N)$ characterizing the ratio of vertical and horizontal length scales, and Re is the usual turbulent Reynolds number $Re=E_k^2/(\varepsilon\nu)$, with E_k being the turbulent kinetic energy and ε its dissipation rate. In strongly stratified flows, $F_h<<1$. If $R<1$, the layers become quasi laminar, thus no small-scale turbulent motion is sustained and no forward energy cascade exists. On the other hand, if $R>1$, healthy small-scale three-dimensional turbulent motion is observed embedded in the layer structure and forward energy cascade occurs. The latter is the situation typical in nature, but it is not so easy to achieve in laboratory and in DNS as F_h must be small and $R=F_h^2Re$ must be large or at least larger than about one.

Brethouwer et al. applied artificial forcing of the lowest horizontal Fourier modes instead of mean shear in their DNS to sustain statistically stationary turbulence. So far, the dynamics of strongly stratified turbulence with mean shear has not been studied from this point of view (whereas weakly stratified shear turbulence has been studied in many works). In the present study, strongly stratified homogeneous turbulence with imposed constant mean shear is numerically studied in the light of the findings by Brethouwer et al. Preliminary results suggest that the U/N-scaling applies to horizontal velocity components also in the presence of mean shear but that the vertical velocity structures show larger length scale not scaling by U/N. The vertical velocities are clearly larger than in non-sheared cases, although still being smaller than the horizontal components. This difference can be explained by the fact that in sheared flow, where E_k slowly decays, reversed energy flux from potential to kinetic energy occurs intermittently whereas in the artificially forced non-sheared case energy always flows from kinetic to potential energy. The reversed energy flux occurs through the vertical velocity component and therefore this component is sustained unlike in the non-sheared case. This difference is likely to be connected to the observed difference in the vertical velocity structures (see Fig. 1). Nevertheless the overall behavior is quite similar to that observed by Brethouwer et al. The two distinct regimes according to R are clearly observed also in this study.

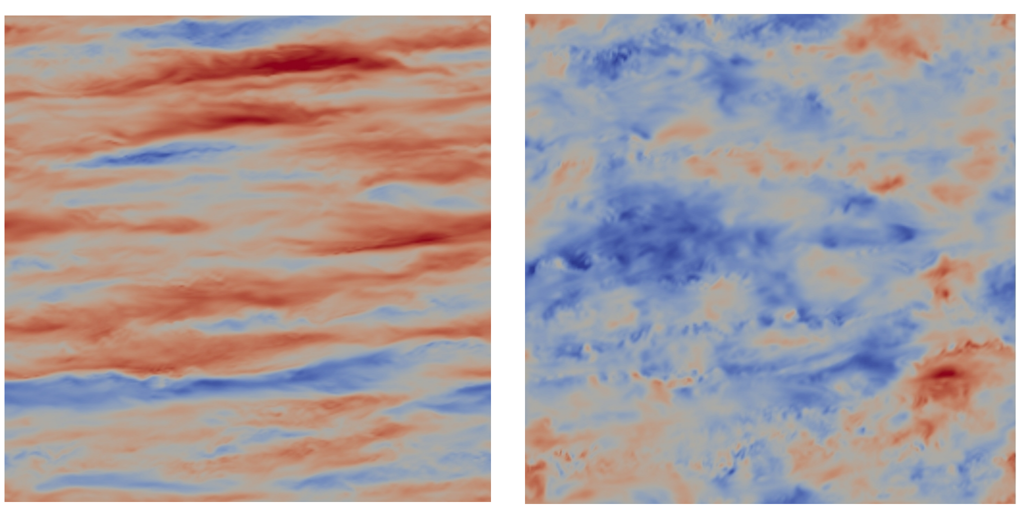

Figure 1. Instantaneous fields of horizontal streamwise velocity component (left) and vertical component (right).