Overturning scales in stratified turbulence

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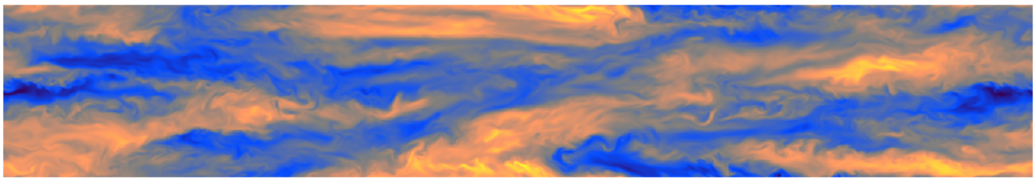
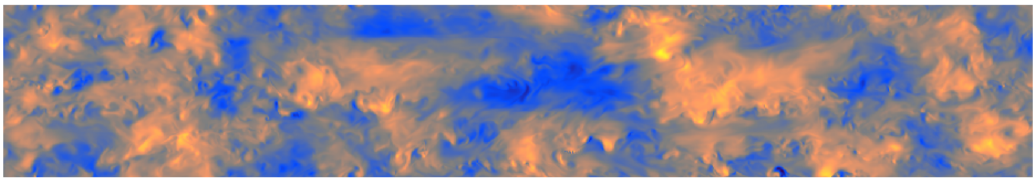
A key quantity regarding turbulent mixing in the atmosphere and oceans is the largest scale of the overturning motions. It has long been claimed that the largest overturning scale is set by the Ozmidov scale ℓ_{oz}, but recent simulations have pointed to the buoyancy scale as being the scale of the large overturning flows [1]. An impartial measurement of the overturning scale is provided either by the Thorpe scale ℓ_T or the Ellison scale ℓ_E, which are based on density profile measurements. Support for the claim that the buoyancy scale ℓ_b is the overturning scale is provided by a recent investigation [2] in which it is found that $\ell_T \sim u_h/N = \ell_b$ for Froude numbers $Fr_h = u_h/N\ell_h < 1$.

We here present some theoretical ideas based on the strongly stratified turbulence theory leading to the result $w_{\mathrm{rms}} \sim \sqrt{Fr_h} u_h$, where w is the vertical velocity. This result stems from the fact that the vertical velocity is a small scale quantity in stratified turbulence. This is confirmed by visualisations from direct numerical simulations (DNS) of turbulence in a linearly stratified fluid, showing layers in all fields except for w, which appears more isotropic (see Figure 1(a) and (b)). At small scales the prediction is indeed that there is a return to isotropy [3]. Now, oceanographic data presented in Ref. [4] highlights that $\ell_T \sim w_{\mathrm{rms}}/N$ in the oceanic thermocline and according to our novel scaling for w_{rms} this simplifies to $\ell_T \sim \sqrt{Fr_h} u_h/N \sim \sqrt{\epsilon_k/N^3} = \ell_{oz}$, estimating the dissipation rate as $\epsilon_k \sim u_h^3/\ell_h$. Hence the competition between buoyancy and Ozmidov scales as an ideal candidate for the overturning scale continues. The difference in parameter range in terms of Fr_h and the buoyancy Reynolds number $\mathcal{R}$ between the DNS that show ℓ_b as being the relevant scale and the ocean data that point towards ℓ_{oz} could be the explanation for the observed discrepancy. We present high-resolution DNS data comparing the Thorpe and Ellison scales to these two candidate scales, ℓ_b and ℓ_{oz}, to try and shed some light on this issue.



(a)



(b)

Fig. 1: Visualisations of a vertical x-z plane from a DNS of decaying stratified turbulence started with $Fr_0 = 0.33$ and $\mathcal{R}_0 = 43$ after 10 eddy turnover times. (a) v (horizontal, y-velocity component) (b) w (vertical, z-velocity component).

References

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