Rotating Stratified Turbulence

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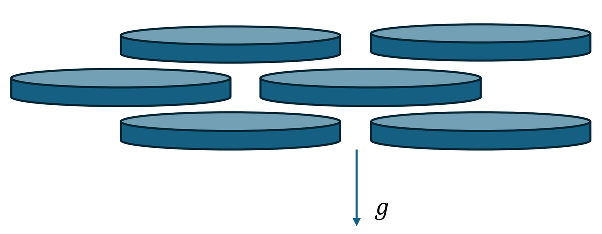
Abstract

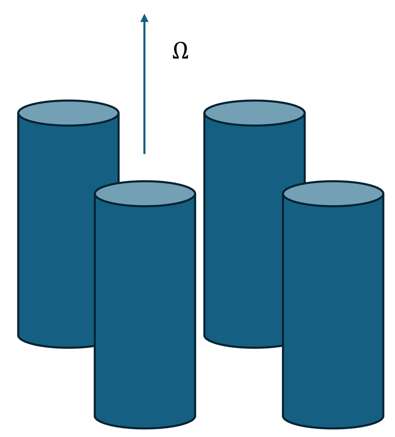
Recent interest in the dynamics of stratified turbulence has led to the development of new models for quantifying vertical transport of momentum and buoyancy (Chini *et al* 2022, Shah *et al* 2024). These models are still incomplete as they do not yet include all of the relevant dynamics often present in real physical settings such as rotation and magnetic fields. Here we expand on prior work by adding rotation. We conduct 3D direct numerical simulations of rotating, stochastically forced, strongly stratified turbulence ($Fr \ll 1$), and vary the Rossby number. We find that rotation gradually suppresses small-scale 3D motions and therefore inhibits vertical transport as Ro decreases towards Fr. The effect is particularly pronounced within the cores of emergent cyclonic vortices. For sufficiently strong rotation, vertical motions are entirely suppressed.

Motivation

Nonrotating stratified turbulence is characterized by strongly anisotropic pancake structures within the flow.



Rotation promotes barotropic structures which are invariant along the axis of rotation.

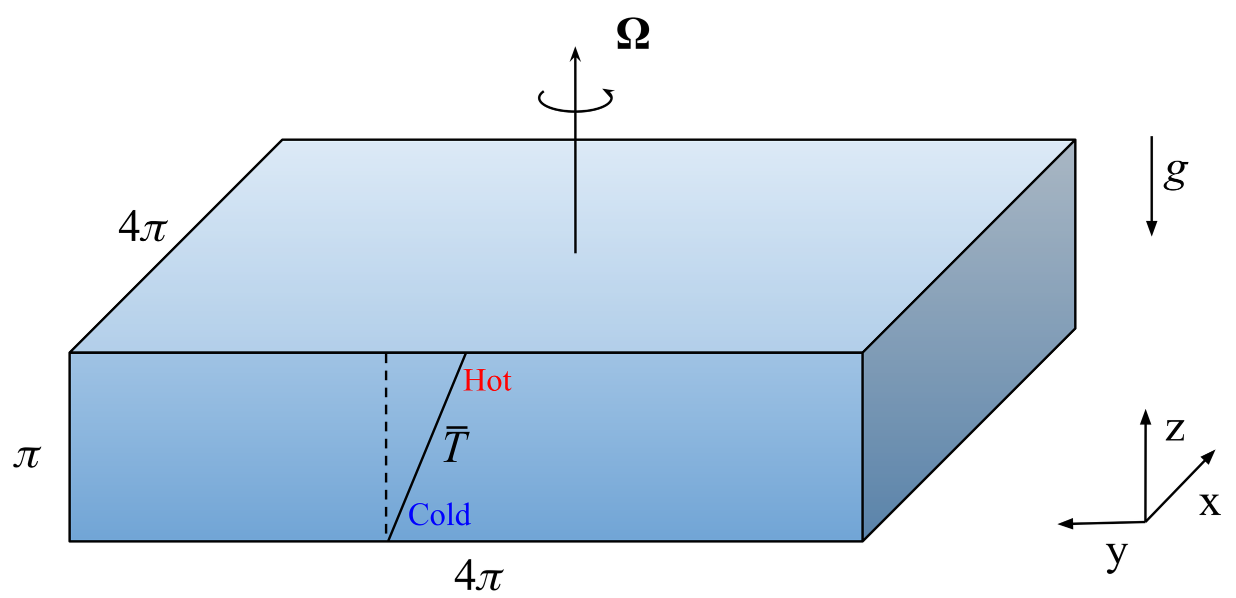


The Equations

$$\frac{D\boldsymbol{u}}{Dt} + \frac{1}{Ro}\boldsymbol{e}_z \times \boldsymbol{u} = -\nabla p + \boldsymbol{F} + \frac{1}{Fr^2}T\boldsymbol{e}_z + \frac{1}{Re}\nabla^2\boldsymbol{u}$$

$$\frac{DT}{Dt} + w = \frac{1}{Pe}\nabla^2 T, \quad \nabla\cdot\boldsymbol{u} = 0$$

$$Re = \frac{UL}{\nu}, \quad Pe = \frac{UL}{\kappa_T}, \quad Fr = \frac{U}{NL}, \quad Ro = \frac{U}{2\Omega L}$$



Stochastic Forcing

We choose the forcing to be purely horizontal and divergence-free stochastic process:

$$\boldsymbol{F} = F_x\boldsymbol{e}_x + F_y\boldsymbol{e}_y, \quad \nabla\cdot\boldsymbol{F} = 0$$

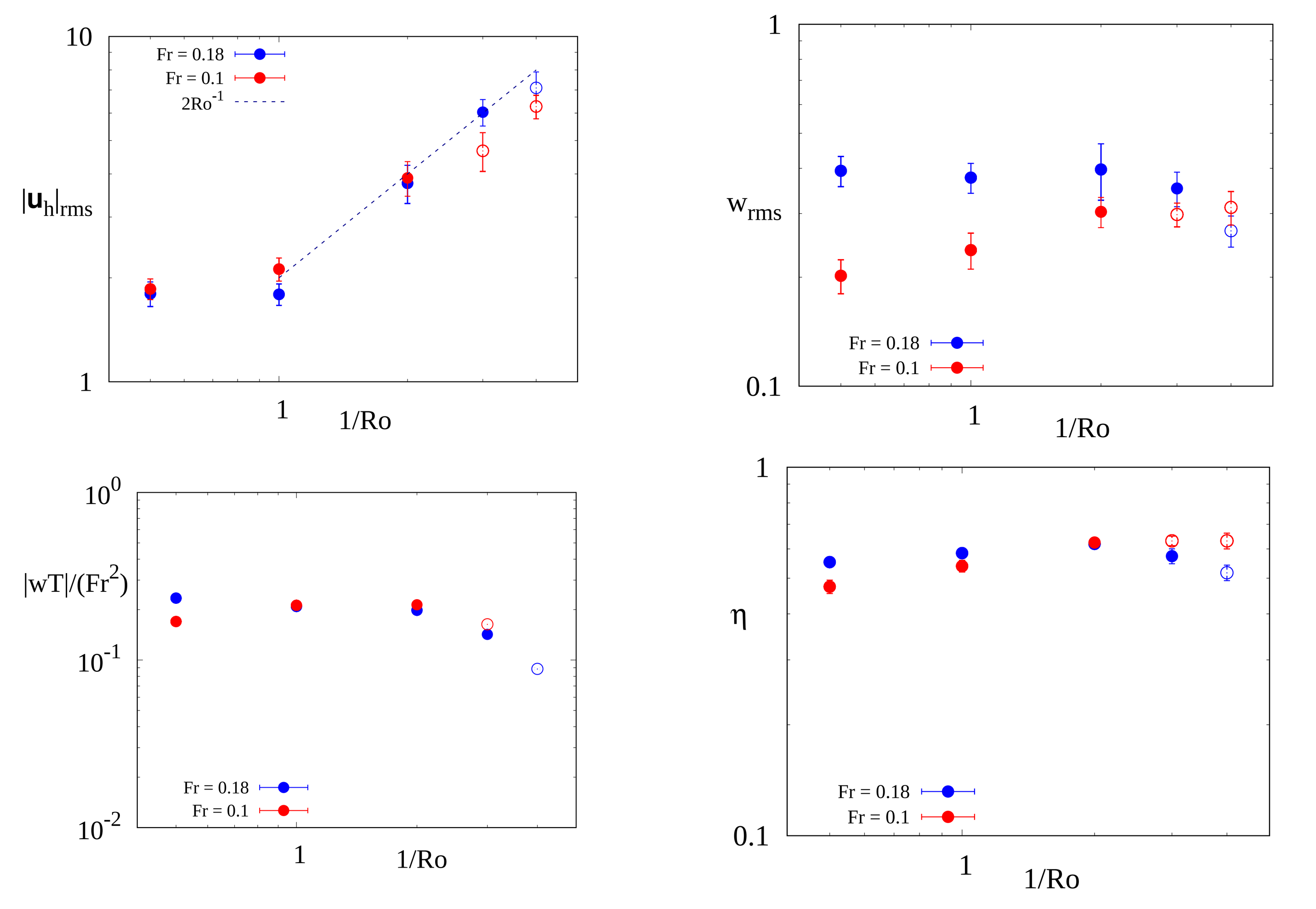
The forcing is applied in spectral space and satisfies $\boldsymbol{k}\cdot\hat{\boldsymbol{F}} = 0$:

$$\hat{F}_x = \frac{k_y}{|\boldsymbol{k}_h|}G(\boldsymbol{k}_h, t), \quad \hat{F}_y = \frac{-k_x}{|\boldsymbol{k}_h|}G(\boldsymbol{k}_h, t)$$

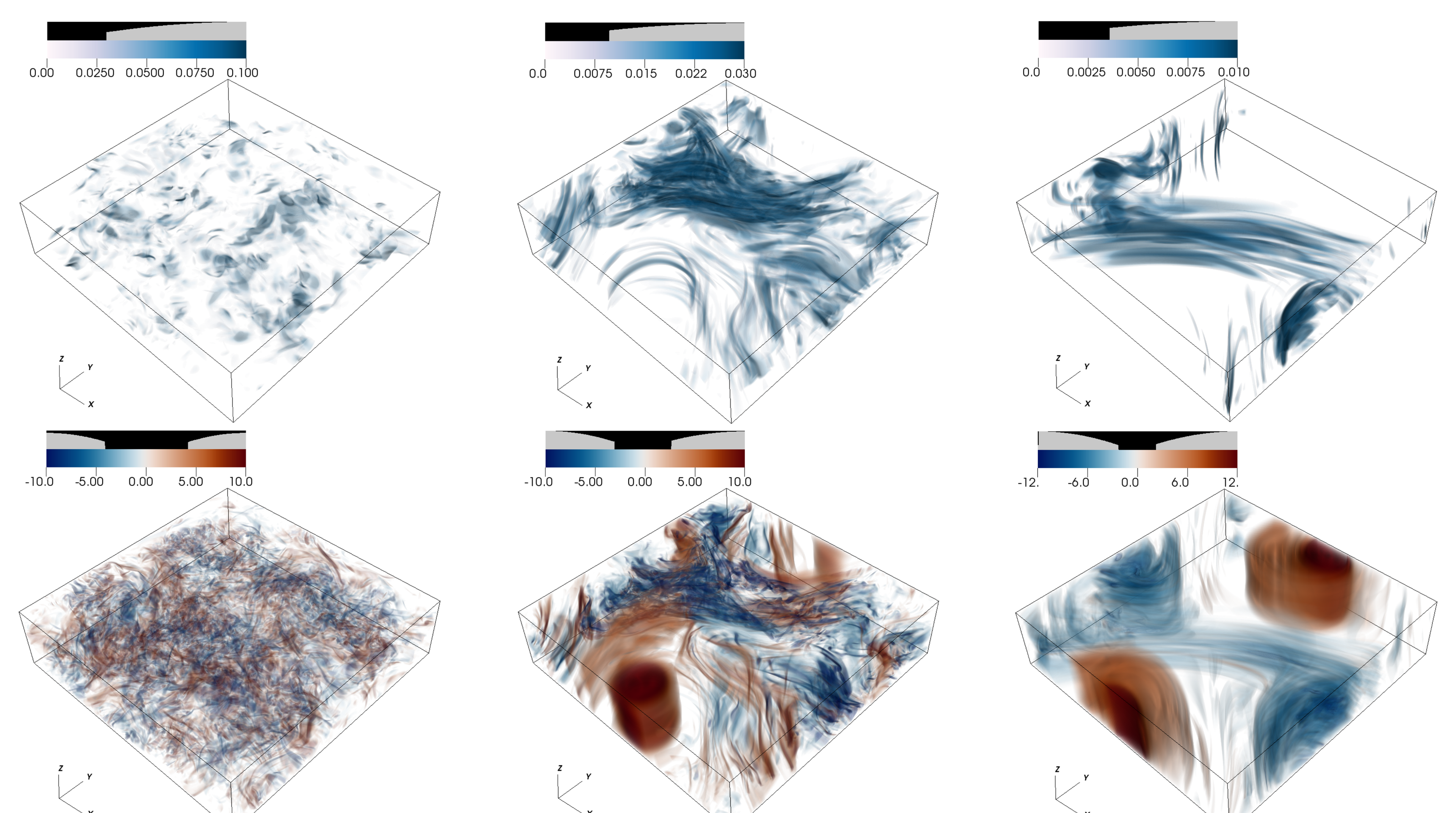
where $G(\boldsymbol{k}_h, t)$ is a Gaussian process of amplitude 1 and correlation timescale 1, and $|\boldsymbol{k}_h| \le \sqrt{2}$.

c.f. Waite and Bartello (2004)

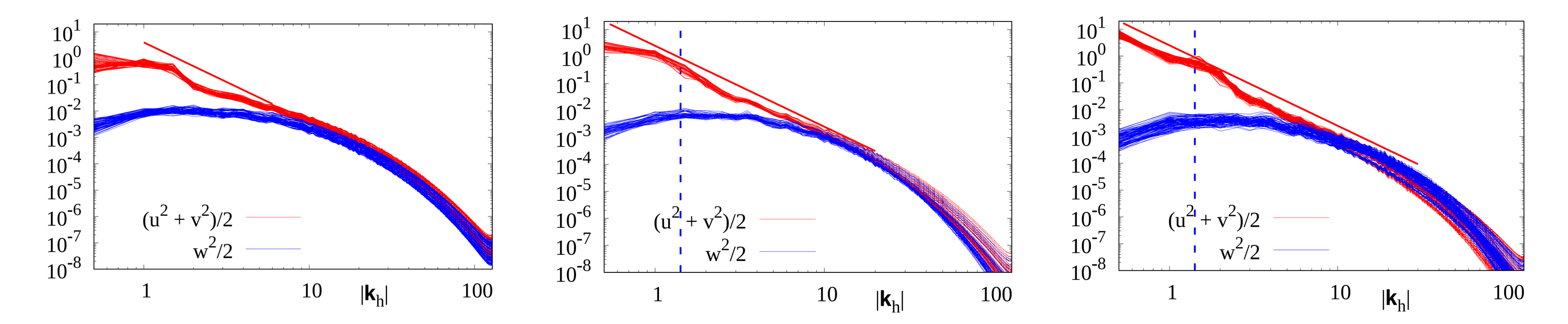
Quantitative Results



Qualitative Results



Qualitative Results



Vertically Averaged Quantities

References

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