Chair: Physics of Fluids group

Swirling Kolmogorov flow

A toy model for ocean mixing driven by near-inertial waves

Description

In the ocean interior, the vertical transport of heat and salt, as well as other scalars such as carbon and nutrients, is determined by the intensity of turbulent mixing. This turbulence is often associated with the breaking of internal waves, which arise due to the stable density stratification and the Earth's rotation [1]. Idealised studies often model the breaking event as a competition between wave shear and stable stratification, leading to a roll-up through the Kelvin-Helmholtz instability. However, when rotation is taken into account, internal waves do not produce a two-dimensional shear flow, but a three-dimensional flow where the direction of the velocity vector changes with depth. This effect is most prominent for near-inertial waves where the dominant restoring force is due to the Coriolis effect [2].

Kolmogorov flow was first introduced as a simple, controlled system for studying the effects of shear on complex fluid flow away from boundaries. A single sinusoidal mode of the horizontal velocity is forced, producing an oscillating shear flow. The laminar solution becomes unstable at moderate Reynolds numbers, leading to a complex flow sustained by the shear forcing [3, 4]. We propose to modify this single forcing mode to include the swirl associated with near-inertial waves. The swirling mean flow can be expected to significantly modify the flow structure compared to the 2-D rolls often seen in classical Kolmogorov flow.

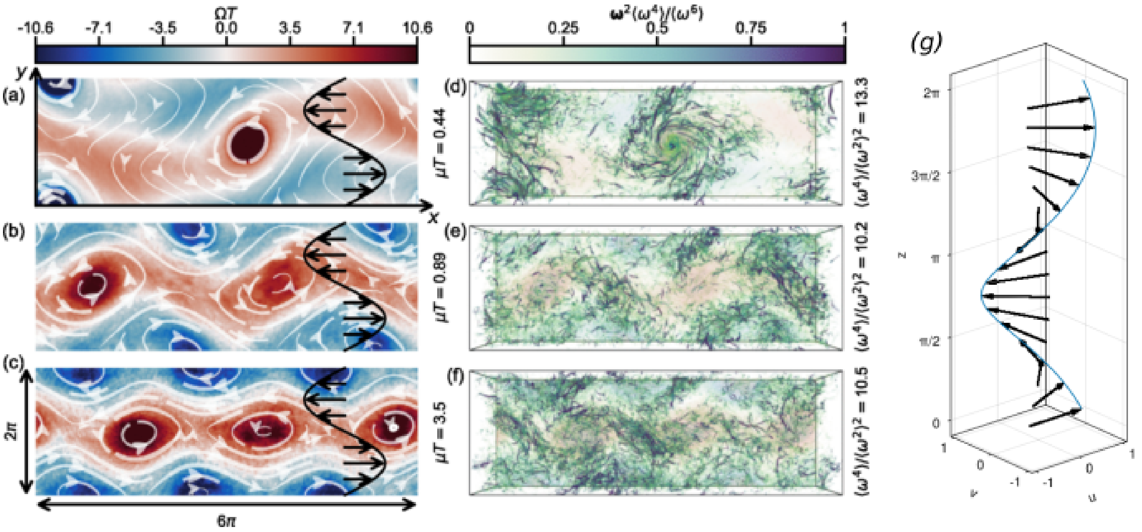

Figure 1: (a)-(f) Example flow fields from simulations of classical Kolmogorov flow by [5] showing the typical 2-D roll structure. (g) Typical helical velocity profile of an inertial wave, and the forcing to be applied to swirling Kolmogorov flow.

Assignment

The student will start the project by reproducing previous results from classical Kolmogorov flow in triply periodic domains, both in 2-D and 3-D to get acquainted with the literature and using the code. Once this is achieved, they will introduce the swirl forcing, and investigate how key properties of the turbulence compare to the classical case. This includes profiles of the Reynolds stress and turbulent dissipation as well as energy spectra. Multiple cases will be run at varying Reynolds number to investigate the effect on these quantities and the flow structures.

The student will learn the basics of high performance computing (HPC), and develop vital skills in data analysis, turbulence research, and flow visualisation.

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References

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[2] M. H. Alford, J. A. MacKinnon, H. L. Simmons, and J. D. Nash, "Near-Inertial Internal Gravity Waves in the Ocean", Annu. Rev. Mar. Sci. **8**, 95–123 (2016).

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[4] S. Musacchio and G. Boffetta, "Turbulent channel without boundaries: The periodic Kolmogorov flow", Phys. Rev. E **89**, 023004 (2014).

[5] C. C. Lalescu and M. Wilczek, "Transitions of turbulent superstructures in generalized Kolmogorov flow", Phys. Rev. Research **3**, L022010 (2021).