Chair: Physics of Fluids group

Simulating the minimal unit of vertical convection

Description

The convection of a fluid in a vertical channel controls the heat flux in a number of important industrial and environmental applications from interior wall cavities to coolers in nuclear reactors. For large-scale applications with strong thermal driving, characterised by a high Rayleigh number Ra, the convection flow becomes more and more turbulent, making purely theoretical descriptions of the dynamics challenging. Direct numerical simulation allows us to investigate such turbulent dynamics, but requires resolution of an increasing range of scales as Ra increases. Research is constantly ongoing to reduce the computational cost of these large-scale simulations.

For pressure-driven turbulent boundary layer flows, past work identified the so-called 'minimal unit' of channel flow: the smallest domain for which the flow statistics are representative of those in larger domains [1]. This allowed the subsequent study of high Reynolds number flows at reduced computational cost. In this project, we aim to find a similar minimal unit for the vertical convection flow geometry. By comparing the flow statistics from various domain aspect ratios, and comparing 2-D and 3-D simulations, we will identify how restricting the domain size affects how heat is transported through the domain.

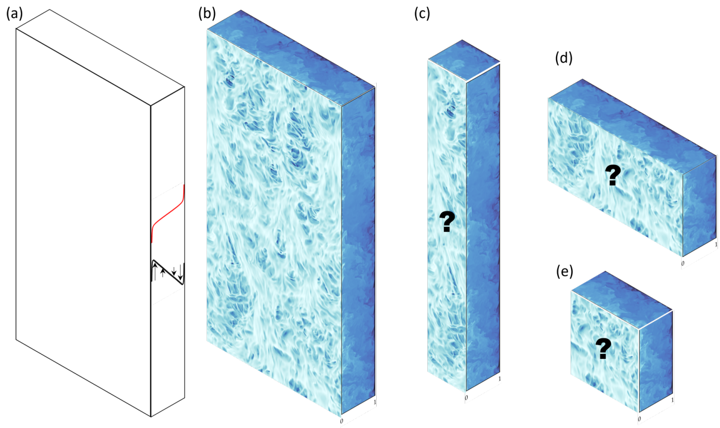

Figure 1: (a) Schematic of the simulation domain, with the mean velocity profile and mean temperature profile shown. (b) Instantaneous snapshot of heat flux and temperature field in fully resolved simulation. (c)-(e) Examples of the smaller domains to be investigated in the project. Will the structures stay the same?

Assignment

This project will involve using a state-of-the-art numerical code to perform numerical simulations of flow in a vertical channel, similar to the setup used by [2]. The student will learn the basics of numerical simulation techniques and using high performance computers (HPC). Analysing the results of the simulations will help the student gain basic skills in data science using Python.

Bachelor responsibilities: Run 2-D and 3-D numerical simulations at various aspect ratios. Analyse variations in mean profiles and second order statistics.

Master responsibilities: As above, but extend simulations to a wider range of parameters (various Ra and Prandtl number Pr). Extend the analysis to include boundary layer widths and energy spectra.

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References

[1] J. Jiménez and P. Moin, "The minimal flow unit in near-wall turbulence", Journal of Fluid Mechanics **225**, 213–240 (1991).

[2] C. J. Howland, C. S. Ng, R. Verzicco, and D. Lohse, "Boundary layers in turbulent vertical convection at high Prandtl number", J. Fluid Mech. **930**, A32 (2022).