Chair: Physics of Fluids group

Simplified atmospheric convection

Comparing idealised models for moisture in Rayleigh-Bénard convection

Description

The presence of water vapour in the atmosphere significantly impacts the fluid dynamics of the air around us. The condensation of water drops to form clouds releases energy through latent heat, which in turn affects the large-scale convection flows that emerge due to temperature variations in the air. Although the thermodynamics of the condensation of water vapour are relatively well understood, the direct dynamical consequences of these effects are not [1].

Shallow water models have been extended to include moisture, capturing the behaviour of some large-scale motions well [2]. However, such models are intrinsically 2-D, and will not accurately capture all the physics of convection. Recent studies have proposed different models to extend three-dimensional Boussinesq sytems with the thermodynamic effects of water vapour [3–5]. Agreement has not been reached in the research community for a single model of how moisture should be treated in such idealised systems, so it is important to identify how the differences in these systems affect the results.

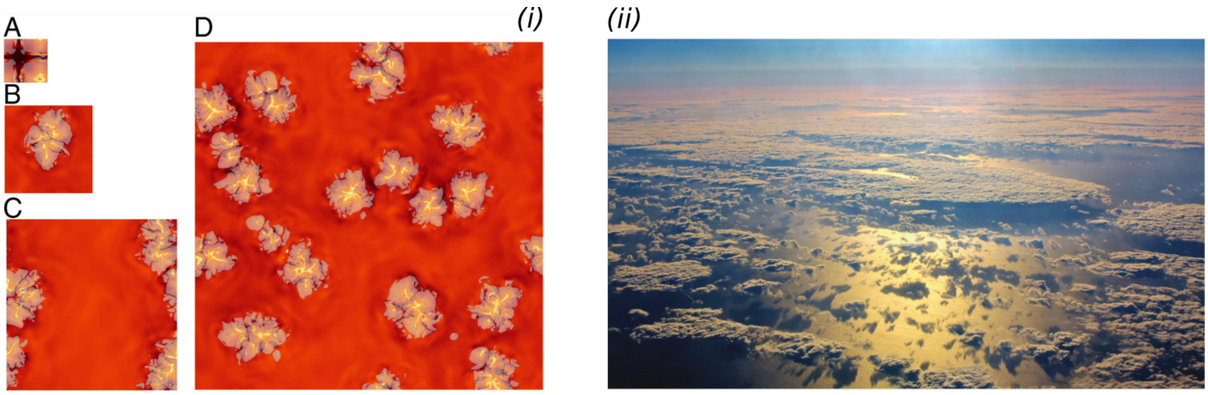

Figure 1: (i) Top-down view of emergent convection patterns in a moist Rayleigh-Bénard system from [6]; (ii) Some beautiful motivating atmospheric dynamics [7]

Assignment

This Masters assignment will involve performing three-dimensional simulations in the classical Rayleigh-Bénard configuration of two horizontal plates held at different fixed temperatures. The student will implement the two models of [4] and [5] into our existing high performance simulation code. Validation against existing results in the literature will be performed, followed by a detailed comparison study between the models. The effect of moisture on the flow structures and heat transport will be quantified in terms of the control parameters of the system. One key difference between the two models is in the treatment of liquid water drops, so we will focus on identifying which phenomena are ubiquitous in moist convection, and which are dependent on the model.

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

[1]G. K. Vallis, "The Trouble with Water: Condensation, Circulation and Climate", Eur. Phys. J. Plus **135**, 478 (2020).

[2]M. Rostami and V. Zeitlin, "An improved moist-convective rotating shallow-water model and its application to instabilities of hurricane-like vortices", Quarterly Journal of the Royal Meteorological Society **144**, 1450–1462 (2018).

[3]J. P. Mellado, B. Stevens, H. Schmidt, and N. Peters, "Two-fluid formulation of the cloud-top mixing layer for direct numerical simulation", Theor. Comput. Fluid Dyn. **24**, 511–536 (2010).

[4]J. Schumacher and O. Pauluis, "Buoyancy statistics in moist turbulent Rayleigh–Bénard convection", Journal of Fluid Mechanics **648**, 509–519 (2010).

[5]G. K. Vallis, D. J. Parker, and S. M. Tobias, "A simple system for moist convection: the Rainy–Bénard model", Journal of Fluid Mechanics **862**, 162–199 (2019).

[6]O. Pauluis and J. Schumacher, "Self-aggregation of clouds in conditionally unstable moist convection", Proceedings of the National Academy of Sciences **108**, 12623–12628 (2011).

[7]J. P. Mellado, "Cloud-Top Entrainment in Stratocumulus Clouds", Annual Review of Fluid Mechanics **49**, 145–169 (2017).