A proof of concept for data-driven parametrisation in Rayleigh-Bénard convection

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Originality statement

I hereby declare that this submission is my own work and to the best of my knowledge it contains no materials previously published or written by another person, or substantial proportions of material which have been accepted for the award of any other degree or diploma at UNSW or any other educational institution, except where due acknowledgement is made in the thesis. Any contribution made to the research by others, with whom I have worked at UNSW or elsewhere, is explicitly acknowledged in the thesis. I also declare that the intellectual content of this thesis is the product of my own work, except to the extent that assistance from others in the project's design and conception or in style, presentation and linguistic expression is acknowledged.

Thomas D. Schanzer
10 November 2023

Author contribution statement

I have produced all code, simulations, analysis and writing associated with this thesis from scratch, with no assistance from others except supervisory guidance from Prof. Steven Sherwood and A/Prof. Scott Hottovy (USNA), and occasional verbal advice from members of Prof. Sherwood's research group.

Data availability statement

All code and raw data needed to produce the results in this thesis have been made publicly available. Availability details, along with a high-level description of the code and instructions for reproducing the results, are given in Appendix A.

Acknowledgements

It is with immense gratitude that I acknowledge the following individuals and groups who have supported me during the last nine months of research.

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A/Prof. Scott Hottovy of the US Naval Academy visited the CCRC on sabbatical earlier this year. He took interest in my project and provided additional guidance from his experience as a mathematician, and has continued to give advice and review my writing since returning to the US.

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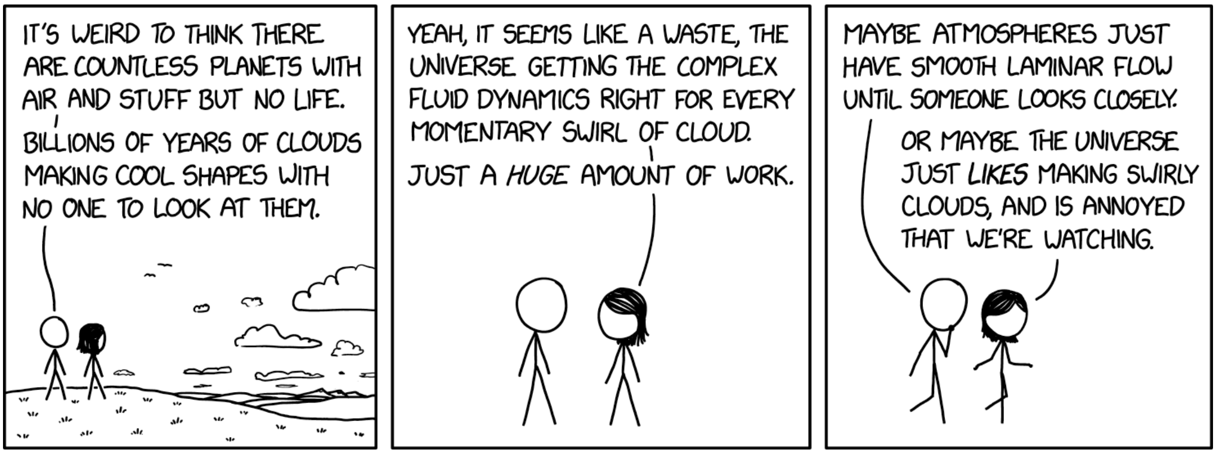
Honours has been a challenging, yet rewarding journey that has developed me both as a scientist and as a person. I again thank everyone who has been involved as I look forward to applying my newfound skills and knowledge in the future.



Randall Munroe, xkcd.com

Abstract

Weather and climate models use so-called parametrisation schemes to emulate the effects of small-scale processes that they cannot resolve explicitly. Data-driven methods for constructing these schemes have attracted considerable research attention in recent years, but remain subject to important outstanding questions. Using the simpler case of two-dimensional Rayleigh-Bénard convection as an analogue for the climate system, this thesis presents a complete proof of concept for a data-driven approach that quantifies subgrid tendencies—the effects of unresolvable processes—by systematically coarse-graining high-resolution training data. A parametrisation scheme constructed using this method is shown to be able to improve both the short-term forecast accuracy and long-term statistical accuracy of a low-resolution model. This work identifies and addresses subtle technicalities associated with the coarse-graining process, establishing concrete computational tools with which future work will be able to address remaining unanswered questions surrounding data-driven methods and potentially inform parametrisation development in real weather and climate models.

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