Effects of thermal boundary conditions on rotating Rayleigh-Bénard convection with implications on geophysical and astrophysical systems

Janet Peifer\textsuperscript{1,2}, Onno Bokhove\textsuperscript{1,2}, and Steve Tobias\textsuperscript{1,2}

\textsuperscript{1}University of Leeds, Applied Mathematics, Leeds, United Kingdom of Great Britain – England, Scotland, Wales (ee17jfp@leeds.ac.uk)
\textsuperscript{2}University of Leeds, Leeds Institute for Fluid Dynamics, Leeds, United Kingdom of Great Britain – England, Scotland, Wales

Rayleigh-Bénard convection (RBC) is a fluid phenomenon that has been studied for over a century because of its utility in simplifying very complex physical systems. Many geophysical and astrophysical systems, including planetary core dynamics and components of weather prediction, are modeled by including rotational forcing in classic RBC. Our understanding of these systems is confined by experimental and numerical limits, as well as theoretical assumptions.

The role of thermal boundary condition choice on experimental studies of geophysical and astrophysical systems has been often been overlooked, which could account for some lack of agreement between experimental and numerical models as well as the actual flows. The typical thermal boundary conditions prescribed at the top and the bottom of a convection system are fixed temperature conditions, despite few real geophysical systems being bounded with a fixed temperature. A constant heat flux is generally more applicable for real large-scale geophysical systems. However, when this condition is applied in numerical systems, the lack of fixed temperature can cause a temperature drift. In this study, we seek to minimize temperature drifting by applying a fixed temperature condition on one boundary and a fixed thermal flux on the other.

Experimental boundary conditions are also often assumed to be a fixed temperature. However, the actual condition is determined by the ratio of the height and thermal conductivity of the boundary material to that of the contained fluid, known as the Biot number. The relationship between the Biot number and thermal boundary condition behavior is defined by the Robin, or ‘thin-lid’, boundary condition such that low Biot number boundaries are essentially fixed thermal flux and high Biot number boundaries are essentially fixed temperature.

This study seeks to strengthen the link between numerical and experimental models and geophysical flows by investigating the effects of thermal boundary conditions and their relationship to real-world processes. Both fixed temperature and fixed flux boundary conditions are considered. In addition, the Robin boundary condition is studied at a range of Biot numbers spanning from fixed temperature to fixed flux, allowing intermediate conditions to be investigated.
Each system is studied at increasingly rapid rotation rates, corresponding to decreasing Ekman numbers as low as $\text{Ek}=10^{-5}$. Heat transport is analyzed using the Nusselt number, $\text{Nu}$, and the form of the solution is described by the number of convection rolls and time-dependency. Further investigations will analyze $\text{Nu}$ and fluid movement within a system with heterogeneous heat flux condition on the sidewall boundary conditions, which is useful in the study of planetary core dynamics. The results of this study have implications for improvements in modeling geophysical systems both experimentally and numerically.