A numerical investigation on Rayleigh–Bénard convection driven by various gravity profiles

張敬

清華大學動力機械工程系

ABSTRACT

Rayleigh–Bénard convection is a widely observed phenomenon in many scientific and engineering settings. In geophysics and astrophysics, it governs the transport of heat, momentum and mass within stars and planets. We numerically investigates thermally driven natural convection in a non-rotating spherical shell using the Boussinesq approximation. Simulations are performed at Prandtl number Pr of unity and Rayleigh number Ra ranging from 10^3, from the convective onset to a turbulent regime of 10^8. A range of radius ratios ($\eta = r_i/r_o$, from 0.2 to 0.8) and radial gravity profiles, including constant gravity, linear gravity ($g \propto r$), and inverse-square gravity ($g \propto r^{-2}$), are considered. Both the laminar flow near the onset of convection and the fully turbulent regime are calculated using a pseudo-spectral method, which provides high-precision solutions of the governing equations in spherical coordinates. Curvature effects and radially varying gravity modify the critical conditions for the onset and lead to asymmetric thermal and momentum boundary layers in turbulent flows. An integral analysis is employed to derive a gravity-dependent factor $\Gamma(\eta)$, defined as a function of the radius ratio and the gravity profile. This factor characterizes the critical Rayleigh number Ra_c at onset, the thermal boundary-layer thickness ratio and the characteristic mid-shell temperature T_{bulk} in the turbulent regime, and the scaling laws for Nusselt number Nu and Reynolds number Re.