Suppression of Rayleigh-Bénard convection and restratification by horizontal convection

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Abstract

We investigate the competition between horizontal convection (HC) and Rayleigh–Bénard convection (RBC) in a fluid layer subject to a uniform destabilizing buoyancy flux at the bottom and a horizontally varying buoyancy distribution at the top. The RBC forcing imposes negative horizontal mean vertical buoyancy gradients at the top and bottom of the fluid layer. But if the HC forcing is sufficiently strong then the volume averaged vertical buoyancy gradient, , is positive i.e. opposite in sign to destabilizing RBC buoyancy gradients at the boundaries. If > 0 we say that the layer has been restratified.

Using scaling analysis based on power integrals and numerical solutions we identify two cases: a neutral stratification state, in which HC first offsets RBC so that = 0, and a strong stratification regime, in which HC dominates and is opposite in sign, and greater in magnitude, than the prescribed destabilizing vertical buoyancy gradient at the layer boundaries. We derive scaling laws for the onset of these regimes in terms of the horizontal and vertical flux Rayleigh numbers, RaH and RaV, finding RaHN _˜ RaV^{4/5} for the neutral state and RaHstrg _˜ RaV for the onset of strong stratification. The results highlight the controlling role of the top boundary layer in setting the mean stratification and clarify the conditions under which HC suppresses RBC.

These findings are relevant to geophysical environments such as subglacial lakes, and the oceans of Snowball Earth and icy moons, where bottom heating and horizontal buoyancy variations jointly shape ocean stratification.<

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sciencesconf.org:rbc2026:696107