The Geostrophic Regime of Rotating Rayleigh-Bènard Convection

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Abstract We report on experimental measurements of rotating Rayleigh-Bènard convection in the geostrophic régime where the convective Rossby number Ro is much less than one. In particular, we explore the scaling of heat transport from the onset of convection up to the transition to boundary-layer dominated turbulent convection. We also characterize the nature of vortical coherent structures using local température measurements and thermo-chromic liquid crystal flow visualization.

Rayleigh-Bènard convection (RBC), a bounded fluid layer heated from below and cooled from above, displays a rich set of phenomena when subjected to rotation about a vertical axis. In particular, the formation of vortical structures is of interest as a model for such behavior in geophysical systems such as atmospheres and oceans. Rotating RBC has been studied fairly extensively, both experimentally and through numerical simulation, for moderate Ra and Ta and in the range of parameters where thin thermal boundary layers limit the heat transport efficiency [1-5]. We investigate heat transport and local temperature and velocity in rotating RBC over a range of parameters where boundary layers are not expected to dominate heat transport and where strong vortical structures in the bulk play important roles in the turbulent dynamics. This range has received considerable recent interest owing to theoretical predictions obtained from asymptotic equations in the limit of very strong rotation [6].

RBC is controlled by three dimensionless parameters, the Rayleigh, Taylor and Prandtl numbers. The Rayleigh number Ra = $g\alpha\Delta TH^3/\nu\kappa$ where g is acceleration of gravity, α is the thermal expansion coefficient, ΔT is the temperature difference DT across the layer of height H, ν is the kinematic viscosity and κ is the thermal diffusivity. The Taylor number Ta = $(4\pi\ f\ H^2/\nu)^2$ where f is the rotational frequency about a vertical axis. The Prandtl number is Pr = ν/κ. A final dimensionless measure of the relative dominance of buoyancy over rotation is the convective Rossby number Ro = $(Ra/(Pr\ Ta))^{1/2}$. The lateral size of the cell L may play a role in the turbulent dynamics so we also specify the cell aspect ratio Γ=L/H. Our experiment is a square geometry with height H=12.1 cm and L=48.5 cm so that Γ=4. We work in a range $10^6 <$ Ra $< 10^8$ and $10^9 <$ Ta $< 5\times10^{10}$ using water at a mean cell temperature of 25 C corresponding to Pr = 6.1. The corresponding range of Rossby number is $0.005 <$ Ro < 0.1, i.e., Ro <<1 implying the dominance of rotation over buoyancy. We have explored these parameter regions and provide new measurements of heat transport and local temperature with corresponding flow visualization to quantitatively characterize the scaling of heat transport and the identification of the coherent vortical structures that dominate turbulence in the geostrophic regime of rotating RBC. In Figure 1, we show strong vertical correlations of temperature that are highly suggestive of convective Taylor columns.

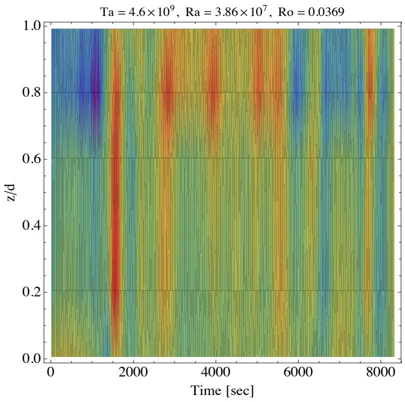

Figure 1. Space-time plot of temperature fluctuations showing strong vertical correlations.

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