Scaling regimes in rapidly rotating turbulent convection

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The geostrophic turbulence regime in rapidly rotating thermal convection exhibits characteristics shared by many highly turbulent geophysical and astrophysical flows. In this regime, the convective length and velocity scales, heat flux, and kinetic and thermal dissipation rates are all diffusion-free, meaning that they are independent of the viscosity and thermal diffusivity. Our direct numerical simulations of rotating Rayleigh-Bénard convection in domains with no-slip top and bottom and periodic lateral boundary conditions for a fluid with the Prandtl number $Pr = 1$ and extreme buoyancy and rotation parameters (the Rayleigh number up to $Ra = 3 \times 10^{13}$ and the Ekman number down to $Ek = 5 \times 10^{-9}$) indeed demonstrate these diffusion-free scaling relations and, in particular, that the dimensionless convective heat transport scales with the supercriticality parameter $Ra_c = RaEk^{4/3}$ as $Nu - 1 \propto Ra_c^{3/2}$, where Nu is the Nusselt number. Under the assumption that with the decreasing Ra_c the geostrophic turbulence regime undergoes a transition into another geostrophic regime which is also governed by the diffusion-free convective length scale, we derive that the convective heat transport in that regime is characterized by a very steep Ra_c-dependence, $Nu - 1 \propto Ra_c^3$. This result as well as the derived scaling relations for the Reynolds number and kinetic and thermal dissipation rates in both regimes are all supported by our direct numerical simulations.

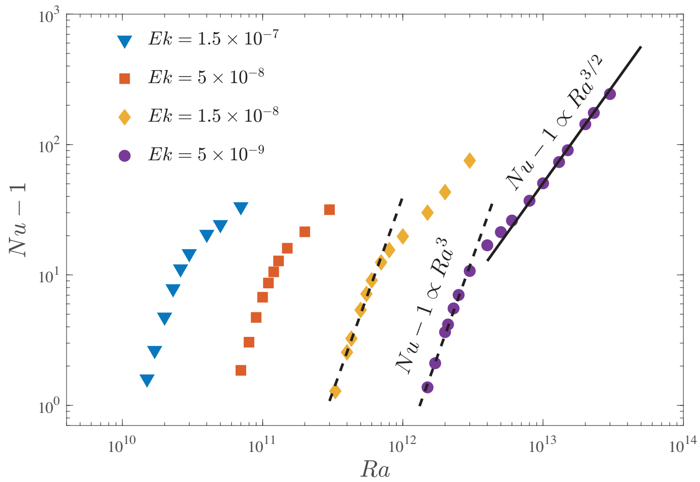

Figure 1: Dimensionless convective heat transport $Nu - 1$ as a function of Rayleigh number with different Ekman numbers. One can see that when Ra is sufficiently large and Ek sufficiently small, the convective heat transport scales as $\propto Ra^3$ for relatively smaller values of Ra and as $\propto Ra^{3/2}$ for larger Ra.

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