The transition from wall modes to quasi-geostrophic rapidly rotating Rayleigh–Bénard convection

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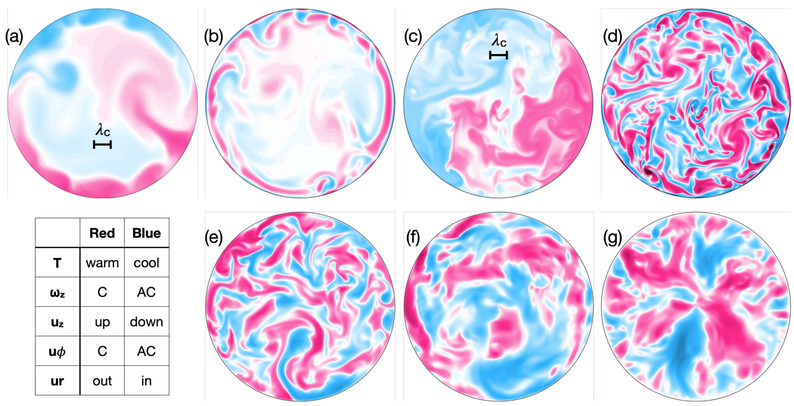
We use DNS to investigate[1 2 3] the states of rapidly rotating Rayleigh–Bénard connection[4] in a cylindrical container with diameter-to-height radio $\Gamma = 1/2$, Ekman number $Ek = 10^{-6}$, Prandtl number $Pr = 0.8$, and Raleigh number $3 \times 10^7 \leq Ra \leq 5 \times 10^9$. We characterize the transition to convection via wall mode instability and the nonlinear growth and instability of the resulting wall mode states including a secondary transition to time dependence. This secondary instability is subcritical and takes the form of hot and cold jets emanating from the wall mode on opposite sides, both with cyclonic vorticity (Figs.1 a-b). The bulk mode appears to nucleate in the wall mode region before spreading out into the interior. The transition to a state of bulk convection is influenced by the presence of the wall mode states as demonstrated using temperature T and velocity fields $\{u_\phi, u_z, u_r\}$ and their associated spatial scales (Figs.1 c-h). Nusselt number Nu and Reynolds number are shown to illustrate their dependencies on radial separation and the response of these global measures to the convective state. Our results elucidate the evolution of the wall state of rotating convection and confirm that wall modes and the Boundary Zonal Flow[2 3] (BZF) are strongly linked: the BZF is the robust remnant of nonlinear wall mode states. We also show how the heat transport (Nu) contributions of wall modes and bulk modes are related and how to disentangle (imperfectly) their relative contributions.



	Red	Blue
T	warm	cool
ω_z	C	AC
u_z	up	down
$u\phi$	C	AC
ur	out	in

Figure 1: Horizontal cross-sections at (a-d) the mid height $z/H = 0.5$ and (e-g) $z/H = 0.8$ of (a, c) T, (b, d) vertical component of the vorticity ω_z, and (e-g) u_z, u_ϕ, u_r, respectively. Field colors as in legend lower left. (a, b) $Ra = 10^9$; (c, d) $Ra = 5 \times 10^9$; (e-g) $Ra = 4 \times 10^9$. (a, c) Length scale depicted in terms of bulk λ_c.

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[1]Ecke et al., *Phys. Rev. Fluids* **7**, L011501 (2022).
[2]Zhang et al., *J. Fluid Mech.* **915**, A62 (2021).
[3]Zhang et al., *Phys. Rev. Lett.* **124**, 084505 (2020).
[4]Ecke & Shishkina, *Annu. Rev. Fluid Mech.* **55**, 603–638 (2023).