Turbulent Rapidly Rotating Rayleigh-Bénard Convection: Cyclones Vs Anti-Cyclones

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The large-scale vortices are an inherent feature in rapidly rotating Rayleigh-Bénard convection. A coexistent large-scale cyclone and anticyclone emerge in the domain at $Ro \sim \mathcal{O}(10^{-2})$ (see Figure 1). Here we study the local heat transfer and Taylor-Proudman balance in the domain for the cyclone and anticyclone separately at $Ra = 5 \times 10^8$, $E = 5 \times 10^{-6}$, $Pr = 1$ and for a range of aspect ratio, $1 \leq \Gamma \leq 16$. The domain is instantaneously decomposed into the cyclone and anticyclone regions based on the stream function. The results reveal that heat transfer is more efficient and dependent on the Γ in anticyclone compared to the cyclone, and even within the large-scale anticyclone, the heat transfer is more pronounced within its central core. The Nusselt number within anticyclones decreases with an increase in Γ as it becomes more rotation dominant. The local Taylor-Proudman balance is predominant in cyclone for all the simulated Γ whereas it is more prevalent at $\Gamma \geq 3$ for anticyclone. The global Nusselt number, Nu, vertical Reynolds number , Re_z, were found to be independent of Γ whereas the horizontal Reynolds number, $Re_h \sim \Gamma^{1.88}$ and takes several thousand free fall time units to attain equilibrium. Here we also show rather two statistically stationary flow states exist at $\Gamma \geq 3$, and the transport properties of the flow, namely, Nu and Re are considerably different in these states. Our results demonstrate that local heat transfer and Taylor-Proudman balance vary based on the investigated region (cyclone/anticyclone) of the flow and the aspect ratio. Also, for the explored regime, the global transport properties alone do not divulge the physics happening within the domain.

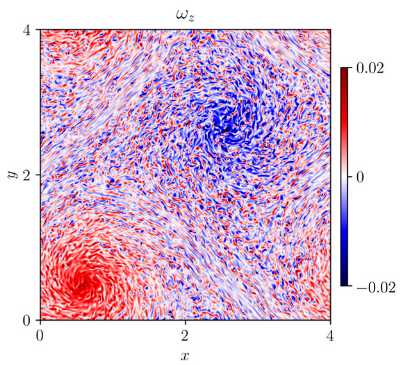

Figure 1: Instantaneous axial vorticity, ω_z, contour at mid-plane for $Ra = 5 \times 10^8$, $E = 5 \times 10^{-6}$, $Pr = 1$ and $\Gamma = 4$.

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