On the Effect of Centrifugal Force in Turbulent Thermal Convection

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Rotation introduces two additional forces in rotating systems, the Coriolis force and the centrifugal force. In turbulent rotating Rayleigh-Bénard convection (RRBC), where a rotating fluid layer is heated below and cooled above, the effects of the Coriolis force have been studied with details. But how the turbulent flow is affected by the centrifugal force (characterized by the Froude number Fr) is far from clear. Even the basic issue concerning when the centrifugal effect starts to manifest itself, or equivalently, what is the onset Froude number Fr_c, is still unresolved.

A critical Froude number Fr_{c2} was obtained by Horn and Aurnou [1], beyond which the centrifugal force becomes *dominant*. In this talk, we will show that the effect of the centrifugal force sets in much earlier than Fr_{c2}[2]. It is found that, after an onset Froude number Fr_c, the bulk temperature measured at cell center increases with Fr. We use this bulk temperature anomaly to determine Fr_c, and find that Fr_c depends on Ra as $Fr_c \sim Ra^{0.53}$, which can be understood by the idea of local force balance. The sidewall temperature measurements show consistent results with the bulk ones, i.e. they start to drop at around Fr_c. After the centrifugal force sets in, the horizontal motion of the hot and cold fluid parcels is enhanced, and thus the possibility of finding hot (cold) fluid parcels at cell center (sidewall) increases, resulting in an enhanced bulk (decreased sidewall) temperature. This physical picture is further proved by subsequent PIV measurements, which shows that the instantaneous flow field is indistinguishable with the one without centrifugal force, but a hot structure emerges at cell center in the long-time averaged mean field [3]. With above results, the phase space can be divided into three regimes. The flow in the regime with $Fr < Fr_c$ is not affected by the centrifugal force. The other two with $Fr_c < Fr < Fr_{c2}$ and $Fr > Fr_{c2}$ are referred to as weak- and strong-Fr regimes, respectively.

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