Magnetic-field-gradient and sidewall effects in magnetoconvection

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We study the influence of spatially-varying magnetic fields on turbulent thermal convection in a horizontally extended rectangular domain[1]. The magnetic field is created in the gap between two semi-infinite planar magnetic poles, with the convection layer located near the edge of the gap. We employ direct numerical simulations in this setup for fixed Rayleigh and Prandtl numbers (Ra $= 10^5$, Pr $= 0.021$), but vary the fringe-width by controlling the gap (δ) between the magnetic poles and the convection cell. The magnetic field generated by the magnets is strong enough to completely suppress bulk convection in the regions of strong magnetic flux. In the regions of weak magnetic flux, the flow organizes into superstructures[2] – prominent and coherent large-scale patterns extending horizontally over scales much larger than the domain height. We observe that as the local vertical magnetic field strength increases, these superstructures become thinner and align themselves perpendicular to the longitudinal sidewalls. This is evident from Fig. 1 which exhibits the contour plots of temperature field for $\delta = 0.3$. We show that the global heat transport decreases with increasing fringe-width for strong magnetic fields but increases with increasing fringe-width for weak magnetic fields.

In the regions of large vertical magnetic fields, the convective motion becomes confined to the vicinity of sidewalls[3]. The amplitudes of these wall modes show a non-monotonic dependence on the fringe-width. We also study the effects of horizontal magnetic field and electric conductivity of the walls on the structure and dynamics of the wall modes.

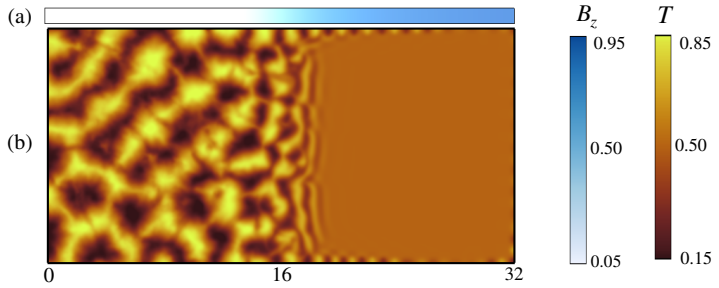

Figure 1: For $\delta = 3$: (a) Distribution of the vertical magnetic field (B_z) in vertical ($y - z$) midplane of the convection cell, (b) instantaneous field of temperature in the horizontal ($x - y$) midplane of the convection cell showing the superstructure patterns and their variations with magnetic field strength. One can also see the wall modes.

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[1]Bhattacharya et al., *arXiv preprint arXiv:2211.00559* (2022)
[2]Pandey et al., *Nat. Commun.* **9**, 2118 (2018).
[3]Busse, *Phys. Fluids* **20**, 024102 (2008).