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Boundary layers of thermal convection at very high Rayleigh numbers

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We perform simulations of Rayleigh-Bénard convection (RBC) at Rayleigh numbers ranging from 10⁵ to 10¹² and a fixed Prandtl number of 0.7. To simulate the canonical RBC setup with infinite horizontal extents, we employ a Cartesian box of aspect ratio 4 and periodic sides. We use the GPU accelerated spectral element solver, NekRS, on the GPU cluster, JUWELS Booster, at Jülich. The excellent scalability of NekRS is demonstrated by the fact that at the highest Ra of 10¹², with a grid of nearly 47 billion points, we report our statistics over 40 free-fall time units within steady-state. This simulation used the full-capacity of JUWELS Booster at nearly 3400 A100 GPUs.

These high resolution simulations have enabled us to study the fine-structure of the boundary layers, identify shear-dominated and plume-dominated regions of the boundary layer flow, and evaluate their effects on heat and momentum transport. Another interesting outcome is that the area-fraction of these two regions is constant for the full range of Rayleigh numbers considered here. Finally, we compare the mean velocity profiles with Blasius profile to probe for signatures of flat-plate boundary layer flow.

Relevance for Nek [100 words max]

The simulations of RBC presented here were performed using NekRS. Furthermore, we push the solver to its limits using very high resolution grids of up to 47 billion points. The scalability of NekRS is also demonstrated by using nearly 3400 GPUs - almost the full capacity of existing GPU computing infrastructure at the Jülich Supercomputing Facility.

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