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LARGE-SCALE DIRECT NUMERICAL SIMULATIONS OF LOW-PRANDTL-NUMBER CONVECTION

D. Krasnov[1], A. Pandey[2], K. R. Sreenivasan[2,3] and J. Schumacher[1,3]

[1] Technische Universität Ilmenau, D-98684 Ilmenau, Germany,
joerg.schumacher@tu-ilmenau.de
[2] New York University Abu Dhabi, Abu Dhabi 129188, UAE
[3] New York University, New York City, NY 11201, USA

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Turbulent convection processes, which are driven by buoyancy forces, are ubiquitous in nature and technology. The specific mechanisms of turbulent heat and momentum transfer are however still poorly understood. One prominent example is turbulent convection in the outer 30% of the interior of the Sun [1]. As in many other stars, convection is here characterized by a very low molecular Prandtl number $Pr = \nu/\kappa \sim 10^{-6}$, the ratio of kinematic viscosity ν (momentum diffusion) to thermal diffusivity κ (temperature diffusion). Furthermore, these convection systems are typically highly stratified with mean state variables pressure p, density ρ, or temperature T that drop by orders of magnitude across the layer. In the present work, we want to investigate some aspects of this complex flow by large-scale direct numerical simulations (DNS) which apply either spectral element or finite difference methods. We conduct these two- and three-dimensional DNS studies mostly in the simplified setting of Rayleigh-Bénard convection in large aspect ratios and decrease the molecular Prandtl number Pr to unprecedented values of $Pr = 10^{-4}$ in the 2d and $Pr = 10^{-3}$ in the 3d cases, the latter obtained with computational grids of more than half a trillion points. For some simulation cases, non-Boussinesq effects are introduced by a temperature-dependent diffusivity, $\kappa(T)$. Low Prandtl number convection is characterized by a highly inertial fluid turbulence. Thus the effective or turbulent Prandtl number Pr_t is expected to be much higher than the molecular one. Our series of DNS present a systematic study of the dependence $Pr_t(Pr)$ for Boussinesq and non-Boussinesq conditions which has important implications for the numerical modeling of these flows. In detail, we show that Pr_t increases significantly beyond 1 with decreasing Pr, such that the flow behaves effectively as a high-Prandtl-number fluid [2].

REFERENCES

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