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Stochastic modeling of temperature and velocity statistics in spherical-shell convection

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Thermal convection is an important process for the radial redistribution of mass, momentum and energy (including heat) in subsurface fluid layers of stars, planets and moons. Convection may dominate when the rotation rate is low, that is, when the Coriolis forces are small compared with buoyancy and inertial forces. In geophysical applications, convective processes are mostly turbulent due to strong buoyancy forcing (high Rayleigh number Ra) by an unstable temperature distribution (hotter towards the core, cooler towards the crust). Numerical simulations of these flows aim at a quantification of the transport properties which is a challenging task because of the wide range of Rayleigh and Prandtl numbers encountered in the applications. Available reference direct numerical simulations have been performed up to Rayleigh number $Ra = 10^9$ for Prandtl number $Pr = 1$ but this is not yet sufficient to clarify the scaling laws for the Nusselt (Nu) and Reynolds (Re) number, respectively. We address this problem by application of the stochastic one-dimensional turbulence (ODT) model, which has been recently extended to cylindrical and spherical geometries. ODT aims to resolve all scales of the flow by reducing the dimensionality. The computational domain is a notional line-of-sight pointing in radial direction. Along this line, turbulent advection is modeled by discrete mapping events. These events are stochastically selected with highest probability where shear and buoyancy yield net extractable energy, whereas diffusion is directly resolved.

In the talk, ODT temperature and velocity statistics will be compared with available reference data. We will focus on a high-Rayleigh-number flow regime ($10^5 \leq Ra \leq 10^9$) for various radius ratios and gravity profiles using unity Prandtl number and the linearized equation of state (Oberbeck–Boussinesq approximation). Preliminary results for even higher Rayleigh and the corresponding Nusselt and Reynolds numbers will also be addressed.