Heat Transfer in Turbulent Rotating Convection

R. P. J. Kunnen*, H. J. H. Clercx*, and B. J. Geurts†

Rayleigh-Bénard convection is a classical problem in which a fluid layer enclosed between two parallel horizontal walls is heated from below. In a rotating frame of reference the dynamics can change considerably through the fundamental involvement of a combination of buoyancy and Coriolis forces. The rotating Rayleigh-Bénard (RRB) setting is important for many applications, e.g., in engineering and climate modelling.

The dynamics of RRB convection can be characterised by three dimensionless parameters. The Rayleigh number $Ra$ characterises buoyancy, the Taylor number $Ta$ is associated with rotation, and the Prandtl number $\sigma$ is a fluid property. Our aim is to gain a better understanding of the transport of heat across the layer that is described by the Nusselt number $Nu$, which is a function of $Ra$, $Ta$, and $\sigma$.

Direct numerical simulation (DNS) is used to calculate $Nu$ at systematically varied $Ta$. The DNS code solves the incompressible Navier-Stokes equations in a rotating frame of reference, coupled to the heat equation within the Boussinesq approximation. Periodic boundary conditions are adopted in the horizontal directions and the vertical boundaries are treated as isothermal, no-slip walls.

The cyclonic thermal plumes that erupt from the thermal boundary layers are the dominant structures in turbulent rotating convection, as shown in figure 1(a). The $Ta$ dependence of $Nu$ is depicted in figure 1(b). At moderate $Ta$, $Nu$ increases, associated with Ekman pumping. At higher $Ta$ a dominant geostrophic inhibition of vertical (convective) motion arises. This figure is for $Ra = 2.5 \times 10^6$ and $\sigma = 1$.

The velocity and temperature averages from this DNS will be compared to measurements in a water-filled cylindrical convection cell. Detailed velocity and temperature data will be obtained using stereoscopic particle image velocimetry and laser induced fluorescence, respectively.

---

*Department of Physics, Eindhoven University of Technology, P.O. Box 513, 5600 MB Eindhoven, The Netherlands
†Department of Applied Mechanics, University of Twente, P.O. Box 217, 7500 AE Enschede, The Netherlands

![Figure 1: (a) Cyclonic thermal plumes as observed in a temperature isosurface plot. (b) $Nu$ as a function of $Ta$. The line on the vertical axis indicates $Nu$ at $Ta = 0$, crosses and circles are $Nu$ calculated at top and bottom walls, respectively.](image-url)