SOFT TURBULENCE IN RAYLEIGH-BÉNARD MAGNETOCONVECTION

Abstract

This dissertation presents the results of a detailed numerical investigation on Rayleigh-Bénard magnetoconvection in the presence of a uniform vertical magnetic field. Direct numerical simulations (DNS) are based on a pseudospectral method to study the statistical properties of soft-turbulence in the magnetoconvective flow. The Coriolis force also affects magnetoconvective instabilities near the instability onset. All the simulations used a periodic cell with thermally conducting, electrically non-conducting and stress-free boundaries.

The thermal flux is computed for different fluids including nanofluids ($0.1 \leq \mathrm{Pr} < 6.5$)) for several values of the Chandrasekhar number Q ($50 \leq \mathrm{Q} \leq 2.5 \times 10^4$). For a fixed value of the Rayleigh number Ra, the time averaged Nusselt number $\langle \mathrm{Nu(Q)} \rangle$ decreases logarithmically with Chandrasekhar number for $\mathrm{Q} > \mathrm{Q}_c(\mathrm{Ra}, \mathrm{Pr})$, which depends on both Ra and Pr. The reduced Nusselt number $\mathrm{Nu_r} = \langle \mathrm{Nu(Q)} \rangle / \langle \mathrm{Nu(0)} \rangle$ rises sharply, reaches a maximum slightly above unity and then start decreasing very slowly to unity as the value of a dimensionless parameter $\sqrt{\mathrm{Ra}/(\mathrm{Q\ Pr})}$ is raised slowly.

We have computed the Probability distribution functions (PDFs) for the thermal flux, velocity fields and convective temperature field from the simulations. The PDFs of horizontal thermal flux are non-Gaussian but symmetric about their maxima. The vertical thermal flux is also non-Gaussian but asymmetric about its maximum. The PDF of the thermal flux shows a cusp at its maximum. A part of the tails of PDFs for thermal fluxes is exponential on both sides of the maxima. The exponential factor depends the values of $\mathrm{Ra}, \mathrm{Pr}, \mathrm{Q}$. The PDFs for the velocity fields and the convective temperature are symmetric about their maxima. The PDFs of the horizontal velocities are Gaussian only at the top, but their tails depend on the values of $\mathrm{Ra}, \mathrm{Pr}, \mathrm{Q}$. The PDFs for the vertical velocity show cusps at their maxima. Their tails fit with two different exponential curves. The PDFs for the convective temperature are very flat at the top and is quite different from all other PDFs.

Power spectral densities (PSDs) in the frequency space for the global quantities (kinetic energy, entropy and heat flux) are computed numerically for different values of Prandtl number Pr ($0.1 \leq \mathrm{Pr} \leq 6.4$). Large values of Pr are relevant for nanofluids, while the lower values of Pr are relevant for Earth's liquid core. All the power spectral densities vary with frequency f approximately as f^{-2} for higher values of Q. This scaling behaviour appears universal and is valid for more than two decades in frequency. The scaling exponent for frequency power spectra of all global quantities is independent of Ra, Q and Pr.

The effects of a combined uniform vertical magnetic field and a uniform rotation about a vertical axis on the magnetoconvective instabilities in a water-based nanofluid ($\mathrm{Pr} = 4.0$) are interesting. The magnetoconvection appears as stationary two-dimensional rolls near the instability onset. As the reduced Rayleigh number $\mathrm{r} = \mathrm{Ra}/Ra_c(\mathrm{Q})$ is raised in small steps, different time-dependent fluid patterns appear. Some of these patterns show hysteresis.

Keywords: Rayleigh-Bénard magnetoconvection, Direct numerical simulations, Bifurcations, Rayleigh number, Chandrasekhar number, Nusselt number, local heat flux, thermal boundary layer, Power spectral density, nanofluids