The evolution of the large-scale flow in magnetoconvection

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Rayleigh-Bénard convection (RBC) in electrically conducting fluids can be influenced by applying external magnetic fields. It is known that a vertical magnetic field suppresses convective flows [1]. Experimental investigations on this topic are scarce [2], since the most suitable working fluids are liquid metals. These pose a considerable challenge for the measurement of the flow structure due to their opaque nature. We present experimental data on the large-scale flow structure as well as the heat and momentum transport in a RBC system with an imposed vertical magnetic field using the liquid metal alloy gallium-indium-tin (Prandtl number $Pr = 0.029$) [3].

The set-up consists of a cylindrical cell with height and diameter of 180 mm, i.e., aspect ratio 1. The bottom plate is made of copper and is heated by an electrical heating pad. The top is cooled by water in a copper heat exchanger. The external magnetic field is generated by the MULTIMAG facility [4] which produces a vertical magnetic field up to 140 mT. With this set-up Rayleigh numbers $10^6 \leq Ra \leq 6 \times 10^7$ and Hartmann numbers $0 \leq Ha \leq 1000$ can be covered.

The flow structure is reconstructed from direct velocity measurements using ultrasound Doppler velocimetry (UDV) and an array of temperature sensors distributed in a semi-circle at half-height of the cell. Without an applied magnetic field, the convective flow is turbulent and consists of a single large-scale circulation roll (LSC). This flow structure exhibits periodic and coherent deformations [5], the so-called torsion and sloshing modes, which are well known from experiments in water. By increasing the Hartmann number we find that the overall flow intensity is continually decreased. At first the LSC is stabilised by the suppression of turbulent fluctuations and regular oscillation modes. Once the magnetic field crosses a critical value, the LSC breaks down into a complex structure comprised of multiple convection cells. A further increase of Ha fully suppresses the flow in the centre of the cell but not near the side walls. Even after crossing the theoretical onset of convection for an infinite layer [1] a flow can still be detected. This destabilising effect of electrically insulating side walls on magnetoconvection has been predicted in theory [6] and direct numerical simulations [7], but is now shown experimentally for the first time.

Références

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