Hot and cold instabilities in a fluid with a strongly temperature-dependent viscosity

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We have studied the characteristics of thermal instabilities developing when a layer of sugar syrup, a fluid with a strongly temperature-dependent viscosity, is heated from below and cooled from above Prandtl numbers ranged between 7.3 10^3 and 1.3 10^6, Rayleigh numbers between 1.7 10^6 and 3.3 10^7, and viscosity ratios between 7 and 4100.
A new visualization technique allowed us to determine both the temperature and velocity fields in situ inside the experimental tank, so that we have access to the local properties of the instabilities.
As the viscosity ratio increases, three regimes are encountered: classical nearly constant-viscosity convection, sluggish lid and stagnant lid. In the latter two regimes, the cold thermal boundary layer (TBL) is thicker than the hot TBL. At high viscosity ratios, convection occurs in a sublayer beneath the coldest and most viscous part of the TBL which remains stagnant. At intermediate viscosity ratios and large Rayleigh numbers, two scales of convection co-exist, a large-scale circulation involving the lid, superimposed on the classical cold and hot instabilities. Scaling laws are determined for their onset, size, velocity, and heat flux. We then applied our results to infer the dynamics of the mantle "box" beneath the Pacific.