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A community benchmark for viscoplastic thermal convection in a 2-D squared box

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Numerical simulations of thermal convection in the Earth's mantle often employ a pseudo-plastic rheology in order to mimic the plate-like behavior of the lithosphere. Yet the benchmark tests available in the literature are largely based on simple linear rheologies in which the viscosity is either assumed to be constant or weakly dependent on temperature. We present a suite of simple test cases based on non-linear rheologies featuring temperature-, pressure-, and strain-rate dependent viscosity. Eleven different codes based on the finite-volume, finite-element, or spectral method have been used to run five benchmark cases leading to stagnant lid, mobile lid, and periodic convection in a 2-D squared box. For two of these cases, we also show resolution tests from all contributing codes. In addition, we present a bifurcation analysis describing the transition from mobile lid to periodic regime and from periodic to stagnant lid regime in dependence of the yield stress. At a reference resolution of around 100 cells or elements in both vertical and horizontal directions, all codes reproduce the required diagnostic quantities with a discrepancy of at most $\sim$3% in the presence of both linear and non-linear rheologies. Furthermore they all consistently predict the critical value of the yield stress at which the transition between different convective regimes occurs. As the most recent mantle convection codes are capable to handle a number of different domain geometries (2-D and 3-D, rectangular, cylindrical, and spherical) within a single solution framework, this benchmark is expected to be a useful tool to validate simulations of viscoplastic thermal convection also in geometries that are more complex and computationally demanding than a simple 2-D box.