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# Comparison of isoviscous and viscously stratified spherical shell and plane-layer convection calculations

Keely A. O'Farrell (1), Julian P. Lowman (1,2), and Hans-Peter Bunge (3)

(1) Department of Physics, University of Toronto, Toronto, ON, Canada (ofarrell@physics.utoronto.ca), (2) Department of Physical and Environmental Sciences, University of Toronto Scarborough, Toronto, ON, Canada., (3) Department of Earth and Environmental Sciences, Ludwig-Maximilians University Munich, Munich, Bavaria, Germany.

Plane-layer geometry convection models remain a useful tool for investigating planetary mantle dynamics but yield significantly warmer geotherms than spherical shell systems with a small inner to outer radius ratio, $f$. For example, in a uniform property spherical shell with the same radius ratio, $f$, as the Earth's mantle; a bottom heating Rayleigh number, $Ra$, of $10^7$ and a nondimensional internal heating rate, $H$, of 23 (arguably Earth-like values) are insufficient to heat the mean temperature, $\theta$, above the mean of the boundary value temperatures (non-dimensional value 0.5). To address this geometrical effect, we implement heat sinks as a method of lowering the mean temperature in 3D plane-layer convecting systems. We analyze the mean temperatures of over 100 convection models to derive a single equation relating $\theta$, $Ra$, $H$ and $f$ in spherical and plane-layer systems featuring free-slip surfaces. For a given Rayleigh number, the derived expression can be used to calculate an appropriate heating or cooling rate for a plane-layer convection model in order to obtain the mean temperature, $\theta$, of a spherical system described by $f$. Our findings have important implications for plane-layer geometry numerical models of mantle convection when emulating spherical shell convection at higher Rayleigh numbers. For higher Rayleigh numbers, the case applicable to the Earth and super-Earths, the mean temperature of a mixed heating mode spherical system decreases faster than a plane-layer system so that the difference in the thermal structure of the two geometries increases. Accordingly, the inclusion of cooling in plane-layer models grows in importance. We extend our comparisons of the differences in plane-layer geometry convection and convection in a spherical shell geometry with the Earth's $f$ value by considering systems featuring a lower mantle that gradually increases in viscosity by a factor of 30 relative to the upper mantle. In this case the cooling required to match plane-layer convection temperatures with spherical shell temperatures is less than in isoviscous convection but still substantial.