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The effect of toroidal flow on mantle mixing efficiency in numerical simulations of 3D spherical convection

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The stirring of heterogeneities by mantle convection is a key process in explaining geochemical observations, but to date most studies have been performed in only two-dimensional geometry. If 3-D convection has only poloidal motion, then its stirring efficiency is similar to that of 2-D convection [Coltice and Schmalzl, 2006], but the presence of toroidal motion could make a major difference because it can lead to chaotic stirring paths even in a steady-state flow [Ferrachat and Ricard, 1998]. Toroidal flow is mainly associated with plate motions. Two previous studies have assessed the influence of steadystate present-day plate motions on mantle stirring [van Keken and Zhong, 1999; Stegman et al., 2002]. Here we instead study flows in which time-dependent plate tectonics is self consistently generated by the rheology in a spherical shell, similar to [van Heck and Tackley, 2008], and has a toroidal:poloidal ratio in the range observed for the Earth.

The stirring efficiency is evaluated using passive tracers. The velocity field is decomposed into poloidal and toroidal components, and by removing all or part of the toroidal component of the velocity field used to advect the tracers we control the amount of toroidal flow the tracers experience. In this way the effect of toroidal flow on the stirring paths is isolated, for flows that are otherwise identical.

Several diagnostics are used to measure the efficiency of dispersion and stretching and their spatial variation as function of toroidal:poloidal ratio of the fluid flow. The average total distance the tracers travelled and the average angular distance tracers travelled give direct insight in how much toroidal motion influences the average velocities. The total amount of strain that each tracer experiences is tracked and lastly a cell counting method is used to measure the dispersion rate of the tracers.

The rms-velocity of the velocity experienced by the tracers increases as more of the toroidal part is removed. Comparing the case where the toroidal part is set to be 50% of the poloidal part (TorPol0.5) to the case where all of the toroidal part is removed, the rms-velocity is lower. Both the total and angular distance tracers travel is higher when all the toroidal motion is removed (compared to TorPol0.5). All these diagnostics indicate that the effect of toroidal motion on mixing efficiency is small and enhancing mixing efficiency. Mixing efficiency increases with the part of toroidal motion but since the rms of the total velocity decreases the effect is small. New calculations with similar flows but with weak time dependance are performed in order to study the importance of time dependent flow.