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Combine Effects of Plate Motions and Small-Scale Convection on Mantle Stirring Efficiency

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Convection in Earth's mantle generates large scale, vigorous motions often thought to be the primary mechanism of mantle stirring. However additional thermal instabilities may progressively develop below lithospheric plates, leading to smaller scale convective motions. While there is growing evidence supporting the presence of small-scale convection in Earth's mantle, little is known of its contribution to the mixing of mantle heterogeneities.

We have thus investigated the influence of small-scale convection on mantle stirring efficiency using 2D numerical modeling of infinite Prandtl number convection with imposed surface plate motion and temperature and pressure dependent rheology. We measure stirring efficiency using Finite Time Lyapunov Exponents (FTLE) and we vary systematically the Peclet number, Pe, defined as the ratio of the advection time scale based on surface plate velocity to a characteristic diffusion time. Our computational domain has an aspect ratio of 1:3. For moderate Pe, small-scale convection is well developed, leading to efficient stirring. However large Pe numbers do not allow the development of small-scale convection and result in significantly lower stirring efficiency, although plate motions are faster. This indicates that (i) small-scale convection contributes significantly to mantle stirring efficiency, (ii) mantle stirring efficiency many spatially vary significantly due to the local magnitude of plate velocity and (iii) the relationship between mantle stirring efficiency and large-scale convective motions may be more complex than previously thought.