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Spontaneous development of arcuate single-sided subduction in global 3-D mantle convection models with a free surface

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The work presented aims at a better understanding of plate tectonics, a crucial dynamical feature within the global framework of mantle convection. Special focus is given to the interaction of subduction-related mantle flow and surface topography. Thereby, the application of a numerical model with two key functional requirements is essential: an evolution over a long time period to naturally model mantle flow and a physically correct topography calculation. The global mantle convection model presented in Crameri et al. (2012a) satisfies both of these requirements. First, it is efficiently calculated by the finite-volume code Stag-YY (e.g., Tackley 2008) using a multi-grid method on a fully staggered grid. Second, it applies the sticky-air method (Matsumoto and Tomoda 1983; Schmeling et al, 2008) and thus approximates a free surface when the sticky-air parameters are chosen carefully (Crameri et al., 2012b). This leads to dynamically self-consistent mantle convection with realistic, single-sided subduction.

New insights are thus gained into the interplay of obliquely sinking plates, toroidal mantle flow and the arcuate shape of slabs and trenches. Numerous two-dimensional experiments provide optimal parameter setups that are applied to three-dimensional models in Cartesian and fully spherical geometries. Features observed and characterised in the latter experiments give important insight into the strongly variable behaviour of subduction zones along their strike. This includes (i) the spontaneous development of arcuate trench geometry, (ii) regional subduction polarity reversals and slab tearing, and the newly discovered features (iii) 'slab tunnelling' and (iv) 'back-slab spiral flow'. Overall, this study demonstrates the strong interaction between surface topography and mantle currents and highlights the variability of subduction zones and their individual segments.

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