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The effect of weak sediments and a free surface on self-consistent plate tectonics

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Previous dynamic models of global mantle convection indicated that a visco-plastic rheology is successful in generating plate tectonics-like behaviour self-consistently (Moresi & Solomatov, GJI 1998; Tackley, GCubed 2000a,b). Yet these models fail to create Earth-like plate tectonics: so far in all models subduction is two-sided and more or less symmetric, whereas terrestrial subduction is one-sided and characterized by a distinctive asymmetry. Kinematic models of subduction (Gerya et al, 2008) indicate that one requirement for stable one-sided subduction is a low strength interface between the plates achieved by the presence of metamorphic fluids in the subduction channel. Such a lubrication layer consisting of weak hydrated sediments accommodates stable one-sided subduction by strain localization, while the absence of a weak shear zone leads to two-sided subduction since in this case the plastic strength of the entire plates needs to be sufficiently low to allow for subduction (Gerya et al, 2008). Here we study the effect of such a lubrication layer on the mode of subduction in 2D and 3D global, fully dynamic mantle convection models with self-consistent plate tectonics by introducing a similar layer of weak crustal material. For this we use the finite volume multigrid code STAGYY (Tackley, PEPI 2008), with strongly temperature-dependent viscosity, ductile and/or brittle plastic yielding, non-diffusive advection of tracers tracking the weak crust, and a specified fractional viscosity decrease where weak crust is present. This viscosity reduction for crustal material (relative to mantle material) supports the formation of subduction zones and stabilizes subduction, and in some cases increases the tendency to asymmetric subduction, although subduction is still typically double sided. A second aspect studied here is the influence of a free surface. As shown by Schmeling et al (PEPI, 2008), it is necessary to include a proper free surface (as opposed to a fixed, free slip surface) in numerical models in order to reproduce laboratory results of subducting slabs. According to their benchmark study, mimicking a free surface by a low viscosity, zero density layer on top of the crust is an adequate approach. For this reason, we have implemented such a "sticky air layer" in our global numerical model, in order to compare the evolution of subduction with and without a free surface.