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Towards Self-consistent Numerical Models of Time-evolving Subduction Systems

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Understanding the time-evolution of subduction systems on Earth, from their initiation into progressive subduction to eventual termination, is lacking in important ways. Numerical models of subducting systems are central to developing an improved understanding, yet achieving Earth-like subduction (asymmetric and single-sided) within a convecting mantle remains a major challenge. A few of the more salient features of subduction zones, such as 1) partitioning of subduction velocity into the two modes of subduction (plate advance and slab rollback), 2) the accurate along-trench curvature of subduction zones, and 3) episodic character of tectonic stress regimes in the overriding plate are not features that emerge self-consistently. Some progress has been made using simplified models of free subduction that avoid prescribing the kinematics (convergence rate, plate speed) or geometry (trench location, dip angle) of the system, thereby allowing it to evolve naturally, driven only by its own negative buoyancy (Faccenna et al., 2001; Funiciello et al., 2003; Schellart, 2004; Morra et al., 2006; Royden and Husson, 2006; Stegman et al., 2006; Schellart et al, 2007; Goes et al, 2008). The strength of the subducting plate controls the particular style of subduction, thereby producing an associated upper mantle slab geometry, (Billen, 2008; Giuseppe et al., 2008; Stegman et al., 2010; Ribe, 2010). However, such models typically adopt simplified descriptions for the subducting plate (uniform viscosity, thickness, and density) and assume no heat transfer (i.e. the energy equation is not included).

We investigate the development of subduction in fully dynamic system within a convecting mantle with initial conditions based on a prescribed thermal boundary layer that includes a single, mature oceanic plate surrounded by younger oceanic plates. We make use of the finite-volume multigrid code StagYY (Tackley, 2008) to run the models. Each model run uses a depth- and temperature-dependent rheology (Arrhenius law). Plastic yielding is used wherein the yield stress has both brittle and ductile components. By specifying a temperature at each grid point, the geometry and physical properties of plates and background mantle are specified. Because the viscosity is a function of temperature and stress, the system is extremely non-linear and the integrated strength of the lithosphere in critical regions (such as where bending occurs) is strongly time-dependent. Subduction is initiated by adding a small perturbation.

The boundary conditions for the 2D models are the same across all model runs. The prescribed thermal boundary layer overlies an isothermal mantle with a bottom insulating (zero heat flux) thermal boundary condition. A zero-density low-viscosity "sticky-air" layer is defined at the top of the model. The sticky-air layer is necessary for producing realistic subduction (Schmeling et al. 2008). At the sidewalls a wrapping boundary condition is applied.

We continue investigating the development of subduction within this model framework, moving towards more realistic schemes. Our future work looks toward modeling in three spatial dimensions and using the results of the simple subduction models to examine more complex interactions.

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