Effect of Plate Coupling and Initial Slab Dip on Dynamic Weakening in the Asthenosphere

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Abstract

This study examines the dynamic weakening of the asthenosphere and surface plate velocity as a function of plate interface coupling and initial slab dip in subduction zones through a systematic parametric study. Time-dependent models varying 6 values of plate interface coupling bounds (3.1×10^{20}, 1.0×10^{21}, 3.1×10^{21}, 1.0×10^{22}, 3.1×10^{22}, 1.0×10^{23} $Pa \cdot s$) and 3 initial subduction angles (30^o, 45^o, 60^o) are run. The two-dimensional numerical models use a composite viscosity in the upper mantle and are run for 2000 time-steps on 48 compute cores, approximating several million years of subduction. The incorporation of a strain-rate dependent rheology results in dynamic weakening in the asthenosphere around the slab and beneath the surface part of the down-going plate, consistent with previous results. In both the instantaneous and time-dependent models, the subducting plate speed increases with decreasing interplate coupling. Models with the initial slab dip of 30^o produce the fastest subducting plate speeds over time. The dimensions of (a) the dynamically weakened asthenosphere surrounding the slab, as well as (b) the thickness of the dynamically weakened asthenosphere beneath the subducting plate near the lithosphere-asthenosphere boundary (LAB), are sensitive to the prescribed interplate coupling values and vary over the course of the subduction evolution, with weaker interplate coupling correlating with greater asthenosphere weakening beneath the subducting plate. The results suggest that the imposed interplate weakening and the dynamically resultant weakening in the asthenosphere are interrelated such that the weaker the interplate coupling, the easier for the slab to descend into the mantle and dynamically weaken the asthenosphere due to the strain-rate dependent rheology. This reduced viscous resistance to slab sinking facilitates faster subducting plate and mantle flow velocities over time, thus easing the subduction process.

In terms of computational costs, the run-time of the models ranges from 36 to 83 hours and increases with decreasing plate interface coupling. The difference in wall-clock time between the weakest and the strongest plate coupling models is 51%, 38%, and 20%, for models with an initial dip 30°, 45°, and 60°respectively. Although the wall-clock time is tractable for 2D models, the large variation in run-times suggest varying plate boundary coupling will have a high impact on run-times for high-resolution 3D models comprised of a greater number of nodes with dynamic viscosity variations.

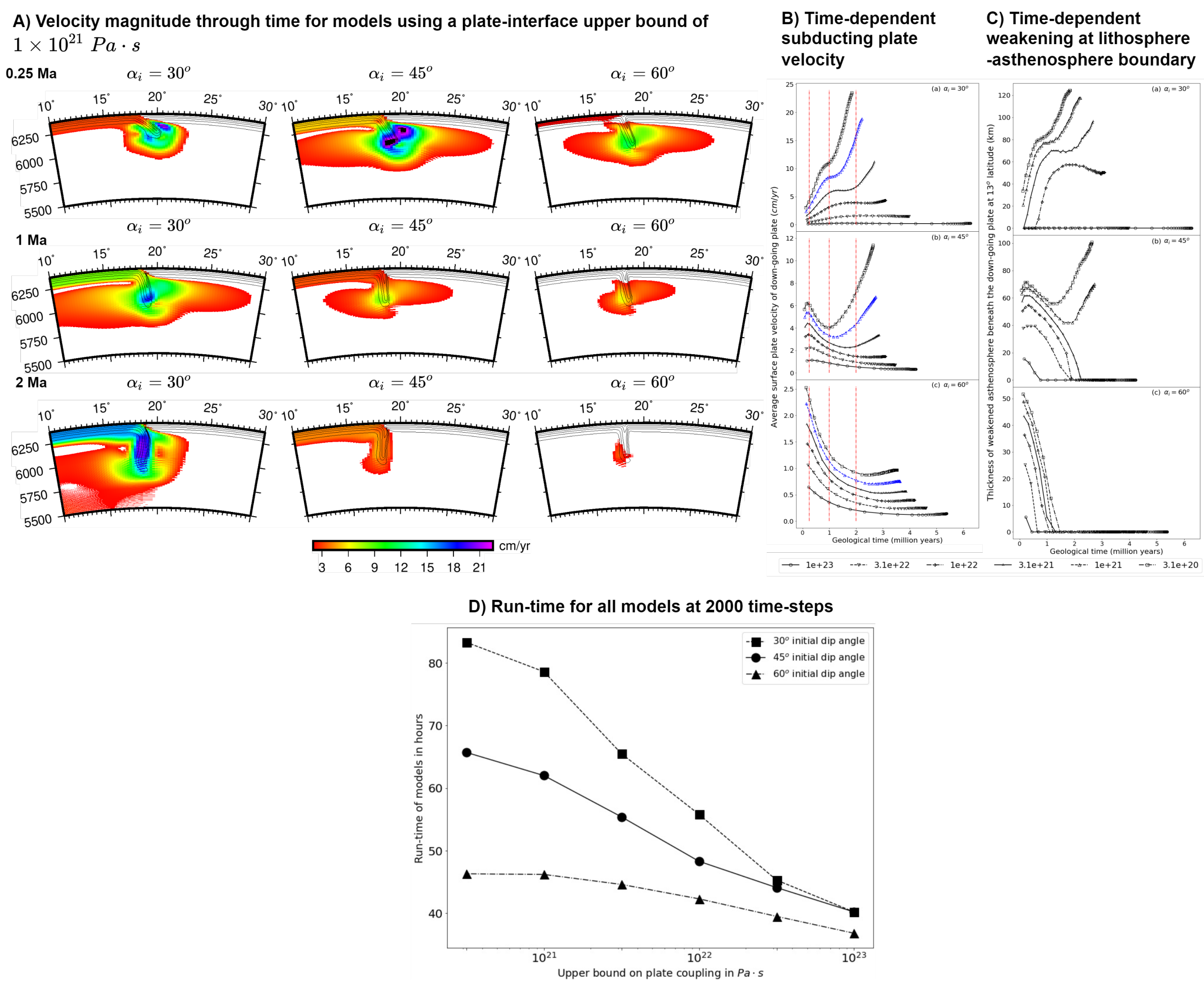

Figure 1: (A) Velocity magnitude through time for models with 1×10^{21} $Pa \cdot s$ plate interface coupling bound. Contours show temperature in 250^oC intervals. (B) Surface plate velocity as a function of time for all models. Blue lines denote models shown in part A at time steps marked by red lines. (C) Thickness of weakened asthenosphere in the LAB region as a function of time for all models. (D) Run-time for all models at 2000 time-steps.