Computing 3-D Viscoelastic Earthquake Cycle Models for Cascadia Using Large-Scale, High-Fidelity Finite Element Methods

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To better understand and plan for the effects of the next great Cascadia subduction zone earthquake, it is important to constrain which areas of the fault are fully locked and may rupture seismically, which areas rupture aseismicially in slow slip events, which areas are freely creeping, and how they relate to one another. In particular, the spatial relationship between the locked zone and the slow slip, or Episodic Tremor and Slip (ETS) zone is poorly resolved in Cascadia but highly important for estimating the potential increase in megathrust earthquake probability during and following ETS events. A number of recently published interseismic locking inversions using geodetic data show a gap between the fully locked zone and the top of the ETS zone, implying that the ETS zone is not significantly stressing the fully locked zone. Current locking models in Cascadia show significant variation in the inferred locking within this critical gap, due in part to epistemic (model) uncertainty. Most geodetic inversions assume a linear or quasi-linear gradient in interseismic creep rate below the locked zone which precludes sharp gradients in transitional creep and likely biases the fully locked zone to shallow depths. Furthermore, many geodetic inversions for coupling in Cascadia also neglect the effects of viscoelastic mantle flow and heterogeneous elastic properties.

In this study we explore the nature of the critical gap between the ETS and locked zones by identifying the range of locking models in Cascadia which adequately fit available horizontal and vertical geodetic data considering both the effects of viscoelastic mantle relaxation following previous earthquakes and elastic heterogeneity of the lithosphere. We conduct backslip inversions using 3D viscoelastic Greens functions generated with finite element code GAMERA. We assume there is some long-term slip rate given by the relative plate motion that doesn’t contribute to deformation of the overriding plate. All deformation is assumed to come from interface coupling. In the forward model, we impose a saw-tooth backslip history on every patch. Steady backslip is interrupted with sudden co-seismic slip events at regular intervals. The unknown for each patch in the inversion is the backslip rate, which is bounded between zero and the long-term slip rate. The co-seismic slip magnitude on each patch is determined by the backslip rate. To compute earthquake cycles, the viscoelastic Greens functions must be computed out to effectively fully relaxed mantle state (~1500-15000 longest material relaxation times). These calculations are computed using an unstructured low-order implicit finite-element method.

Keywords: earthquake cycle, viscoelastic mantle, interseismic coupling