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# Crack models to constrain time-dependent interseismic stress- and slip-rate distributions in northern Cascadia

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In northern Cascadia, interpretations of interseismic slip deficit on the megathrust are complicated by an unresolved "gap" between the down-dip limit of the locked region, inferred from kinematic inversions of deformation rates, and the top of the ETS (Episodic Tremor and Slip) zone. Rate-state friction models of slow slip events (SSE) match the average SSE displacements; yet, when the fault is locked to the top of the ETS zone, predict too much interseismic locking when compared to decadal-scale GPS and tide gauge/leveling deformation rates. Inversions that seek interseismic slip rates as close as possible to the physics-based models have shown that larger slip rates, relative to the physics-based solutions, are necessary within both the gap and the ETS zone. Inversions for shear stress rates on the megathrust confirm this, finding that negative shear stress rates within both the gap and the ETS region, up to 2.5kPa/yr at a depth of 25km, and deep locking depths, around 21km, are required to fit the data. Possible explanations for this include a slow decrease in normal stress within the gap, possibly due to an increase in pore pressure, or a long-term reduction in fault friction [Bruhat & Segall, JGR, 2016].

However, previous studies all assume the locking depth, and then the depth distribution of interseismic fault slip rate, to be time invariant. High interseismic slip rates in the gap could also result from the up-dip propagation of slip into the locked region.

In this work we investigate models where interseismic slip penetrates up dip into the locked region. We model the region defined by the gap and the ETS zone as a long-term quasi-static crack driven by the plate motion velocity at the fixed down dip limit of the ETS region. Following classical crack models of a fault [e.g., Bilby and Eshelby, 1968], we present a simple model that allows crack growth over time, and derive analytical expressions for stress drop within the crack, slip and slip rate along the fault. These expressions allow us to expand any non-singular slip rate distribution in a combination of Chebyshev polynomials. The decomposition in polynomials leads to a massively under determined problem. However, it allows us to test particular solutions, such as, solutions that provide bounds on the possible up-dip propagation rate, or solutions that optimize known characteristics of the slip and stress distribution.

As a first step we explore the simplest case, retaining only the first Chebyshev polynomial in the expansion. Using MCMC methods, we invert the decadal-scale deformation rates for the locking depth and the up-dip propagation velocity. Best fitting models reveal that a very slow up dip propagation, around 30m/yr along fault is needed to fit the data and that the gap seems to act as a region of fault weakening.