The Effect of Dynamic Weakening on Earthquake Sequences and Ductile Shear Zone Structure

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In this project, we will incorporate dynamic weakening into our existing earthquake cycle code, SCycle. We will explore the interaction between seismic and aseismic fault slip and ductile deformation, and the impact of these interactions on the earthquake cycle. We will implement the dynamic weakening mechanism of flash heating, in which local temperature increases at asperity contacts weaken the asperities, leading to a macroscopic drop in strength. Both grain-size insensitive dislocation creep and grain-size sensitive diffusion creep will operate in parallel in the lower crust and upper mantle. Grain size will evolve using the physics-based paleowattmeter, in which grain size increases through static grain growth and is reduced by work done through dislocation creep. This rheology depends on temperature, lithology, water content, and strain rate, and we will use the large amount of data available in southern California, including the developing Community Thermal Model (CTM) and Community Rheology Model (CRM), to select these parameters. We will make quantitative predictions of the evolution of grain size and viscous strain throughout the earthquake cycle, and of the effect of these mechanisms on earthquake size and recurrence interval. We will qualitatively compare our predictions with observations of surface heat flux, observations of the grain size in exhumed shear zones, and the depth of microseismicity and large ruptures in southern California.

Thus far, we have implemented and tested the implementation of flash heating in the context of elastic earthquake cycle simulations. Figure 1 shows two example elastic earthquake cycle simulations, performed in 1D with the quasidynamic approximation. In both cases, the state variable is evolved using the slip law. In the simulation with flash heating, the frictional strength drops to about 10 MPa during the coseismic period. The frictional strength recovers quickly as the slip velocity begins to drop and the earthquake resolves, and it recovers to 20 MPa at the start of the interseismic period. In contrast, in the simulation without flash heating the frictional strength is about 7 MPa higher at the beginning of the interseismic period. This difference explains the lower temperature rise that occurs in the simulation with flash heating compared with the simulation without flash heating (difference of 40 K). Additionally, and perhaps most strikingly, the recurrence interval is approximately twice as long in the simulation with flash heating as in the simulation without flash heating.
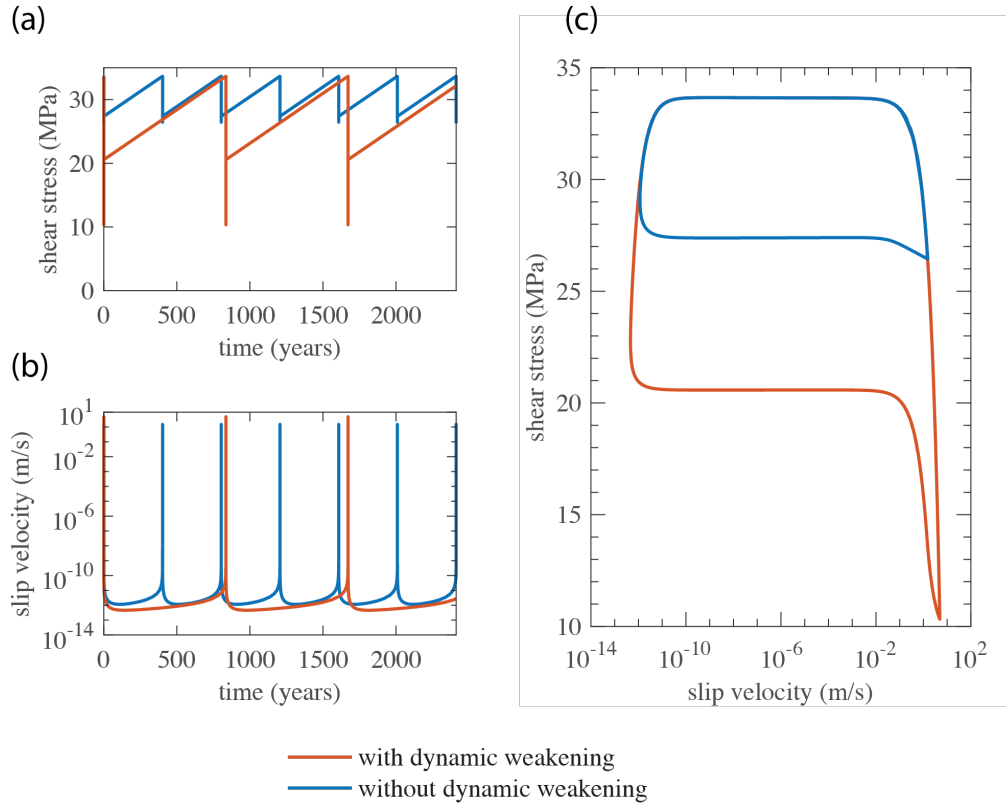
Figure 1: Elastic earthquake cycle simulations in 1D, with dynamic weakening (red) and without dynamic weakening (blue). (a) Evolution of shear stress over time. (b) Evolution of slip velocity over time. (c) Phase diagram demonstrating the effects of dynamic weakening on the interseismic and coseismic phases of the earthquake cycle.

Our future work will focus on performing these simulations in 2D. PI Allison will spend 1.5 month on code development. This will consist of two tasks. First, extending the existing steady-state iteration method to account for the effects of flash heating. Second refining the switching criteria used in simulations with inertia during the coseismic period and the quasidynamic approximation during the interseismic period. Finally, in consultation with unfunded collaborator Montesi, PI Allison will spend 1.5 months performing simulations representative of the San Andreas and Elsinore faults in southern California. These simulations will be performed on Stampede2. Simulation results will primarily be analyzed by PI Allison, and both Allison and Montesi will refine the parameter choices to qualitatively match observations of brittle-ductile transition (BDT) depth and surface heat flux. Results will be shared with the SCEC community at the SCEC annual meeting in 2022.