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Fault geometric complexity and how it may cause temporal slip-rate variation within an interacting fault system

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Slip-rates along individual faults may differ as a function of measurement time scale. Short-term slip-rates may be higher than the long term rate and vice versa. For example, vertical slip-rates along the Wasatch Fault, Utah are 1.7+/-0.5 mm/yr since 6ka, <0.6 mm/yr since 130ka, and 0.5-0.7 mm/yr since 10Ma (Friedrich et al., 2003). Following conventional earthquake recurrence models like the characteristic earthquake model, this observation implies that the driving strain accumulation rates may have changed over the respective time scales as well. While potential explanations for such slip-rate variations may be found for example in the reorganization of plate tectonic motion or mantle flow dynamics, causing changes in the crustal velocity field over long spatial wavelengths, no single geophysical explanation exists. Temporal changes in earthquake rate (i.e., event clustering) due to elastic interactions within a complex fault system may present an alternative explanation that requires neither variations in strain accumulation rate or nor changes in fault constitutive behavior for frictional sliding. In the presented study, we explore this scenario and investigate how fault geometric complexity, fault segmentation and fault (segment) interaction affect the seismic behavior and slip-rate along individual faults while keeping tectonic stressing-rate and frictional behavior constant in time.

For that, we used FIMozFric–a physics-based numerical earthquake simulator, based on Okada's (1992) formulations for internal displacements and strains due to shear and tensile faults in a half-space. Faults are divided into a large number of equal-sized fault patches which communicate via elastic interaction, allowing implementation of geometrically complex, non-planar faults. Each patch has assigned a static and dynamic friction coefficient. The difference between those values is a function of depth–corresponding to the temperature-dependence of velocity-weakening that is observed in laboratory friction experiments and expressed in an [a-b] term in Rate-State-Friction (RSF) theory. Patches in the seismic zone are incrementally loaded during the interseismic phase. An earthquake initiates if shear stress along at least one (seismic) patch exceeds its static frictional strength and may grow in size due to elastic interaction with other fault patches (static stress transfer). Aside from investigating slip-rate variations due to the elastic interactions within a fault system with this tool, we want to show how such modeling results can be very useful in exploring the physics underlying the patterns that the paleoseismology sees and that those methods (simulation and observations) can be merged, with both making important contributions.

Using FIMozFric, we generated synthetic seismic records for a large number of fault geometries and structural scenarios to investigate along-fault slip accumulation patterns and the variability of slip at a point. Our simulations show that fault geometric complexity and the accompanied fault interactions and multi-fault ruptures may cause temporal deviations from the average fault slip-rate, in other words phases of earthquake clustering or relative quiescence. Slip-rates along faults within an interacting fault system may change even when the loading function (stressing rate) remains constant and the magnitude of slip rate change is suggested to be proportional to the magnitude of fault interaction. Thus, spatially isolated and structurally mature faults are expected to experience less slip-rate changes than strongly interacting and less mature faults. The magnitude of slip-rate change may serve as a proxy for the magnitude of fault interaction and vice versa.