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Develoment and implications of "effective friction laws" for large-scale dynamic rupture modeling

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Because the data available for empirical ground motion prediction is limited, especially in the large magnitude and near-fault distance ranges that are critical for the assessment of potential damage, there is a need for physics-based approaches for ground motion modeling that integrate dynamic earthquake rupture modeling. Each of the key inputs for dynamic rupture models - fault geometry, initial stresses and fault strength parameters - has large uncertainties and spatial variability which may have significant impact on ground motion prediction. In addition, the computational demands in large-scale simulations impose that fault strength must be modeled at a coarse resolution scale. There is hence a need to develop coarse-scale "effective friction laws" that account for important mesoscopic effects of the micromechanical processes of dynamic weakening and healing without modeling them explicitly. An "effective friction law" is here defined as a coarse-grained fault zone constitutive equation, relating fault shear stress to slip and slip velocity, that includes fault friction as well as dynamic weakening processes involving the thermo-hydro-mechanical response of fault zone and off-fault materials. Here we synthesize the constraints available from field, seismological and laboratory observations and from theoretical considerations on the strength of active faults that are relevant for physics-based ground motion modeling. Two main weakening mechanisms, thermal pressurization and flash heating, can be parametrized as power-law slip-weakening and velocity-weakening, respectively. Off-fault dissipation can also be approximately incorporated as power-law friction and slip-velocity limits. Healing at dynamic time scales, which has received less attention in previous studies, is here tentatively parameterized as an additional slip-strengthening component. We develop non-dimensional analysis, fracture mechanics analysis and generic dynamic rupture simulations to probe the implications of these effective friction representations on macroscopic features of dynamic rupture. Our results help identifying the parameters that are most important for ground motion modeling, especially those critical input parameters whose quantification requires more research.