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Dynamic rupture models of subduction zone earthquakes with off-fault plasticity

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Simulations of subduction zone earthquakes based on purely elastic seafloor displacement typically underestimate the potential seafloor displacement and hence their tsunami genesis. Dynamic rupture simulations allow to analyse whether plastic energy dissipation is a missing rheological component by capturing the complex interplay of the rupture front, emitted seismic waves and the free surface in the accretionary wedge.

Here, we present 3D dynamic rupture simulations of the 2004-Sumatra earthquake in which we investigate the effects of inelastic material response on earthquake source parameters and seafloor displacement Specifically, we include splay faults at high angles to the curved megathrust, high-resolution bathymetry and 3D subsurface material properties.
Dynamic rupture, off-fault plasticity and seismic wave propagation are modelled using the software package SeisSol (www.seissol.org). The software is based on tetrahedral unstructured meshes, specifically suited for the representation of complex fault zone structures and topography. SeisSol is highly optimized for the efficient use on HPC infrastructure, particular important for this event due to its large spatial and temporal extent.
Our results indicate that off-fault plastic deformation considerable enhances or decreases horizontal and vertical seafloor displacements, in strong correlation with the assumed tectonic background stress field and fault orientations.
Although our simulation results compare well to static observations, constraining the initial stress and strength conditions for dynamic rupture simulations remains challenging.

Thus, the second part of this study constrains 2D dynamic rupture models of subduction zones by long-term seismo-thermo-mechanical (STM) modeling.
The STM model provides self-consistent slab geometries, as well as stress and strength initial conditions which evolve in response to tectonic stresses, temperature, gravity, plasticity and pressure (van Dinther et al., 2013). The imported initial conditions allow spontaneous rupture nucleation taking the form of a multitude of rupture pulses. A closeness of failure (CF) ratio of $\sim$0.85 is suggested by the coupling for sediment and fluid rich regions. As a consequence, high inelastic deformation accumulates in the accretionary wedge, smearing out rupture pulses, preventing surface rupture and enhancing fault slip at depth.