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The Great 2004 Sumatra-Andaman Earthquake: Insights from dynamic rupture modeling

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The 2004 Mw 9.1-9.3 Great Sumatra-Andaman Earthquake is one of the strongest and most devastating earthquakes in recent history. It generated a powerful tsunami, causing more than 220,000 fatalities. Despite its huge spatial extent, the analysis of the earthquake is impeded by a lack of near-source observations. Static ground-deformation data, polluted by significant after-slip in the near-source region, and teleseismic data do not fully constrain the source, leading to significant differences in its characterization. Specifically, the tsunamigenic aspects of the earthquake, such as the large but mostly horizontal seafloor displacements and potential splay fault activation, remain puzzling.

In this study, we investigate the earthquake using high-resolution 3D dynamic rupture simulations. We use the open-source software SeisSol (www.seissol.org) which is based on an arbitrary high-order accurate DERivative Discontinuous Galerkin method (ADER-DG). We account for complex megathrust-splay fault geometries, high resolution topography and bathymetry, 3D subsurface structure and off-fault plasticity. We resolve the full frictional sliding process as well as the seismic wave field in the to-date longest (500 s) and largest (1500 km) dynamic rupture earthquake scenario.

We discuss macroscopic earthquake source characteristics inferred from a smoothly initialized model, in which we prescribe regional, smoothly varying fault pre-stresses constrained by earthquake focal mechanisms, interacting with frictional fault conditions changing only depth-dependently. The interplay of complex fault geometry and simple pre-stress state yields good agreement of ground-deformations in the near field and very long-period teleseismic data. We are specifically interested in the effects of off-fault plasticity: overall reducing rupture speed but increasing or decreasing fault slip depending on regional stress orientation in conjunction with the fault geometry. We then refine the regional stress state based on static inversion and mechanical viability arguments to fully capture dynamic features such as lower slip release in the Southern megathrust and slow rupture velocity at around 8° latitude. Our models are verified by generating synthetic geodetic, teleseismic and tsunami records, employing off-line coupling of SeisSol to established global seismic wave propagation and tsunami simulation tools.