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Dynamic rupture simulations of the 2016 Mw7.8 Kaikōura earthquake: a cascading multi-fault event

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The Mw7.8 Kaikōura earthquake struck the Northern part of New Zealand's South Island roughly one year ago. This event, considered the most complex rupture observed to date, caused surface rupture of at least 21 segments of the contractional Marlborough fault system. Dense field observations combined with satellite data suggest a rupture path challenging our understanding of earthquake source processes. The rupture involved partly unmapped faults separated by apparently large stepover distances (> 5 km), implying rupture transfer mechanisms potentially not yet considered in seismic hazard assessment.

We present a high-resolution 3D dynamic rupture scenario of the Kaikōura earthquake under physically self-consistent initial stress and strength conditions. Our numerical simulations are based on recent finite-fault slip inversions that constrain fault system geometry and final slip distribution from remote sensing, surface rupture and geodetic data. We assume a uniform background stress field, without lateral fault stress or strength heterogeneity. 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). Our method can account for complex fault geometries, high resolution topography and bathymetry, 3D subsurface structure, off-fault plasticity and modern friction laws. It enables the simulation of seismic wave propagation with high-order accuracy in space and time in complex media.

We show that a cascading rupture driven by dynamic triggering can break all fault segments that were involved in this earthquake without mechanically requiring an underlying thrust fault. Our prefered fault geometry connects most fault segments: it does not feature stepovers larger than 2 km. The best scenario matches the main macroscopic characteristics of the earthquake, including its apparently slow rupture propagation due to zigzag cascading fusing strike-slip and thrust faulting, the moment magnitude release and the overall inferred slip distribution. We observe a high sensitivity of cascading dynamics on fault-step over distance and off-fault energy dissipation. We show, that dynamic rupture modeling integrated with data inversion efforts allows physics-based interpretations of the dynamics of earthquakes rapidly following an event.