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Dynamic viability of the 2016 Mw7.8 Kaikōura earthquake: a cascading rupture on weak crustal faults

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On 14 November 2016, the Northern part of New Zealand's South Island was struck by the Mw7.8 Kaikōura earthquake, an event of unprecedented geometric complexity rupturing at least 21 segments of the contractional North Canterbury and of the Marlborough fault systems. Geological, geodetic, tsunami and seismic data reveal puzzling features as well as observational difficulties of the event leading to competing views on its key features, such as the role played by the Hikurangi subduction interface, the exact rupture sequence, and the higher than expected local tsunami.

We present a dynamic rupture model of the 2016 Mw 7.8 Kaikōura earthquake to unravel the event's riddles in a physics-based manner and provide insights on the mechanical viability of competing hypotheses proposed to explain them. The event is modeled using the open-source software SeisSol (www.seissol.org), based on a arbitrary high-order accurate DERivative Discontinuous Galerkin method (ADER-DG). We verify our model with strong ground-motions, high rate GPS, long-period teleseismic and tsunami data.

Our model reproduces key characteristics of the event and constraints puzzling features inferred from high-quality observations including a large gap separating surface rupture traces, the possibility of significant slip on the subduction interface, the non-rupture of the Hope fault, and slow apparent rupture speed. We show that a rupture cascade sequentially breaking the Papatea and Kekerengu faults is dynamically consistent with regional stress estimates and a crustal fault network geometry inferred from seismic and geodetic data. A coseismically triggered tsunami caused by the rare occurence of an earthquake starting on-land and crossing to two faults off-shore matches local tide gauge data.

We find, that such complex rupture cascade links the crustal fault system when operating at low apparent friction thanks to the combined effects of overpressurized fluids, low dynamic friction and stress concentrations induced by deep fault creep. Understanding the physical conditions that allow rupture cascades on complex fault systems advances our ability to quantify earthquake hazard, especially to evaluate the possibility of extreme events on real fault networks.