



Filling a missing piece of the 1855 Wairarapa earthquake: Rupture characteristics and implications for regional seismic hazard

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How large earthquakes rupture across mechanically distinct fault systems remains a fundamental unresolved problem in seismology. New Zealand straddles the Australia–Pacific plate boundary, where relative plate motion is partitioned between deep Hikurangi subduction and widespread dextral strike-slip faulting in the upper plate, such as the Marlborough Fault System. This tectonic configuration favours complex, multi-fault earthquakes, as illustrated by the 2016 Mw 7.8 Kaikōura earthquake and the 2013 Mw 6.5 and Mw 6.6 Cook Strait sequence in central New Zealand. Investigating the source physics of such complex ruptures and their relationship to plate-boundary architecture will provide essential constraints on fault interaction processes and seismic hazard in large-scale convergent margins.

On the evening of 23 January 1855, a major earthquake struck central New Zealand with intense ground shaking across much of the North and South Island. Empirical ground intensity was estimated up to ten, and local tsunami waves reached nearly 10 m in the Cook Strait (Grapes and Downes, 1997; Clark et al., 2019). This event is remarkable for having generated significant uplift - maximum uplift of 6.4 m measured in the southern Wellington coast (McSaveney et al., 2006) - and extreme dextral slip, measured as ~18.7 m at Pigeon Bush along the Wairarapa fault (Rodgers and Little, 2006). Seismological evidence suggests an offshore hypocentre at ~25 km depth and a magnitude exceeding 8.0; however, in the absence of instrumental observations, it remains unclear whether significant slip also occurred on the Hikurangi subduction interface (Beavan & Darby, 2005). Resolving the role of the deeper Hikurangi megathrust, particularly its potential synchronous activation with upper-plate faults, is therefore crucial for understanding the rupture mechanics of this event and for improving seismic hazard assessments in densely populated plate-boundary regions.

In this study, we investigate the source complexity and associated ground motions of multi-fault earthquakes using physics-based dynamic rupture simulations of the 2016 Kaikōura and 1855 Wairarapa earthquakes in central New Zealand. We construct dynamic source models accounting for updated geological and seismological constraints, including regional tectonic stress fields (Townend et al., 2012), national fault networks (Seebeck et al., 2024), nonlinear rheology, and three-dimensional subsurface structures. These key geophysical constraints are essential in reproducing

the instrumental observations in the case of the 2016 Kaikōura earthquake (e.g. Ulrich et al. 2019). Rupture magnitude and ground shaking of historical earthquakes are validated against geological measurements, landslide inventories, and tsunami run-up. Beyond observation-driven scenarios, we systematically explore the sensitivity of rupture dynamics and ground motions to variations in tectonic conditions in historical earthquakes. These simulations will provide physical constraints on rupture kinematics and fault interactions, offering insights into improving near-source ground-motion models and regional seismic hazard assessments.