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Stochastic multi-fault rupture modelling in PSHA

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Traditionally, combinations of fault ruptures in the same earthquake have only been modelled if either historical or geological evidence existed for such specific combinations having occurred previously. Doubt over whether a fault combination could rupture together has been treated as an epistemic uncertainty; if the historical catalogue or fault trenching database were more extensive, the uncertainty would be reduced.

This basic empirical rule of seeing is believing has the virtue of simplicity, but it exposes seismic hazard analysts to surprise and criticism when new combinations of fault ruptures occur. The Kaikoura, New Zealand, earthquake of 14 November 2016 is the most striking and astonishing example of this phenomenon, which has led to calls for a revision to the methodology of seismic hazard assessment.

The fundamental problem with purely empirical rules is that the past is just one realization of what might have happened. What happened in the past was not inevitable, as determinists might wish to believe; indeed, the past may have been rather unlikely - or even very unlikely. By treating the past earthquake record as one specific realization out of a multiplicity of possibilities, probabilistic seismic hazard assessment is liberated from the bias that the past is somehow special and deterministic, rather than merely being a sample from an underlying fundamentally stochastic geological process.

For a given magnitude historical earthquake with an epicentre on a specific known fault, the set of faults that might have ruptured is the outcome of a stochastic process that could be modelled. The variability in the set of faults that might rupture in an earthquake of a given magnitude is part of the aleatory uncertainty in seismic source modelling, just as is the geometry and directivity of rupture.

In the formalism developed by Black and Jackson (BSSA, 2008) for the probability of multi-fault rupture, the magnitude-frequency relationship for a group of faults can be expressed in terms of the magnitude distributions for the component faults, and the probabilities that different fault combinations rupture together. The sensitivity of these magnitude-frequency relationships to remote rupture combinations can be explored to ascertain what potentially surprising multi-fault ruptures might occur, which would be consistent with present knowledge of magnitude-frequency recurrence. Some examples are given which are of special practical significance for seismic risk.