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Modelling Active Faults in Probabilistic Seismic Hazard Analysis (PSHA) with OpenQuake: Definition, Design and Experience

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The Global Earthquake Model (GEM) has, since its inception in 2009, made many contributions to the practice of seismic hazard modeling in different regions of the globe. The OpenQuake-engine (hereafter referred to simply as OpenQuake), GEM's open-source software for calculation of earthquake hazard and risk, has found application in many countries, spanning a diversity of tectonic environments. GEM itself has produced a database of national and regional seismic hazard models, harmonizing into OpenQuake's own definition the varied seismogenic sources found therein. The characterization of active faults in probabilistic seismic hazard analysis (PSHA) is at the centre of this process, motivating many of the developments in OpenQuake and presenting hazard modellers with the challenge of reconciling seismological, geological and geodetic information for the different regions of the world. Faced with these challenges, and from the experience gained in the process of harmonizing existing models of seismic hazard, four critical issues are addressed. The challenge GEM has faced in the development of software is how to define a representation of an active fault (both in terms of geometry and earthquake behaviour) that is sufficiently flexible to adapt to different tectonic conditions and levels of data completeness. By exploring the different fault typologies supported by OpenQuake we illustrate how seismic hazard calculations can, and do, take into account complexities such as geometrical irregularity of faults in the prediction of ground motion, highlighting some of the potential pitfalls and inconsistencies that can arise. This exploration leads to the second main challenge in active fault modeling, what elements of the fault source model impact most upon the hazard at a site, and when does this matter? Through a series of sensitivity studies we show how different configurations of fault geometry, and the corresponding characterisation of near-fault phenomena (including hanging wall and directivity effects) within modern ground motion prediction equations, can have an influence on the seismic hazard at a site. Yet we also illustrate the conditions under which these effects may be partially tempered when considering the full uncertainty in rupture behaviour within the fault system. The third challenge is the development of efficient means for representing both aleatory and epistemic uncertainties from active fault models in PSHA. In implementing state-of-the-art seismic hazard models into OpenQuake, such as those recently undertaken in California and Japan, new modeling techniques are needed that redefine how we treat interdependence of ruptures within the model (such as mutual exclusivity), and the propagation of uncertainties emerging from geology. Finally, we illustrate how OpenQuake, and GEM's additional toolkits for model preparation, can be applied to address long-standing issues in active fault modeling in PSHA. These include constraining the seismogenic coupling of a fault and the partitioning of seismic moment between the active fault surfaces and the surrounding seismogenic crust. We illustrate some of the possible roles that geodesy can play in the process, but highlight where this may introduce new uncertainties and potential biases into the seismic hazard process, and how these can be addressed.