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Bayesian Estimation of 3D Non-planar Fault Geometry and Slip: An application to the 2011 Megathrust (Mw 9.1) Tohoku-Oki Earthquake

Rishabh Dutta and Sigurjón Jónsson

King Abdullah University of Science and Technology (KAUST), Thuwal, Saudi Arabia (rishabh.dutta@kaust.edu.sa)

Earthquake faults are generally considered planar (or of other simple geometry) in earthquake source parameter estimations. However, simplistic fault geometries likely result in biases in estimated slip distributions and increased fault slip uncertainties. In case of large subduction zone earthquakes, these biases and uncertainties propagate into tsunami waveform modeling and other calculations related to postseismic studies, Coulomb failure stresses, etc. In this research, we parameterize 3D non-planar fault geometry for the 2011 Tohoku-Oki earthquake (Mw 9.1) and estimate these geometrical parameters along with fault slip parameters from onland and offshore GPS using Bayesian inference. This non-planar fault is formed using several 3rd degree polynomials in along-strike (X-Y plane) and along-dip (X-Z plane) directions that are tied together using a triangular mesh. The coefficients of these polynomials constitute the fault geometrical parameters. We use the trench and locations of past seismicity as a priori information to constrain these fault geometrical parameters and the Laplacian to characterize the fault slip smoothness. Hyper-parameters associated to these a priori constraints are estimated empirically and the posterior probability distribution of the model (fault geometry and slip) parameters is sampled using an adaptive Metropolis Hastings algorithm. The across-strike uncertainties in the fault geometry (effectively the local fault location) around high-slip patches increases from 6 km at 10km depth to about 35 km at 50km depth, whereas around low-slip patches the uncertainties are larger (from 7 km to 70 km). Uncertainties in reverse slip are found to be higher at high slip patches than at low slip patches. In addition, there appears to be high correlation between adjacent patches of high slip. Our results demonstrate that we can constrain complex non-planar fault geometry together with fault slip from GPS data using past seismicity as a priori constraint.