Simultaneous Bayesian Estimation of Complex Non-planar Earthquake Fault Geometry and Spatially-variable Slip from Geodetic Data

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Earthquake fault ruptures are typically complex and can consist of en echelon segments, have bends, large step-overs, and be curved or warped at different spatial scales. Although surface fault ruptures can be mapped using a variety of geological and geophysical techniques, the subsurface topology of faults is challenging to estimate. One of the main options is to use geodetic data (InSAR and GPS) of coseismic surface deformation to estimate the subsurface earthquake fault geometry along with the distributed slip. The general practice is to assume a planar fault surface and estimate the strike and dip of a simple rectangular fault prior to the spatially-variable slip estimation. Using such simplistic fault geometry during source fault estimations of large earthquakes rarely captures all the crustal deformation details seen in the data and can cause biased estimation results of the fault slip. Here, we show how complex non-planar fault geometry can be estimated simultaneously with spatially-variable slip from geodetic data in a Bayesian framework, where our non-planar fault geometry parametrization approach allows for various undulations of the fault surface in both the along-strike and down-dip directions.

We exemplify this approach through synthetic tests considering a checkerboard-like slip pattern on a listric non-planar fault. The results show that fault slip can be over-estimated by about 50-100% when using pre-assumed planar fault geometry. In contrast, both the non-planar fault geometry and spatially-variable slip are better retrieved when using our estimation approach. We then apply this modeling approach to the 2011 $M_{W}9.1$ megathrust Tohoku-Oki (Japan) earthquake. Here we use prior information like the location of the trench and earthquake hypocenters during the Bayesian estimation to reduce the extent of the model space. The resulting fault geometry shows variations in fault dip in both the along-strike and down-dip directions that compare well with Hayes' slab1.0 model of the subduction interface. The estimated fault slip is also comparable to the results that pre-defined the fault geometry using the slab1.0 model. In the future, the proposed method could lead to more realistic source models of major earthquakes, aided by improving computational resources and spatial resolution of geodetic data.

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