Bayesian multi-model fault slip estimation considering the uncertainty of underground structure

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When estimating fault slip distribution based on geodetic and seismic waveform data, it is necessary to assume the underground structure (here we assume elastic structure and fault geometry) in advance. Assuming that only uncertain information about the underground structure is available, the assumption of a "single model" of the underground structure may increase the prediction error of the response at the observation points made by the model and may cause a large bias in the results of slip estimation. Several previous studies have attempted to address this issue by considering the contribution of model prediction error to the data covariance due to uncertainty in the Green's function (e.g., Yagi & Fukahata 2008, 2011; Duputel et al. 2014). Expanding on these ideas, we have recently developed a Bayesian multi-model method for estimating the fault slip distribution. Instead of assuming a "single model" for the estimation, this method uses an ensemble of multiple models ("multi-model") of the underground structure to account for its uncertainty. This allows the estimation to take into account the model prediction error in a more general way and reduces the error associated with the assumption of Gaussian distribution. In addition, this method allows us to estimate the posterior probability density function (PDF) of the underground structure parameters by calculating the likelihood for each model included in the multi-model.

The proposed method was applied to the estimation of slip distribution using geodetic observation data during long-term slow slip events (L-SSE) that occurred around 2010 and 2018 under the Bungo Channel in southwest Japan. Here, we focus on two advantages of adopting this multi-model-based approach. First, the proposed full Bayesian estimation, which accurately takes into account the stochastic properties of the model prediction error due to model uncertainty, can be used in estimation of the slip distribution without strong prior information such as the smoothness of the slip distribution, despite that such estimation is typically classified as an ill-posed inverse problem. Second, the PDF characterizing the underground structure can be sequentially updated for fault slip estimation of recurring events at the same location, such as L-SSE. The estimation results of slip distribution obtained using the proposed method suggest that the spatial distribution of the Coulomb failure stress change is in better agreement with the distribution of the tectonic tremors on the down-dip side that occurred during the L-SSE than that obtained based on the strong prior information. This result shows more clearly the mechanical relationship between the L-SSE and the synchronized slow earthquakes in the surrounding area, and suggests that it is more effective to estimate the slip distribution without unphysical constraints in discussing the relationship between the obtained slip distribution and other events. In addition, when the PDF of the underground structure updated in the estimation for the 2010 event was used as input for the analysis of the 2018 event, the value of the information criterion was reduced, which indicates that a more favorable Bayesian estimation could be performed.

In the future, we would like to apply this method to inversion of source processes using seismic waveforms, where the assumption of underground structure is more critical to the results. We also expect to expand this method to a more data-driven approach by setting up multi-models based on the estimation results of the underground structure including uncertainty estimation.

Keywords: Long-term slow slip events, Uncertainty of underground structure, Bayesian multi-model estimation