A simultaneous correlation length estimation method for coseismic slip distribution estimation under the assumption of self-similarity

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An estimation of slip distribution is essential to understand the detail of the physics of the fault rupture. However, the discretization of the fault plane increases the number of unknown parameters more than that of data, making the problem ill-posed. To overcome this issue, we often impose regularization based on prior information to solve it. There is a regularization method using a self-similarity of the fault slip, indicated by earthquake simulations, geodetic and seismological data analyses, and field surveys of fault outcrops. Mai and Beroza (2002) showed the self-similarity by the spectral analysis of coseismic slip distribution models and the characteristics have the power spectral decay approximated by von Karman autocorrelation function (ACF) controlled by two parameters ―the correlation length and the Hurst parameter. Then, they constructed a scaling law between the moment magnitude and these parameters. Based on these previous works, Amey et al. (2018) developed the slip distribution estimation method of restricted by von Karman ACF following the scaling law. Then, they showed that the method using self-similar regularization can acquire a more correct slip distribution model than the Laplacian smoothing constraint generally used. Thus, they argue that the estimation should be conducted using physics-based regularization. On the other hand, they regard an uncertainty of the scaling law as a problem for accurate estimation. Since the scaling law is constructed using only a few earthquakes that have the moment magnitude over 8.0, it may be large uncertainty to apply the scaling law to such earthquakes. Therefore, the method to estimate the fault slip and its correlation length and Hurst parameter is required.
In this study, we first focused on the correlation length and developed the method to estimate it and slip distribution simultaneously from ground deformation data. Then, we developed the Bayesian approach to evaluate the uncertainty of model parameters, including some non-linear parameters. Finally, the sampling algorithm we used is the Hamiltonian Monte Carlo method for efficiently solving the high-dimensional problem.
We conducted numerical experiments using three random slip distributions whose correlation length was assigned previously to validate our method. We also assumed the two observation networks to discuss the effect of the slip resolution on the correlation length estimation. Under the assumption of dense observations, the input slip and the correlation length were retrieved accurately for each experiment. In the experiment assuming that the observations distribute at only the down-dip side of the fault, the model which has the slip pattern indicating the longer spatial wavelength than the input model was estimated. However, the longer correlation length has also been explored than the result under the dense observations; its posterior distribution had a peak near the assumed value.
Then, we also tested the effect of the Hurst parameter treated as a hyperparameter in our method, because the parameter has an almost constant value with some uncertainty. Two experiments assumed the larger or smaller Hurst parameter than the input value was conducted additionally. As a result, the slip distribution model was estimated with almost equal accuracy. Nevertheless, the estimated value of the correlation length indicated a negative correlation with the assumed Hurst parameter. This may be the trade-off between the two parameters restricting the short wavelength component of slip distribution. Therefore, a quantitative evaluation of the Hurst parameter is required to assess the correlation length correctly.

Keywords: Self-similarity, Bayesian inversion, Hamiltonian Monte Carlo, Uncertainty evaluation

