Development of the algorithm to estimate the coseismic fault and its uncertainty using Hamiltonian Monte Carlo

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Rapid estimation of coseismic fault model in real-time and quantitative assessment of the estimation uncertainty is extremely important to predict the expected seismic hazards such as the strong motion and tsunami occurrence. The estimation uncertainties can be classified into observation and modeling error during the inversion analysis. Especially, it is difficult to assume the fault geometry for non-interplate earthquakes such as inland and intra-slab earthquakes in advance. If we try to estimate the slip distribution for such an event, the uncertainty of the assumed fault geometry may bring a large effect to the estimated slip distribution. Therefore, quantitative assessment of the observational and modeling error including the evaluation of the fault geometry uncertainty is essential.
Bayesian fault estimation methods are effective and often used for the estimation of uncertainty as the posterior probability density function (PDF) of fault parameters. Markov chain Monte Carlo (MCMC) algorithm is frequently adopted for these purposes, especially the Metropolis-Hastings (M-H) algorithm is utilized for many inverse problems. However, the M-H can require a relatively long mixing time for particularly high dimensional problems because of a relationship of a trade-off between the parameter's exploration distance and the acceptance ratio of parameter candidates. Thus, a more efficient algorithm is needed for the sake of rapid model estimation with uncertainty evaluation. To overcome this problem, we focused on the Hamiltonian Monte Carlo (HMC) algorithm, one of the MCMC algorithms and more efficiently than others. Although the HMC realizes the efficient sampling by taking differential information of the posterior PDF, there are no previous studies to estimate the coseismic fault model. In this study, we developed the single rectangular fault estimation and slip distribution estimation method using the HMC algorithm, and investigated its applicability.
We applied the HMC algorithm to estimate the single rectangular fault model for the 2016 Kumamoto earthquake (M_{JMA} 7.3) and confirmed the sampling convergence within 2×10^4 chains including 1×10^3 burn-in chains. The estimated parameters correspond to the previous study and the calculated model could explain the input data well. Comparison with the M-H's estimation indicates the efficiency about the number of chains that the HMC could predict the comparable model to M-H's one by 2% to M-H's chains.
Next, we applied the HMC algorithm to estimate the slip distribution while assuming several fault geometries based on the single rectangular fault estimation result. We imposed a prior constraint of spatial smoothing on slip amount, and simultaneously estimate its roughness parameters. As a result, right-lateral slips including slight normal slip were estimated in a shallow area over the Futagawa fault. The uncertainty of the slip on each subfault was also estimated by a 95% confidence interval of obtained posterior PDFs. We also acquired an existence probability of a large slip on the assumed fault by using numerous samples. This presentation will discuss the specifics of the developed method using the HMC and its results. In addition, we will mention the application of the second method to an interplate earthquake.

Keywords: Hamiltonian Monte Carlo, Global Navigation Satellite System (GNSS), Bayesian inversion, Uncertainty evaluation