Estimation on fault-slip distributions without smoothing constraints by Reversible-jump MCMC

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1. Introduction

Estimation of fault-slip distributions from geodetic data is generally performed by least squares methods with a spatial smoothing constraint on the slip distribution based on ABIC or L-curve. However, a viscoelastic inversion simultaneously estimating co- and post-seismic slip distributions [Tomita et al., 2018] require high computational costs due to many hyper-parameters for the spatial smoothing and data weights. Moreover, the inversion also requires non-negative slip constraints. When the non-negative slip constraints are imposed, it is known that ABIC cannot be accurately calculated [Fukuda & Johnson, 2008] and that its computational cost dramatically increases.

Therefore, we have developed a viscoelastic inversion approach using Reversible-jump MCMC (Rj-MCMC) [Green, 1995]. The method can estimate solutions based on a posterior density function (PDF) with non-negative slip constraints and can search numbers of unknown parameters. Tomita et al. [2019, SSJ] applied the Rj-MCMC method to synthetic data and showed that it can estimate slip distributions as well as the conventional ABIC inversion. However, it still has problems on efficiency and convergency of solutions. Here, we developed a Rj-MCMC method using Parallel Tempering (PT) that efficiently searches solutions [e.g., Sambridge, 2013].

2. Method & Data

This study employed the Voronoi-cell spatial separation and the formulations of Bodin & Sambridge [2009]. Because of the Voronoi-cell spatial separation, spatial smoothing constraints are unnecessary. PT prepares multiple replicas with different temperatures and swaps their temperature conditions to avoid local minimum solutions. To accelerate the computational speed, parallel calculation of replicas was performed by MPI.

We calculated synthetic data as responses to assumed fault-slips in an elastic media [Okada, 1992]. To investigate convergency and reproducibility of the slip distribution by Rj-MCMC, we assumed the single window slip distribution in the simple elastic media. The assumed fault geometry is a planer fault (300 km ×500 km) with the dip of 15 degrees imitating a subduction zone, which is composed by 20 km ×20 km subfaults. The assumed slip distribution is a smooth slip with a peak slip of 8 m at 75 km from trench. We prepared two patterns of the observational site distributions: (1) 150 onshore sites & 5 offshore sites and (2) 150 onshore sites & 150 offshore sites assuming the coast line of 200 km from the trench.

3. Results & Discussion

We performed the Rj-MCMC inversion to the above synthetic data with various numbers of PT replicas (4–16), of maximum temperatures (4–16), and of samples (10^5–10^7). As a result, the Rj-MCMC inversion successfully reproduced the assumed slip distribution regardless of the numbers of replicas and maximum temperatures when the samples were over 10^6. Moreover, we found fast convergence of the solutions when the number of replicas was large. Number of unknown parameters was reduced to ~10 for the site distribution (1) and to ~20 for the site distribution (2). This difference reflects their spatial resolutions depending on the site distributions. The PDF for each parameter at a subfault for the site distribution (1) showed a smooth distribution, while that for the site distribution (2) showed multiple steep peaks. This suggests that the site distribution (2) has evident local minimums. However, we successfully reproduced the assumed slip distribution because ensemble of the multiple replicas prevented the slip distribution from biasing.

In this study, we confirmed that PT improved convergence of the solutions and that Rj-MCMC can reproduce the assumed slip distribution. We'll investigate whether the local minimums for the site distribution (2) can be avoided by changing the numbers of PT replicas and maximum temperatures. Moreover, we'll also investigate reproducibility of the slip distributions by Rj-MCMC assuming various patterns of the assumed slip distribution.

Keywords: Geodetic inversion, Smoothing constraint, Reversible-jump MCMC, Trans-dimensional inversion

