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Estimation of three-dimensional layer interface topography of subsurface structure using a MCMC method

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The deep sedimentary structure has strong influence on long-period ground motion. Waveform inversion is an effective way to construct the deep subsurface structure that can reproduce the observed seismic waveform. A waveform inversion method for estimating three-dimensional (3D) layer interfaces of sedimentary basins was proposed by Aoi (2002), in which the inverse problem is quasi-linearized on the assumption of weak nonlinearity between the data and model. The method was applied to real seismic data by Iwaki and Iwata (2011), which suggested its high potential for practical uses. One of the major difficulties of the inversion method is the nonuniqueness of the solution that is inevitable in such optimization procedures, which can cause problems such as strong dependency on the initial model and failure of convergence.

In this study, we formulate the basin topography waveform inversion using a Monte Carlo method. Instead of searching for one best-fitting model by quasi-linearized inversion, we take a global optimization process using a Markov Chain Monte Carlo (MCMC) method, in which the statistical characteristics of the sampled model parameters can be analyzed by Bayesian approach.

We perform a numerical test to investigate the applicability of MCMC method to be used in construction of the deep subsurface structure models. The target model is a 3D basin model with irregular boundary shape whose size is 25 km x 20 km and the maximum bedrock depth is 2500 m. The change in bedrock depth with respect to the initial value is the model parameters to be estimated in this inverse problem. The period range of the analysis is 3-10 sec. The search range is from -400 to 2200 m at 200 m intervals. The basin boundary shape is described by cosine basins functions with 35 nodes; therefore there are 14ˆ35 possible models in the model space. In MCMC method, the probability density function (PDF) of the objective function is sampled from the model space by the accept-rejection sampling of the Metropolis-Hastings algorithm. After 9000 trials, we took the mean and standard deviation of the accepted model parameters. The obtained mean model is sufficiently similar to the target model within the resolution of the basins function. It is suggested that global search based on MCMC method is applicable to construction of deep subsurface structure models. It can be combined with the local search, such as the quasi-linearized waveform inversion, especially when there is poor information on initial structure model.

Keywords: subsurface structure, inverse problem, Monte Carlo method