MCMC-based joint determination of earthquake hypocenters and 1-D velocity structures around a fault zone

*Takahiro Shiina[1], Masayuki Kano[2]

1. National Institute of Advanced Industrial Science and Technology (AIST), 2. Graduate School of Science, Tohoku University

Determination of earthquake hypocenters is the fundamental analysis in seismology. For example, locations of a large earthquake and its aftershocks provide information for understanding generation mechanisms of the mainshock and spatiotemporal activity of the aftershocks. Earthquake locations are estimated from arrival times of P and S waves picked from observed seismic records. In order to calculate theoretical travel times to compare with observed ones, velocity structure between earthquakes and stations has to be given. In general, a pre-estimated velocity model (e.g., JMA2001 model [Ueno et al., 2002]) is used to determine the earthquake locations. Meanwhile, the activity of earthquakes often concentrates on structural boundaries. Across such structural boundary, seismic velocity varies to reflect spatial variations of materials. Methods for simultaneously estimating earthquake locations and velocity structures were proposed to accurately determine earthquake hypocenters in such heterogeneous structures [e.g., Zhang and Thurber, 2003; Ryberg and Haberland, 2019].
For simultaneous determination of earthquake locations and velocity structures from a limited amount of dataset, e.g., in the case when immediately after a large earthquake, it would be practical to assume a one-dimensional (1-D) velocity model that varies only in the depths. The structural boundary related to the inland earthquakes often has a nearly-vertical dip angle. In that case, the estimation accuracy of earthquake hypocenters can be improved by assuming a different 1-D velocity model in each station group divided by the structural boundary [Sakai et al., 2004; 2005]. However, because prior constraints of subsurface heterogeneity should be necessary for dividing station groups, applications for determining earthquake locations using several 1-D velocity models are limited in the region where the subsurface velocity structure has been investigated well.
In this presentation, we propose a method for simultaneously determining earthquake hypocenters and 1-D velocity models, in addition to station clustering reflecting subsurface velocity structure. The target is considered to be an active earthquake area where velocity structures vary horizontally. In the proposed method, we perform the estimation based on the Markov chain Monte Carlo (MCMC) method: the Metropolis-Hasting algorithm for estimating locations of hypocenter and station corrections in travel times, and the reversible-jump MCMC algorithm [Green, 1995] for determining 1-D velocity models with the number of layers. The stations are clustered in a data-driven manner using the framework of the Metropolis-Hasting algorithm. Numerical experiments will demonstrate to verify the proposed method. Moreover, we estimate earthquake locations and velocity structures around the source area of the 2004 mid-Niigata prefecture earthquake by the proposed method to examine the application to real seismic data.

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