Geodetic Data Inversion Based on a Bayesian Model with Direct and Indirect Prior Information: Application to the Kanto Earthquake

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Mechanical interaction between adjacent plates, which causes crustal deformation in plate convergence zones, is rationally represented by tangential displacement discontinuity (fault slip) at plate interfaces. Given fault slip distribution on a plate interface, we can compute surface displacements on the basis of elastic dislocation theory. Then we can formulate the inverse problem of estimating unknown fault slip distribution on a plate interface from observed surface displacement data. The inversion analysis of geodetic data is very useful to reveal the source of crustal deformation in plate convergence zones. For this purpose Matsu'ura et al. (1986) and Yabuki & Matsu'ura (1992) have developed the inversion methods based on Bayesian modeling with direct prior information and with indirect prior information, respectively. We succeeded in unifying these two methods by constructing a Bayesian model with both the direct and indirect prior information.

The construction of the Bayesian model is performed as follows. We represent both observed data and prior information in the form of probability density distribution, and construct a Bayesian model governed by hyperparameters by combining them with Bayes' rule. The optimum values of the hyperparameters can be objectively determined by using Akaike's Bayesian Information Criterion (ABIC). By the way we have two different types of prior information; one of which is the direct prior information given by the most likely model and its uncertainty before getting data, and another is the indirect prior information that constrains model structure. Combining both direct and indirect prior information with observed data, we can construct a generalized Bayesian model.

Procedure for the mathematical formulation of our inversion method is similar to Yabuki & Matsu'ura (1992), except that we use not only indirect information but also direct information. First, following Fukahata et al. (2004), we integrate the direct and indirect prior information in a proper way. Then, combining the integrated prior information with observed data, we construct a generalized Bayesian model. The inversion method based on the generalized Bayesian model includes both inversion formulae by Jackson & Matsu'ura (1985) and Yabuki & Matsu'ra (1992) as special cases.

We applied the generalized inversion method to the case of the 1923 Kanto earthquake to confirm the effectiveness. We used the vertical and horizontal displacement data obtained by comparing the pre- and post-seismic leveling and triangulation, respectively. We used a realistic 3-D model of the North American-Philippine Sea plate interface, on which the Kanto earthquake occurred. In the analysis, we decompose the fault slip vectors into the primary components parallel to the direction of plate convergence and the secondary components orthogonal to it.

First, we inverted the geodetic data by the method of Yabuki & Matsu'ura (1992), where only the indirect prior information that constrains the roughness of slip distribution is used. The result shows that the inverted slip vectors take opposite direction in the eastern and western parts of the seismic fault. From the viewpoint of plate tectonics such a inversion result is incomprehensible. Next, we used the generalized inversion method to invert the geodetic data. In this case, on the basis of the postulate of plate tectonics, we used the direct prior information that the secondary components obey normal distribution with zero mean and adjustable variance in addition to the indirect prior information. The inverted slip distribution has two peaks near Miura Peninsula and Odawara. The slip vectors are almost parallel to the direction of plate convergence except for their clockwise rotation near the Sagami trough. From these results of inversion analysis we can see that the generalized inversion method enables us to successfully incorporate the postulate of plate tectonics into inversion analysis.