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An Inversion Method to Estimate Internal Stress Fields from Centroid Moment Tensors of Seismic Events

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The earthquake occurrence can be regarded as a stress release process in the crust. This means that the observed seismological data contain first-hand information about the stress state in the crust. In the 1980s, to estimate the stress state of the crust from focal mechanism data, several stress inversion methods have been developed [Gephart & Forsyth, 1984; Michael, 1984, 1987]. The common idea of these methods is to determine the pattern of average deviatoric stress for each partitioned area by minimizing the difference between observed fault slip directions and the directions of the tangential component of traction vectors acting on fault planes in the least-squares sense. However, these methods have a serious problem that the inverted stress pattern strongly depends on the way of area partition. This means that these conventional methods do not have any reasonable criterion to determine the size of area partition. These methods have also the weakness that observational errors in determining focal mechanism solutions and unavoidable ambiguity in choosing true fault planes would degrade the reliability of inversion results [Michael, 1987; Hardebeck & Hauksson, 2001].

In order to extract reliable information about the stress field related with earthquake generation, which is called seismogenic stress field hearafter, from seismological data, we developed a method of CMT (Centroid Moment Tensor) data inversion, following the inversion algorithm developed by Yabuki & Matusuura (1992). This method is based on the idea that each seismic event releases a part of the seismogenic stress field around its source. We can represent the CMT of a seismic event by a weighted volume integral of the true but unknown seismogenic stress field, since the moment tensor is defined by the total moment release in its source region. As for the weighting function we take the 3-D normal distribution with its peak at the hypocenter and the variance proportional to the two-thirds power of the seismic moment (the square of the source dimension). In this method we need not partition the study area in advance. Instead, we represent the seismogenic stress field by the superposition of a finite number of known basis functions and obtain a set of linear observation equations to be solved for the expansion coefficients (model parameters). Incorporating prior constraints on the smoothness of the seismogenic stress field with observed data by Bayes rule, we can construct a highly flexible model with unknown hyperparameters, called a Bayesian model. We use the ABIC minimum criterion that compromises the reciprocal requirements for model resolution and estimation errors in a natural way to determine the optimal values of hyperparameters objectively. Once a specific parametric model is selected, we can use the maximum likelihood method to determine the optimum values of the model parameters. Applying this method to a set of CMT data, we can estimate the six components of stress tensor at any point in the study area together with estimation errors. If we adopt boxcar functions as the basis function and neglect the prior constraints, the present method reduces to the conventional methods.

With the CMT data inversion method we analyzed about 2500 seismic events (M 3.5 - M 5.0) in northeast Japan (the NIED Seismic Moment Tensor Catalogue, 1997-2005), and estimated the average pattern of the seismogenic stress field associated with the subduction of the Pacific plate. Through the analysis, we can expect the occurrence of normal and reverse faulting with the strike parallel to the trench axis in the shallow part of the outer rise region and the continental crust, respectively. These stress patterns are consistent with those expected from geophysical and geological observations. Through this examination we can confirm that the present method of CMT data inversion is valid for the estimation of the seismogenic stress field.