Modeling 3-D configuration of Plate Boundaries in and around Japanese Islands

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Abstract

We constructed very fine configuration model of plate boundaries in and around Japanese islands. We modeled Pacific plate and Philippine Sea plate. The mesh interval is 8km x 8km. We parameterized the plate configuration from hypocenter distribution with superposition of basis functions using ABIC criterion. In numerical calculation, we modified algorithm to use only non-zero terms in matrices, and we could reduce execution count drastically.

Introduction

Interaction between plates is one of main causes of stress accumulation in plates and at plate boundaries. Important factors to evaluate plate interaction are configuration of plate boundaries, relative plate motion vectors, rheology of lithosphere and asthenosphere, etc. Hence, we need a realistic 3-D configuration of plate boundaries for simulation of tectonic loading process at and around plate boundaries.

We have been modeling 3-D configuration of plate boundaries in and around Japanese Islands for simulation of earthquake generation process in Japan region (Hirata et al, 1999). So far, we constructed a plate boundary model which was covered from longitude 125°E to 155°E, from latitude 20°N to 50°N, and from depth 0km to 100km. The mesh interval of this model is 1° x 1° (about 110km x 110km). This mesh size, however, is too sparse for realistic estimation of stress accumulation in Japan region. In this study, we develop a very fine configuration model with 8km x 8km mesh interval.

Data and Method

We model two plate boundaries, Pacific plate and Philippine Sea plate. We base on hypocenter distribution determined by ISC. From cross sections of the hypocenter distribution across the trench axes, we estimate plate boundary, and we make data sets with 0.05° x 0.05° mesh interval.

We represent spatial distribution of plate boundary depth ($z(x, y)$) by linear combination of basis functions $\Phi i(x, y)$, (x-axis is along latitude, y-axis is along longitude), which is made from the normalized bicubic B-spline function of order 4 (Yabuki and Matsu'ura 1992);

$$z(x, y) = a_i \Phi_i (x, y) \tag{1}$$

where a_i is model parameter. Then, we parameterize the data sets (**d**) as follows;

$$\mathbf{d} = \mathbf{Ha} + \mathbf{e}; \qquad H_{ij} = \Phi_j (x_i, y_i) \tag{2}$$

where **a** is model parameter vector, **e** is error vector, and we assume the errors are Gaussian with covariance $\sigma^2\mathbf{E}$.

Original data have considerable irregularities in depth, and we should smooth the local heterogeneity. We determine a trade-off of spatial resolution and the least roughness condition by ABIC criterion. We define roughness as follows;

$$r = \int_S \left[\left(\frac{\partial^2 z}{\partial x^2} \right)^2 + 2\left(\frac{\partial^2 z}{\partial x \partial y} \right)^2 + \left(\frac{\partial^2 z}{\partial y^2} \right)^2 \right] dS \equiv \mathbf{a}^T \mathbf{G} \mathbf{a} \qquad (3)$$

Using Bayes' theorem, we may write posterior probability density function;

$$p(\mathbf{a}; \sigma^2, \alpha^2 \mid \mathbf{d}) \propto \exp\left[\frac{-1}{2\sigma^2} \left\{ (\mathbf{d} - \mathbf{Ha})^T \mathbf{E}^{-1} (\mathbf{d} - \mathbf{Ha}) + \alpha^2 \mathbf{a}^T \mathbf{Ga} \right\} \right] \qquad (4)$$

Our problem is to find the values of **a**, σ^2, α^2, which maximize the posterior pdf. The values of σ^2 and α^2can be found using ABIC. Then we can obtain the best estimate of **a** as follows;

$$\mathbf{a} = \mathbf{C}^{-1} \mathbf{H}^T \mathbf{E}^{-1} \mathbf{d}; \qquad \mathbf{C} = \mathbf{H}^T \mathbf{E}^{-1} \mathbf{H} + \alpha^2 \mathbf{G} \qquad (5)$$

In numerical calculation, we use Cholesky decomposition to solve equation (5), because the matrix **C** is symmetric and positive definite. Since **H** and **G** are sparse matrices, we modify the algorithm to use only non-zero terms. This modification reduces execution count from $N^3/6$ to $mN^2/6$, where N is number of model parameters, m is maximum number of non-zero terms of each column in the matrix **C**. In this study, N is about 10000~30000 and m is about 50~60.

Results and discussion

Figure 1 shows a parameterized model of plate boundaries in and around Japanese islands. Philippine Sea plate is subducting beneath the southwest Japan, Pacific plate is subducting beneath the northeast Japan and Philippine Sea plate. This model can represent fine structure of plate boundaries at most part, but the configuration of east end of Philippine Sea plate is not determined well. Now we refine this part using results of former studies.

This study mainly uses hypocenter data. Recently, many seismic refraction/reflection surveys are conducted around Japanese islands. These surveys reveal very fine structure of crust and upper mantle. We will include these results in this model.

Acknowledgments

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References

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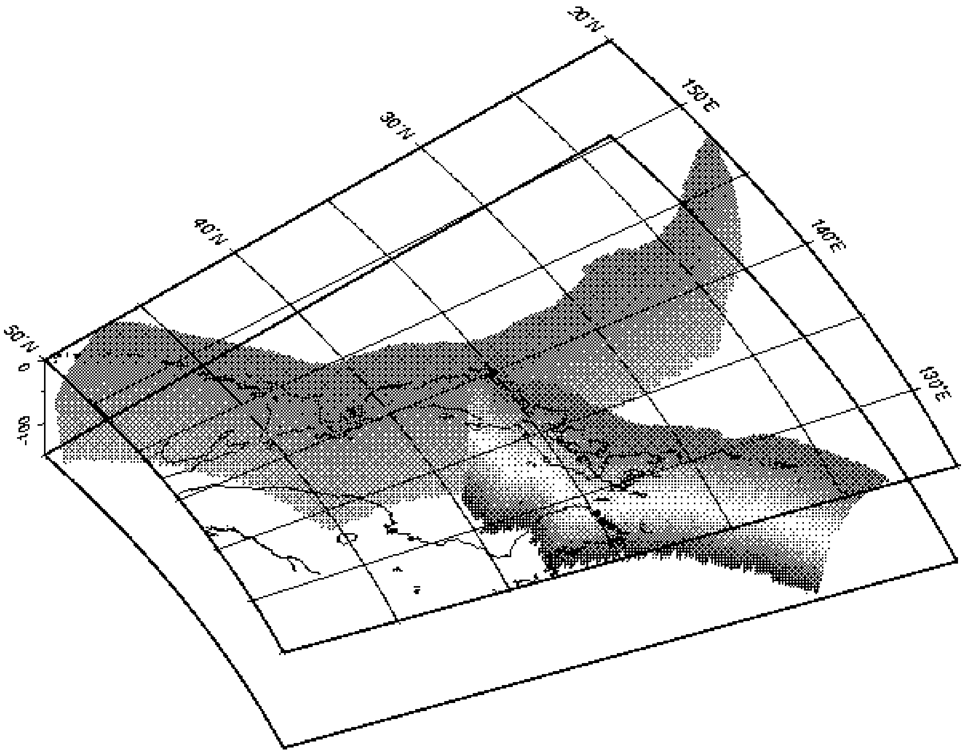

Figure 1: Plate boundary model. The mesh interval of model parameters is 8km x 8km. We parameterize plate boundaries above the depth of 150km