

## Large-scale earthquake cycle simulations with Hierarchical Matrices Method

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Recently, the inland and offshore seismic and geodetic observations have revealed a variety of slip events in the wide-range of spatiotemporal scale on the plate interface at subduction zones. These slip events are densely populated on the plate interface, and interact to each other. For example, Ariyoshi et al. (2014), assuming the plate interface along the Nankai Trough, showed the possibility that the activities of the shallow and deep low frequency earthquakes increase before the occurrence of the Nankai and Tonankai earthquakes, in the simulation. Their result shows the possibility that evaluating the interaction of multiple slip events may leads to getting the information of the next large earthquakes. For the evaluations, ECS (Earthquake Cycle Simulation) will be useful. In ECSs, we assume the friction on the plate interface, and simulate the earthquake cycle, i.e., the iterative stress accumulation during the interseismic period and the stress release as slip events on the plate interface. As we simulate the whole period of earthquake cycles, we can simultaneously consider the slip events with various scales in space and time and with the timing of occurrence. In this talk, we discuss the problem of performing large-scale ECS for the actual large earthquakes.

For considering the multi-scale slip behaviors, we need to model the large region with fine resolution. Then, the model becomes large, leading to much computational cost. For such large-scale ECSs, we often use the boundary integral element method (BIEM) and the quasi-dynamic scheme that approximates the inertial term. Then, the computational amount is  $O(N^2)$ , where  $N$  represents the number of discretized fault cells. To realize large-scale ECSs with large  $N$ , further reduction of computational time and memory is essential.

In this study, for the strategy of fast computation, we use the Hierarchical Matrices (H-matrices) method, developed by Hack-bash (1999). This method compresses the dense matrix into H-matrix, consisted of submatrices which are approximated to be low rank. We can apply this method to the matrix that has large values in its diagonal and takes smaller values as being apart from the diagonals. In quasi-dynamic ECSs, we perform the multiplication of the slip response matrix and the slip vector to get the stress on the plate interface. When we order the series of the fault cells as the neighboring cells to have neighboring numbers, we can apply the H-matrices method. Applying this method enables us to reduce of the computational memory and time to  $O(N) \sim O(N \log N)$ . In this study, we use the library HLib for constructing the H-matrices.

There is also another problem. There are some effects which are not considered in the existing BIEM quasi-dynamic cycle simulations. For the ECSs of actual large earthquakes, we need to evaluate these effects and examine to what extent the models should be realistic. In this study, we focus on the geometry of the fault system. The existing ECSs consider the problems only in homogeneous full-space medium or half-space medium with flat Earth's surface, where analytic solutions for the slip response matrix exist. However, actual subduction zone has the non-flat Earth's surface. For example, in the region off Miyagi, Tohoku, in northeast Japan, where the 2011 Tohoku earthquake occurred, the seafloor topography close to the Japan Trench where the Pacific plate subducts has an amplitude of 7 km. Therefore, in this study, we developed the efficient way of taking into account the topography of the Earth's surface into quasi-dynamic ECS, following Hok and Fukuyama (2011) which takes into account the free surface into dynamic rupture model, and examined its effect.

Finally, we note that our developed method for the actual Earth's surface enables us to simulate the whole Japan Island-scale cycle simulations, which include both inter-plate earthquakes along the Japan Trench and the Nankai Trough with different trench depths.

Keywords: quasi-dynamic, earthquake cycle, Hierarchical Matrices method