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Large-scale earthquake cycle simulations in an infinite homogeneous elastic medium with Fast Multipole Method

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Earthquake cycle simulations based on laboratory-derived rate and state friction laws have recently reproduced the historical complex earthquake sequences at subduction zones such as the Off-Sanriku in northeast Japan (Kato,2008) and the Nankai trough, southwest Japan (Hori,2006). In these simulations, by trial and error, they have searched frictional parameter distributions on plate interfaces to well explain the observed complex interactions between asperities or rupture segments. Then, these simulations have provided us with some hope for forecasting the future occurrence of earthquakes there. The next step to be taken toward the earthquake forecasting is to apply rigorous data assimilation methods used in weather forecasting and hydrology to estimate the frictional parameter distributions as well as initial values of variables. Some trials have been executed along this direction. These are, however, limited in very simple theoretical studies. The strong non-linearity involved in friction laws requires a huge number of iterations in simulation. The most serious problem is that it takes too much time to run an earthquake cycle simulation, which causes the difficulty in estimating frictional parameters for actual earthquake cycles in a large scale region. Therefore we need to fasten the simulation.

In this study, we apply the Fast Multipole Method (FMM) to the product computation of a slip response function matrix and a slip (rate) vector which appears repeatedly in cycle simulations. FMM was developed for rapid evaluation of the long-ranged forces in N-body problem in astrophysics and has widely applied to a variety of problems. It enables this by expanding the system Green's function using a multipole expansion, which allows one to group sources that lie close together and treat them as if they are a single source. In fact, the direct product computation of product requires the operational counts of O(N*N), where N is the number of dived cells on the plate interface. FMM product computation requires counts of only O(N). And requires memory size is also reduce from O(N*N) to O(N). The cell size is determined by the frictional parameter values (Rice,1993) and usually set to be several 0.1 km. If we analyze the region with 1000 x 500 km using a cell size of 1 x 1 km, then N is 5x10**5. Or the cell size would be 0.1x01 km, and N is 5 x10**7. Then FMM fasten the part of the product O(5x10**5) or O(5x10**7) times faster than the direct computation. Thus, FMM would be very powerful, if analyzing the larger region such as the Sumatra and the Nankai trough, or the multi-scale problems including events with a wide range of magnitudes due to a variety of spatial distributions of frictional parameters even in a small region.

As reported in Hirahara et al.(2009), we developed the FMM computation code for the product based on the FMM formulation of slip response function on a flat fault in a finite homogeneous elastic medium given by Yoshida et al.(2001), and according to the quad-tree structure in Liu and Nishimura (2006). And we implement our developed FMM code in the earthquake cycle simulation code by Kato (2008) where FFT algorithm is originally used for fast computation assuming cyclic boundary conditions for four edge regions.

In this study, first, we state the significance of the development of FMM in earthquake cycle simulations. Then, we refer to the accuracy of FMM computation and the comparison of CPU times in the product computation. And the comparison of the simulated earthquake cycles is also given. Finally, we note that we are developing FMM algorithm in a semi-infinite homogeneous elastic medium in Ohtai and Hirahara in this session.

Keywords: Fast Multipole Method, Earthquake cycle, Large scale simulations, Subduction zone, Co-rupture, Rate and state friction law