An easy-to-use parallel finite difference method numerical simulation code for seismic wave propagation

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Numerical simulation of the seismic wave propagation is a fundamental tool for various aspects of the earthquake seismology, such as the estimation of the inhomogeneous structure, seismic source process, physics of wave propagation in earth media. The significant improvements on the simulation method, unified inhomogeneous velocity structure, and the computer itself eventually enabled us to use the 3D numerical simulation for regular data processing studies with present parallel computers. In this study, we developed the 3D numerical simulation code based on the finite difference method for parallel computers, which is easy to use for non-specialists of the numerical simulations for wider utilization of the earthquake seismology.

Our numerical simulation code is originally developed for cutting-edge supercomputers. It has adopted the generalized Zener viscoelastic body to simulate the wide-band realistic anelastic attenuation, and finely tuned for the machine architectures to achieve the high-efficiency in terms of the computational speed. On the other hand, the code was specialized too much for specific supercomputer environments, and therefore it was not easy to handle by non-specialists.

In this study, we fully restructured the code for improving usability. The new codes allocates the memory dynamically, generate 3D inhomogeneous velocity model automatically, and export the computation result with seismologist-familiar formats. The behavior of the code is perfectly controllable by a simple input file, and it is not necessary to write and/or modify the code for users. In particular, unification of pre-process such as the velocity model preparation and post-process such as the output data handling and conversion are unified to the computation code, resulting a considerable lighten of the user's burden on manipulation.

Although the code uses the Cartesian coordinate, however, the users can use longitude and latitude coordinate for source and receiver location because it implements the Gauss-Krüger's geographical transformation. As for the velocity structure, the code automatically generates the uniform 3D grid model from input set of layers of velocity discontinuity described in longitude-latitude coordinate system. For the seismic source, one can use not only for the moment tensor source but also the body-force source, plane wave incidence from the bottom. One also can efficiently calculate the impulse response of the velocity model by using the reciprocal theorem. These various behavior also can be controlled by the parameter file.

For an example, we simulated broad band seismograms for earthquake occurred nearby Japan with moment magnitude ranging 6.0-6.5. We used 1D velocity profile of the NIED F-net and the Japan Integrated Velocity Structure Model with moment tensor solution based on the F-net catalog, and measured the goodness-of-fit by measuring the cross correlation between simulated and/or observed seismograms.

The numerically simulated seismograms show quite high cross-correlation value at longest period band of 50-100 s, however the correlation rapidly drops as decreasing periods. We note that the source locations and mechanisms used in this study were originally estimated assuming a simple 1D velocity structure, therefore observed waveforms are not necessarily fit the simulation result under 3D velocity model. However the simulated waveforms based on 1D and 3D velocity models sometimes differs at even long period range around 50 s with regionality. This result suggests the 3D effect is still strong, and expects significant improvement on determining source and mechanism by introducing 3D numerical simulation as Green's functions.

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