OpenSWPC + JAGURS: Towards waves-of-all-kinds simulation associated with significant earthquakes

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Thanks to the DONET and DONET2 in Southwest Japan and S-net in the Japan Trench, dense seismic and tsunami observation networks have been established around Japan. From these records, it was found that the pressure fluctuations on the seafloor, especially near the epicenter, were a complicated mixture of seismic waves, ocean acoustic waves, coseismic deformation, and tsunamis. It is necessary to deal with these records above the epicenter of giant subduction-zone earthquakes in real-time analyzes for early forecasts of strong ground motion and tsunamis. However, it is rare that a large earthquake accompanied by a tsunami occurs beneath a dense observation network. Thus, it is a pressing task to synthesize these realistic records by means of numerical simulations. There has been proposed a method for hybridizing these simulations by considering the equation of motion in the gravitational field (Maeda and Furumura, 2013), but it required enormous computational resources. Based on the recent development of tsunami generation theory and numerical calculation technology, this study proposes a method to perform realistic simulation of a tsunami and seismic waves by combining two independent open-source numerical simulation codes of OpenSWPC and JAGURS.

JAGURS (Baba et al., 2015) is a code for calculating the two-dimensional nonlinear long-wave equation with the dispersion effect by the finite difference method. A nesting algorithm is implemented so that the target area can be simulated with a high resolution. OpenSWPC (Maeda et al., 2017) is a code that solves three-dimensional ground motions by the finite difference method. Adopting appropriate surface and absorbing boundary conditions, it simulates broad-band seismic waves including coseismic deformation. Both codes can seamlessly handle various problems, from small-scale calculations using a PC to large-scale calculations using supercomputers by modifying input parameter sets.

In this study, we synthesized seismic waves and tsunamis based on the weak coupling method proposed by Saito and Tsushima (2015) and Saito et al. (2019). First, a seismic wave simulation from a finite fault is performed by OpenSWPC without gravity effect, and then the vertical-component displacement on the sea surface is input to JAGURS as the sea surface fluctuation at that time. Coupling calculation is performed only in one direction from OpenSWPC to JAGURS. Since JAGURS calculates tsunamis based on the long-wave approximation, dynamic changes of normal stress components due to seismic waves calculated by OpenSWPC is applied to pressure change due to tsunami wave height calculated by JAGURS. The effect of vertical-component of crustal deformation is also superimposed. In this way, it is possible to uniformly and easily simulate all kinds of wave phenomena caused by significant earthquakes, such as coseismic deformation on land and seafloor, seismic ground motion, ocean acoustic waves, and tsunamis.

In this scheme, the two simulations are performed independently and later combined using a coupler tool that absorbs the differences of coordinate systems between JAGURS and OpenSWPC. OpenSWPC simulates in the Cartesian coordinate and is associated with geographic coordinates through a map projection. JAGURS, on the other hand, mainly performs simulations in the polar coordinates. Therefore, based on OpenSWPC's velocities on the sea surface at fixed time intervals, the coupler tool estimates the displacement fluctuation per unit time at the JAGURS grid points by the bicubic interpolation and exported as an input data files of JAGURS. JAGURS can take time-varying water level fluctuations as input data, so the output of the coupler tool can be used directly in JAGURS.

A test of the coupled numerical simulation was performed under a simple earth model having constant sea depth and homogeneous Poisson solid as a subseafloor structure. The thickness of the seawater layer was set to 4 km, and a rectangle reverse-fault of 100 km x 50 km was placed at the 10 km below the seafloor. Although it is a simple medium and source process, we succeeded in synthesizing the mixture of various wave types in this proposed method. However, it was found that when the time interval between passing surface displacement from OpenSWPC to JAGURS was 1 second or more, numerical noise was mixed into the tsunami waves just above the epicenter. This is because the seismic waves containing high-frequency components are roughly sampled beyond the Nyquist frequency. It is necessary to apply an anti-aliasing filter to all grids connected from OpenSWPC to JAGURS or to connect with sufficiently finer temporal sampling interval to remedy this problem.

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