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Large-scale FDM Simulation of Seismic Waves and Tsunamis based on Seismic-Tsunami Compound Equation

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1. Introduction

As seismic waves generated from an earthquake source propagate, coseismic deformation occurs on the ground surface. In particular, when earthquakes occur beneath the ocean, the upheaval or submergence of the sea bottom cause sea water change, and it propagates as a tsunami. We have proposed a unified approach for modeling of all of these phenomena from seismic wave to tsunami in a single numerical scheme based on the compound equation of motion (Maeda and Furumura, 2011). Here, we extended our numerical model for large-scale parallel computation, and we performed the finite-difference method (FDM) simulation of seismic waves and tsunamis for 2004 Off-Kii earthquake.

2. Large-Scale Parallel Computation of the Compound Equation

The our method directly solves the equation of motion of linear elasticity in the elastic medium and water taking the effect of gravity into account. By considering equilibrium between quasi-static pressure and gravity, and finite amplitude of displacement amplitude at the ocean surface, we can directly evaluate tsunami in equation of motion. Synthesized dispersive tsunamis by means of the compound equation shows very good agreement with those by Navier-Stokes equation.

For large-scale 3D simulations, we partition the 3D model to allow parallel simulation on a large number of processors. This partitioning produces equal sized regions with some degree of overlap between them, and each is assigned to a separate processor or processor core. In addition to the inter-processor communications between neighborhood nodes, the tsunami terms, calculated in the uppermost column of the partitioned domain, should be transferred to all lower subdomains. To do this, we use a collective MPI communication function to send the current values of the tsunami terms downward from the uppermost domain to all subdomains during each time step. The parallel performance for the present simulation is estimated to be 99.839% by measuring relative speedup by increasing number of CPU cores.

3. Numerical Simulation of 2004 Off-Kii earthquake

We applied our parallelized code to the FDM simulation of 2004 Off-Kii earthquake of M7.4. Model area of 460 km x 307 km x 115 km is discretized with grid spacing of 300 m in horizontal and 150 m in vertical directions, respectively. We adopted J-EGG500 for bathymetry, 500 m-mesh GSI model for topography, subsurface structure model by J-SHIS, and plate boundary model from Daidaitoku for constructing velocity and topography models. Finite fault model is set up by referring studies of Yamanaka (2004) and Saito and Furumura (2009).

We confirmed that the clear tsunami initiation together with the radiation of seismic and ocean acoustic waves. In particular, behavior of ocean acoustic waves is quite complex, reflecting the inhomogeneous bathymetry. For example, down-slope conversion to effectively radiate wave energy to deep-ocean side, and boundary wave along the coastline have been observed. Different from the seismic waves in the elastic medium, ocean acoustic waves remain oscillating at around the epicenter up to 10 min. after the earthquake origin time because of multiple reflection between sea surface and bottom. As a result, tsunamis and high-frequency ocean acoustic waves are overlapped each other in a distance range of more than 100 km, suggesting importance on taking the ocean-acoustic waves into account for the study using ocean-bottom pressure gauges.

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