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Unified Dynamic Numerical Simulation of Seismic, Ocean Acoustics, and Tsunami Waves

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Introduction

Recently developed ocean-bottom cabled tsunami sensors enable us to monitor the tsunami on real time. During large earthquakes, recordings of these sensors contain very wide range frequency signals of seismic, ocean acoustics, and tsunami waves. On the other hand, numerical simulation approach of seismic and tsunami waves are usually separated; a permanent deformation of ocean bottom estimated by seismic or geodetic method is used as a initial condition of the tsunami calculation. In this study, we propose a unified way to simulate these three kind of waves based on the finite difference approach.

A Unified Numerical Simulation

We consider water column on the elastic half medium. The oceanic column is treated as an elastic media having zero rigidity. A linear equation of motion of elastic medium under hydrostatic equilibrium is numerically solved by using staggered-grid FDM method. Because of the existence of gravity, diagonal components of stress tensor in the water column consists of dynamic part and static part which corresponds to the propagation of ocean acoustic waves and isotropic pressure of water under the equilibrium. Since the density variation in the water column is expected to be larger than that in the elastic solid, linearized equation of continuity, or mass conservation is incorporated (e.g., Podyapolsky, 1968; Novikova, et al., 2002). This scheme does not take a non-linear advection term into account. Under the assumption of incompressibility of fluid, the vertical displacement of the water column in our scheme coincides with two-dimensional linear long wave tsunami equation.

Numerical synthesis of seismic and tsunami waves in the dynamic and unified scheme requires small and large time step in numerical integration to express wide range of velocity of waves. Since the artificial reflection of fast seismic waves from model boundary may affect slow tsunami waves, we adopted a perfectly matching layer boundary condition (Moczo, et al., 2007) to minimize the artificial reflection.

Numerical Results

We performed a numerical simulation in 3D space. We set elastic half-space of Poisson medium with S wave velocity of 4 km/s and mass density of 2.7 g/cm^3. Oceanic column has depth of 5000 m, and P-wave velocity of 1.5 km/s. A point source having thrusting mechanism is located at 4 km depth from the ocean bottom. Seismic waves are generated by stress drop at the source with Herrmann-type source time function (Herrmann, 1979) of characteristic duration of 2 s. Elastic waves generated at the source are converted to ocean acoustic waves at the ocean bottom boundary. A part of elastic waves contribute to form a permanent deformation at the ocean bottom. The ocean acoustic waves push up the surface of the water column. This corresponds to the permanent deformation of ocean column; however, due to the existence of gravity and hydrostatic equilibrium, this peak starts propagate in horizontal direction, which forms tsunami waves. In this simulation, we succeeded in synthesizing tsunami waves without assuming initial height of the ocean surface. Ocean acoustic P wave in the water column acts as an alternative career of deformation at the ocean bottom.

By introducing more realistic, inhomogeneous seismic velocity structure and bathymetry, this unified approach on simulating seismic, acoustic and tsunami waves have a potential power to synthesize complex ocean-bottom tsunami recordings.

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