Tsunami Formation as a Result of Resonant Pumping of Energy into the Compressible Water Column

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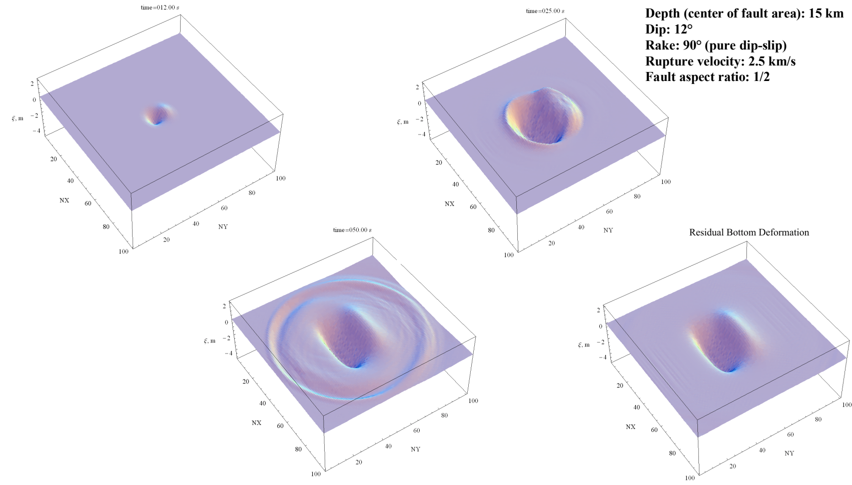
Strong bottom earthquakes that excite gravitational tsunami waves give rise to hydroacoustic waves as well. Coseismic bottom shaking in a tsunami source involve both high-frequency trembling as well as relatively long-lasting process of residual bottom deformation. Ousting the water, this residual bottom deformation results in long gravitational waves - tsunamis; whereas the high-frequency trembling is mostly responsible for the formation of hydroacoustic waves (Nosov, 1999). Under certain conditions, bottom trembling may provide a resonant pumping of energy to the compressible water column. Due to non-linearity, intensive elastic oscillations may provide additional contribution to tsunami energy (Novikova and Ostrovsky, 1982; Nosov and Kolesov, 2005; Nosov et al., 2008). The aim of this work is to examine effectiveness of hydroacoustic resonance in a tsunami source. Thereto we perform 3D numerical simulation of compressible water column excited by realistic dynamic co-seismic bottom oscillations modeled with the QSGRN/QSCMP software. We consider various earthquake magnitudes (Mw = 7 and 8) and various ocean depths ranging from 100 m to 10000 m. We demonstrate that for the Mw=8 earthquake, mass water velocity in elastic oscillations reaches value of 2.5 m/s. Contribution of hydroacoustic non-linear effects to tsunami energy and amplitude is estimated as well.

Dynamic Bottom Deformation

The dynamic ground motion is calculated by a self-developed software package QSGRN/QSCMP which is implemented using a similar Green's function approach as used in the software PSGRN/PSCMP for modeling quasi-static earthquake deformation (Wang et al. 2006). The first code QSGRN generates synthetic seismograms of a given layered viscoelastic earth model [e.g. IASP91 (Kennett 1991)] for all fundamental impulsive double-couple sources at different depths (Wang 1999). The output of QSGRN is a Green's function data base for the second code, QSCMP, which discretizes the finite earthquake rupture into a number of discrete point sources and calculates the dynamic ground motion by linear superposition. Each point source is defined by 6 parameters: the seismic moment, the strike, dip and rake angles, the rupture time and the corner frequency (or rise time). The former 4 parameters are the same as in the static case. The rupture time is calculated by assuming a uniform rupture velocity. The corner frequency is used to characterize the moment release with time by the Brune's source time function (Brune 1970) and is a crucial parameter determining the seismic energy radiated from the point source. A measure for the total seismic energy of the earthquake is the energy magnitude which can be easily estimated by teleseismic observations (Domenico et al. 2008, 2009). In the present version of QSCMP, the corner frequency is assumed to be proportional to the rupture velocity and is scaled in such a way that it yields the desired energy magnitude.

Depth (center of fault area): 15 km
Dip: 12°
Rake: 90° (pure dip-slip)
Rupture velocity: 2.5 km/s
Fault aspect ratio: 1/2

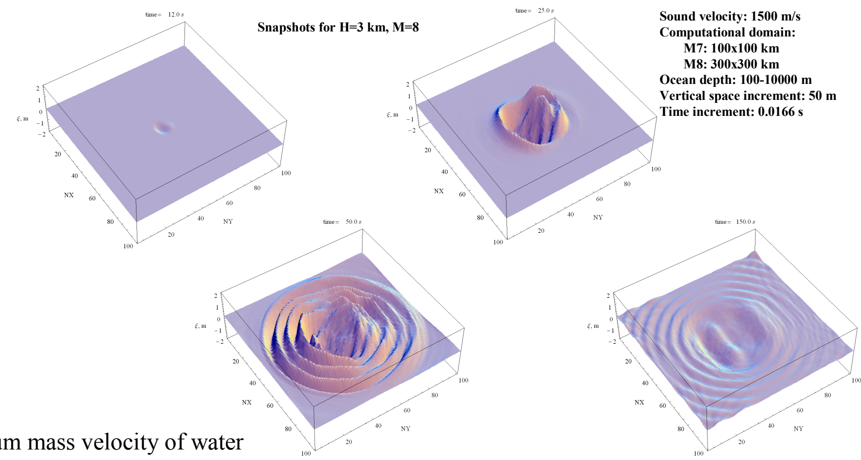


Disturbance of Water Free Surface

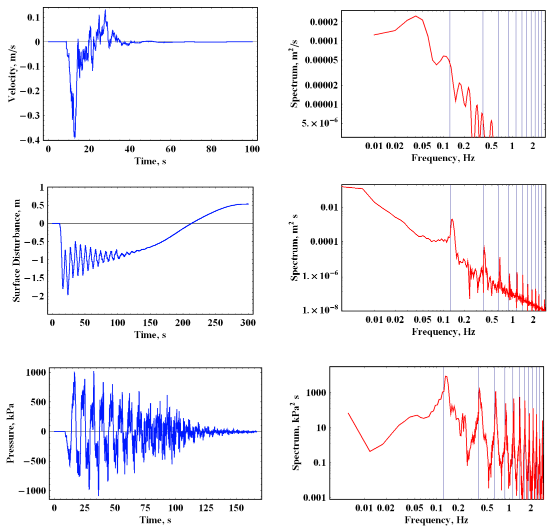
The behavior of compressible water column is calculated with use of 3D numerical model in the framework of linear potential theory (Nosov and Kolesov, 2007). We consider ideal compressible homogeneous fluid in the field of gravity. The water column is bounded by a free surface above and by an absolutely rigid moving bottom below. The dynamic bottom deformation is considered as input data for the model of water column. The traditional explicit Finite Difference scheme (z-leveled model, rectangular grid) is used to solve the wave equation. The criterion for stability of the scheme is CFL condition.

Snapshots for H=3 km, M=8

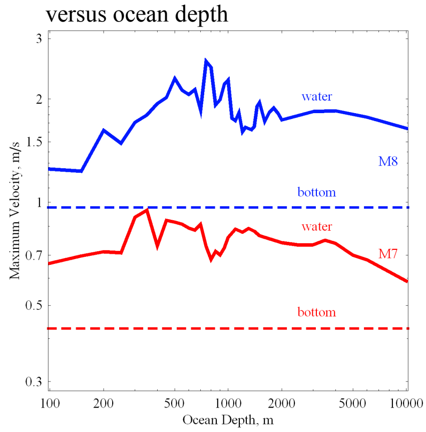
Sound velocity: 1500 m/s
Computational domain:
M7: 100x100 km
M8: 300x300 km
Ocean depth: 100-10000 m
Vertical space increment: 50 m
Time increment: 0.0166 s



Velocity of bottom displacement, free surface disturbance and bottom pressure in the centre of the calculating area. Grid lines stand for the positions of normal frequencies ($\nu_k = (1+2k)c/4H$) at depth of 3 km.



Maximum mass velocity of water versus ocean depth



Estimated contribution of nonlinearity to tsunami amplitude:
$$A^{M7}_{non-linear} \sim V^2_{max}/g \approx 0.1\,m$$
$$A^{M8}_{non-linear} \sim V^2_{max}/g \approx 0.64\,m$$

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