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Three-Dimensional Tsunami Generation due to the Sea-Bottom Deformation

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The present study simulates the tsunami generation caused by the sea-bottom elevation based on 3-D Navier-Stokes equations and interprets the simulation results based on analytical linear-approximation theory. Although conventional numerical tsunami simulations often assumed that the initial tsunami distribution was identical to the sea-bottom deformation, this assumption is too simple for modeling tsunami sources. For example, the assumption fails when the sea-bottom deformation is restricted to small area, which often occurs in intraplate earthquakes. To accomplish the higher accuracy in tsunami simulations, it is important to investigate the relation between the sea-bottom deformation and the initial tsunami distribution, and to recognize the limitation of the simple assumption used in conventional studies.

At first, we solve 3-D Navier-Stokes equations numerically for tsunami generation process. In the simulation, the sea-bottom deformation is given by the vertical flow at the sea-bottom in constant water depth H. The spatial distribution of the vertical flow is supposed to be Gaussian function characterized by the spatial scale size 2a, and the flow is constant in duration T. Conducting the tsunami simulations with various model parameters, we investigate the relation between the sea bottom deformation and the initial tsunami distribution. The height of the initial tsunami distribution is, in general, the same as the bottom deformation when the source size 2a is much larger than the depth H. And the height decreases with increasing the depth, and the duration T. When the duration is small, we obtain a simple relation between the initial height distribution and the source size normalized by the water depth. It indicates that the initial tsunami distribution becomes smaller when the source size is smaller than 20 fold of the water depth (2a is smaller than 20H). However, when the duration increases, the relation varies, and the initial height distribution cannot be represented by a simple function of the normalized source size.

Then, we interpret the above simulation results based on the analytical solutions for tsunamis derived by using the linear approximation [Takahashi 1942]. The analytical solutions and the simulation results show good agreement. The agreement supports the reliability of the tsunami simulation code used in this study [Saito and Furumura, 2007, IUGG]. Furthermore, examining the analytical solution, we can interpret tsunami generation process as filtering process; the 2-D spatial spectrum of the surface elevation is obtained by applying the two low-pass filters on the spatial spectrum of the bottom deformation. A corner wavenumber is given by the inverse of the water depth, H-1, and the other is by inverse of the characteristic distance L^{-1} (= c^{-1} T^{-1}) defined by phase velocity c and the duration T. Especially, when the bottom deformation occurs suddenly (T is much smaller than a/c), the initial tsunami distribution is given by a function of the source width normalized by the depth. This relation is also obtained by the numerical simulations.