A trial separation between tsunami height and coseismic deformation from ocean-bottom pressure gauge records using data assimilation method

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Data assimilation method provides a successive estimation of tsunami wavefield rather than the seismic source fault slip or initial sea height. This method avoid ambiguities on inverting source slip, and well assimilate the tsunami also for far-field or tsunami earthquakes without relying on seismic waves, which is preferable and suitable for real-time monitoring and forecasting. The widely-adopted ocean bottom pressure gauge records, however, contain an offset due to coseismic deformation beneath the sensor. This is a common problem among various tsunami real-time forecasting methods, and it made difficult to estimate and/or forecast tsunami until tsunami propagates outside of the source area. This study focuses to separate the coseismic deformation effect from the true tsunami height based on the data assimilation.
First we consider the effect on using tsunami height measured by ocean bottom pressure gauges (hereinafter referred to as pressure height) in linear long-wave tsunami problem. Ocean bottom pressure gauge measure the differential height between the true tsunami height and coseismic deformation, while the true tsunami height obeys the long-wave tsunami equation. The pressure height therefore satisfies the wave equation having inhomogeneous term due to the coseismic deformation. This inhomogeneous term is the origin of offset appeared on the data assimilation with pressure gauge data. The inhomogeneous term contains second-order temporal and spatial derivatives. The former should disappear after the source rupture and arrival of seismic wave, while the latter remains at long elapsed time.
Based on the above understandings of the effect of coseismic deformation, we propose a two-step method to estimate tsunami wavefield based on the data assimilation. First, the pressure gauge data are directly assimilated to the linear long-wave equation. The tsunami height at one-time step future is forecasted by numerical simulation, and the tsunami height at pressure gauge station location is compared with the observed data. The residual between forecast and observation is used to assimilate the surrounding tsunami wavefield by the optimum interpolation method.
Since the data assimilation uses the pressure height, the assimilated tsunami wavefield should be contaminated by the coseismic deformation. As a second step, this contamination effect is eliminated. By numerically calculating the second-order derivatives in space and time from the assimilated tsunami wavefield, we obtain the inhomogeneous term of the wave equation. If we omit the temporal derivative of the coseismic deformation, this inhomogeneous term should obey the Laplace equation of the coseismic deformation, which can be solved numerically. Then the real tsunami height is estimated by subtracting the coseismic deformation term from the pressure height. Though the estimated tsunami flow velocity also was affected by the offset problem, the true tsunami velocity can also be extracted from the derivative of the true tsunami height with respect to space.
A simple 1D numerical experiments for the proposed method was performed. The synthetic tsunami was simulated under the homogeneous sea depth of 3000 m, and recorded at evenly-spaced ocean bottom synthetic stations at intervals of 30 km. At the first step, the data-assimilated tsunami height from pressure height did not detect the initial tsunami due to nearly identical motions between sea bottom and surface. At longer elapsed time the assimilated tsunami height has fictitious negative offset. By applying the second-step of the proposed method, it correctly separated the coseismic deformation, although the result was a little bit wobbled. It is noteworthy that the initial

tsunami rise-up at very early time due to the coseismic deformation was clearly detected by this separation, which could be useful for further shortening the necessary time for forecasting tsunami.

Keywords: Tsunami, Realtime forecasting, Data assimilation, Ocean bottom pressure gauge, Coseismic deformation

