Improvement of tsunami-forecasting method based on tsunami inversion: small-size and large-amplitude tsunamis

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Since 2000, real-time tsunami forecasting methods based on inversion of offshore tsunami data have been proposed for tsunami disaster mitigation (e.g., Titov et al., 2005; Tsushima et al., 2009). In the previous studies, we developed a tsunami-forecasting method based on inversion for initial sea-surface height distribution, named tFISH (Tsushima et al., 2009, 2012). In the tFISH algorithm, tsunami source that is initial sea-surface height distribution is expressed by a linear superposition of elementary tsunami sources. The size of elemental sources is about 20 km that can well express tsunami sources of moderate to large interplate earthquakes. However, tsunamis that affect coastal communities are sometimes generated by a spatially small-size source. For example, a Mw 6.9 intraplate normal-faulting earthquake occurred off Fukushima prefecture, northeastern Japan, on 22 November 2016, and the 1.4-m-height tsunami was observed at coastal tide gauge. The area of the source is comparable or smaller than that of elemental source, and thus the tFISH may not resolve the source and decrease accuracy of tsunami forecasting. Considering that the tsunami height at the coast was large (> 1 m) enough to cause the disaster, the accurate forecasting for this event is important. In this study, we try to improve the tFISH algorithm for accurate forecasting of small-size and large-amplitude tsunamis.

I performed numerical simulation of tsunami forecasting assuming the 2016 Nov. off Fukushima earthquake. An earthquake faulting of the 2016 earthquake is assumed by referring the aftershock distribution, and then the resultant tsunami was calculated numerically to obtain tsunami waveforms at offshore and coastal tsunami observing points. The obtained waveforms are regarded as observation data and used in the tFISH inversion.

Firstly, to know the tFISH performance for the event, the tFISH was applied to the synthetic data. Tsunami waveform data at S-net and GPS buoys from the origin time to 30 min of the earthquake were fed into the tFISH inversion. As a result, the estimate of initial tsunami height distribution did not resemble to the assumed one (i.e. true source in the simulation): long-axis of the estimated source is north-south direction, although the true one is northeast-southwest direction. The difference of the long-axis direction directly leads to the difference of tsunami-energy directivity, resulting in degrading tsunami-height prediction along the coast. The cause of the source misestimation is that the spatial size of the elemental source is too large to express the true source. Actually, short-period tsunami waveforms observed at S-net are less modeled in the inversion.

Then, to solve the problem, a two-steps inversion is proposed in this study: at the first step, the conventional tFISH inversion is performed. Then, we consider that if the estimated source is expressed by extremely small number of elemental sources (e.g., one source only), the true source may be smaller than the elemental one. When this criterion is satisfied, we go to the next step. At the second step, we perform tsunami-waveform inversion with elemental sources whose sizes are much smaller than the original ones (here, 4 km size, the one-fifth of the original). In the inversion, the small-size elemental sources are distributed to sea area where tsunami source is imaged in the first-step inversion, in order to reduce the number of unknown parameters. After that, we decide whether or not the source model at the second step is chosen as the final solution by using the following criterion: the comparison between observed tsunami waveforms and the calculations in the inversion shows the better agreement than in the first-step inversion. We used tentative values for two criteria in the new approach and applied this algorithm to synthetic data from the 2016 Nov. off Fukushima earthquake and succeeded in avoiding the misestimation of long-axis of the source that is critical for tsunami directivity.

Keywords: Tsunami, Real-time forecasting, Inverse problem