Tsunami inundation forecast based on precomputed scenarios and pattern recognition algorithms

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We utilized a precomputed tsunami database comprised of pairs of low- and high-resolution maximum tsunami elevations and flow depths originating from various hypothetical earthquake scenarios. After constructing the database, we applied our proposed method to rapidly generate tsunami inundation forecasts by transforming a low-resolution tsunami simulation result from a linear model into a high-resolution inundation map. In the actual tsunami event, assuming that the source model is available in real-time, our method works by finding the best matched solution in the low-resolution database relative to the input resulted by the linear model. Based on the selected scenario, we can obtain the associated inundation map from its paired high-resolution database. Therefore, the use of a nonlinear model in the real-time computation can be circumvented. However, a projection to an optimal subspace is necessary to accurately find the closest samples in the database relative to the input. To that end, we constructed a projection matrix based on a principal component analysis (PCA) and a linear discriminant analysis (LDA), commonly used in the computer vision field for the purpose of pattern recognitions. With the projection to the PCA and LDA subspace, the transformation from the low- to high resolution model result can be done within seconds. This is a significant improvement to the conventional approach using the direct forward modeling to forecast the tsunami inundation.

Our proposed method was applied to the 2011 Tohoku tsunami, with the study site around the Rikunzentakata bay. We assumed that the tsunami sources were generated based on thrust earthquakes with simple rectangular faults and various fault parameters. A total of 532 hypothetical tsunami source scenarios were distributed along the subduction zone of the Japan Trench. Subsequently, we run 3 h tsunami simulations based on the predefined sources using a nested grid system. We employed a linear long wave model at grid sizes of 30, 10, and 3.33 arc-sec, and a nonlinear model with inundation at the smallest grid size of 1.1 arc-sec. To construct the database, we store maximum tsunami heights at the largest grid (30 arc-sec ≈926 m) and at the smallest one (1.11 arc-sec ≈35 m) including flow depths. The high-resolution database with 35 m grid size covered the entire Rikuzentakata bay, while the low-resolution database of 926 m grid size was defined at approximately the same area by cropping the original model domain.

Similar to the direct forward modeling method, the algorithm can be executed when the source estimate is available, typically 10 to 30 min after the earthquake. Here we used the source estimates inferred from tsunami waveform data by the "tsunami Forecasting based on Inversion for initial sea-Surface Height" (tFISH) algorithm. The estimated inundation heights by the direct forward modeling method, which required approximately 40 min computing time, were quite accurate when compared with the 2011 observations. However, the 40 min computing time is probably insufficient for a real-time application, especially in near-field cases. In contrast, our method can achieve a comparable accuracy with a significantly less computing time, i.e., ~5 min computation of the linear propagation model plus a few seconds transformation from the low- to high resolution map using the PCA-LDA approach. This indicates that our method is capable of producing rapid tsunami inundation forecasts compared to the conventional approach, thus it is more reliable for a real-time application.

Keywords: Tsunami inundation forecast, Pattern recognition algorithms, Precomputed database