Regional Probabilistic Tsunami Hazard Assessment for the Sea of Japan

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The Sea of Japan is known to host large tsunamis generated by earthquakes (M>7) on several active fault systems: the 1993 South-west Hokkaido (M7.8), 1983 Japan Sea (M7.7), 1964 Niigata (M7.5), 1940 Shakotan-oki (M7.5), and 1833 Shonai-oki (M7.5). The aforementioned tsunamis were responsible for severe destructions and many casualties in the coast of the Sea of Japan region. As part of disaster countermeasures, we conducted a probabilistic tsunami hazard assessment (PTHA) at 154 coastal locations for municipalities along the Sea of Japan coast, divided into six regions: Hokkaido, Tohoku, Chubu, Kinki, Chugoku, and Kyushu. The study was supported by the Integrated Research Project on Seismic and Tsunami Hazards Around the Sea of Japan from the Ministry of Education, Culture, Sports, Science and Technology of Japan.

Here we analyzed the regional tsunami hazard associated with 60 active faults beneath the eastern margin of the Sea of Japan, which were identified based on seismic reflection surveys (MLIT, 2014). In our PTHA study, we set a minimum magnitude of *M*w 6.5 at all faults, while a maximum magnitude at each fault varies from *M*w 6.8 to 7.9 according to the estimated fault sizes. We discretized the faults into a 10 km ×10 km subfault size to take into account the slip heterogeneity and to facilitate the Green’s function summations. We generated a large number of stochastic slip realizations using a Monte Carlo approach at each fault. The method is implemented in a software package called SlipReal (http://equake-rc.info/cers-software/rupgen/, accessed 1 April 2020) developed by Mai and Beroza (2002). The corresponding tsunamis at the 50-m isobaths were calculated by applying the precalculated Green’s function to the randomly generated slip. Subsequently, we applied an amplification factor by the Green’s Law, assuming that the final tsunami heights were calculated at a water depth of 1 m. Based on the Monte Carlo convergence analysis, the total number of considered scenarios is 76,685. Such a large number of samples is expected to account for the epistemic uncertainty on the slip distribution of faults. Furthermore, the variance parameter (β) representing aleatory uncertainty in the PTHA was determined from the comparison with four most recent historical tsunamis using a logarithmic standard deviation κ of Aida (1978), such that $\beta=\ln(\kappa)$. The β values for the four events are: 0.615 for the 1940 and 1983 events, 0.713 for the 1964 event, and 0.784 for the 1993 event. We then applied a logic-tree approach to incorporate those β values in the PTHA with weights of 0.5 for the β of 0.615, and 0.25 for the remaining β of 0.713 and 0.784. Lastly, we estimated the earthquake recurrence rate of each fault based on *a* and *b* values of the Gutenberg-Richter frequency magnitude distribution (Gutenberg and Richter, 1944) derived from observed seismicity in the study area from the Japan Meteorological Agency unified hypocenter catalog over a period of 1997-2017. Additionally, we also analyzed the effect of variations of *a* and *b* values to the tsunami hazard assessment, which in this study, is apparently not very sensitive.

Our probabilistic analysis indicates that the tsunami hazard generally increases from southwest to northeast, which is consistent with the number and type of the identified fault systems, i.e. many reverse faults exist in the northeastern parts whereas strike-slip faults dominate the southwestern parts. More specifically, tsunami hazard in Chubu, Tohoku, and Hokkaido regions are considerably higher than that of

Kyushu, Chugoku, and Kinki regions. The highest maximum coastal tsunamis of approximately 3.7, 7.7, and 11.5 m for the return periods of 100-, 400-, and 1000-year, respectively, are expected to occur at a coastal point in Niigata prefecture of Chubu region. Most coastal points in Tohoku, several in Chubu, and one in Hokkaido have more than 10% probability of experiencing maximum coastal tsunami of higher than 0.5 m at any given year, while in Kyushu, Chugoku, and Kinki, the probability is generally less than 5%. Furthermore, the deaggregation of hazard suggests that tsunamis in the northeast are predominated by local sources, while the southwestern parts are likely affected by several regional sources. These local sources raise concerns on the appropriate measure for tsunami mitigation, because near-field tsunamis render a timely warning less effective due to the extremely short lead time. Therefore, more attention should be given to Chubu, Tohoku, and Hokkaido regions in ensuring an efficient and effective regional tsunami disaster mitigation strategy for the Sea of Japan coast.