Probabilistic tsunami inundation assessment for the maximum possible earthquake A case study of the Sagami Trough megathrust earthquake in Japan

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Abstract

The purpose of this study is to conduct a probabilistic tsunami inundation assessment for the maximum possible earthquake magnitude in the Sagami Trough megathrust earthquake in Japan, showing the uncertainties of the assumed tsunami by performing a numerical simulation of tsunami inundation considering various uncertainties and reduce the computational costs using the mode decomposition method. First, we developed 9 cases of fault parameters of the Sagami Trough megathrust earthquake (Mw 8.7) considering these uncertainties, where the reference Mw was changed to ±0.1 and the reference fault depths were changed to -1 km and +2 km. Then, we evaluated the tsunami inundation areas and depths for all 9 cases using a nonlinear longwave equation. Next, we applied singular value decomposition to the inundation depth data and evaluated the spatial inundation modes. We can obtain a large number of possible inundation areas and probability density distributions of tsunami inundation depths in each mesh by combining these inundation modes. Finally, we obtained tsunami inundation hazard curves and tsunami inundation distribution within the next 30 years by applying the Brownian Passage Time (BPT) distribution. The proposed method can be used to evaluate the tsunami inundation area considering the uncertainty of the largest earthquake with a relatively low computational cost and could be an effective method to evaluate the uncertainty of tsunami hazard maps and the probability density function of tsunami inundation depths at each point.

① A target earthquake source and earthquake uncertainties

Based on the theoretical framework outlined in our paper, we consider the uncertainties in earthquake Mw and fault depth. Figure 1. shows the slip distribution of the generated Sagami Trough megathrust earthquake.

This was generated based on the fault parameters of the Sagami Trough megathrust earthquake (western model) (Mw 8.7) published by the Cabinet Office in 2012. Using the initial water level as an input value evaluated by using the theory of Okada, we performed tsunami numerical simulations via nonlinear shallow water equations and the continuity equation with a time interval of 0.6 seconds and a grid spacing of 270 m - 90 m - 30 m - 10 m.

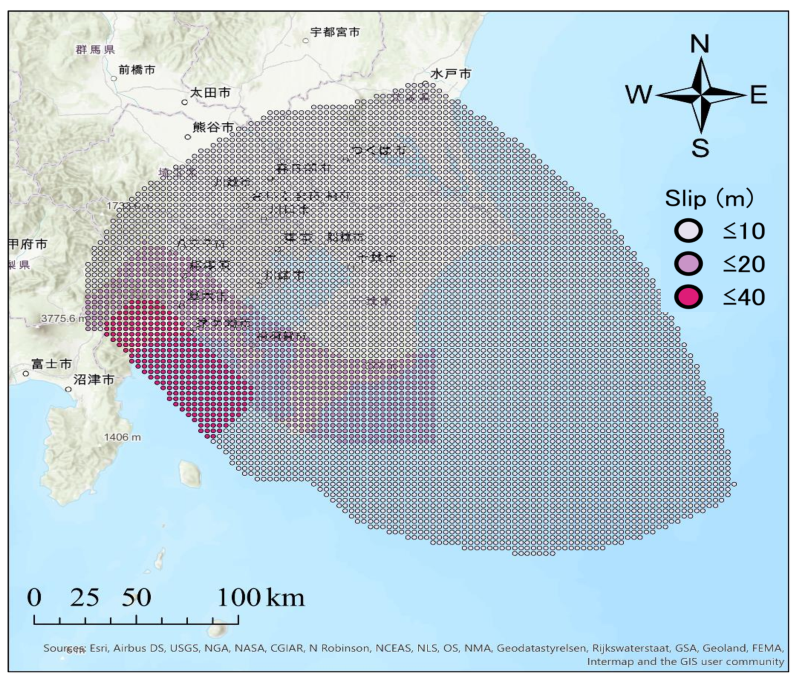

Figure 1. The target sources of this study (The Sagami trough earthquake in Japan)

Figure 2. shows the distributions of the maximum tsunami inundation depths for the target area, Zushi city in Japan, simulated for 9 seismogenic faults with three Mw values and three fault depths. Changes in Mw were achieved by adjusting the amount of slip.

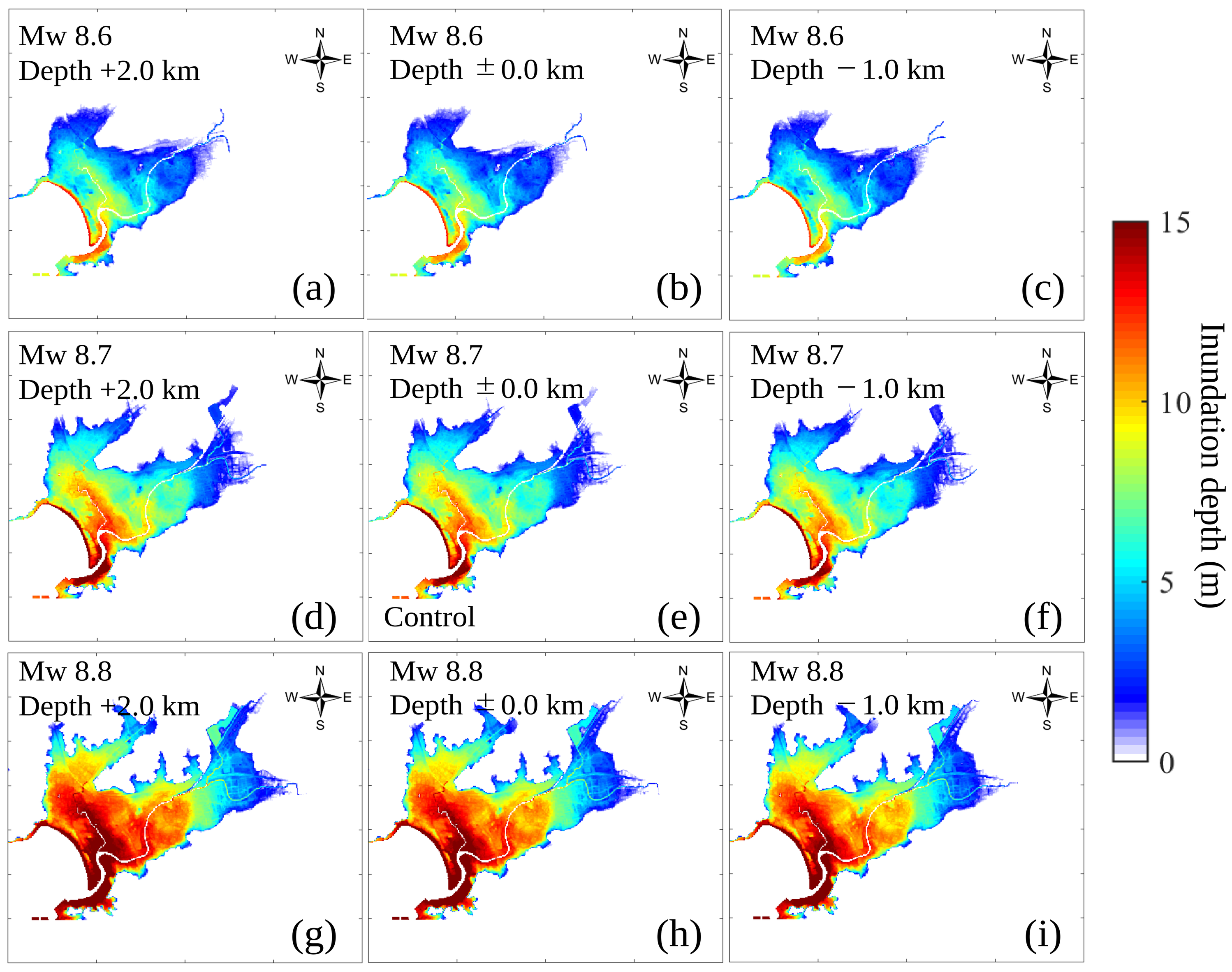

Figure 2. Tsunami inundation results for Zushi city, Japan

② Mode decomposition and Surrogate model

We generated data matrix X from the 9 tsunami inundation depth data and decomposed the matrix into singular vectors as following:

Singular Value Decomposition:

$$\boldsymbol{X} = \boldsymbol{U}\boldsymbol{\Sigma}\boldsymbol{V}^{T}$$

$$\Longleftrightarrow \quad \boldsymbol{x}_j = \sum_{k=1}^{N} \boldsymbol{u}_k (\lambda_k v_{kj}^{T}) = \sum_{k=1}^{N} (\lambda_k v_{jk}) \boldsymbol{u}_k = \sum_{k=1}^{N} (\alpha_{jk}) \boldsymbol{u}_k$$

Figure 3. shows the spatial distribution of column vectors $\boldsymbol{u}_j$ (j = 1, …, 9) comprising the left-singular vector. These column vectors are called modes, and we can identify 9 mode distributions corresponding to various tsunami inundation depths. We determined the coefficients α_{jk} using random numbers following probability distribution of the input parameters (see Table 1.) and randomly generated the inundation depth distribution using the surrogate model.

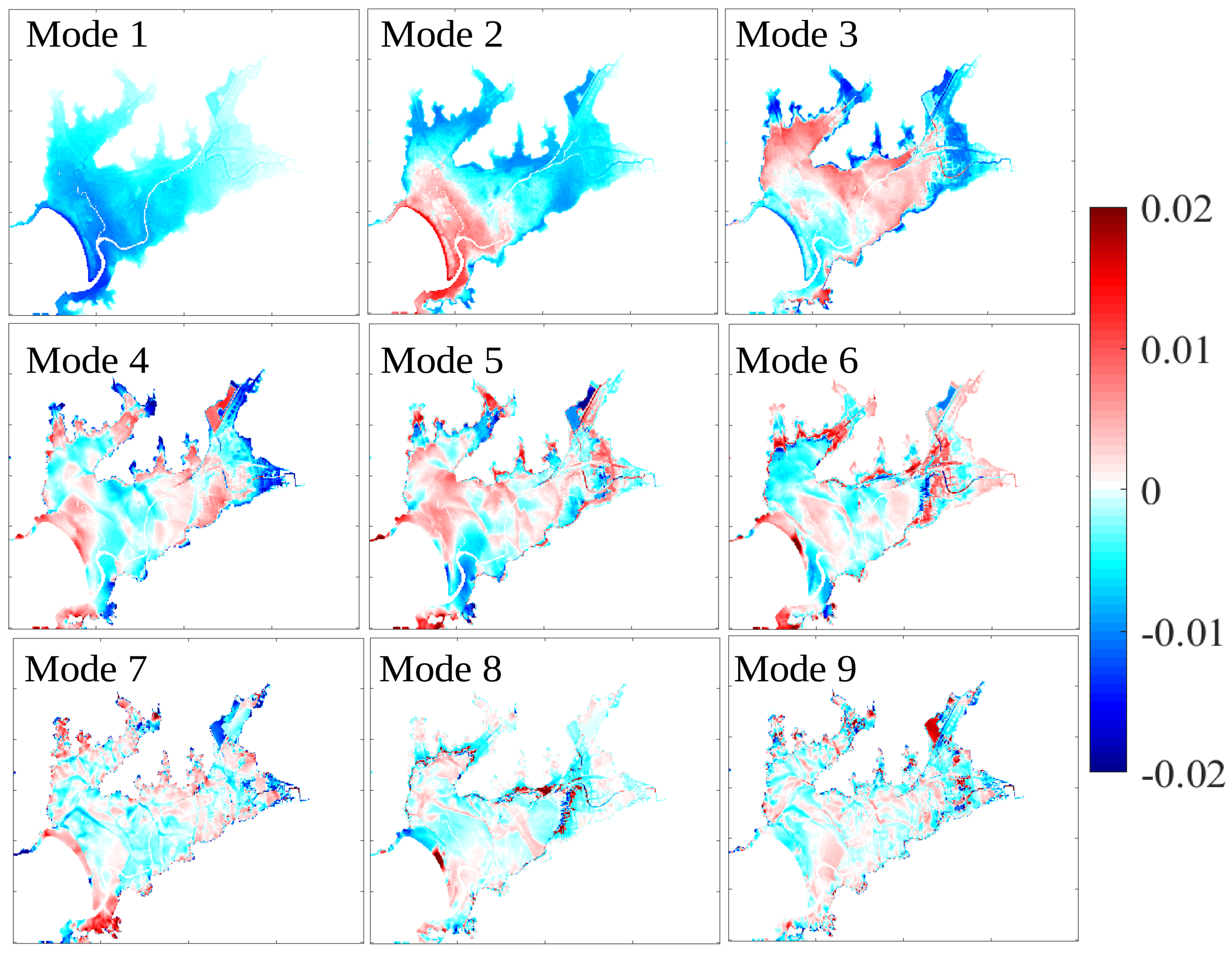

Figure 3. Mode decomposition results for tsunami inundation depth data

Table 1. Probability distribution of slip scale and fault depth for generating tsunami inundation depths

Variables	Average	Standard dev.	Probability distribution	Basis for variability setting
Slip scale factor **S**	1.00	0.35	Log normal	Mw is suggested to vary by about ±0.1, considering previous earthquakes with the same fault area. (The Nuclear Civil Engineering Committee, JSCE, 2011)
Fault depth **D** [km]	0.00	2.0	Normal	There was a standard deviation of several kilometers based on the results of research evaluating the depth of the upper edge of the Philippine Sea Plate.

Figure 4(a) shows the average inundation depth in each mesh evaluated by using 10,000 random numbers, and Fig. 4(b) shows the maximum inundation depth in each mesh sampled with 10,000 simulations. The mean values in Fig 4(a) are similar to the inundation depth distribution for the control case in Fig 2(e), and the maximum values in Fig 4(b) are similar to the inundation depth distribution for the Mw 8.8 case in Fig 2(g), (h) and (i), indicating that we were able to reproduce the spatial distribution of tsunami inundation depths produced from the numerical analysis by using the surrogate model. Fig 4(c) shows the standard deviation of tsunami inundation depth. This allows us to understand the characteristics of the variability of the tsunami inundation depth when considering the earthquake source uncertainty.

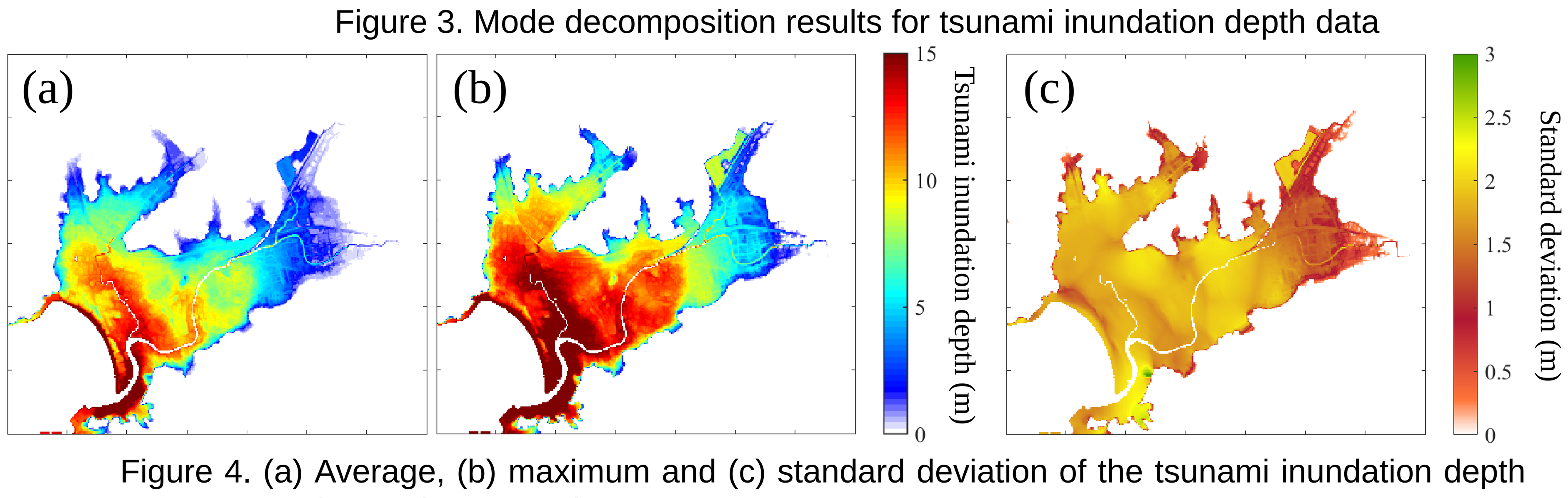

Figure 4. (a) Average, (b) maximum and (c) standard deviation of the tsunami inundation depth by Monte Carlo simulation results

③ Summary

We proposed a probabilistic tsunami inundation assessment method using proper orthogonal decomposition as a method to determine the buffer zone of tsunami hazard maps. The current tsunami hazard maps are prepared for the largest class of earthquakes, and this method can be effective when considering the uncertainty of tsunami hazards from the largest class of earthquakes.

Reference

Yo Fukutani, Shuji Moriguchi, Kenjiro Terada, Yu Otake (2021) Time-Dependent Probabilistic Tsunami Inundation Assessment Using Mode Decomposition to Assess Uncertainty for an Earthquake Scenario, Journal of Geophysical Research: Oceans, Vol.126(7), e2021JC017250. DOI:10.1029/2021JC017250.