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主 論 文 の 要 旨

論文題目　**STUDY ON REAL-TIME TSUNAMI INUNDATION, WAVEFORMS, AND WAVEFIELD FORECASTING**
(津波の波形，流動場および津波浸水域のリアルタイム予測に関する研究)

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論 文 内 容 の 要 旨

The best method to forecast tsunami waveforms, inundation, and wavefields caused by a submarine earthquake is by conducting linear or non-linear tsunami simulation. However, these methods have the disadvantages of a relatively high computational cost and the necessity for immediate warning announcements when a tsunami is imminent. The main objective of this study is to forecast tsunami inundation, waveforms, and wavefields in a timely manner shortly after an earthquake occurs.

In the first part of this study, tsunami inundation is forecasted by utilizing a database. The method aims to provide tsunami inundation forecasts without conducting non-linear tsunami model. The database consists of tsunami inundation and waveforms from multiple fault scenarios. The system is divided into two stages. In the first stage, preliminary earthquake information is used to find the appropriate tsunami inundation scenario in the database. In the second stage, a real-time tsunami waveform simulation is conducted to find the best-case scenario by minimizing the error between computed tsunami waveforms and those in database. Furthermore, this method is able produce good tsunami inundation forecasts in a reliable time.

The second part of this study involving machine learning algorithms for tsunami inundation forecasting. Two machine learning models, a convolutional neural network and a multilayer perceptron, are used to estimate tsunami inundation in real-time. Non-linear tsunami simulation from same fault scenarios as mentioned in the first part of this study is conducted. The result of the maximum tsunami amplitude in a low-resolution grid and the associated tsunami inundation in a high-resolution grid are then stored in the database. The convolutional neural network selects tsunami inundation in the high-resolution grid as the forecast based on pattern similarity between the input, which is the results of linear forward modeling in the low-resolution grid, and the precomputed patterns in the database. Slightly different from the convolutional neural network, instead of selecting the best-fit scenario in the database, the multilayer perceptron directly generates the inundation forecast based on knowledge acquired during the training process. The methods have been conducted by using the hypothetical future Nankai megathrust earthquake with Atashika and Owase Bays in Japan as the study cases. The results show that the proposed methods are extremely fast (less than 1 s) and comparable with nonlinear forward modeling. Therefore, the proposed methods can be used as a deterministic model for real-time simulation.

In the third part of this study, the performance of three data-driven models, including unfine- and fine-tuned probabilistic regularized extreme learning machines, and a support vector machine are examined to forecast tsunami waveform at coastal stations in real-time. The proposed methods are applied to an experimental case with the 2004 Kii (M7.5) and the 2011 Tohoku earthquake (M9.0). The results show that a fine-tuned probabilistic regularized extreme learning machine can produce better prediction accuracy compared to the conventional tsunami waveform inversion and the other data-driven models with quick calculation time. The support vector machine is also a promising method as the maximum tsunami height prediction is closer to the observation than the other models. Furthermore, the proposed data-driven models are also compared with a conventional waveform inversion, and the results show that the proposed models provide a better general approximation. Therefore, the proposed methods can be used as a surrogate for the deterministic model for real-time computation. Furthermore, our proposed methods produce a consistent prediction which is an important factor for the real-time warning system.

The last part of this study is integrating a deep predictive coding network with the data assimilation method. Unlike the original data assimilation, which continuously compute the wavefield when the observed data is available, this study only use a short sequence of the previously assimilated wavefields to forecast the future wavefields. Since the predictions are computed through matrix multiplication, the future wavefields can be estimated in seconds. The proposed method is applied to the simple bathymetry case and the 2011 Tohoku tsunami. The results show that the proposed method is very fast and comparable to the original data assimilation. Therefore, the proposed method is promising to be integrated with the data assimilation to reduce the computational cost.