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Combining High-Performance Computing and Neural Networks for Tsunami Maximum Height and Arrival Time Forecasts

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Operational Tsunami Early Warning Systems (TEWS) are crucial for mitigation and highly reducing the impact of tsunamis on coastal communities worldwide. In the North-East Atlantic, the Mediterranean, and connected Seas (NEAM) region, these systems have historically utilized *Decision Matrices* for this purpose. The very short time between tsunami generation and landfall in this region makes it extremely challenging to use real-time simulations to produce more precise alert levels and the only way to include a computational component in the alert was to use precomputed databases. Nevertheless, in recent years, computing times for a single scenario have been progressively reduced to a few minutes or even seconds depending on the computational resources available. In particular, the EDANYA group at the University of Málaga, Spain, has focused on this topic and developed the GPU code Tsunami-HySEA for Faster Than Real Time (FTRT) tsunami simulations. This code has been implemented and tested in TEWS of several countries (such as Spain, Italy, and Chile) and has undergone extensive testing, verification and validation.

In this study, we propose the use of neural networks (NN) to predict the maximum height and arrival time of tsunamis in the context of TEWS. The advantage of this approach is that the inference time required is negligible (less than one second) and that this can be done in a simple laptop. This allows to consider uncertain input information in the data and still providing the results in some seconds. As tsunamis are rare events, numerical simulations using the Tsunami-HySEA are used to train the NN model. This part of the workflow requires producing a large amount of simulations and large HPC computational resources must be used. We utilized the Tsunami-HySEA code and the Spanish Network for Supercomputing (RES), to apply neural networks (NN) and obtain the numerical results.

Machine learning (ML) techniques have gained widespread adoption and are being applied in all areas of research, including tsunami modeling. In this work, we employ Multi-Layer Perceptron (MLP) neural networks to forecast the maximum height and arrival time of tsunamis at specific locations along the Chipiona-Cádiz coast in Southwestern Spain. In the present work, initially several individual models are trained and we show that they provide accurate results. Then ensemble techniques, which combine multiple single models in order to reduce variance, are explored. The ensemble models often produce improved predictions.

The proposed methodology is tested for tsunamis generated by earthquakes on the Horseshoe fault. The goal is to develop a neural network (NN) model for predicting the maximum height and arrival time of such tsunamis at multiple coastal locations simultaneously. The results of our analysis show that deep learning is a promising approach for this task. The proposed NN models produce errors of less than 6 cm for the maximum wave height and less then 212 s for the arrival time for tsunamis generated on the Horseshoe fault in the Northeastern Atlantic.