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Real-Time Tsunami Simulations with Surrogate Modeling

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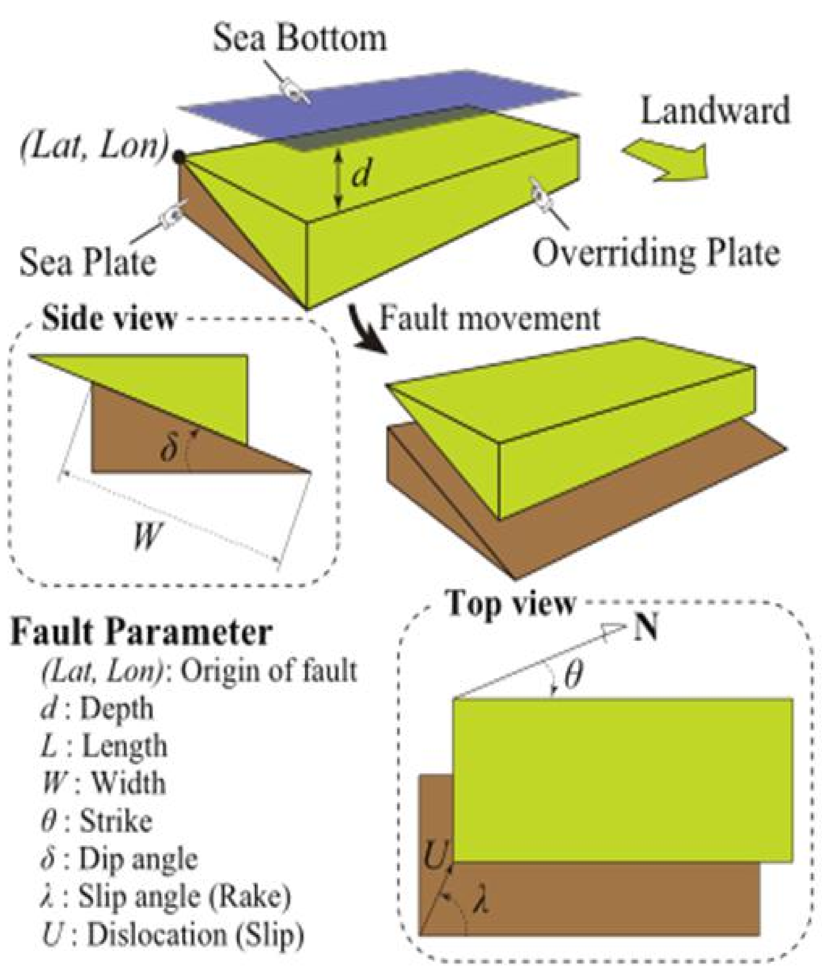
Introduction

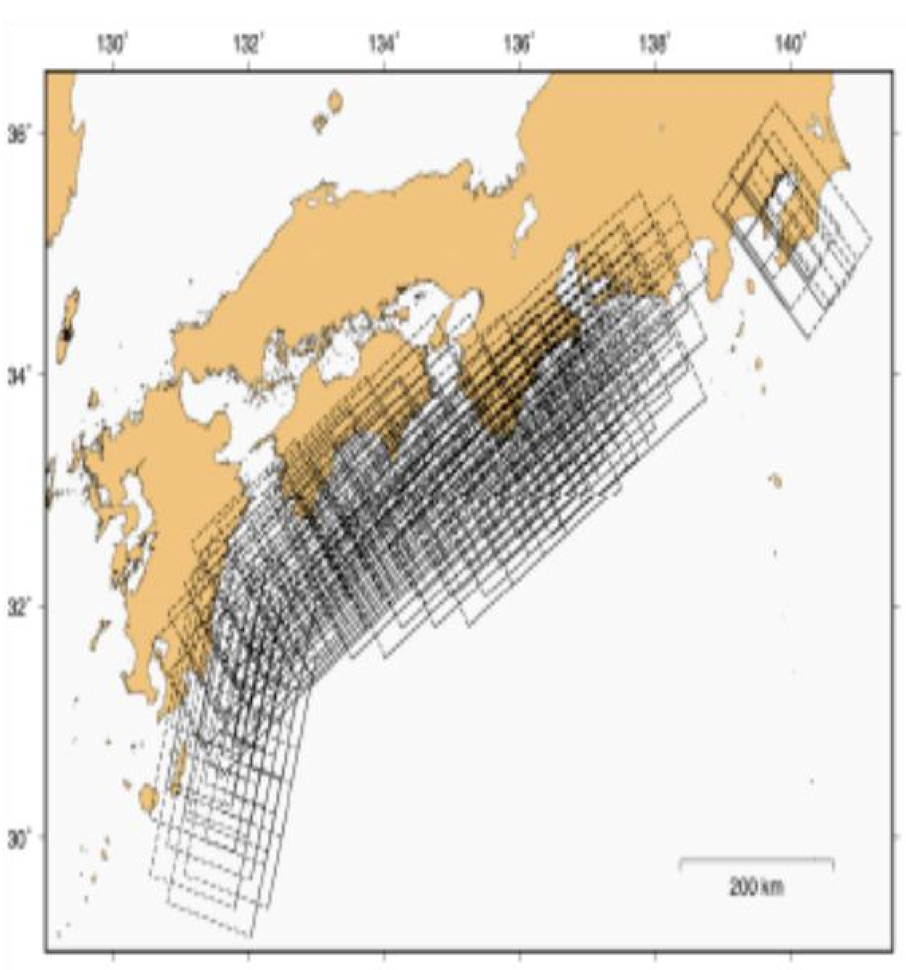
There have been many numerical models proposed for tsunami propagation simulations. They are all very numerically intensive, requiring days to complete the calculations. For probabilistic risk analysis, which requires many simulations, these methods are infeasible. Therefore, in this paper, we propose a framework of surrogate modeling based on proper-orthogonal decomposition (POD), which introduces the potential of real-time risk assessment. To create the surrogate model, we extract the prominent modes by applying POD to from the given data, after which we use radial-basis function interpolation (RBF) for mapping the input data points to their corresponding coefficients. The surrogate model thus constructed is expected to be accurate, given the simulation cases used are sufficiently dense for the complexity of the results.

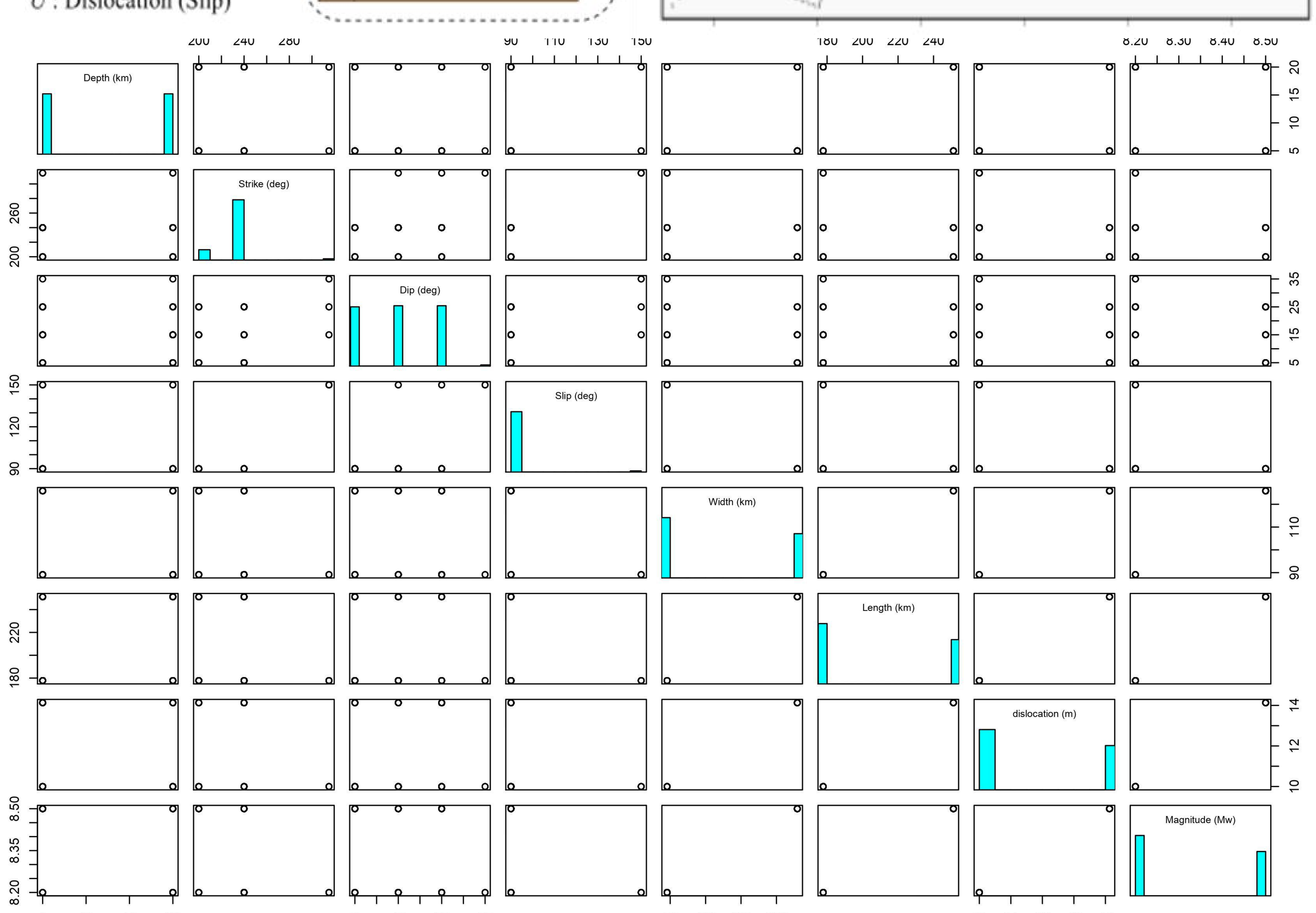
Simulation Parameters

Seafloor Deformation (The Okada Model)

The Okada model is a commonly used earthquake source model, which assumes an elastic half-space containing the fault. The initial sea-floor deformation is computed using this model, while the tsunami propagation uses the depth-averaged shallow water equations. The Okada model has nine input parameters, as shown in the diagram below. To train our POD-RBF model, we used simulation results using various different parameters obtained by Igarashi et al. (2016). These parameters were combined to create 666 scenarios with the locations of the active faults varried acording to the diagram below. The target area is a 35,000 meter by 23,600 meter rectangle containing Kochi with a spacial resolution of 10 meters.



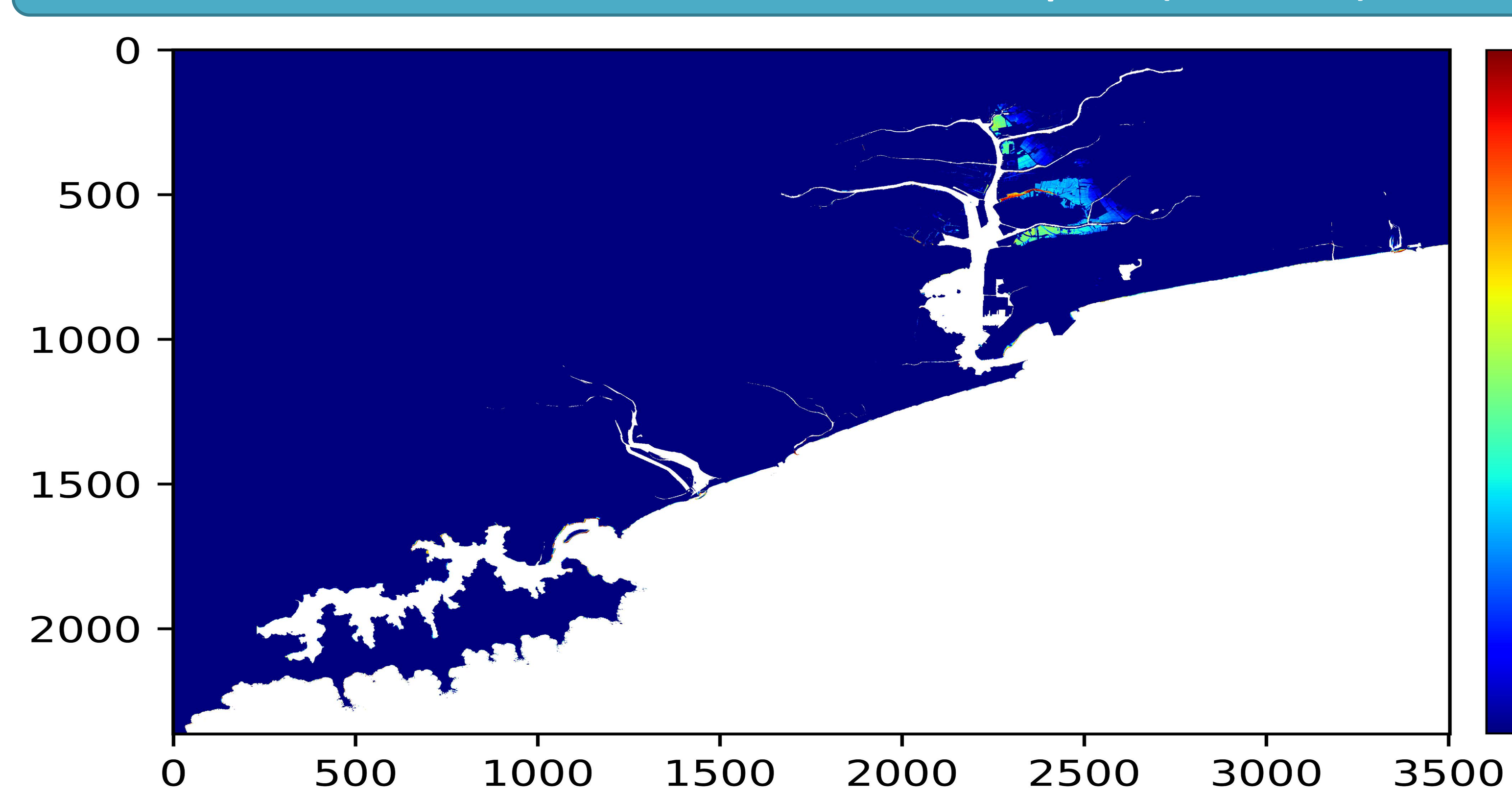




POD-RBF Surrogate Modeling

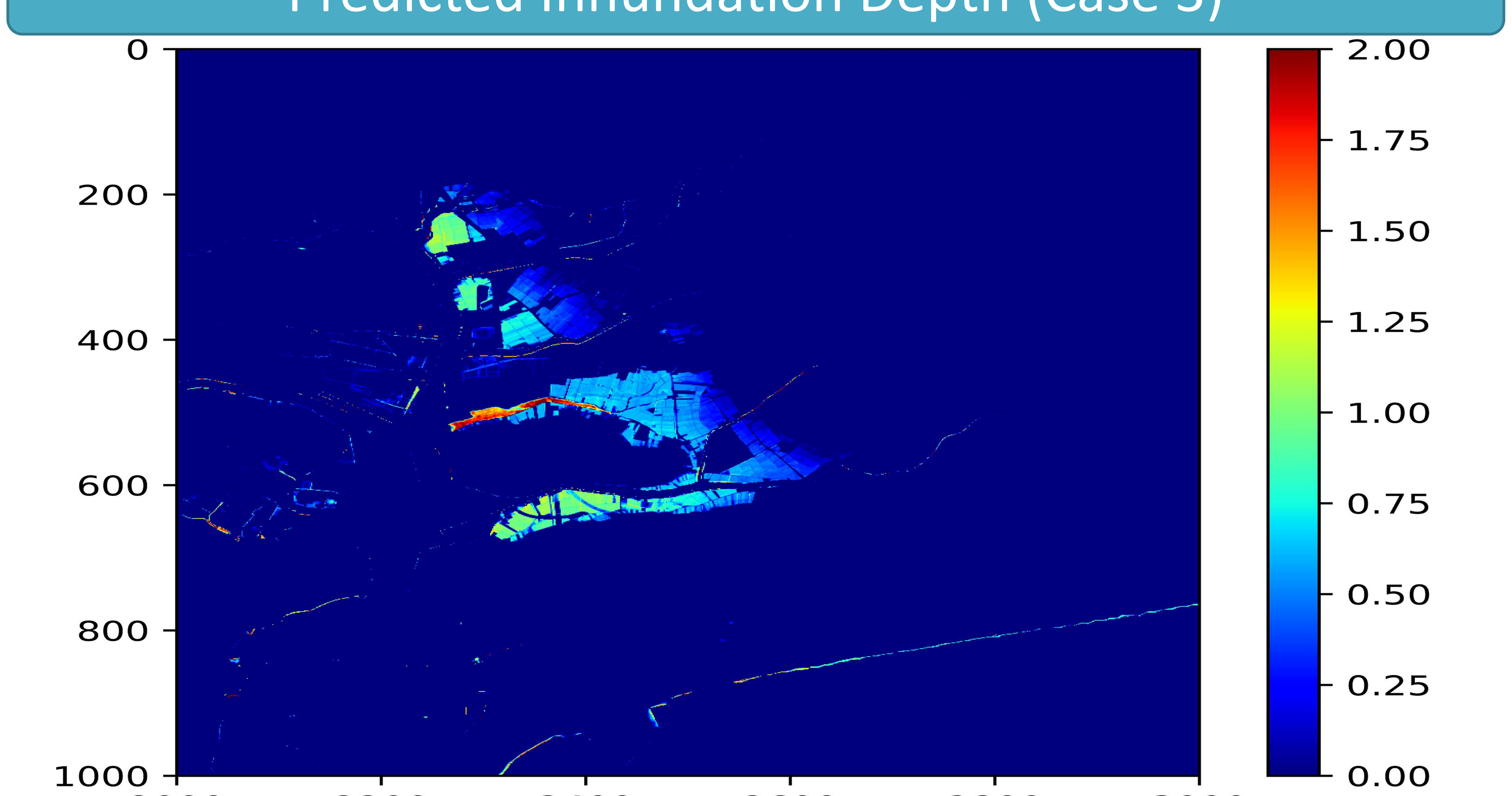
Proper orthogonal decomposition (POD) is a dimension reduction technique, which minimizes the Frobenius norm of the difference between the original data set and the reduced-order model. We obtain the modes of our data and their reduced-order coefficients using POD. Then we use radial basis function (RBF) interpolation to create a function that seamlessly maps the inputs to the coefficients for each of our modes. One of the simulated cases we set aside to test our POD-RBF model is shown below.

Simulated Innundation Depth (Case 3)



For the RBF we used a Gaussian function and optimized the shape parameter using the Euclidian distance between input vectors. The input vectors were normalized before applying RBF interpolation so as to prevent the input vector's distance from being more affected by one variable than another. The figure below shows the predicted inundation for a 1km square area within the above-simulated area. The result predicted by the proposed surrogate model is very similar to the original, although it shows slightly lower values than the original simulated result.

Predicted Innundation Depth (Case 3)



Conclusion / Expanding on Disaster Mitigation Methods

The method proposed here is efficient at predicting tsunami risk in real-time. The results showed that the predictions are accurate, given sufficiently dense data. Most of the existing models for tsunami propagation simulation are very numerically intensive and requiring days to complete the calculations. For real-time risk assessment, our proposed method is better suited to the problem. The proposed surrogate model in this study can also be applied to probabilistic tsunami risk assessment, which requires many simulations.