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Surrogate-Based Forward Uncertainty Propagation for Large-Scale Seismic Wave Propagation

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Summary

The goal of uncertainty quantification in a forward problem is to estimate the uncertainties in the model output induced by uncertainties in model inputs.

Introduction

The goal of uncertainty quantification in a forward problem is to estimate the uncertainties in the model output induced by uncertainties in model inputs. We are interested in large-scale physics-based earthquake ground motion predictions subjected to uncertainties in the seismic wave velocity model. The site of interest is a sedimentary basin characterized by an uncertain geological structure that consists of two layers where the shear wave velocity profile and the attenuation factor are randomly defined. Our quantity of interest is the Peak Ground Motion (PGM) at the free surface and the main difficulty that we have overcome to accurately take into account uncertainties comes from the computational load due to the size and resolution of the domain of simulation, $64 \times 42 \times 5$ km with 7,053,889 unstructured hexahedron elements.

Method

As the PGM at the free surface is discretized by 10^9 degrees of freedom, the representation of an uncertain field of that size cannot be done directly by building a statistical approximation for each degree of freedom. We then rely on dimension reduction technique to obtain a representation involving a limited number of spatial basis functions. Specifically, we use the Empirical Orthogonal Functions (EOF) (Lorenz, 1956) associated with the spatial covariance matrix assembled from the ensemble model output. In this work, the PGM field exhibits a simple feature, the first EOF mode describes the uncertainty due to the body wave inside the sedimentary basin while the next modes capture the uncertainty due to the surface wave along the boundary of the basin. To perform the statistical analysis, the EOF coefficients (or coordinates) are represented by functional approximations, the Polynomial Chaos (PC) expansions (Ghanem and Spanos, 1991; Le Maître and Knio, 2010). The low number of realizations relating to the size of the parametric domain guide us to a compressed sensing technique (Chen et al., 1998; Berg and Friedlander, 2007) in order to identify the main contributions in the PC series. Our validation results show a negligible cross-validation error reflecting a faithful prediction capacity of the EOF-PC surrogate.

Conclusions

The surrogate allows us to derive different kinds of statistical information anywhere in the sedimentary basin. First, the global sensitivity analysis highlights that the PGM is mainly controlled by the parameter that changes the damping of the medium (the scaling factor). Second, the interval probability maps show that the realizations of the PGM range from 2.5 to 3.5 (times the unit impulse). Third, the PGM probability density functions at three stations located inside the basin exhibit different support and shape.

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