ARTIFICIAL INTELLIGENCE

A deep learning-based earthquake simulator: from source and geology to surface wavefields

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Recent advances in scientific machine learning have led to major breakthroughs in predicting Partial Differential Equations' solutions with deep learning. Neural operators, for instance, have been successfully applied to the elastic wave equation, which governs the propagation of seismic waves. They give rise to fast surrogate models of earthquake simulators that considerably reduce the computational costs of traditional numerical solvers. We designed a Multiple-Input Fourier Neural Operator (MIFNO) and trained it on a database of 30,000 3D earthquake simulations. The inputs comprise a 3D heterogeneous geology and a point-wise source given by its position and its moment tensor coordinates. The outputs are velocity wavefields recorded at the surface of the propagation domain by a grid of virtual sensors. Once trained, the MIFNO predicts 6.4s of ground motion velocity on a domain of size 10km x 10km x 10km within a few milliseconds. Our results show that the MIFNO can accurately predict surface wavefields for all earthquake sources and positions. Predictions are assessed in several frequency ranges to quantify the accuracy with respect to the well-known spectral bias (i.e. degradation of neural networks' accuracy on small-scale features). Thanks to its efficiency, the MIFNO is also applied to a database of real geologies, allowing unprecedented uncertainty quantification analyses. This paves the way towards new seismic hazard assessment methods knowledgeable of geological and seismological uncertainties.