Reduced-order modeling for physics-based ground motion simulation

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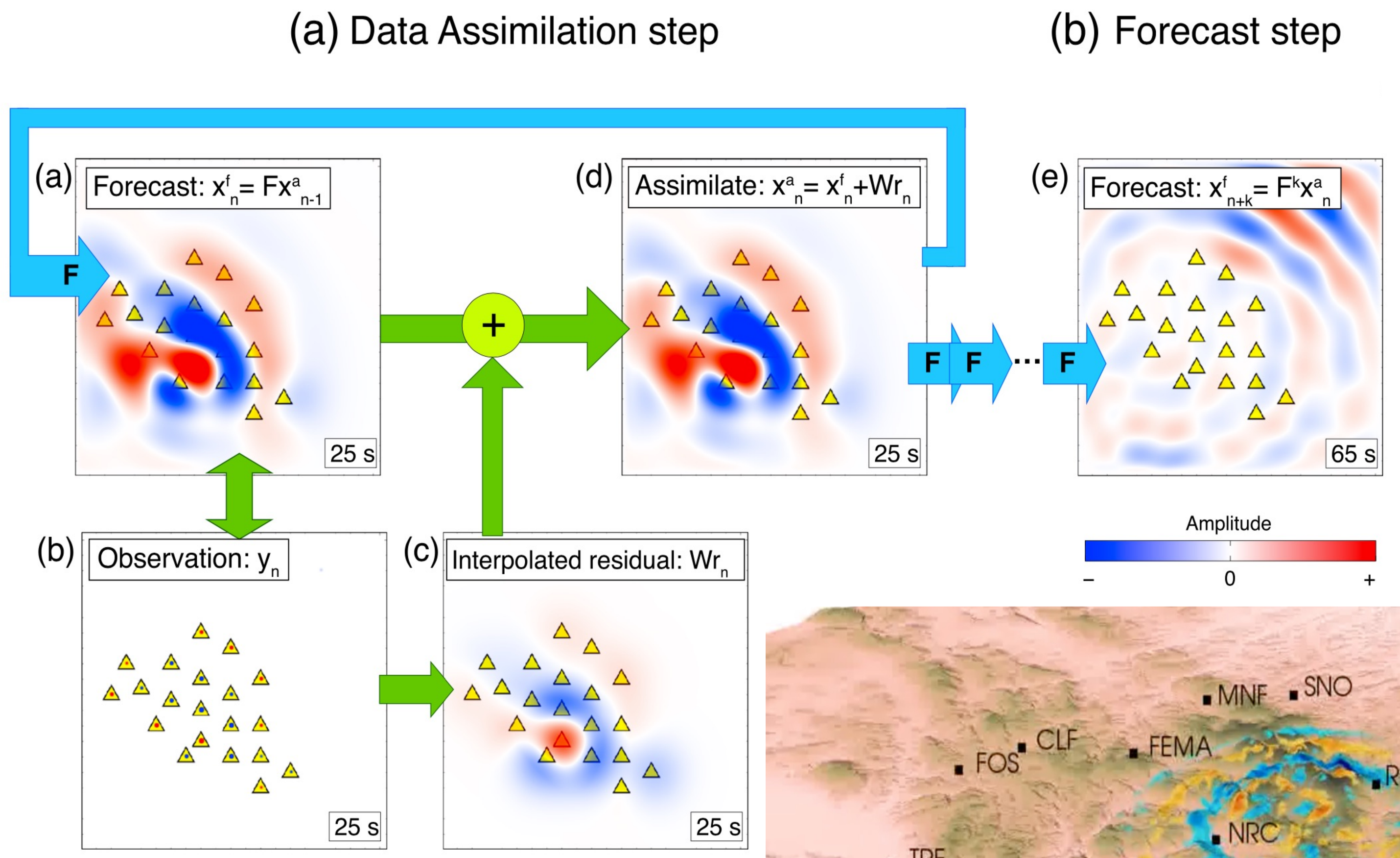
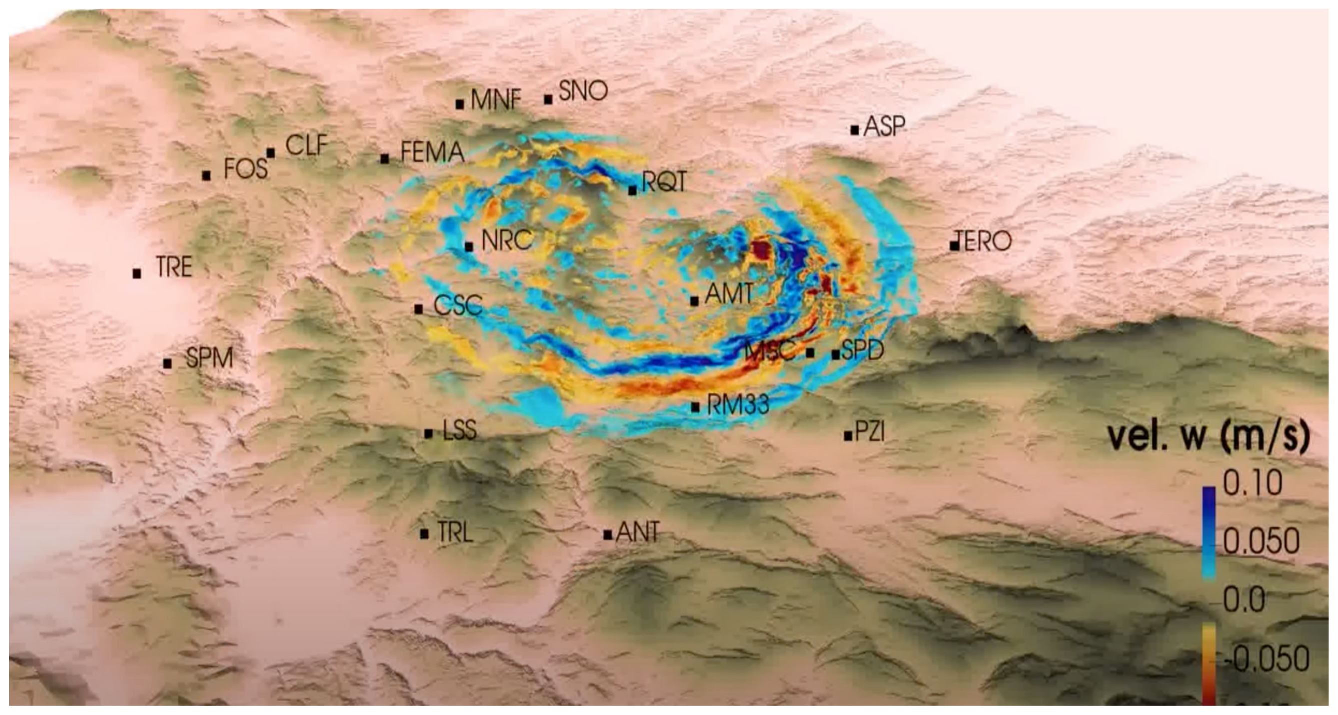
Motivation

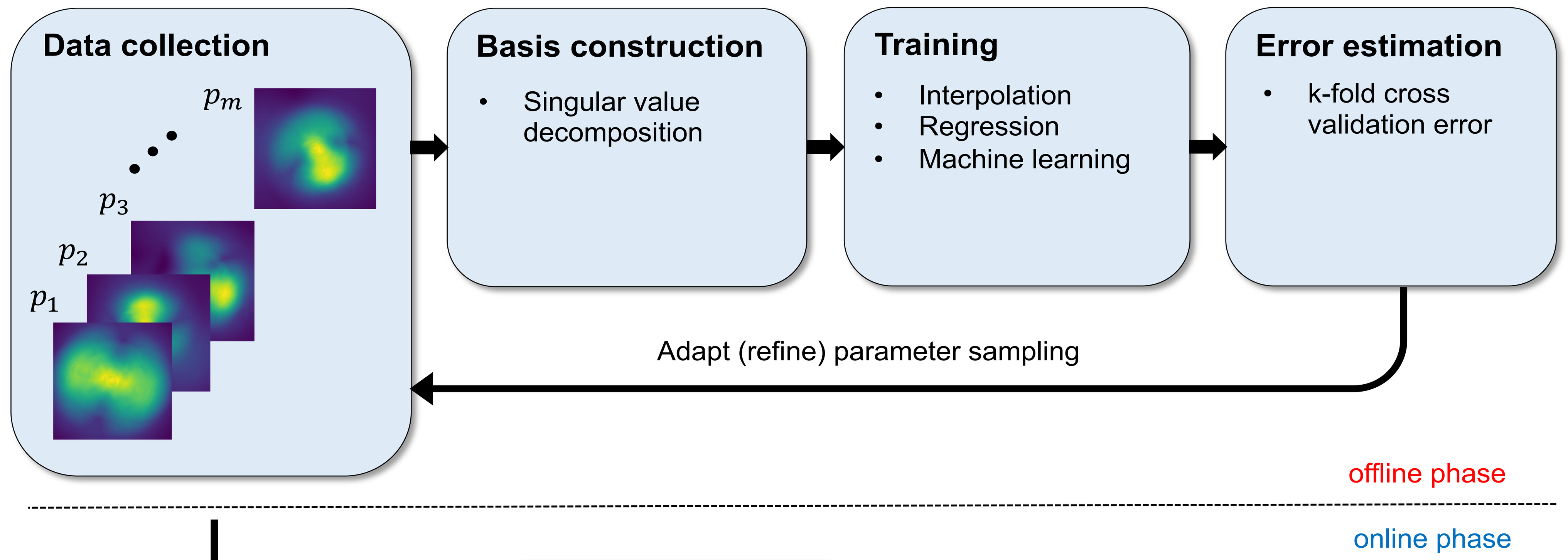


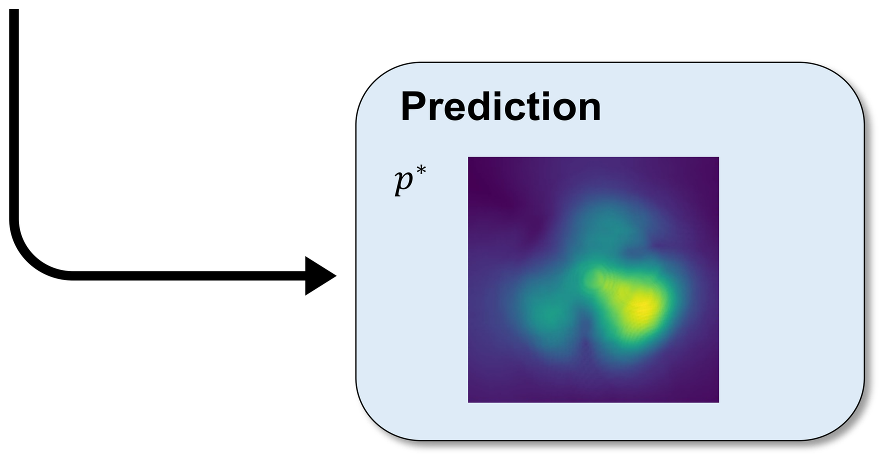
Earthquake ground motion simulations have potential to advance earthquake hazard assessment and post-earthquake rapid response. In particular, ground motion-based **early warning** (e.g., Oba et al. 2020), **ShakeMap** generation, and **seismic hazard assessments** (Milner et al., 2021) could all be improved with physics-informed estimates. However, the computational expense of these calculations precludes their use in real-time. Here, we present a **physics-based reduced order model (ROM)** capable of accurately emulating the numerical simulations in real-time.



Above: Illustration of Oba et al. (2020) ground motion prediction that requires fast and accurate wavefield predictions. Right: Dynamic rupture simulations using high-performance computing may help inform ground motion predictive models for early warning, accounting for wavefield and rupture complexities (simulation of the 2016 Amatrice earthquake produced by Taufiqurrahman et al., 2022).

Reduced-order modeling workflow

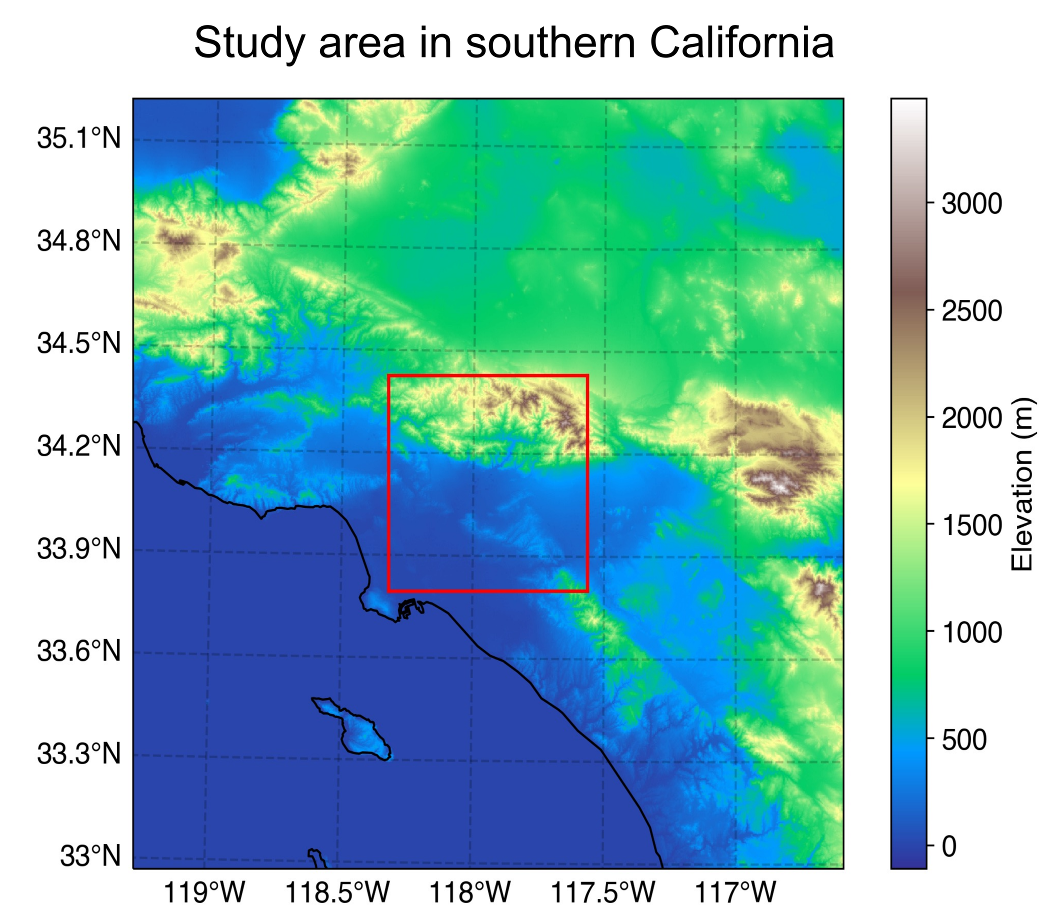


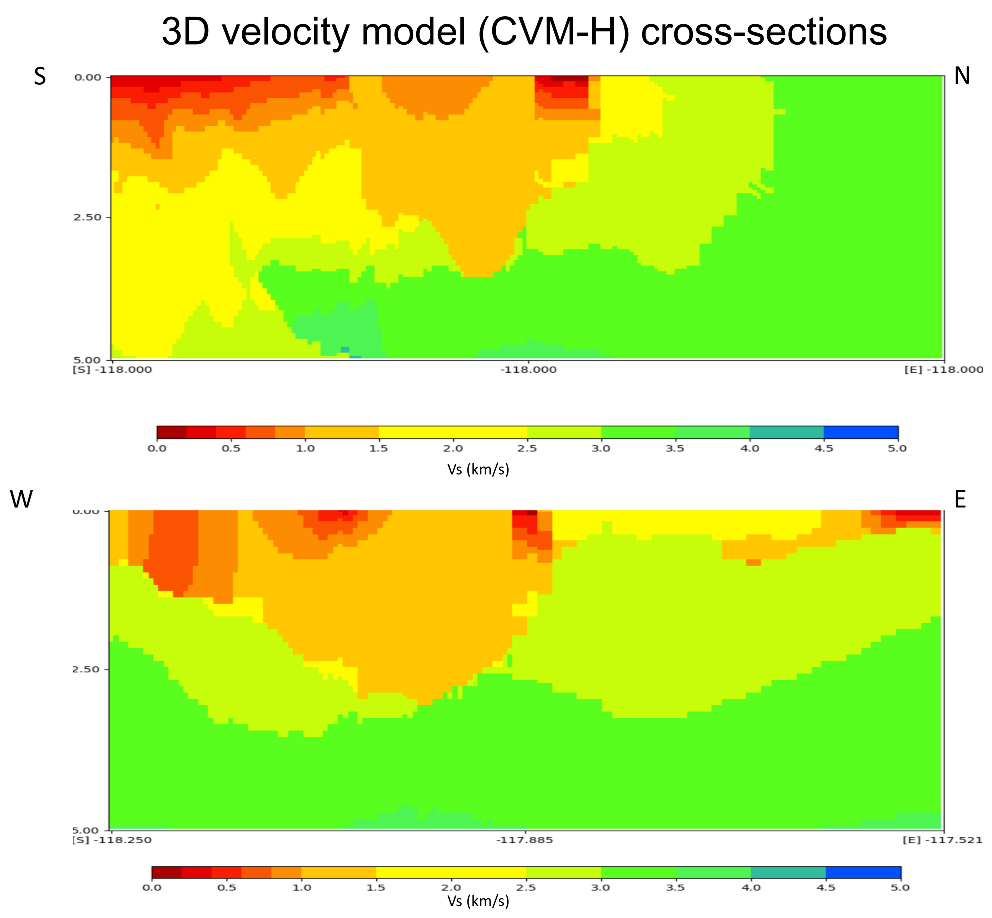


Reduced-order models (ROMs) help to overcome the computational expense of a forward problem by **emulating the high-fidelity numerical simulation** with a **controllable accuracy** (Berkooz et al. 1993; Swischuk et al. 2019). We use an **automated workflow** to develop a ROM for ground motion simulations in southern California, varying four earthquake source parameters: depth, strike, dip and rake.

Study area and data collection

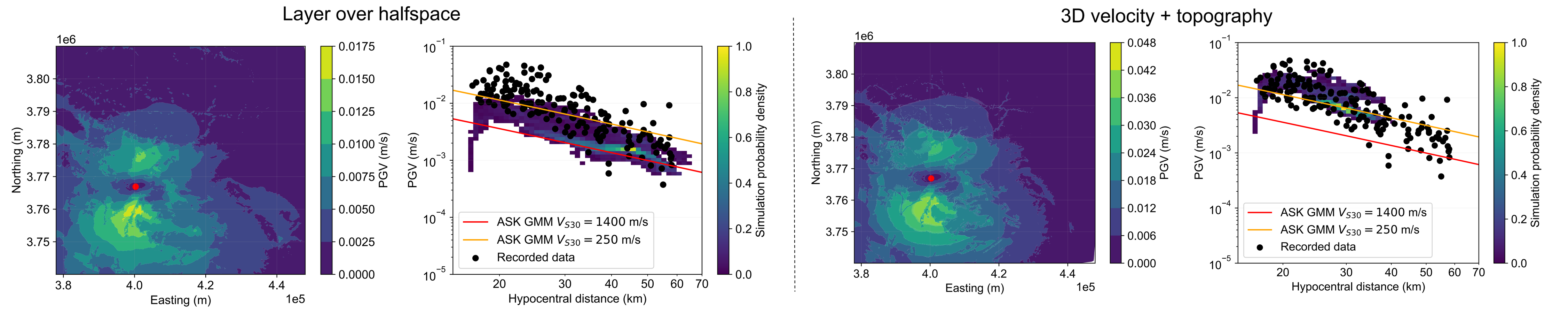
We perform high-order ground motion simulations for earthquake sources in southern California, using both 1D and 3D velocity models (CVM-H including topography, Shaw et al., 2015). We generate 5000 forward models of peak ground velocity (PGV) varying the earthquake source parameters in each simulation. The simulations run on SuperMUC-NG (Leibniz Supercomputing Centre, Germany) with the open-source SeisSol simulation software, requiring ~10 CPU * hours per simulation.



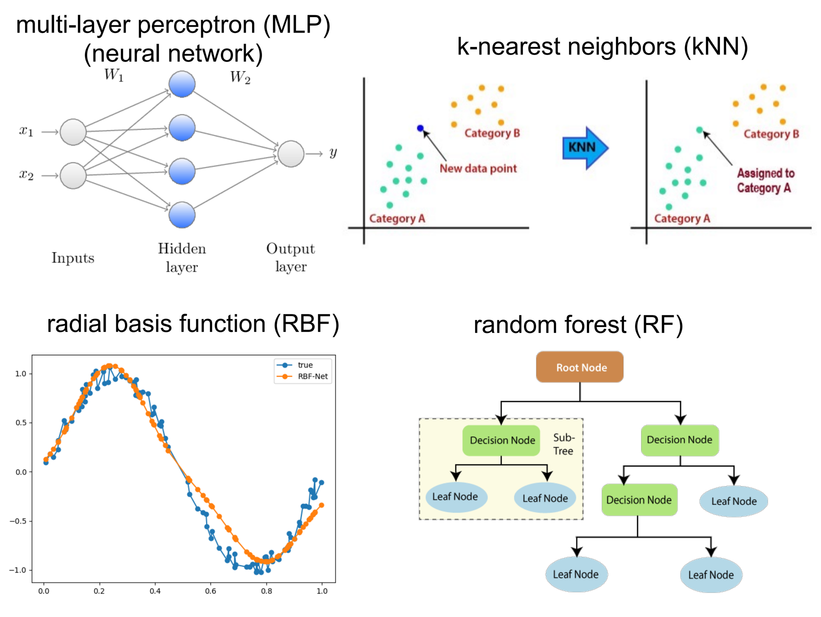


Forward model validation

We validate the forward models with observed PGV data from the 2020 M4.5 El Monte earthquake. Here we simulate frequencies up to 5.0 Hz and correct for linear site response using the frequency-domain method proposed by Rodgers et al. (2020).

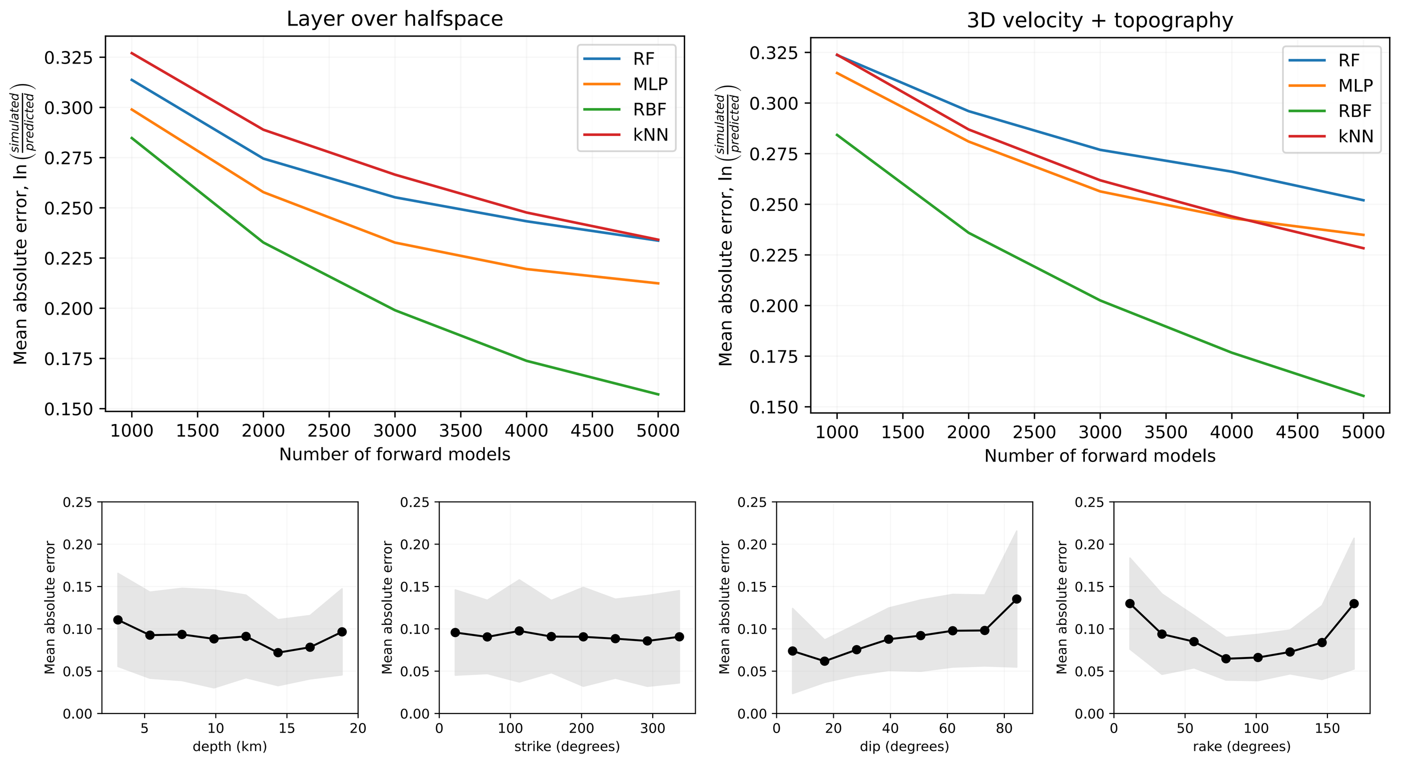


Interpolator training

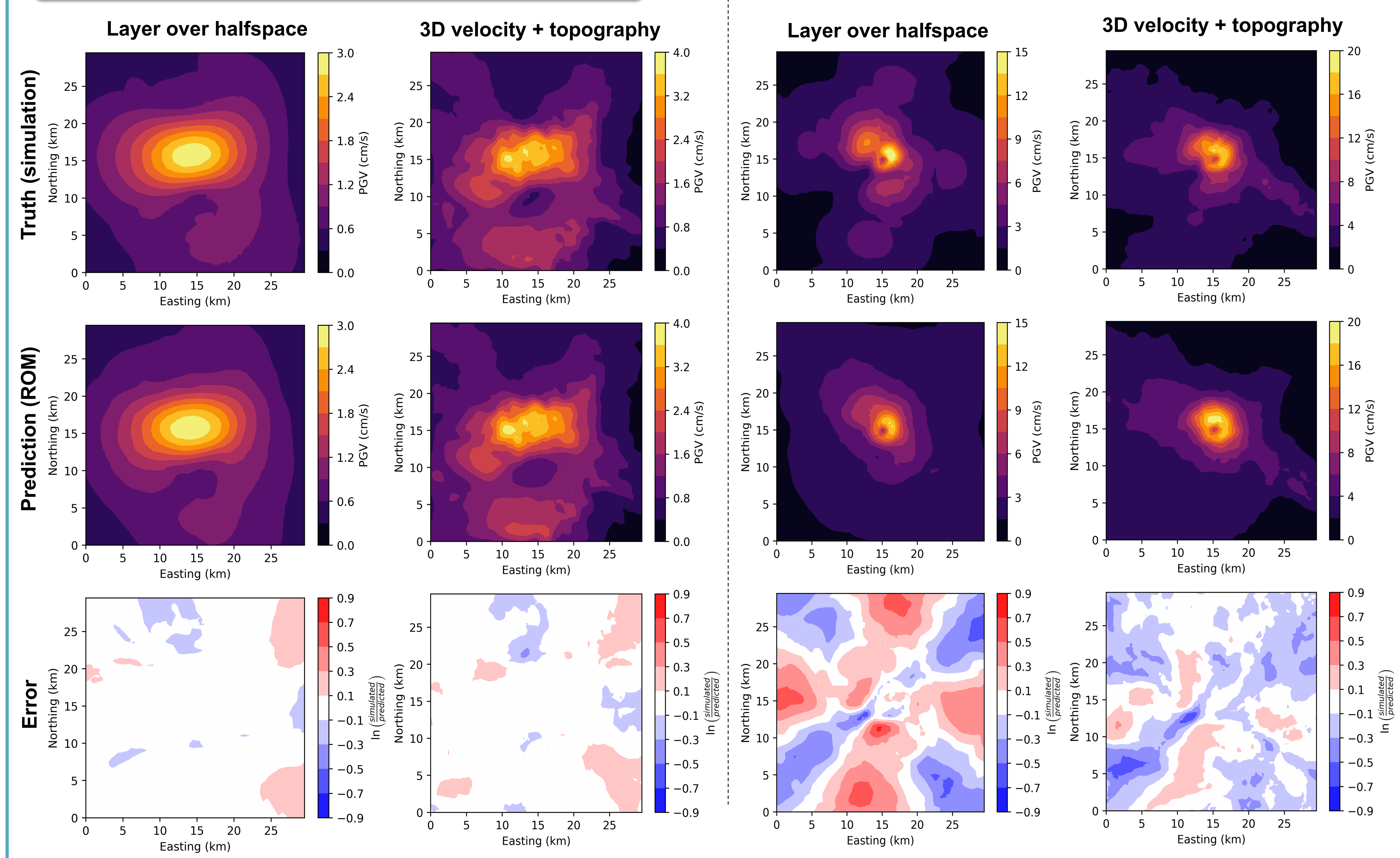


Conceptual diagrams of the four interpolators/regressors considered in this study. Images adapted from Pederegosa et al. (2011).

Error estimation



Results: PGV prediction maps



Source parameters: Depth: 9 km, Strike: 217°, dip: 11°, rake: 45°

Source parameters: Depth: 2 km, Strike: 254°, dip: 40°, rake: 121°

Conclusions and outlook

- The reduced-order models provide an **efficient method** (~2.0 ms time to solution) of generating **physics-based maps** of expected ground motion intensity for different earthquake sources.
- We achieve high accuracy (< 0.1 ln units of error) in reproducing the ground motion simulations with both 1D and **3D velocity structure (including topographic effects).**
- We will include **time-dependent modeling** for producing predicted seismograms useful for early warning algorithms and to compare the **physics-informed POD approach** against generative **ML-predictive approaches** (e.g., convolutional neural network).

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