1. Introduction

Seismic surveys come in different shapes – the ideal coverage is rare.

Local high-resolution basin models can be used to improve seismic hazard assessment when properly embedded into regional models.

The approach is computationally cheaper and will likely become standard as local dense seismic surveys are the new trend.

Here, we present a case study using Salton Seismic Imaging Project (SSIP) derived local models.

Figure 1. Map of Salton Trough showing the simulation domain and active source seismic surveys from the 2011 Salton Seismic Imaging Project (SSIP) and 1979 SUGS experiment. The red stars are SSIP shots scaled by their explosive weight in kilograms; blue circles are SSIP receivers; yellow stars are shots from the 1979 experiment; green circles are receivers from the 1979 experiment. Purple dots represent the Hauksson et al. (2012) relocated earthquakes from 1991 to 2019, with magnitudes between 3.5 and 5.5. Blue triangles are Southern California Seismic Network (SCSN) stations. Thin black lines are surface traces of mapped faults from Fenby and Garri (1991), Jennings and Bryant (2010), and Rockwell et al. (2015). Red polygons represent the extent of high-resolution local travel time tomographic models developed in Coachella and Imperial valleys (Ajala et al., 2019; Persaud et al., 2016) using a subset of the active source data and local earthquakes. Blue irregular polygons represent areas in the local models with good ray coverage. Arrows in the inset map show the Pacific-North American relative plate motion, and the red line represents the plate boundary.

2. S Cec UCVM update

UCVM is a SCEC program used to simultaneously retrieve information from multiple Earth models using a model tillig concept, enabling the development and verification of hybrid models (Small et al., 2017).

One shortcoming of UCVM is that the hybrid models can contain sharp contrasts at the boundaries of the different models that may not be geologic and can adversely affect simulations of the seismic wavefield.

Another limitation of UCVM is that the well-resolved areas of the different models may not be represented by cuboid volumes.

We developed an external model blending library that defines window functions like a cosine taper, tapered cosine function, or boxcar function in arbitrarily shaped space capable of embedding irregularly shaped local models in regional models.

The UCVM API was then updated to incorporate our blend library to enable the construction of smooth hybrid models that incorporate local models of arbitrary shape.

3. Validation exercise

We used ten earthquakes that occurred in Salton Trough with Mj 5 to 5.5.

Event (7) is used to find the best representation of the community and hybrid models in the presence of topography by benchmarking (section 4). The other nine events are used to get an average assessment of the best models.

Empirical relationships from Brocher et al. (2005) between Vs, Vs, and density are used to compute missing model parameters. Olsen attenuation ratio is used to derive the attenuation model from Vs (Olsen et al., 2003) simulations in viscoelastic media.

The SPECFEM3D Cartessian package (Komatitsch & Tromp, 2002a, 2002b, and many more) is used in all simulations and the wavefield is validated in a 6 to 30 period window.

We embed our local models in regular support (sup1 – red polygon) and irregular support (sup2 – blue polygon) areas using different boundary smoothing ratios for the hybrid models.

Figure 3. Earthquake simulation domain in Salton Trough showing the locations of the earthquakes and stations used for validation. The triangles are SCSN stations color-coded by the number of events that they record with small earthquakes. The circles are the earthquakes color-coded by depth and accompanied by local mechanism plots that indicate the focal mechanism quality and magnitude of the event. Red polygons are the areal extent of the high-resolution local models developed by Ajala et al. (2019) and Persaud et al. (2016). The blue polygons represent areas where the models are well-resolved with high ray coverage.

4. Benchmark and validation results

We benchmarked the community and hybrid models in the presence of topography by validating model subspaces and different representations of the models. Event (7) in Figure 3 is used for benchmarking.

For CVM-H 15.1 (cvm H – Tape et al., 2009, 2010) Event 4a, we incorporate the addition of Ely geotechnical layer (Ely et al., 2016) and elastic and anelastic rheology. In anelastic media, we use different Olsen attenuation ratios indicated in parenthesis in the legend of Figure 4.

For CVM-S 4.26 (cvmS – Lee et al., 2014) Event 4d developed without topography, we experiment with three topographic representations – a default model that pulls the model up to the free surface (pull-up), a 10 model extension (1D), and a linear model extension (linear). The 1D and linear representations preserve geologic structures and have been implemented to UCVM as well.

The model subspace for the hybrid models (Figures 4b & 4d) include our local models (cv – Coachella Valley model; iv – Imperial Valley model) embedded into the best representations of the community models (red models in Figures 4a & 4c) using different support areas (see section 2) and smoothing boundary ratios indicated in parentheses in the legend of Figures 4b and 4d. The first support in the label corresponds to the cv model, and the second, iv model.

5. Misfit maps

Figure 6. Maps showing the SCSN stations color-coded by average relative waveform misfit of the recorded events for the best community and hybrid models (Figure 5) in the simulation. The improvement in wavefield prediction from CVM-H 15.1 to CVM-H 15.1 hybrid is more evident than CVM-S 4.26 to CVM-S 4.26 hybrid. It is important to note that areas of improved wavefield prediction are not restricted to where the local models are embedded.

6. Waveform example

Figure 7. Example showing the comparison of ground displacement records between predicted and observed waveforms in the best community and hybrid models (Figures 5 & 6). Left map showing the location of the event and recording station (right) is in black; component waveform comparisons, with labels indicating the models that produce the predicted seismograms.

7. Summary

We have shown that properly embedding high-resolution local models into the community models can improve the community models’ waveform prediction ability. We find that local travel time models developed using active source data can outperform the community models when merged correctly.

The overall extent of improved waveform misfit is not restricted to where we embed our local models, which implies that high quality local models can improve regional models on a larger scale.

By implementing our blend library to S Cec UCVM software, we foster the reproducibility of hybrid models. Additional updates to UCVM include other topographic representation for CVM-S4.26, which are more geologically reasonable than the default method of pulling the model up to the free surface.

The approach presented in this research can produce improved community models relatively quick and cheaply and will likely become standard since local dense seismic surveys are the new trend.

References

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