Validation of the southern California seismic velocity models with full-waveform simulation

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ABSTRACT

Crustal seismic velocity models play a crucial role in seismology as they are the starting point for many applications, such as earthquake ground-motion prediction, seismic hazard analysis and localization of seismic events. However, even with the number of tomographic approaches increasing, quantitative assessment of the accuracy and consistency of the resulting models is mostly neglected.

In this study, we evaluate various seismic velocity models available for the southern California region, including CVMS-4.26, CVM-S4.26,M01, CVMH as summarized in Small et al. 2017, Berg et al. 2018 model and our new model under development. For each candidate model, we perform 3D visco-elastic simulations (up to 1 THz generally and 4THz for selected models and events) of 34 moderate-magnitude regional earthquake events and compare simulated waveforms to those recorded by seismic networks. We measure and analyze the spatial features of phase delays and waveform similarities between the synthetics and observed waveforms at multiple-frequency bands. In general, all the candidate models show good phase and waveform agreements for body waves below 0.5Hz and for surface waves, the remaining misfits mainly appear in the basin areas and fault zones, suggesting that the shallow soft layers could affect tomography and accuracy of the resulting model even at depth. At frequencies above 0.5 Hz, the synthetics and observations start to show significant mismatches, indicating poorly constrained small-scale heterogeneities and near-surface structures. Our results clearly reveal the need of an accurate structural representation of shallow layers, which is the key for improving current crustal models of the southern California. In a broader perspective, this study suggests the potential of improving data fitting by merging velocity models.

Table 1: Candidate models.

1. DATA AND METHOD

Figure 1: Left: 34 earthquakes used in this study. Right: example of the observed waveforms and synthetics (Z-component) computed based on the CVM-4.26 for the earthquake event 1027573.

Step.1 Forward simulation: we simulate 34 moderate-magnitude (Mw 3-5) earthquakes using point source moment tensor solutions from Wang & Zhan 2020 (red in Fig 1 left) and SCVM moment tensor catalog (blue in Fig 1 left). We compute synthetic waveforms with the 3-D SEM, visco-elastic wave-equation solver of SEM46 package (Seiscope consortium, Trinh et al. 2019). Each model is parameterized by isotropic Vp, Vs, Rho and Q.

Step.2 Time delay measurements: we compute cross-correlation type lag time between the observed and synthetic waveforms for P-waves (2-5 s) and Surface-waves (multiple-bands: 3-6 s, 5-10 s, 8-15 s, see example of windowed and selected Rayleigh waves in Fig 1 right).

Step.3 Time delay analysis: we show the results in the following two ways: i) we build misfit maps by averaging the time delay measurements in each pixel; ii) we calculate the mean and standard deviation of the time delay measurements. (see Fig 2)

RESULTS

Figure 2: We show spatial distributions of average misfit for the five candidate models. The colour scale displays the mean value of misfits for all paths crossing each 5×1° cell assuming ray paths are great circles. The mean and standard deviation of misfits are displayed in the upper left corner of each map. Results are shown in s/100km, a negative value (blue) means that synthetics arrive earlier than observation. Surface waves in period band 3-6 s can not provide reliable misfit measurements due to large delays.

Figure 5: Mofit histograms of merged models using Fang et al. model as background model and CVM-4.26,M01 for the shallow layer (1, 3, 5 km deep).

While the long period waves mostly exhibit a time shift between the observation and synthetic, Fig 4 highlights the striking differences in their waveforms at higher frequencies, which implies that the velocity structures in the shallow layer are still poorly resolved.

CONCLUSIONS

1. The shallow layer (primarily basins and fault zones) dominates misfits of long-period surface waves.
2. Current SoCal velocity models can provide good data fitting of surface waves down to 5 s, which indicates that the shallow layer (~4 km) is still poorly constrained.
3. The data fitting could be improved by properly merging models using areas/depth ranges with good performances.
4. The validation results (spatial and statistic analysis) provide a database for merging regional velocity models.

REFERENCES