Full-3D Tomography of the Crustal Structure in Southern California Using Earthquake Seismograms and Ambient-Noise Correlagrams

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Abstract

We have conducted a high-resolution model for the Southern California crust, CVM-S4, 26, by inverting more than half a million waveform misfit measurements from about 38,000 earthquake seismograms and 12,000 ambient noise correlagrams. The inversion was initiated with the Southern California Earthquake Center’s Community Velocity Model, CVM-S4, and seismograms were simulated using K. Ohno’s staggered grid finite-difference code, AWP-ODC, which was highly optimized for massively parallel computation on supercomputers by Y. Cui et al. We navigated the tomography through 26 iterations, alternating the inversion sequences between the adjoint-wavefield (AW) method and the more rapidly converging, but more data-intensive, scattering-integral (SI) method. Earthquake source errors were reduced at various stages of the tomographic navigation by inverting the waveforms for the earthquake centroid moment tensors. All inversions were done on the Mira supercomputer of the Argonne Leadership Computing Facility. The resulting model, CVM-S4.26, is consistent with independent observations, such as high-resolution 2D refraction surveys and Bouguer gravity data. Many of the high-contrast features of CVM-S4.26 conform to known fault structures and other geological constraints not applied in the inversions. We have conducted several other validation experiments, including checking the model against a large number (>20,000) of seismograms not used in the inversions. We illustrate this consistency with the excellent fit at low frequencies (c. 0.2 Hz) to three-component seismograms recorded throughout Southern California from the 17 Mar 2014 Encino (MW4.4) and 29 Mar 2014 La Habra (Ms=5) earthquakes, and we show these fits to be much better than those obtained by two community velocity models in current use, CVM-S4 and CVM-H1.9. We conclude by describing some of the novel features of the CVM-S4.26 model, which include unusual velocity reversals in some regions of the mid-crust.

Iterative Inversions

Figure 1. (a) Red solid line with circles: the relative waveform misfit (RWM) for a set of waveforms selected for monitoring the improvements of our model. Vertical bar: the number of misfit measurements used in each iteration. Colors of the vertical bars indicate the different types of the misfit measurements used. Vertical dash lines separate iterations carried out using the AW method from those carried out using the SI method. Black arrows indicate the iterations in which SI-modes were performed. In addition to earthquake seismograms, which were included. The number of earthquakes used in each iteration is shown following the SI=“.” Source-receiver paths for the AW71 earthquake waveforms used for monitoring the RWM reduction. Black stars: earthquake epicenters; red triangles: broadband stations. (c) The reason for the 370 Rayleigh waves on the attentions concertopeline. Appendic A used for monitoring the RWM reduction. Black triangle: stations used as virtual sources; red triangle: stations used as receivers. The source-receiver paths for these selected waveforms are shown as green lines in Figures 1b and 1c.

Basis Structures

(a) Isostatic Gravity Anomaly
(b) $Z_k$ of CVM-S4
(c) $Z_k$ of CVM-S4.26
(d) $Z_k$ of CVM-H1.9

Figure 2. Maps of isostatic gravity anomaly and (b–d) Zk maps for CVM in Southern California. The basin structures not well represented in the initial model, CVM-S4, are numbered: (1) Santa Maria Basin; (2) Southern San Joaquin Basin (SSJB); (3) Owens Valley (OV); (4) Inland West Valley (IWV); (5) Santa Barbara Channel (SBC); (6) Santa Monica Basin; (7) Antelope Valley (AV); and (8) the offshore Basin (OB). Some faults are marked on the map: (a) San Andreas Fault (SAF), White Wolf Fault (WF), Sierra Nevada Fault Zone (SNFZ), Arroyo Parida Fault (APF), Garlock Fault (GF), Eastern California Shear Zone (ECSZ), and San Jacinto Fault (SJF).

Fault Structures

Figure 4. Cross sections of CVM, including the CVM-S4, CVM-S4.26, and CVM-H1.9. (a) the velocity profiles of the fault displacement predicted fault surfaces from the SCEC Community Fault model (CFM) (14); the purple lines in the sets of observations appear to be well correlated with the fault boundaries (12) and the CMT solutions from the USGS. The white lines are interpreted de-collelment from LARSE surveys. The velocity contrasts on the cross-sections of CVM-S4.26 show high consistencies with the 3D fault models. The numbers on the map indicate the 15 seismic zones: (1) SMFZ; (2) SB; (3) San Andreas Fault; (4) San Jacinto Fault; (5) Whiticker Fault (WF); (6) Sierra Madre Fault Zone (SNFZ); (7) Banning Fault (BF); and (8) Johnson Valley Fault (JVF).

Waveform Comparisons of La Habra Event (Not Used in the Inversion)

Figure 5. Examples of observed (black) and synthetic (red) seismograms for the La Habra earthquake. For each station, observed and synthetic seismograms from the vertical, radial, and transverse components are shown from top to bottom and synthetics computed using CVM-S4, CVM-S4.26 and CVM-H1.9 are shown from left to right. The broadband CMT solution used for computing the synthetics. Yellow star: epicenter location; white triangles: 3-component broadband stations whose seismograms are shown.

References & Acknowledgements