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Tomographic Imaging of Southern California Mantle: Applying Modern Methods

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The goal of the proposed work is to integrate several improvements to the tomography imaging of southern California using teleseismic arrivals. These include: (1) 3-D ray tracing, (2) incorporation of the SCEC crustal velocity model (with proper volumetric averaging), (3) use of finite-frequency sensitivity kernels, and (4) preparing to create joint inversions using body and surface waves.

(1) Development, testing and debugging a fast 3-D ray tracer is a major accomplishment. Although other 3-D ray tracers exist, none were fast and stable enough to use with the large southern California data set during finite-frequency imaging. Our 3-D ray tracer has the required speed, accuracy and stability.

(2) Incorporation of the SCEC crustal velocity model to calculate site-specific crustal corrections is shown in Fig. 1. As crustal velocity models improve, new crustal corrections are easily updated. This now is working quickly, accurately and routinely.

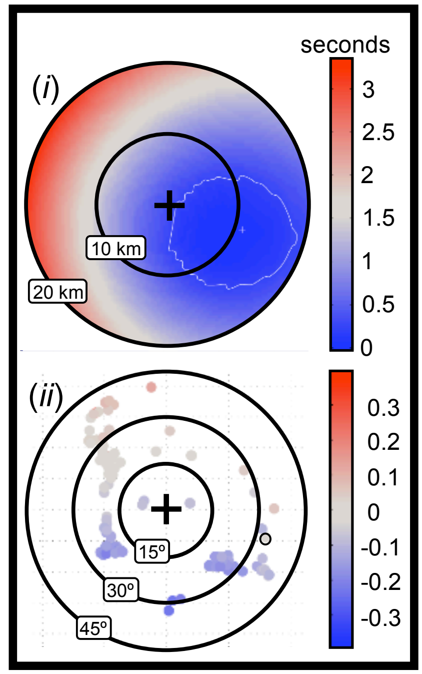

Fig 1. Crustal corrections for station BAR, calculated with finite frequency calculations for 3-D heterogeneous crust and Moho of variable depth. (*i*) travel time excess for non-geometric rays about the geometric ray, which crosses the Moho ~10 km from vertical (small white "+"). Fresnel area for rays that arrive 0.25 sec late (white line). (*ii*) difference between old crustal correction (based on structure directly below site) and new crustal correction (as a function of ray parameter and upper mantle angle of incidence). The crust beneath BAR is relatively heterogeneous, creating differences between the two crustal delay estimates of ±0.25 s.

(3) We now calculate finite-frequency sensitivity kernels using a paraxial formulation.

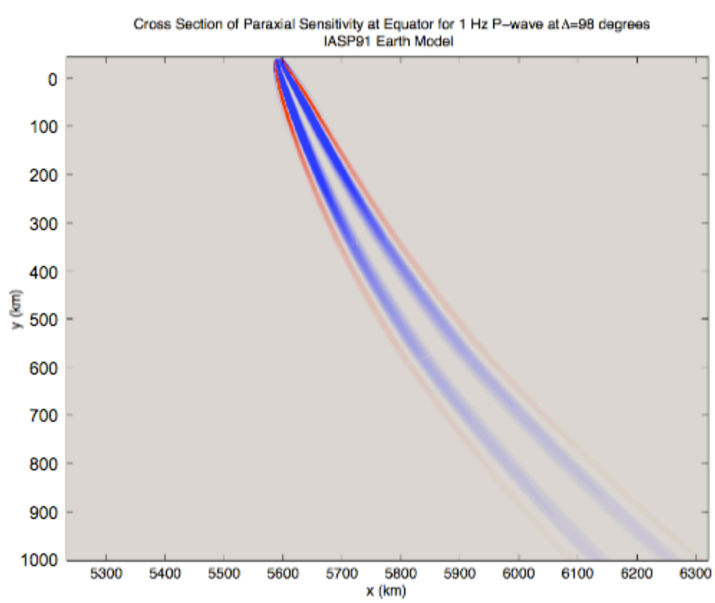

Fig 3. Finite-frequency sensitivity kernel, calculated for a 1-Hz wave, calculated with the paraxial approximation.

(4) Initial work on formulating a joint inverse using body and surface waves has begun. We also have started to pick P- and S-wave data at 20s period to create data that are consistent with the surface-wave data.

In preparation for our finite-frequency tomography, we also have re-coded (and debugged) our tomography algorithm to use nodes instead of blocks so that, with the use of intra-note linear interpolation, we have eliminated the first-order discontinuities associated with blocks (and attain greater levels of resolution). A major motivation for this has been an improved awareness of the causes of vertical streaking in teleseismic tomography: when anything degrades horizontal resolution, vertical resolution is degraded by a factor of about five (because of the near-vertical ray geometry). Causes of degraded horizontal resolution include discrete the representation of the Earth (large blocks are the worst offenders. Small blocks help, similarly spaced nodes are better), using rays (when real rays have finite-frequency sensitivities), miss-located rays (through poor ray tracing), and imposing horizontal smoothing constraints. See Fig. 3.

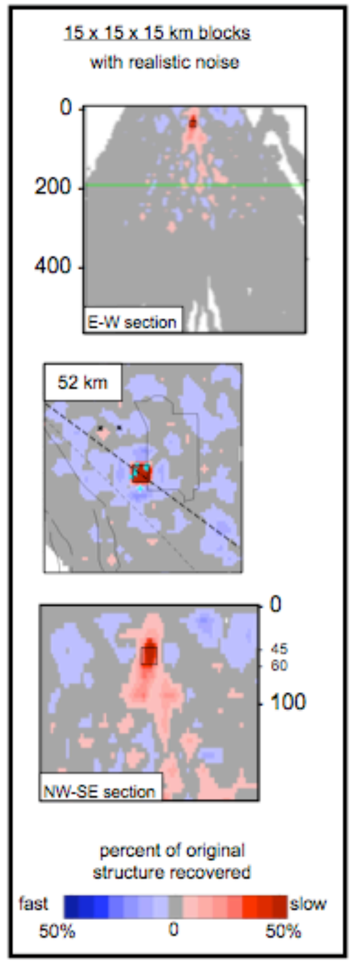

Figure 3. Resolution test of an anomalous block (indicated with black line) using a realistic ray set and block-inversion tomography. Anomaly is located midway between blocks. Note the strong vertical streaking. When smaller blocks are used with the identical input structure, vertical streaking is reduced in proportion to the block size.

Finite-frequency kernels are now working (see Fig. 4), although we are recoding to get the algorithm to run fast enough to be routinely practical. We also have station statics, ray tracing, etc., incorporated into the inversion.

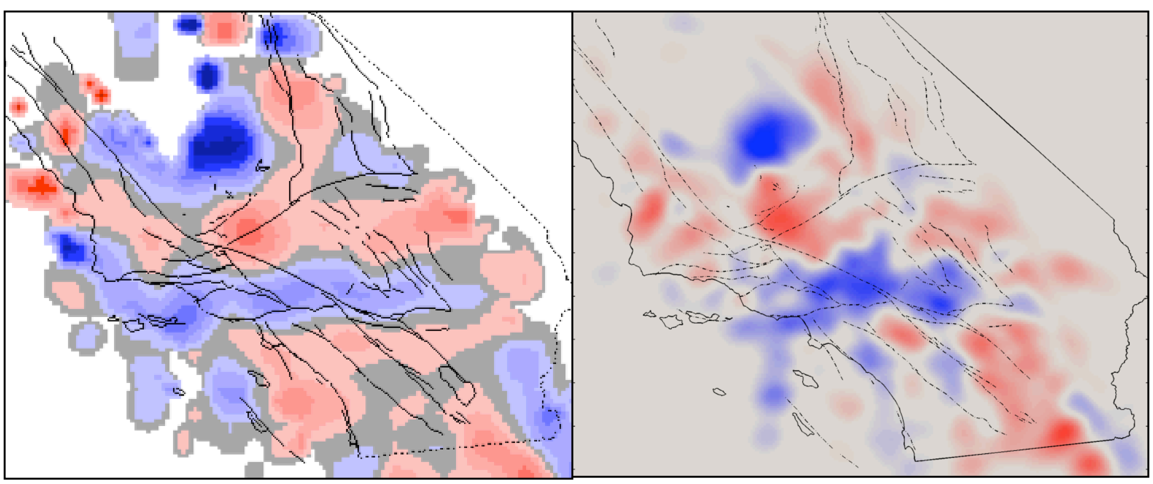

Fig. 4. Tomographic inversion for southern California mantle structure at 100 km depth, using 20-km node spacing, and ~20,000 rays to 210 stations. **Left** figure is a reference image representing older-style tomography (blocks, SIRT inversion, rays, rays traced in 1-D Earth, simple station statics). **Right** figure is a similar inversion, but using finite-frequency sensitivity kernels, nodes, LSQR inversion, rays traced in a 3-D Earth, and station statics as described in Fig. 1. Smoothing is chosen to be similar to the left figure.