Imaging the upper Mantle Structure of the Western United States from the USArray, Part I

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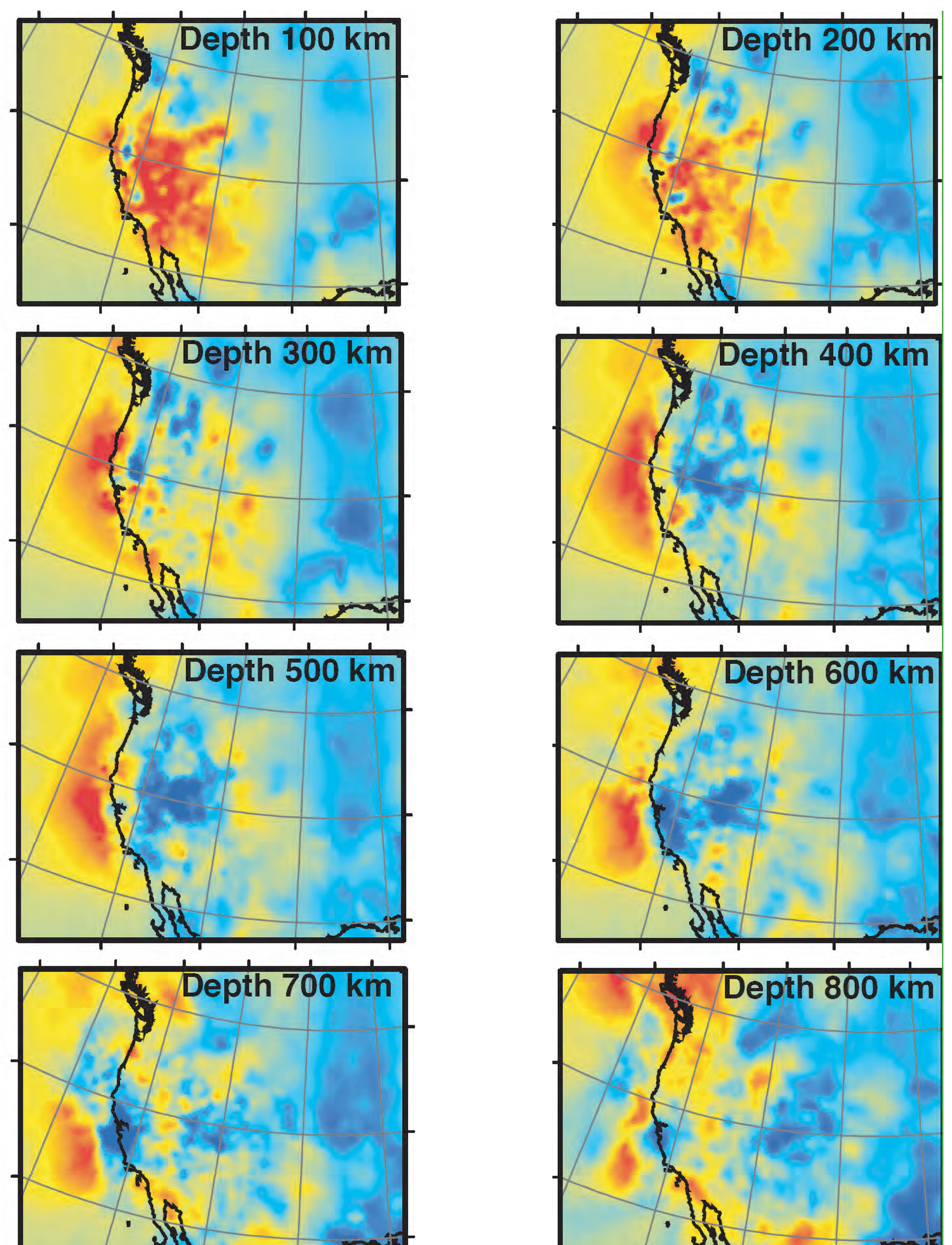
Abstract

Recent upper-mantle triplication data recorded by USArray display sharp variations in both travel time and differential times between branches similar to that reported by *Song and Helmberger* (2006). Jumps between branches by up to 8 second are common in *S*-data. Generally, the recent tomography images of P-travel time data by the EarthScope community, *Burdick et al* (2008), predicts the horizontal geometry quite well, but does not predict the waveform triplications because of the choice of the reference model. The present western US reference triplication *P*-model, GCA, has the 410 discontinuity at 395 km, which is incompatible with recent *S*-models. Hence, we propose a modified *P*-model that can be used with *S* to construct a travel-time delay map of paths sampling above the 410 and in the transition zone similar to that derived by Chu and Zhu (2008) for Tibet. Such data can then be added to conventional datasets using a hybrid tomographic method correcting for realistic path corrections in the upper mantle. Models with low-velocity zones and high-velocity zones should greatly help in producing accurate synthetics modeling.

Deep events provide best sources, such as the November 26, 2007, Guerrero, Mexico earthquake. This event provided a complete map of triplications from 10 to 30 degree. Based on this dataset, a 1D *P*-wave velocity model has been constructed for western US. In this model, the 410 velocity discontinuity is at 420 km, which is 25 km deeper than the GCA. The 660 velocity discontinuity is at 648 km, 12 km shallower than the GCA model. Velocity jump at the 660 discontinuity is 4.20%, compared to 5.78% for the GCA model.

We can also use both the techniques of multi-path detector and waveform modeling to model the teleseismic S wave data recorded by USArray for events arriving from different directions. The regions with complex S waveform correlate with the velocity anomaly in Burdick's tomography model. Some large travel time jumps and waveform distortions in the data suggest the possible existence of some sharp structures.

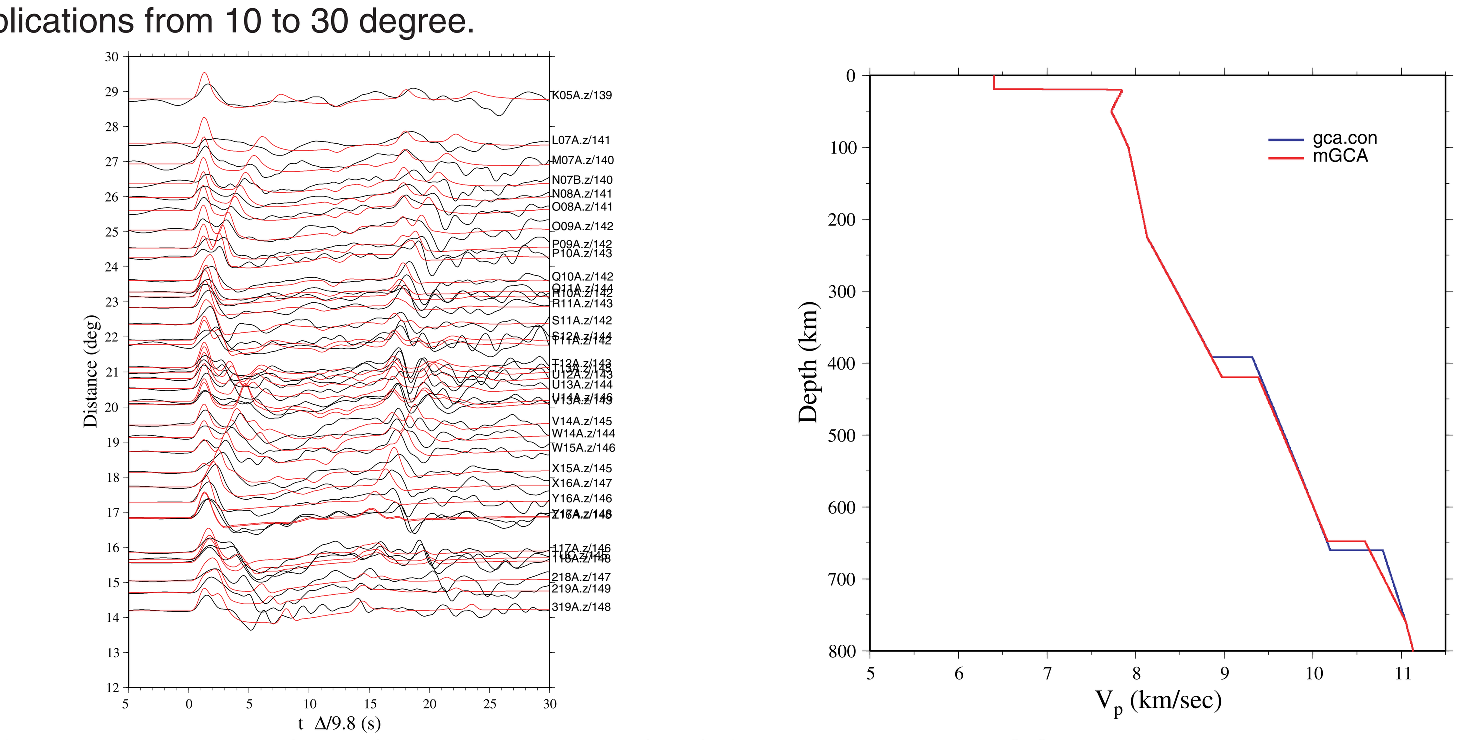
New P tomography model derived from USArray



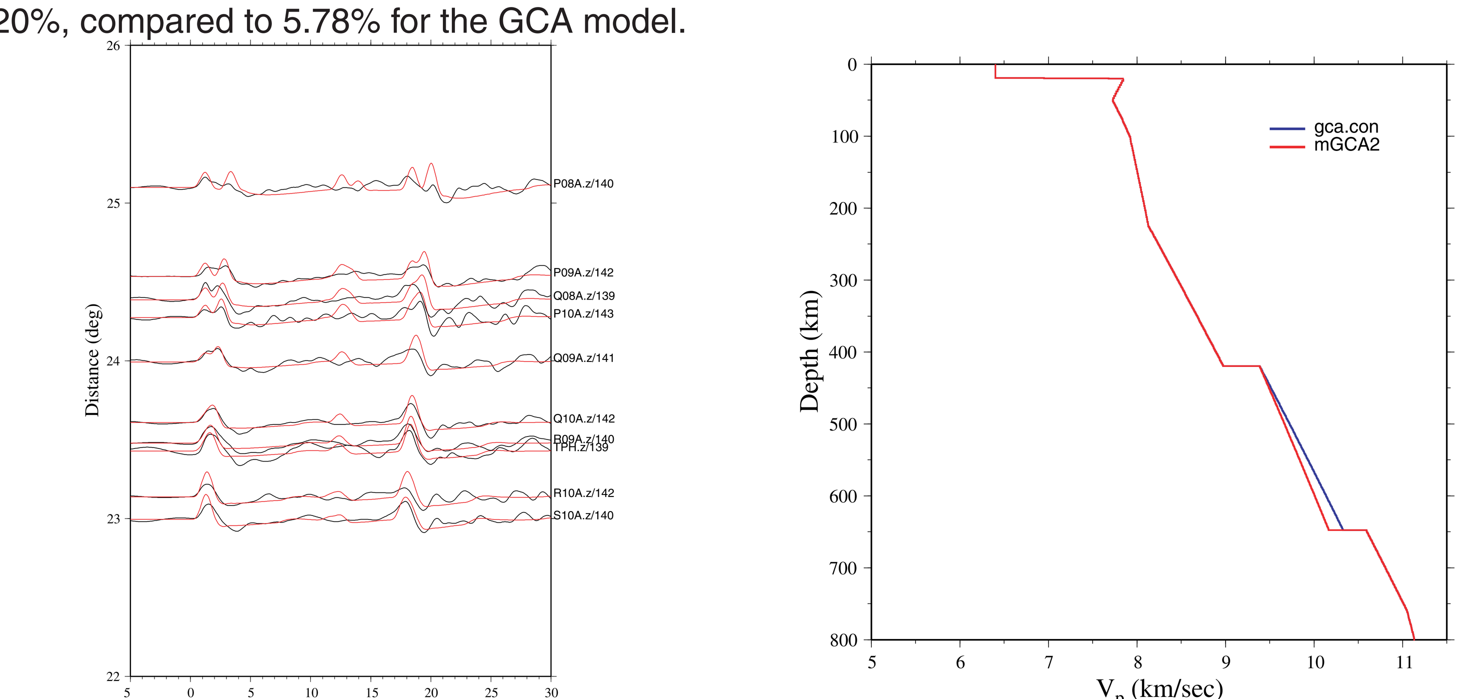
MIT P-wave travel time tomography model for the United States created from the global EHB catalogue plus USArray Transportable Array from 2004 to November 2007 (From *Burdick et al*, 2008).

P-wave triplication

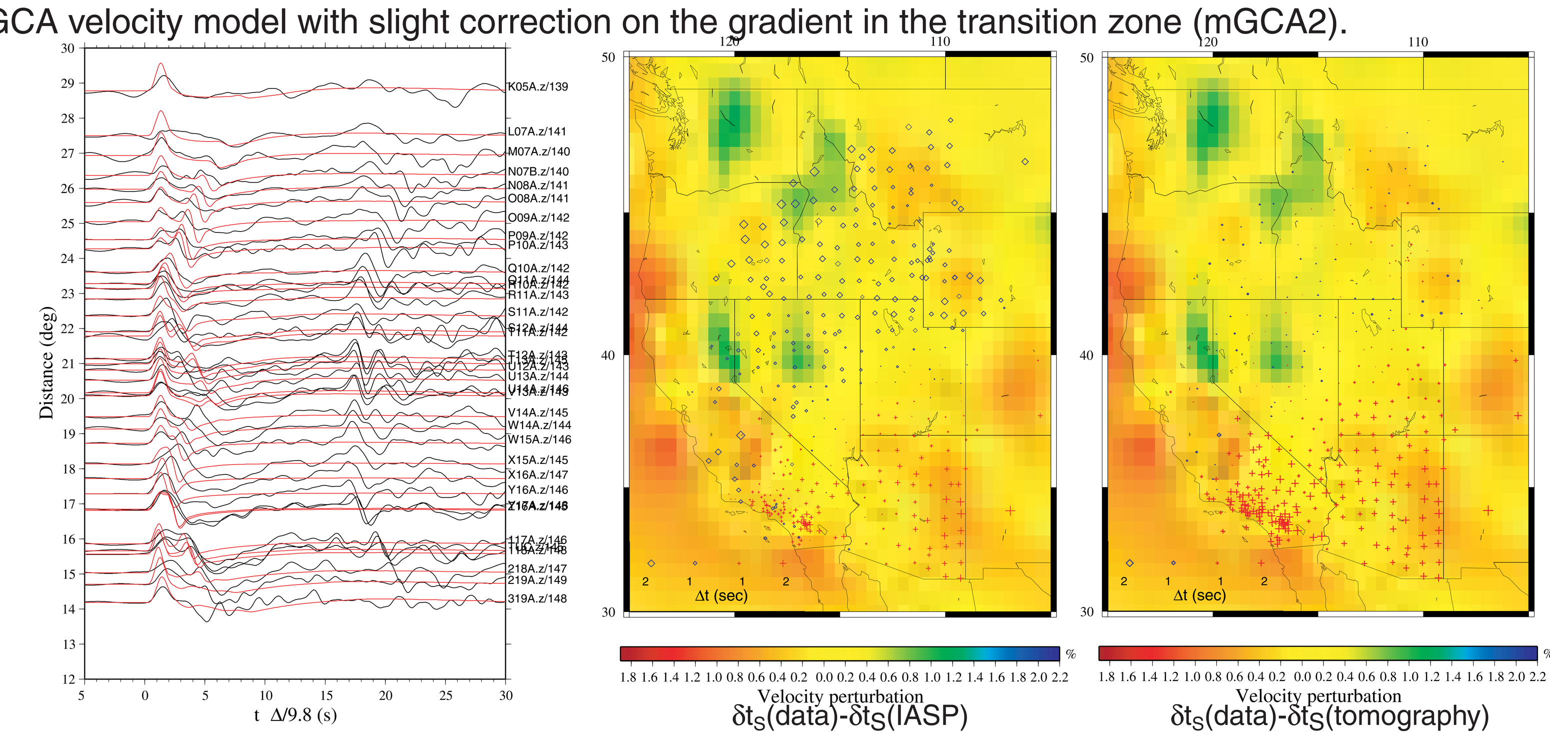
Waveform data from a deep event at Guerrero, Mexico (November 26, 2007). We first inverted the focal mechanism and earthquake depth from teleseismic seismograms using a grid search algorithm. The best-fitting solution shows normal faulting at the depth of 52 km. This event provided a complete map of triplications from 10 to 30 degree.



Left shows the data (black) and synthetics (red) from 1D model mGCA displayed on the right. For the records with azimuth of 327°, the AB and CD branches of P waves cross at the distance of 17 degree, which is 0.5 degree larger than that predicted by the GCA velocity model (gca.con at the right). The separation between CD and EF branches is about 0.5 second smaller at 20 degree compared with the GCA prediction, which the separation aggress with the GCA prediction at larger distances. Based on this observation, 1D p-wave velocity model (mGCA) has been constructed for western US. In this model, the 410 velocity discontinuity is at 420 km, which is 25 km deeper than the GCA. The 660 velocity discontinuity is at 648 km, 12 km shallower than the GCA model. Velocity jump at the 660 discontinuity is 4.20%, compared to 5.78% for the GCA model.



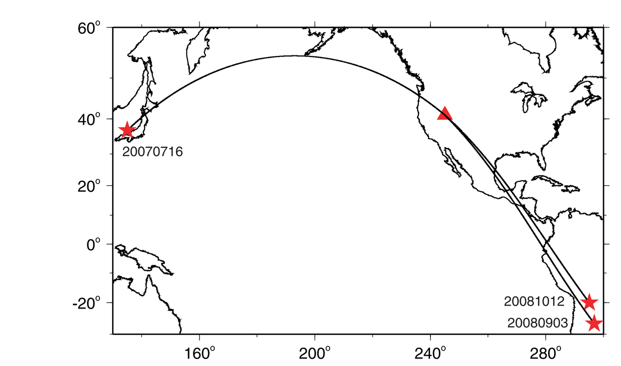
For the data recorded at the azimuth of 329°, the triplication behavior can be explained very well by GCA velocity model with slight correction on the gradient in the transition zone (mGCA2).



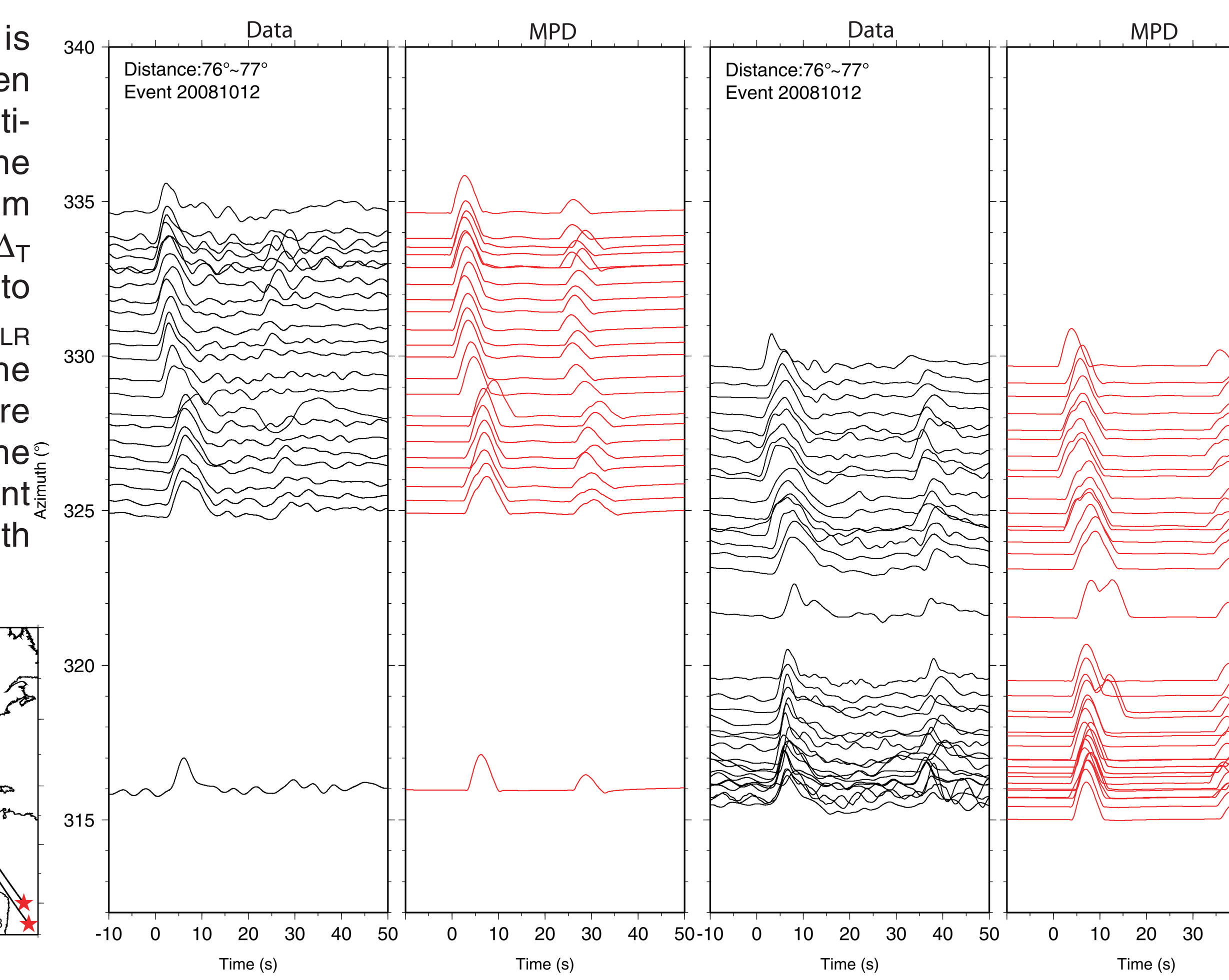
Left displays the 2D synthetic predictions (red) from the Burdick's tomography model. The differential travel times between data and synthetics for IASPEI91 and Burdick's tomography model are shown on the right two columns found by cross-correlation of synthetics and data. Crosses mean the travel time of data is slower than synthetics. The data with faster travel time are indicated by diamonds. The near "zero" time difference in the northern part of the array suggests that the model predicts the P data very well. The slow region recorded by stations in Southern California and Arizona indicates that some slow velocity structures may be missed in Burdick's model along the path form Mexico to Western US.

Multi-path detector for teleseismic S wave

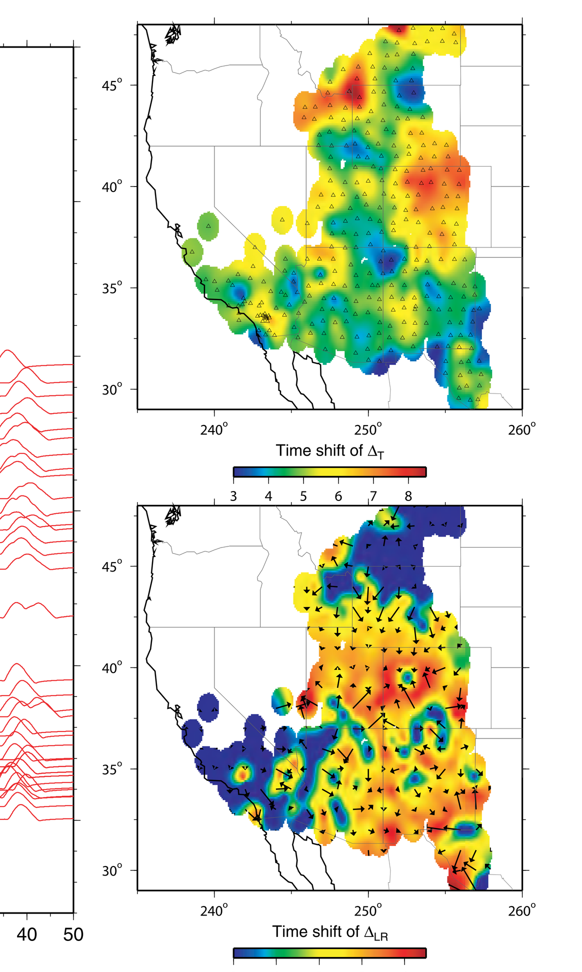
Multi-path detector (MPD) is particular useful to detect between horizontal structure (in-plane multi-pathing) vs. vertical (out-of-plane multi-pathing) directly from processing array waveforms. Δ_T shows the travel time delay relate to a reference model (PREM). The Δ_{LR} indicates the complexity of the waveform. The waveform is more complicate with larger Δ_{LR}. The overlain arrows in the footprint patterns indicate the gradients of th



Display of two South American event, one Kuril event, and the great circle paths to USArray.



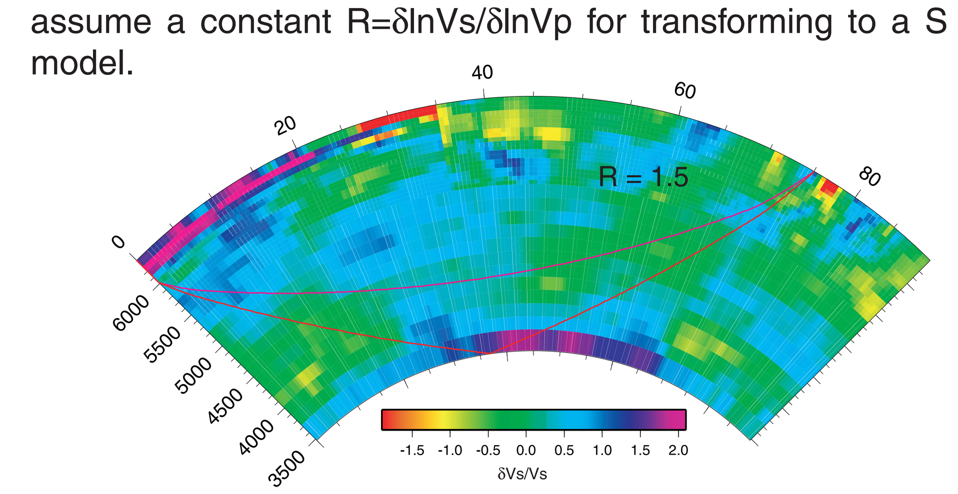
Examples of data and multi-path detector synthetics for event 20081012.

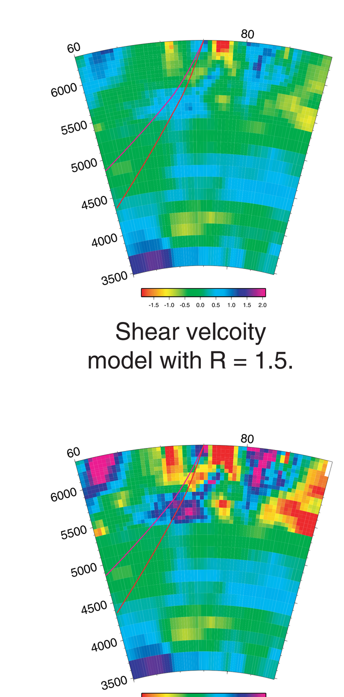


Delay time results for event 20081012 with MPD. The data show strong multi-pathing from YellowStone to the Colorado Plateau, which is shown on the tomography image below.

Waveform modeling

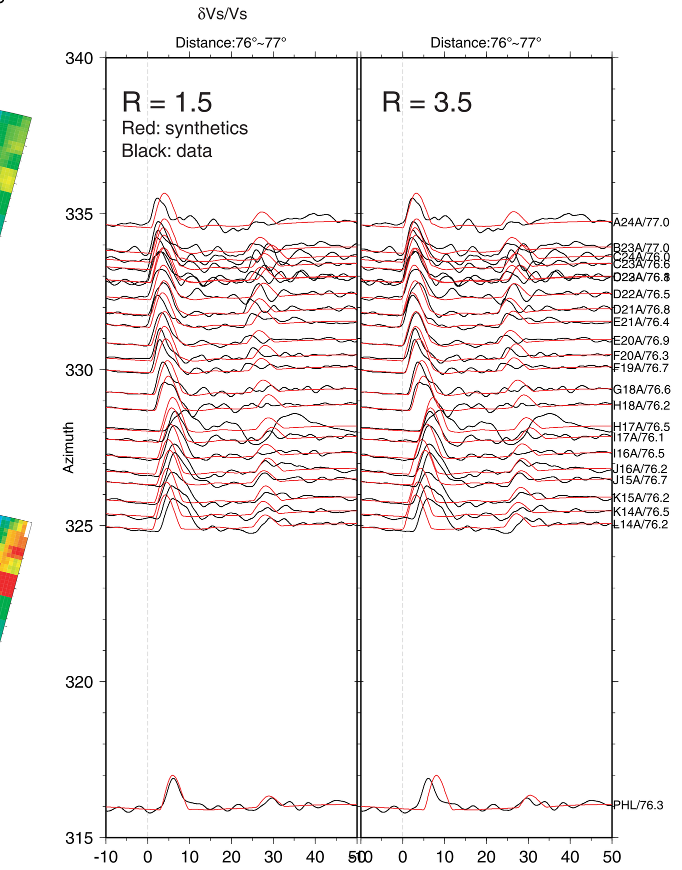
To calculate the synthetics for teleseismic S wave, we implement the Burdick western US regional tomography model into Grand's global tomography model. The figure below shows a cross section from the event 20081012 to station H17A. Because Burdick's model is P model, we assume a constant R=δlnVs/δlnVp for transforming to a S model.



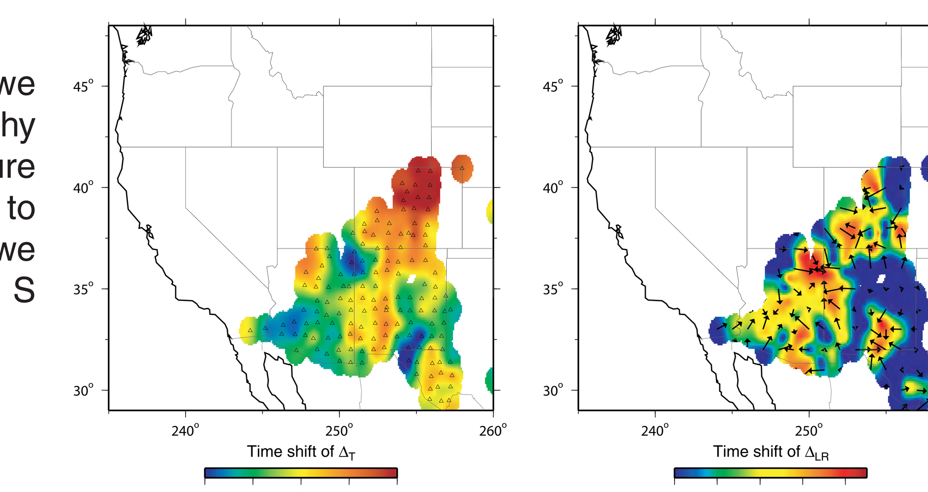


Shear velocity model with R = 1.5.

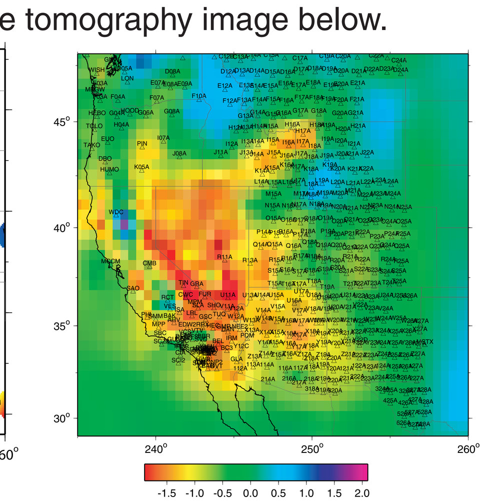
Shear velocity model with R = 3.5.



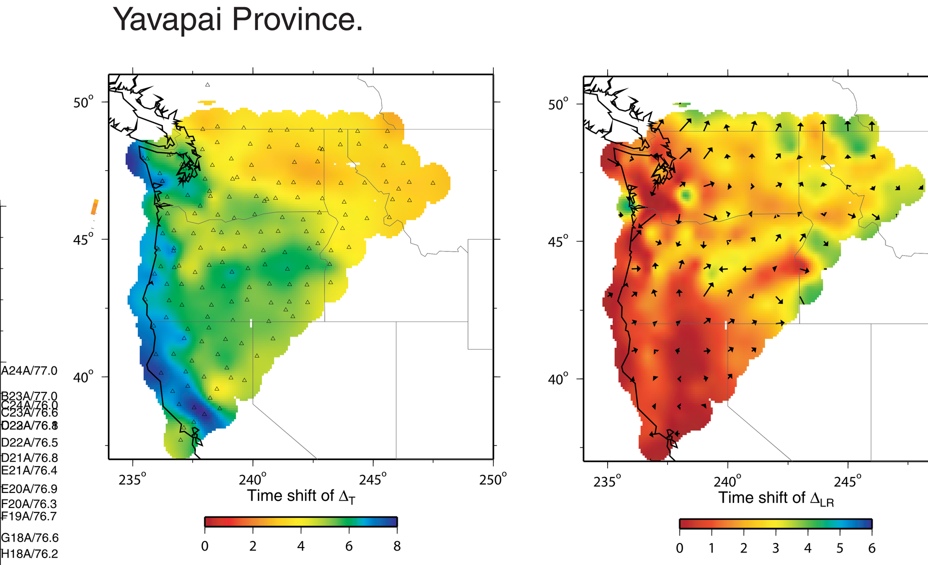
With larger R value, we can predict the abrupt travel time change at azimuth of 328° (from station H18A to H17A). But the model predictions are too fast for smaller azimuth. Although the calculation is 2D, strong out-of plane multi-pathing is expected when crossing this region.



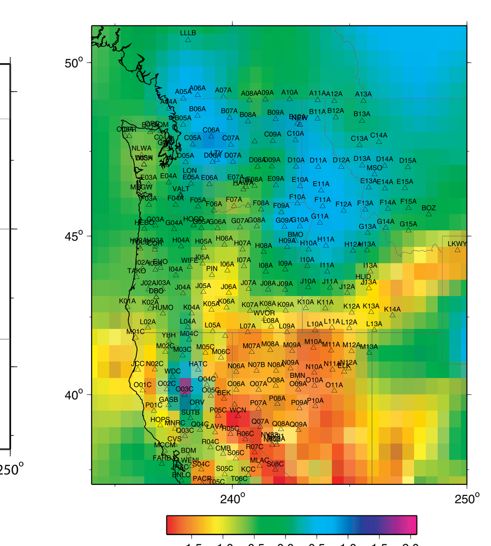
Delay time results for event 20080903 with MPD. The multi-pathing pattern is strong along the Jemez Lineament and Yavapai Province.



Burdick's tomography model at depth of 100 km.



Delay time results for event 20070716 from the north. Most of this dataset show small multi-pathing. Note the small pattern with large Δ_{LR} at the south east of Seattle, see Part II.



Burdick's tomography model at depth of 100 km.

Summary and Future efforts

The preferred 1D model from triplication data has a deeper 410 and shallower 660 than the GCA model.

The patterns produced from the multi-path detector show strong indications of of where the sharp boundaries along the edges of the anomalies.

To model both P and S wave data, we can obtain a good constraint on the R values for different anomalies, which is critical to understand the chemical or thermal original of those anomalies, such as YellowStone, Rio Grande Rift etc, *Song and Helmberger* (2007).