Model Update January 2013: Upper Mantle Heterogeneity beneath North America from Travel-Time Tomography with Global and USArray Transportable Array Data

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Online Material: P-wave tomography model for the United States; scripts for plotting maps and cross sections.

INTRODUCTION

As of January 2013, the Transportable Array (TA) of USArray (http://www.iris.edu/USArray/, last accessed September 2013), the seismological component of EarthScope (http://www.earthscope.org/, last accessed September 2013), has extended east of the Great Plains and into the Midwest and Gulf Coast regions, offering routinely processed data for travel-time inversions in regions where little data were previously available. In previous research notes (Burdick et al., 2008, 2009, 2010, 2012) we presented 3D tomographic models of mantle P-wave-speed from global and USArray-TA travel-time data recorded through November 2007, December 2008, January 2010, and March 2011, respectively. Here we present our global model updated with USArray-TA data through January 2013. As before, we make the new model, MITP_USA_2013JAN, available as an electronic supplement to this paper. Full interpretation of the 3D tomographic model is beyond the scope of this brief research note.

METHODOLOGY

A full description of the tomographic method used here can be found in Burdick et al. (2008) and Li et al. (2008), but we include a brief summary. We perform global inversions of P-wave travel-time residuals using an adaptable grid with a minimum grid spacing of 0.35° × 0.35° × 45 km within 10° of the USArray-TA footprint and 1.4° × 1.4° × 45 km outside. Grid cells are merged into larger ones in poorly sampled mantle volumes. The data included in the inversion consist of ~10 million P-wave residuals from the International Seismological Centre and the National Earthquake Information Center, which are processed using the algorithms developed by Engdahl et al. (1998), hereafter referred to as the EHB dataset, and the database of USArray-TA P-wave residuals picked by the Array Network Facility (ANF) (available online at ANF site; http://anf.ucsd.edu/tools/events/download.php, last accessed September 2013). For each update we refine the grid in response to the addition of ray paths associated with new USArray-TA data picks. The tomographic inversion is linearized using the 1D reference model ak135 (Kennett et al., 1995). Wavespeed variations represented in model MITP_USA_2013JAN are given as a percent difference from the average wavespeed at each depth in ak135.

WHAT IS NEW?

The January 2013 update of the USArray-TA dataset includes ~800,000 new P-wave travel-time residuals from around 4700 teleseismic events mostly occurring between March 2011 and January 2013. The updated set includes data recorded at 415 new USArray-TA stations (Fig. 1) and new data from continuously recording stations elsewhere, particularly in the western United States. The total number of USArray-TA picks used in the inversion now stands at ~2,560,000. The expansion of the TA brings the data coverage in the Great Plains region close to parity with that in the west and begins to improve coverage in regions as far east as the Appalachian range where data in the global catalog are sparse.

Cognizant of the shortcomings of checkerboard tests as a diagnostic tool for assessing spatial resolution, we use them nonetheless to obtain a qualitative measure of the mantle volumes where data coverage is adequate for resolving structure at a specified spatial wavelength. For this purpose we define the resolving power, R, at all points in the models by comparing
Figure 1. Geographical distribution of seismograph stations in and around the United States from which data are used. Black dots represent stations contributing to the EHB dataset; the worldwide station distribution is depicted in Burdick et al. (2008) or Li et al. (2008). Black and gray triangles represent USArray-TA station locations from the previous model update for data through March 2011 (Burdick et al., 2012). Gray stations have additional picks made after the previous update while black stations do not. White triangles represent the new TA stations included in the dataset.

Figure 2. Checkerboard resolution was used to determine areas of the model with lateral heterogeneity on the scale of 1.5\degree by 1.5\degree (i.e., around 150 \times 150 km). (a) True checkerboard model at 200 km depth. (b) Checkerboard pattern recovered by inversion. The shaded area ($R = 0.7$) represents parts of the model where 1.5\degree resolution is unavailable at this depth.
the recovered checkerboard model, \( m \), with the input checkerboard, \( m_0 \):

\[
R = \left[ \frac{(m - m_0)^T W (m - m_0)}{m_0^T W m_0} \right]^{1/2},
\]

in which \( W \) is a function that adds weighted contributions from adjacent cells, chosen here as a Gaussian with width on the order of the checker size. We consider the model resolved if \( R \) exceeds a threshold value. A threshold value of \( R = 0.7 \) was used for the resolution contours in Figures 2–5. Figure 2 suggests that the data generally resolve model features of the order of 1.5° by 1.5° (~150 km by 150 km) beneath the USArray-TA footprint. Resolution expands eastward with depth, and we begin to resolve structure in the mantle transition zone beneath the eastern margin.

The new model grid (shown in Fig. 3) is adapted based on the expanded coverage provided by the new data. Compared with the 2011 inversion, the most significant grid refinements center around (1) the shallow mantle beneath the northern Great Plains and the central Gulf Coast (due to continued data accumulation at stations installed at the time of the previous update) and the Midwest and eastern Gulf coast (due to data from new station locations), and (2) the mantle transition zone beneath the Midwest and Appalachia.

Figures 4 and 5 depict mantle heterogeneity according to the latest model update. To the west of the Great Plains, the addition of a year’s worth of new data has not had a great effect on the tomographic image of mantle heterogeneity, but the additional ray paths have refined certain features at transition zone depths and below. Shallow mantle structures related to subduction on the western margin continue to improve with continued data collection. The definition between presumed Farallon slab fragments and the fast structure associated with the craton appears better defined and more continuous than in the previous model updates. Beneath the Midwest and the Gulf Coast, the new data improve constraints on mantle heterogeneity at all depths. The Midcontinent Rift System leaves a slight low-velocity signature from Lake Superior to Iowa at depths down to 100 km. The New Madrid fault zone and the Reelfoot Rift show as strong slow anomalies and Ozark Plateau as a fast structure. Thanks to the equal coverage provided by the TA, it is apparent that the variability of the structure in the craton is less pronounced than in the tectonically active west, although sharp variations exist between the Midwest and the Gulf region.

CONCLUDING REMARKS

In this brief research note we present the latest MIT USArray-TA \( P \) model. This model includes more than 2,560,000 \( P \)-wave travel-time residuals (from 2004 through January 2013) obtained from nearly 1600 USArray-TA seismograph sites. A
A year’s worth of new travel-time data has improved the resolution of the model, particularly in the Midwest and Great Lakes regions and in the Gulf lowlands where little global data were available previously. Beneath the center of the continent, the data continue to define the craton and now reveal it to be more uniform than in the west, but with well-defined boundaries.

Model MITP_USA_2013JAN and scripts for making horizontal and vertical cross sections through it are available as an electronic supplement to this research note. ANF phase data are also available to the community as CSS monthly files at http://anf.ucsd.edu/tools/events/download.php (last accessed September 2013) or at the Incorporated Research Institutions for
Seismology Data Management Center (IRIS DMC) through their Product section at http://www.iris.edu/dms/products/ (last accessed September 2013).

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REFERENCES


