Pn TOMOGRAPHY AND LOCATION IN EURASIA

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ABSTRACT

We are exploring the use of Pn tomography for improving seismic event location in Eurasia. Toward this end, we have developed a new approach based on travel-time differences for two stations recording the same event. The premise of the station-differencing method is that by using travel-time differences among station pairs, the effect on the inversion of location errors inherent in the bulk of seismic bulletin origins can be significantly reduced. This permits the use of events previously discarded due to large location uncertainty, providing additional needed travel-time constraints in areas with sparse data coverage. The ability to include these lower-quality events in the inversion significantly expands our available constraints and enhances the quality of the tomographic results. We have applied our method to the preliminary Annual Bulletin of Chinese Earthquakes (ABCE), yielding a map of Pn velocity perturbations and station delay terms. This map is similar in character to earlier, single-ray tomography results, although the perturbations from our differential method tend to be more smoothly varying within tectonic provinces. Preliminary location tests using the tomographic Pn results show improvement over IASPEI91-based locations on the order of 30%. We intend to compare travel times from our study to those of previous research efforts to assess relative strengths of different approaches. We also plan to extend our study by applying our new method to the Michigan State University (MSU) eastern Russia database. Station differencing can also be used to perform quality control on seismic catalogs themselves, helping to identify bad phase arrival picks, stations with intermittent timing errors, and other sources of erroneous travel-time information. Results from an inversion for timing errors reveal questionable performance for some ABCE stations, as well as 10, 20, and 60 s timing residuals that may arise from typographical errors.

OBJECTIVE(S)

The objectives of this study are to improve location calibration through the use of velocity models derived from Pn tomography and to develop methods for catalog quality control. Our approach in both cases is based on the use of station differencing of travel-time residuals, implemented to extract useful information from plentiful but poor quality ground-truth data.

RESEARCH ACCOMPLISHED

Interstation Arrival Time Differences

The premise for our work is that the difference between regional arrival times from one seismic event to a pair of receivers is insensitive to source location (Figure 1). Therefore, poorly located events may still provide useful information on regional seismic wave propagation. This premise is subject to some geometric constraints, such as the region between the two stations where sensitivity to location is high. Figure 2 illustrates the sensitivity to event location for a pair of stations in China. For this figure, event locations were perturbed in three dimensions using 200 realizations of 20 km Gaussian random noise. The sensitivity is plotted as the logarithm of the root-mean-square time differences between the true location and the perturbed locations. From this figure it is clear that there are large regions within regional distances where sensitivity to 20 km mislocation is low. The rings at 1700 and 2000 km correspond to triplications arising from gradient changes in the upper mantle. Interstation differences have been widely used to eliminate source effects from seismic studies, going back to Brilliant and Ewing (1954) for determination of Rayleigh wave group velocity and Aki et al. (1977) for teleseismic travel-time inversion for upper mantle structure. In this paper we present only a brief outline of our approach to inverting regional travel-time residual differences for Pn velocity. For full details, see Phillips et al. (2005).

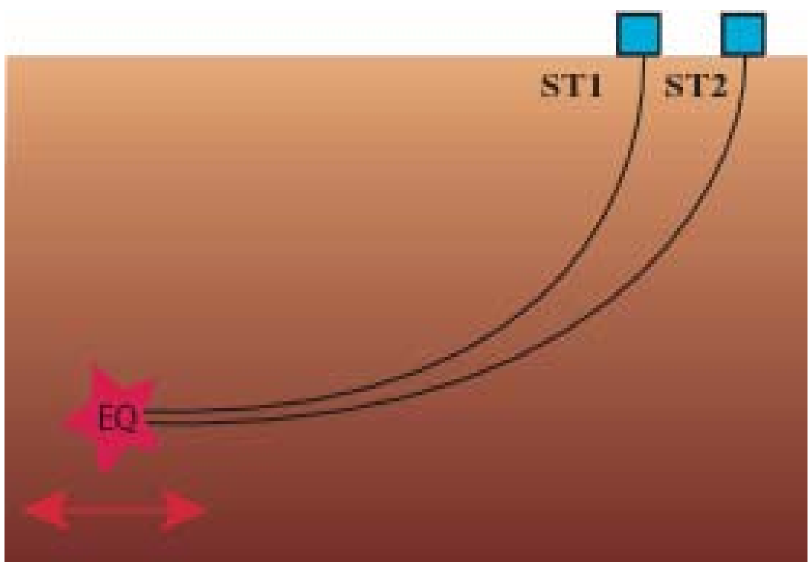

Figure 1. Cartoon showing the relationship between a regional seismic event and two observing stations. Interstation travel-time differences are insensitive to event mislocation, with some geometric constraints (after Rowe et al., 2003).

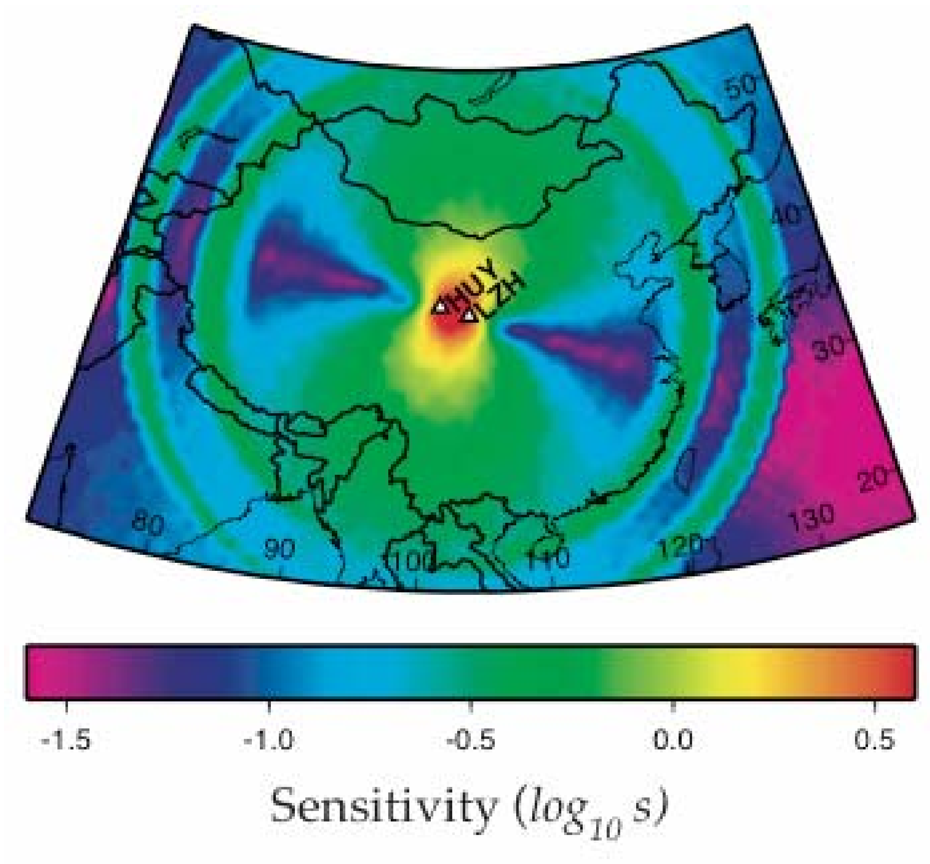

Figure 2. Sensitivity of interstation travel-time residual differences to geographic position for stations HUY and LZH in China.

Pn Tomography Results for China and Location Performance

To study the Pn propagation characteristics of China, we use the Annual Bulletin of Chinese Earthquakes (ABCE) (Lee et al., 2002). We began by relocating the ABCE catalog using IASPEI91. We then select data for events with depth < 50 km, distances between 1.6^o to 20^o, horizontal 95% confidence errors < 100 km, and travel-time residuals < 7.5 s. This resulted in nearly 1.5 million arrival time differences. To ensure stability, these data were limited to event locations whose sensitivity **S**, as shown in Figure 2, was less than or equal to 1.6s ($\log_{10}\mathbf{S}\leq 0.2$s). Lastly, median smoothing was applied over a 0.5^o grid, requiring at least 5 data points per cell. The resulting dataset consisted of 20,415 high quality time differences for 133 stations and 2819 events. An example of data for the station pair LZH/XAN is shown in Figure 3. These data are then inverted to produce Pn velocity perturbations and site terms for each station. Pn velocity variations and site terms are shown in Figure 4, top and bottom, respectively.

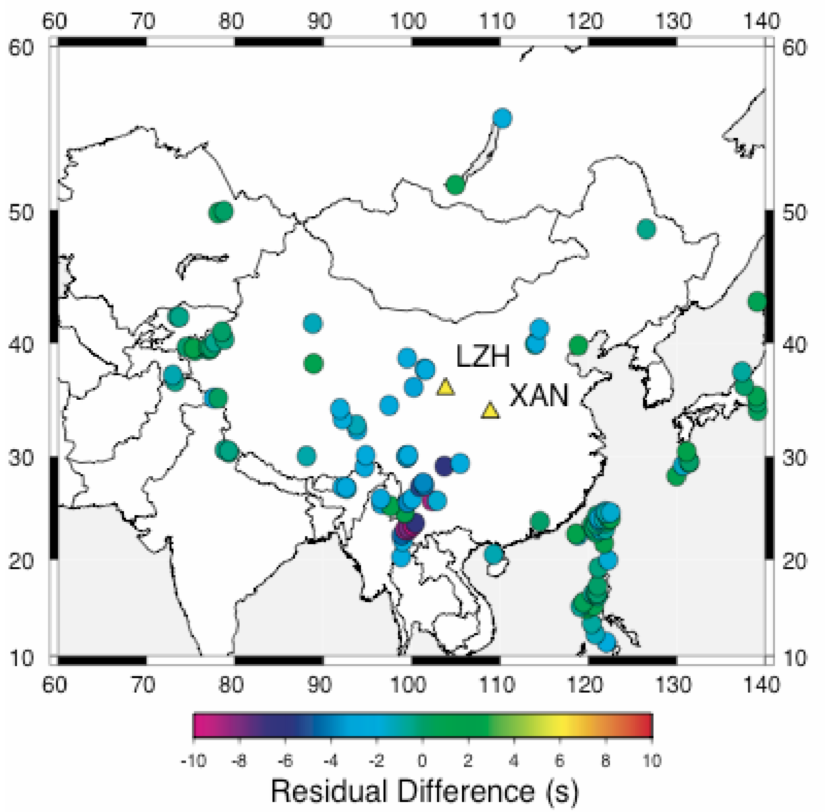

Figure 3. Travel-time residual difference data for station pair LZH/XAN (after Rowe et al., 2003).

The velocity variations we observe (Figure 4a) are qualitatively similar to those of previous studies (Hearn et al., 2004; Liang et al., 2004). Velocity is high across western China, particularly beneath the Sichuan (E), Tarim (F), Junggar(G), and Qaidam (H) basins, all areas of competent media associated with relatively undeformed, accreted micro-continents. Velocity is low across eastern and southeast China and Indochina, suggesting higher mantle temperatures. We also see low velocities in Mongolia, north-central and eastern Tibet (A), the Qilian Shan (C), and the western Tian Shan (B). Site delays are low (early) across east and southeast China and generally increase towards western China. Large delays (Figure 4b) seen for stations around the Bohai Sea (D) are not likely due to crustal thickness; rather, they appear to reflect upper mantle effects as noted by Hearn et al. (2004).

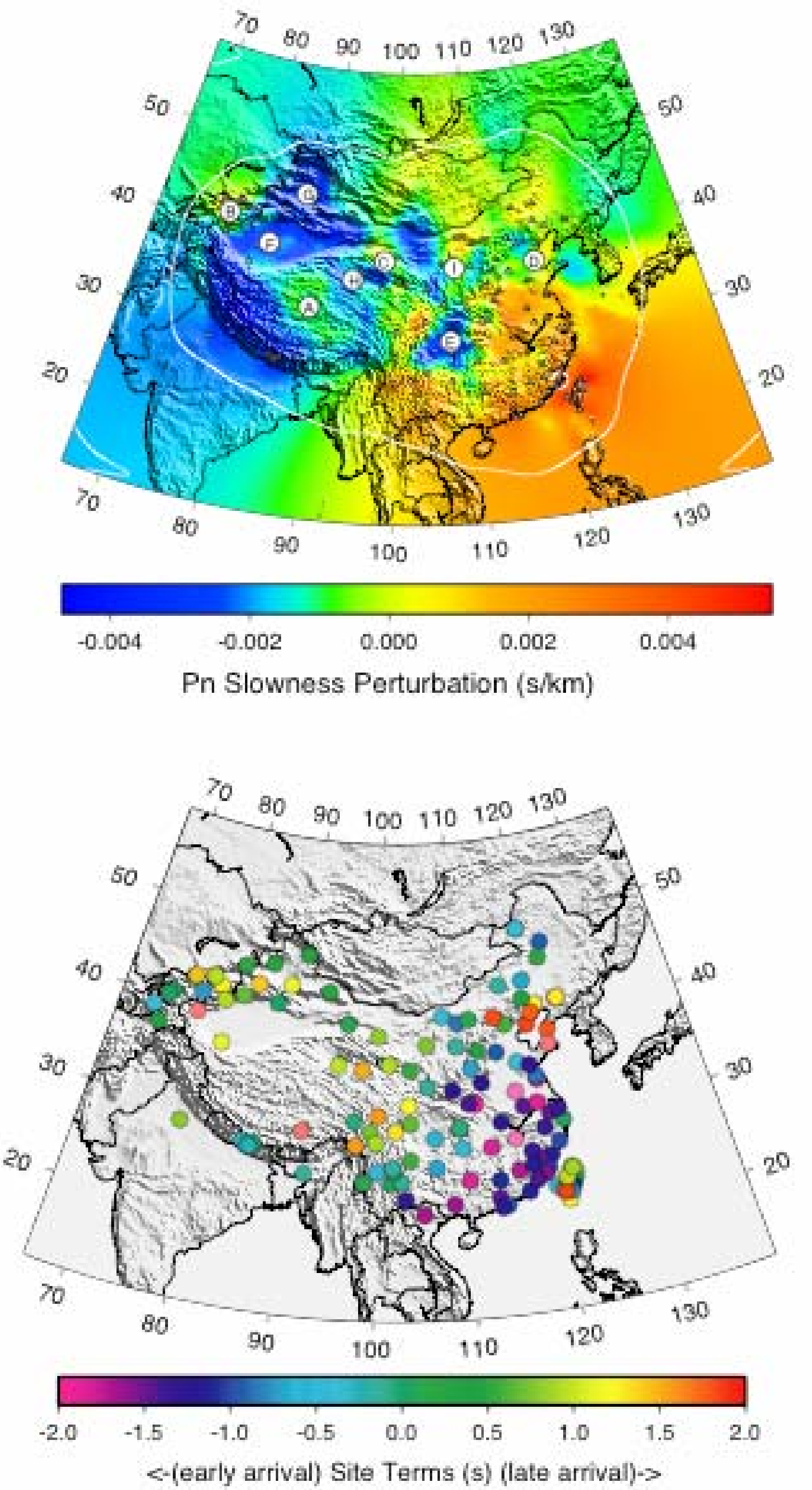

Figure 4. (Top) Pn velocity variations across China from tomographic inversion of travel-time differences. (Bottom) ABCE station site terms from the same areas (from Phillips et al., 2005).

To test the inversion results we integrated travel times calculated from the Pn perturbations and station corrections into the Knowledge Base Calibration Integration Tool (KBCIT) and created Pn travel-time correction surfaces for the ABCE stations. We then used these stations to relocate nuclear tests at the Chinese Test Site with and without corrections to the IASPEI91 model (Figure 5). Use of corrections results in a 30% improvement in location accuracy. There is a bias in both relocation sets that may reflect poor resolution in our model through Tibet, where station coverage is sparse. Future work in this area will involve using merged data for the China region from the National Nuclear Security Administration (NNSA) Knowledge Base, including as many stations and events as possible.

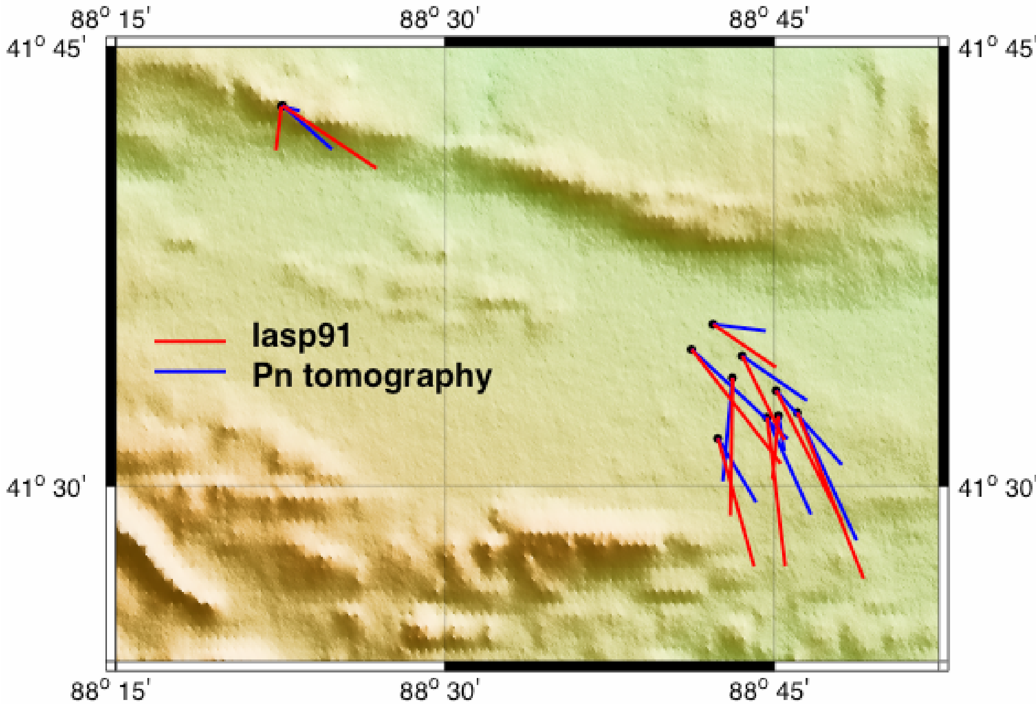

Figure 5. (Top) Pn velocity variations across China from tomographic inversion of travel-time differences. Black dots are satellite locations from Fisk (2002). Red lines connect uncorrected locations to the Fisk locations; blue lines are for the corrected relocations using Pn tomography results.

Pn Tomography of Eastern Russia – a Progress Report

We are beginning to compile a dataset for Pn tomography of the MSU Eastern Russia Database. We have identified over 100,000 event-station-station triplets that fall within 1.6° to 20° with depths < 50 km. These are for 53 stations and nearly 8200 events. Inversion runs are currently in progress and results should be available by the time of this year's Seismic Research Review.

Catalog Quality Control

In addition to its potential for improving tomographic images of velocity perturbations, travel-time differences can be used to assess the quality of travel times and station performance. An expected stable time difference that is anomalous relative to neighboring events indicates that one or both arrival times are poorly determined. We have developed a simple inversion that compares all stable pairs and assigns error estimates to individual arrival times. Results from this inversion are shown in Figures 6 and 7 (Rowe et al., 2004).

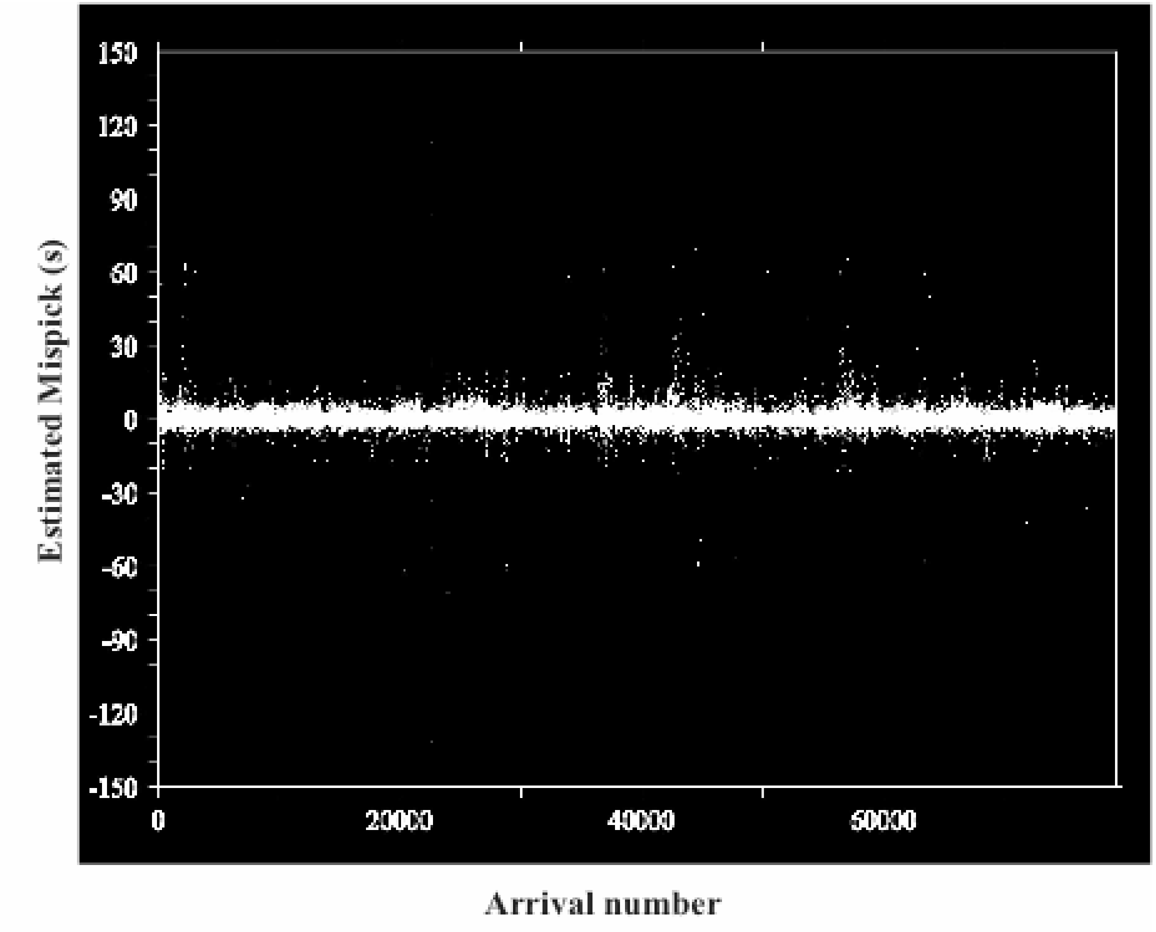

Figure 6. Inversion results for quality control of the ABCE catalog (from Rowe et al., 2004).

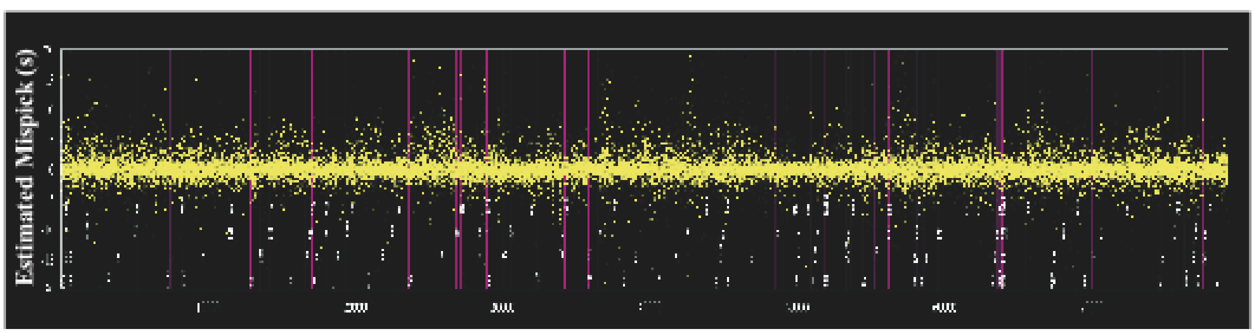

Figure 7. The same data as in the previous figure, but sorted by station and time with estimated mispick limited to +/- 20 s (from Rowe et al., 2004).

<u>CONCLUSIONS AND RECOMMENDATIONS</u>

We find that event/station-pair time differences have several valuable uses. This approach should be further investigated for both regional tomography efforts and for quality control studies of seismic catalog data. Correction surfaces from Pn tomography in China improve location accuracies at the Chinese test site by about 30% over those from the IASPEI91 global travel-time model.

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