

Supplementary Material for Global Long-wavelength Body-wave Catalog (GLoBoCat) for Lower Mantle P and S Wave Travel Times

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S1 Justification for the summary ray analysis

We explain the choice of 1σ to filter the outliers in the summary ray analysis with statistics. Before the summary ray analysis, the standard deviation in a 5 degree bin ranges [4.3, 6.7] seconds for P and [4.2, 6.4] seconds for S. Assuming a measurement x follows a normal distribution and cluster mean Y represents the correct value, the probability that $x - Y$ is within the range of $1\sigma_{layer}$ with picking error σ_{err} equals $erf(\frac{x-Y}{\sqrt{2}\sigma_{err}})$. Therefore, a decent (not outlier) P wave pick has at least 98.3% probability, and a decent S wave pick has at least 91.4% probability located within $1\sigma_{layer}$ from the cluster mean, given the picking error from $p = .7$ for P and $p = .5$ for S. Thus, we can remove problematic picks by sacrificing up to 8.6% of decent picks. If we use $2\sigma_{layer}$, the tolerance is unnecessary large ($> 3\sigma_{err}$) and barely removes any problematic picks.

The summary ray analysis removed 17,960, 26,907, 36,916, and 18,079 records, leaving 127,886, 180,659, 246,768, and 120,706 for P arrivals in the distance range $60^\circ-70^\circ$, $70^\circ-80^\circ$, $80^\circ-90^\circ$, and $90^\circ-100^\circ$, respectively. For S arrivals in the same ranges, it removed 16,895, 23,323, 38,436, and 12,190 records, leaving 176,496, 234,428, 278,777, and 112,210 passing the quality control. In average, 12.9% of P and 10.2% of S arrivals are removed. The removed P wave data relative to the expected number from decent picks are more than that of S wave data, indicating that P wave picks are more susceptible to outliers. This tendency may be responsible for the larger variations in the long-period travel time residuals.

Besides from the summary ray analysis we also remove the problematic picks from the doublet event and the NZ network depicted by travel time residual distribution (Fig. S1). The doublet event has similar source time at 2012-12-07T08:18:34.9Z and 2012-12-07T08:18:46.9Z and source locations are only 52 km apart, resulting in a difficulty of

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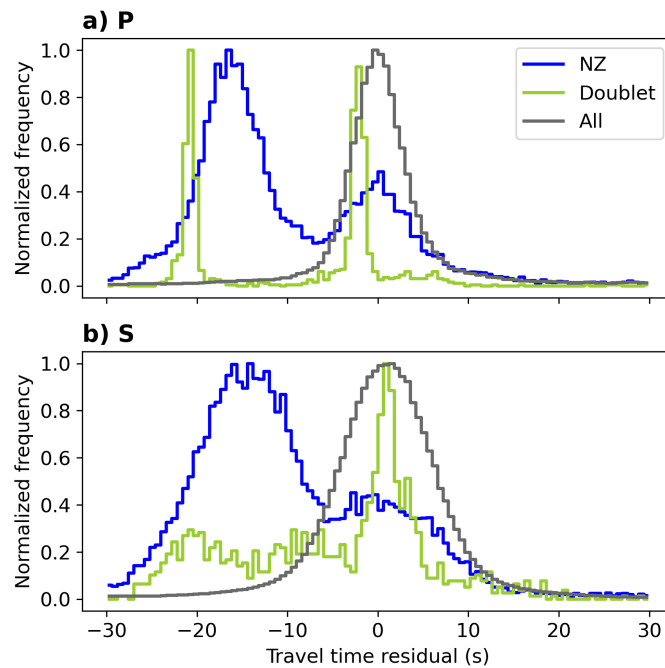


Figure S1 Problematic picks from doublet event and the NZ network depicted by travel time residual distribution for P and S waves.

picking the correct arrival time. The picking results for waveforms recorded by the NZ network are also removed due to an apparently problematic bimodal distribution of travel time residuals. The number of picks removed for NZ is 1088 out of 917879 for P ($p > 0.7$) and 3647 out of 1191384 for S ($p > 0.5$). The number of picks removed for the doublet event is 466 for P and 473 for S.

Below we discuss how quality check (QC) process makes the statistical distribution of the new data closer to previous studies (Fig. S1). We discard δt larger than 20 sec or smaller than -20 sec, and remove distinct picks relative to their neighbors using summary ray analysis. The original GLoBoCat distribution using thresholds with picking errors comparable to the Houser dataset (lines in pink) shifts from that of Houser's (lines in light green) and Masters' (lines in blue), but is improved by QC (lines in black). Since the new dataset significantly improves the southern hemisphere coverage, we examined whether the coverage changes the distribution. When comparing only north hemisphere traces (defined by turning point latitude > 30 deg), we found that the distributions (lines in red) are even closer to that of Houser's and Masters'. Nevertheless, we will exploit the improved coverage in the southern hemisphere and we do not limit the turning point latitude in the analysis in the main text.

Finally, we compare the geographical distribution of travel time residual of GLoBoCat after QC with previous studies (Figs. S3–S4). One can see that GLoBoCat shares similar pattern with previous studies in general, but dramatically improves the raypath coverage, especially for the southern hemisphere. It is noteworthy the GLoBoCat observed delayed P wave arrivals in the lowermost mantle underneath the Africa, whereas early P wave arrivals are observed in the Houser's dataset. The difference in correction terms cannot explain this deviation, and it is still unclear what causes this variation.

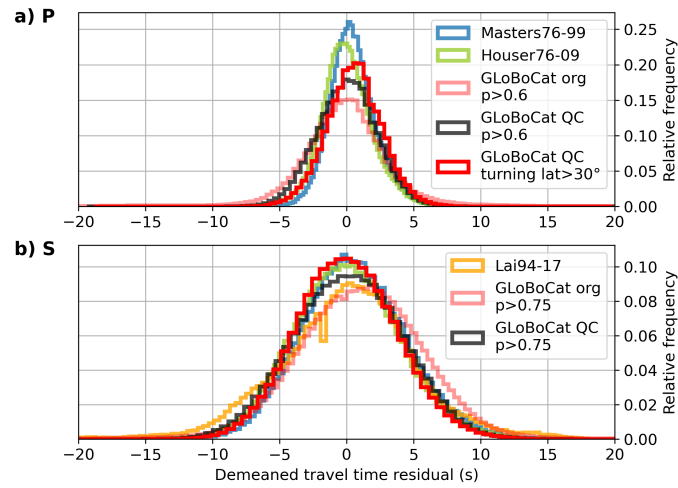


Figure S2 Travel time residual (δt) distributions of GLoBoCat with different QC standards compared to previous studies.

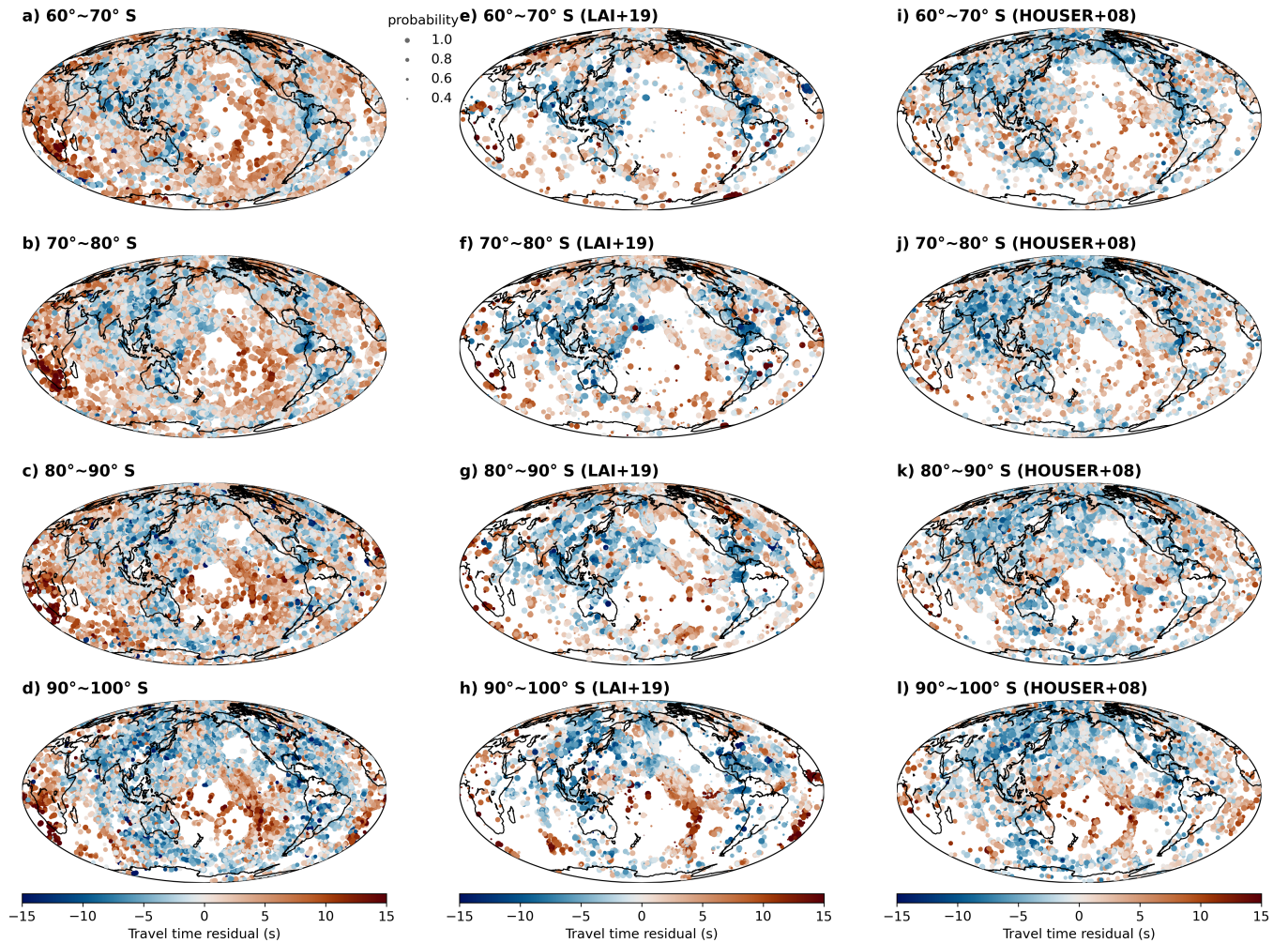


Figure S3 Geographical distribution of travel time residual of GLoBoCat after QC compared to previous studies for S waves.

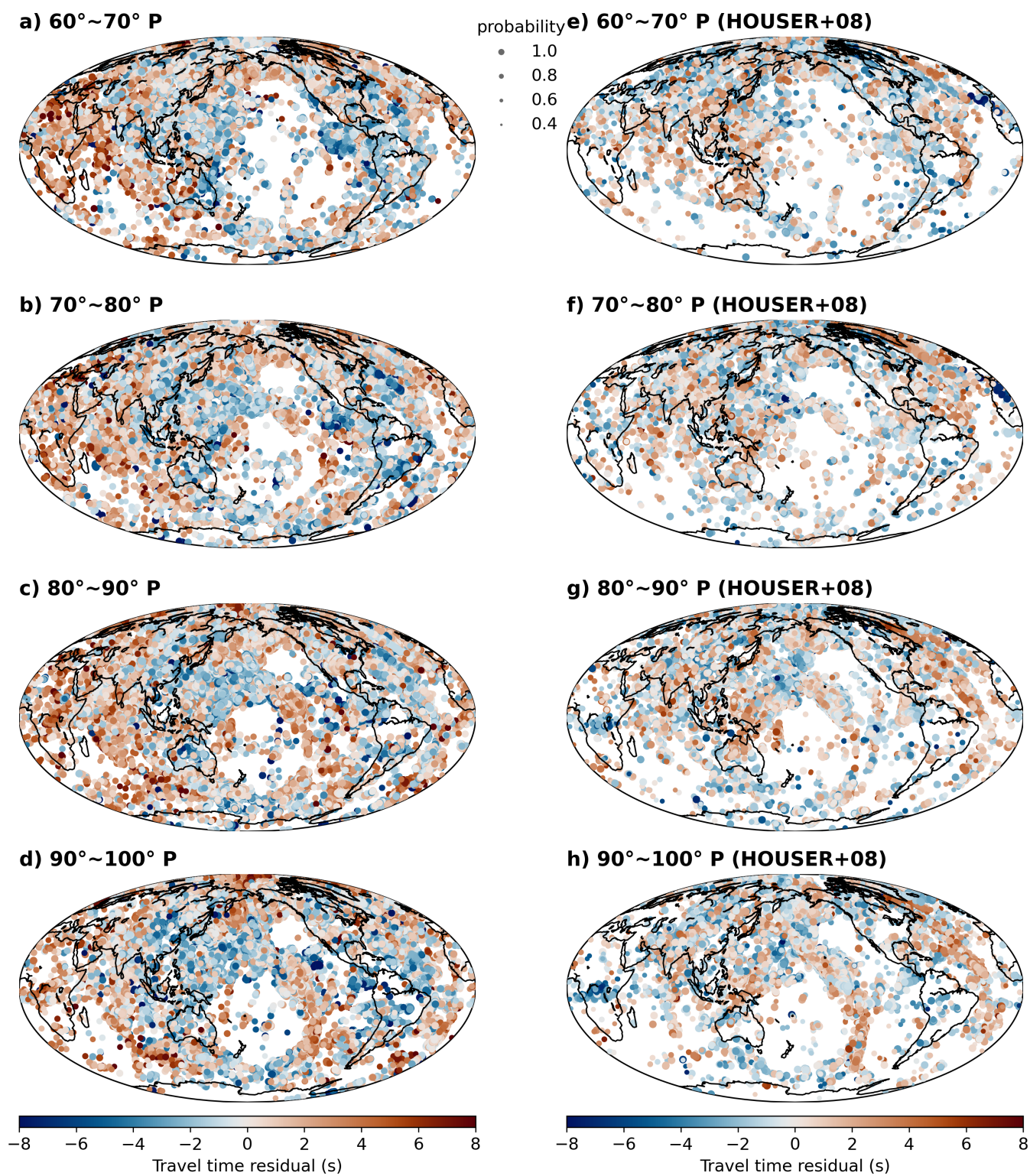


Figure S4 Geographical distribution of travel time residual of GLoBoCat after QC compared to previous studies for P waves.

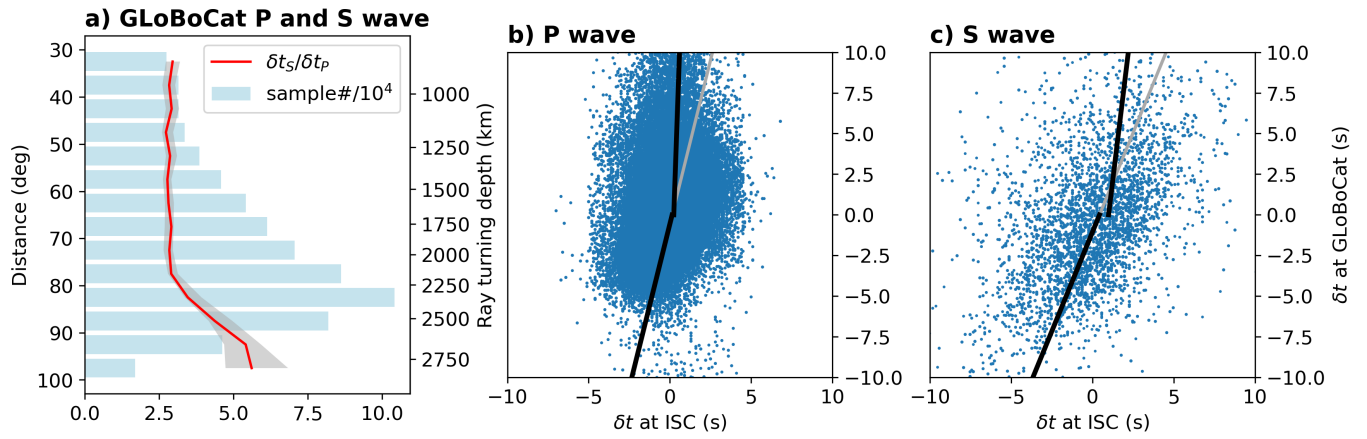


Figure S5 Similar to Fig. 5, but using the travel time residuals without summary ray analysis.

S2 Assessment of long vs short period travel time residuals

In this section, we assess the long vs short period travel time residuals and show the robustness of the change in slope for early versus late arrivals. First, we compare the travel time residual ratio between P and S waves ($\delta t_S / \delta t_P$) with and without summary ray analysis (Fig. S5a) and confirm the increase in $\delta t_S / \delta t_P$ is not an artifact. Without the summary ray analysis, the long versus short period travel time residual scatters (Figs. S5b–c) contain much more problematic picks, especially for late arrivals of P waves. This explains that the summary ray analysis is necessary to remove outliers, which only reduces the number of mutual P wave picks for GLoBoCat and ISC from 111,916 to 101,617. We checked extreme anomaly (> 7.5 s), and removed the incorrect picks due to cycle skipping with a number of 315 (demonstrated in Fig. S6), resulting a final number of 101,302 samples shown in Fig. 5b.

With the QC results, we investigated the geographical distribution of long and short period travel time residuals of P and S waves and found no significant influence from turning point locations (Figs. S7–S8). We also confirmed the change in slope is robust by the scatter plot of travel time residual ratio across all depth groups for the lowermost mantle (Fig. S9).

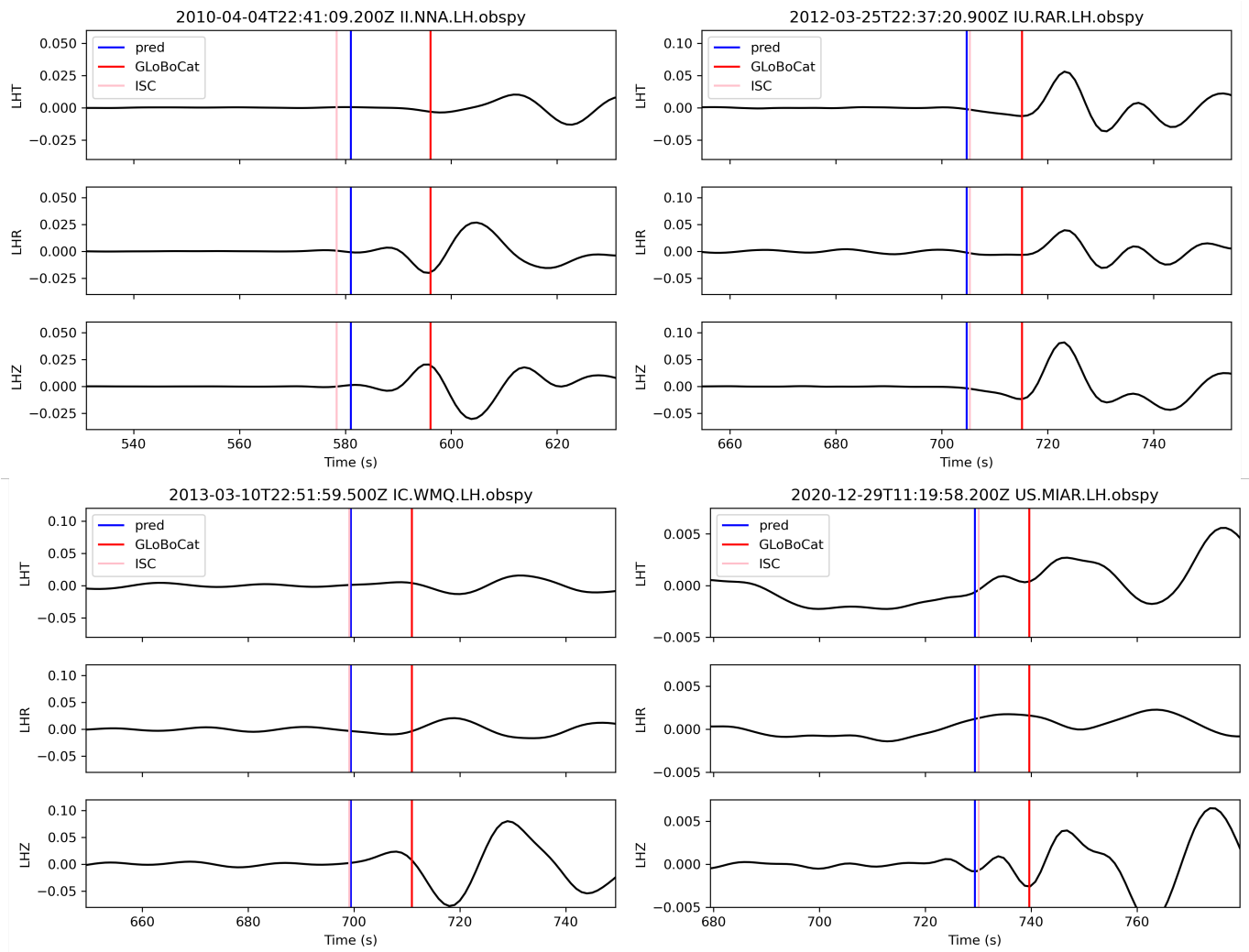


Figure S6 Four example waveforms from the 315 removed incorrect picks.

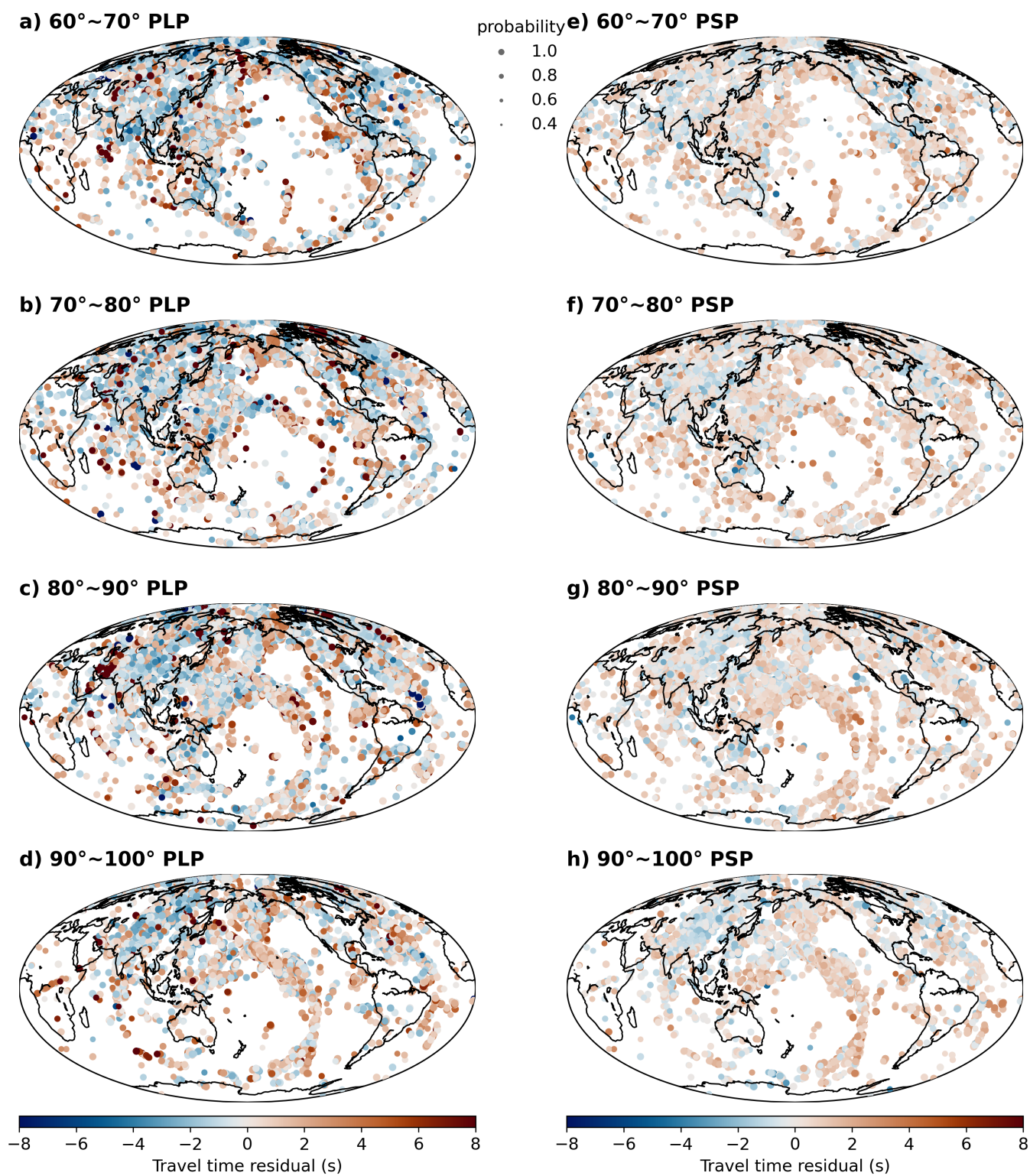


Figure S7 Geographical distribution of long and short period travel time residuals of P wave.

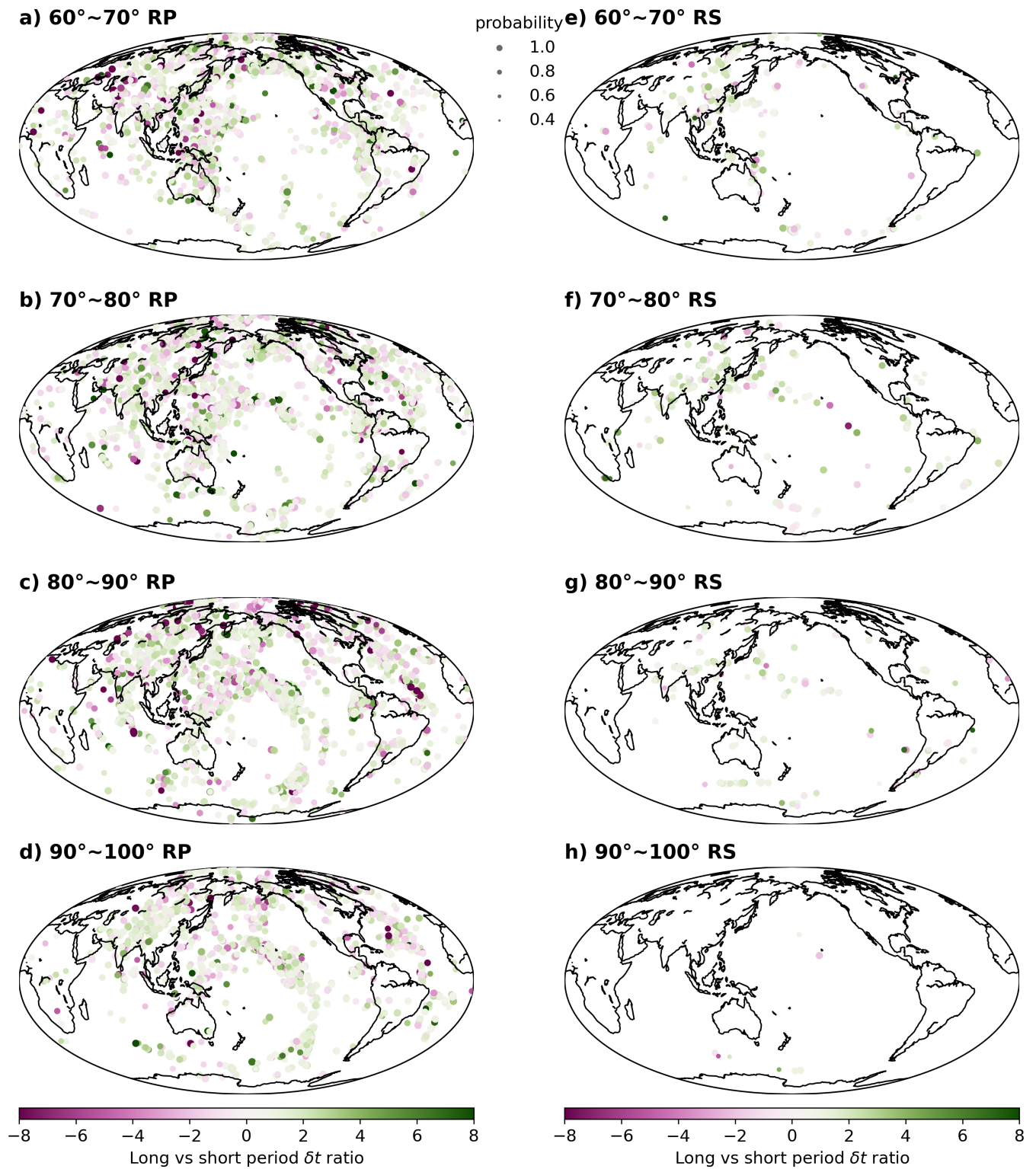


Figure S8 Geographical distribution of long and short period travel time residual ratio for P and S waves. Ratios for residuals smaller than ± 1 sec are not shown.

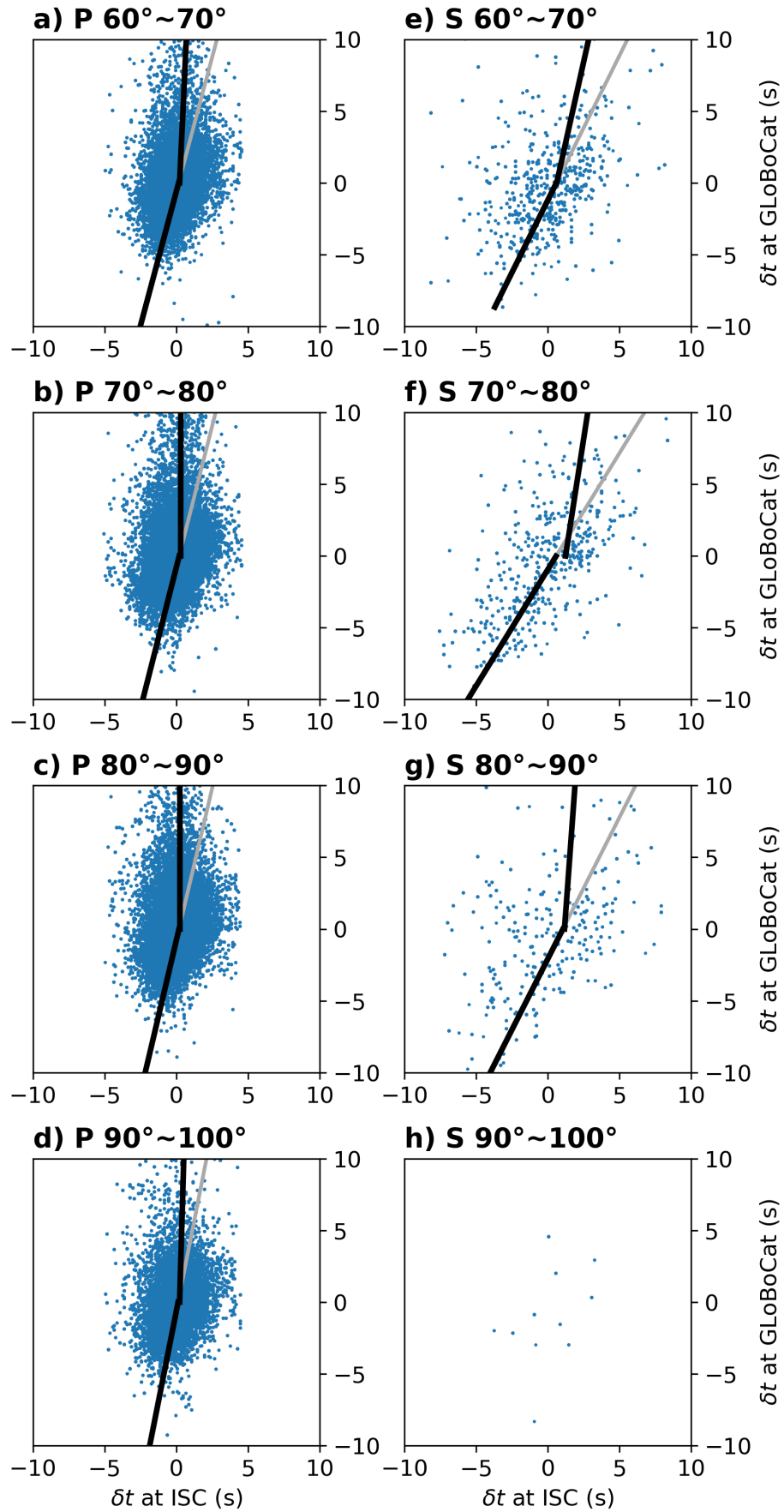


Figure S9 Long versus short period travel time residuals and slopes for early and late arrivals measured in depth groups.