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Supporting Information for

**Isolated Crustal Partial Melting along the Yarlung-Zangbo Suture and Distinct
Central Lhasa Block from H- κ -c Method**

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Introduction

This supplementary document provides additional information on the source for receiver functions, the H - κ - c results, quality control process, and robustness of the results. The detailed descriptions are summarized as below:

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Text S1. Quality control for H - κ - c results.

Although the seismic instrumentation in the central-southern TP has been expanding heretofore, the spatiotemporal coverage is still not abundant to carry out H - κ - c method ideally in general. Therefore, it is necessary to design an expedient quality control process and balance the trade-off between limited instrumentation and the quality of H - κ - c results.

In general, the basic idea for quality control is by sorting all H - κ - c results by quality indices, and then trim the result by given criteria. However, this is difficult in practice. First of all, quantitative description of quality indices is hard to achieve. Although we can define some experiential indices, they are only referential as they can't describe the quality precisely. Second, the trade-off between limited instrumentation and the quality of H - κ - c results is hard to describe. Third, the complex crustal structure of the Tibetan Plateau lead to a great variety of abnormal traits in RFs. This may result in inconsistent experiential indices, as it is difficult to anticipate and evaluate all types of abnormal RFs beforehand.

In practice, we adopted the following general processes for quality control:

- (1) **Independent Selection:** Perform H - κ - c stacking on all RFs. Use Matlab app Hkc-Pick to record all results with stability tests (see Data Set S1). Pick one best possible correction plan among 5 stability tests for every station independently according to single-station data selection criteria. Record the stations with excellent data quality and very clear and certain H - κ - c results. They will serve as the benchmarks for the next step. Delete the H - κ - c results which is definitely unsuitable (e.g., maximum BAZ gap far greater than 150° ; RFs seriously affected by sedimentary layer, etc.).
- (2) **Joint Adjustment:** List all remaining H - κ - c results and check them one by one. Compare the current checking station with its nearby stations. Check the spatial consistency of time separations among these stations (mainly t_{Ps-P} and t_{PpPs-P} , because the $PpSs+PpPs$ is very complicated and it affects little on H - κ energy map with a small weight), especially if the benchmark stations exist nearby. Adjust the window for harmonic searching (i.e., reference model) and searching range for harmonic correction parameters if necessary. Record the experiential quality index and remark for every station.

- (3) **Joint Selection:** After Adjustment is done, manually check every station again.

However, in this step adjusting H - κ - c results is not our main purpose. The main task for this step is deciding which stations to preserve and which to discard. The trade-off considering data coverage is also considered in this step. The selection is done based on experiential quality index and remarks to speed up.

During the above process, we summarized possible influence factors of the quality for H - κ - c results:

(1) **Signal to Noise Ratio (SNR):**

- a) Whether abnormal signal appear in RFs (e.g., RFs containing abnormal low-frequency oscillation or unrealistically large pulse). Abnormal signals are very likely to be scanned by H - κ scanning. It can change the relative energy of different local extrema if the energy of abnormal signals is superposed on the H - κ energy of normal signals.
- b) Number of RFs in each BAZ bin. In practice, stacking of individual RFs at the same station is required to mitigate data overfitting in single RF. The H - κ - c method corrects the arrival time of Moho-related phases relative to BAZ. Therefore, it strengthens the data requirement on RF stacking since the stacking (binning) of individual RFs is performed on BAZ bins during the stage of harmonic correction. If the majority BAZ bins only contain very few RFs (e.g., only 1 RF in each BAZ bin), the SNRs in these BAZ bins are more possibly to be unsatisfying, and the harmonic searching might be strongly affected by noise.
- c) Sparsity of BAZ bins that containing RFs. An extreme example (although not realistic) is that only 4 RFs are recorded. These RFs are evenly spaced in BAZ so that maximum BAZ gap is 90° . However, the harmonic searching is also possibly dominated by noise in such situation. In our practice at the central-southern TP, the common situation is that BAZ bins containing RFs is sparse in a $\sim 180^\circ$ range.

(2) **Model Error:**

- a) Maximum BAZ deficiency. If the maximum BAZ deficiency is greater than 90° , the harmonic correction may not successfully recover $\cos 2\theta$ feature, as suggested by Rümpker et al. (2014). This may produce errors in H and κ .

- b) Mismatch between the posit and the real situation. The H - κ - c method is hardly able to correct the situations of (I) the influence by thick sedimentary layer; (II) absence of Ps energy and/or PpPs energy (i.e., Ps or PpPs signal is at the noise level in most BAZ bins); (III) abysmal uncertainty in Ps energy (e.g., the main characteristics of Ps segment in RFs can be described as, multiple Ps-like energy at some BAZ bins, plus strongly-diffusing Ps signal at some BAZ bins that seems to be disconnected with the other BAZ bins).

As we want to select relatively good H - κ - c results under insufficient data coverage, we need to at least qualitatively evaluate the relative damage on the H - κ - c results caused by each factor. Among them, we found that the BAZ threshold of 90° seems to be too strict for data selection, at least for the central-southern TP. Figure S2a shows that applying the BAZ threshold of 90° will result in many data/station gaps in spatial coverage. Such sacrifice may not be the best choice, because (1) Using a BAZ threshold of 90° alone is insufficient to eliminate all poor H - κ - c results caused by other factors (e.g., RFs with abysmal uncertainty in Ps energy); (2) some stations present acceptable ambiguity in H - κ - c results even if their maximum BAZ gap is slightly larger than 90° . In summary, although the idea of sorting all H - κ - c results by integrated quality indices is hard in practice, we still need to comprehensively evaluate all the factors rather than directly apply an optimal threshold for a single factor, considering the limited RF data coverage in the study region hitherto.

After careful examination of RF data in the central-southern TP, we prefer 120° to be the threshold of maximum BAZ gap. This threshold does not derive from 90° too far, and preserves $\sim 33\%$ more stations comparing to the threshold of 90° . A forward modelling test (Figure S8) and comparison of stricter or looser BAZ threshold (Figure S9) show the influence of using 120° instead.

From Figures S8a and c, we can see that H - κ - c method is more easily to produce seriously deviated H results under very large BAZ gap (e.g., 300°), which is possibly due to biased correction. This implies H - κ - c method may be depreciated than H - κ method under extreme BAZ deficiency situations, as it introduces additional model error.

However, at smaller BAZ deficiencies, H - κ - c method performs better than H - κ method by mitigating model error. From Figures S8b and d, we can see that if maximum BAZ

gap is smaller than 120° , the H - κ - c method would produce comparable κ results regardless of the center of BAZ gap. When maximum BAZ gap is bigger than 120° , H - κ - c method would produce clearly biased κ results at certain BAZ centers. As a comparison, the traditional H - κ method would produce clearly biased κ results at some certain BAZ centers even if only a small gap (e.g., 5°) exists. This may also explain why the H - κ - c method could produce more consistent spatial variation pattern of H and κ than H - κ results (Figure S5), besides the mutual constraint strategy we employed.

Figure S9 shows that regardless of the BAZ threshold used, the main characteristics of the studied region, such as the two isolated high- κ regions around the YZS, high κ in the SQB, thick crust in the western part of central LB, and thinned crust in the eastern part of central LB, remain consistent. This indicates that our main results are robust and not significantly affected by the choice of BAZ threshold.

Text S2. Discarded stations with maximum BAZ gap smaller than 120° .

As discussed in Text S1, we set the threshold of 120° for BAZ gap. All stations with BAZ gap bigger than 120° will be discarded. Some stations that are not rejected by BAZ gap threshold may be rejected by other considerations. Here we list these rejected stations and the detailed reason for rejecting them. Note we only list the main reason for every rejected station. Some stations may have multiple adverse factors. The complete record of data quality assessment for every station can be found in Data Set S1.

(1) RFs with certain abnormal characteristics and show tremendous inconsistency

in H - κ - c results comparing with its nearby stations. Although these abnormal characteristics may possibly arise from locally intensified complexity in crustal structure which depreciates the relatively simple Earth model that H - κ - c method assumes, these H - κ - c results may not necessarily be erroneous (see Data Set S1 for their RF waveform and H - κ - c energy map). Due to the difficulty in conforming these results, they are ignored for simplicity in the main body of our article.

- a) **Within the YGR:** BB10, BB08, BB05
- b) **Near the YZS:** YS66, YS87, YS96

(2) Complex RF structure that may raise large uncertainty in harmonic correction, due to significant deviation from the hypothesize of H - κ - c method.

- a) **Strongly diffusing and thus undeterminable Ps-like & PpPs-like phases:**
YS42, NY05, YS69, YS62, YS71, LM46
- b) **Multiple Ps-like and PpPs-like signals with abnormal or undeterminable H - κ - c solution:** YS43, YS89, YS47, YS64, YS58, NY01, YS98, LM47, LM48, LM49, NP082
- c) **Absence of Ps or PpPs energy:** YS57, NG020
- d) **Influence of sedimentary layer shown by intensely distorted P signal:**
NP010, NP020, BIRA, BHE01
- e) **Influence of sedimentary layer shown by intense reverberation:** NP040
- f) **Large error in H or κ which is hard to be reduced by adjusting harmonic correction parameters & dense station distribution nearby:** YS94, YAMJ

(3) RFs show possible large uncertainty for correction curve, and meanwhile the effective BAZ coverage is much scarcer than the apparent BAZ coverage. Only one or two RFs occur in a large BAZ range, meanwhile the signals in these RFs are too faint to constrain the variation of correction curves in this BAZ range.

- a) **Gap from 210° to $360^\circ+30^\circ$:** YS55
- b) **Gap from 175° to 315° :** YS48, YS70
- c) **Gap from 150° to $360^\circ+40^\circ$:** LM53
- d) **Gap from 140° to $360^\circ+30^\circ$:** BHE14

(4) Other considerations:

- a) **YS73 and YS72:** similar RF waveform with strongly diffusing Ps. However, the searched t_{ps} is at $\sim 8.2s$ for YS72 and is at $\sim 6.8s$ for YS73. The $\sim 1.4s$ time difference will lead to a large difference in H or κ between these two adjacent stations. Considering the uncertainty in t_{ps} , we discard the H - κ - c result of these two stations.

- b) **LM47 and X9A:** two stations located in the same place. Both stations show two possible Ps-like signals. However, the $H\text{-}\kappa\text{-}c$ results of these two stations is not compatible. Discard both stations for simplicity.
- c) **BHW02:** According to mutual constraints of t_{Ps} relative to its nearby stations, signals at $\sim 4s$ is not likely to be Ps signal. However, signals at $\sim 4s$ are too strong, that dominates the $H\text{-}\kappa$ energy map of BHW02. Discard this station for this reason.

Table S1. *List of RFs Used in This Study.**

Network name	Number of stations (with RFs)	Array information	RF source
Hi-CLIMB	145 ^a	doi.org/10.7914/SN/XF_2002	Lupei Zhu & Yuming Zhou ^c
Hi-CLIMB	36		
HIMNT	27	doi.org/10.7914/SN/YL_2001	
INDEPTH II	56	fdns.org/networks/detail/XR_1994/	
INDEPTH III		doi.org/10.7914/SN/XR_1997	
Tibet 91-92	5	doi.org/10.7914/SN/XC_1991	
Two Linear Arrays	110	doi.org/10.1073/pnas.2000015117	Danian Shi ^d
SANDWICH	76	doi.org/10.1785/0220150243	Zhen Liu ^b
SANDWICH	53		Shitan Nie ^c
GANSSER	44	doi.org/10.12686/sed/networks/xa	(This study)
Bhutan Pilot	5	doi.org/10.7914/SN/XA_2002	
INDEPTH IV	5	doi.org/10.7914/SN/X4_2007	

*The 145 linear Hi-CLIMB stations are already applied with $H\text{-}\kappa\text{-}c$ stacking by Li & Song (2021). We apply $H\text{-}\kappa\text{-}c$ stacking to the rest 36 Hi-CLIMB stations. There are two sources for SANDWICH RFs. Liu et al. (2021) provides RFs with Gaussian factor of 1.0 at all 76 SANDWICH stations. Nie et al. (2023) provides RFs with Gaussian factor of 2.5 and generally boarder BAZ coverage at 53 SANDWICH stations. For some arrays, part of them may locate outside the study area. We only utilize stations within the study area. Therefore, the number of stations in Table S1 may be fewer than the actual total number of stations in these arrays. The two linear arrays provided by Shi et al. (2020) are trimmed at 92°E. Tibet 91-92 and INDEPTH IV are cut within the limit of 92°E and 33.5°N.

^aLi & Song (2021). ^bLiu et al. (2021). ^cNie et al. (2023). ^dShi et al. (2020). ^eZhou (2013).

Table S2. Statistics for H and κ Measurements in Each Compartment.*

Compartment	Mean and STD				Range and RMS for fitting			
	$\bar{H}$ (km)	$\bar{\kappa}$	σ_H (km)	σ_κ	$\tilde{H}$ (km)	$\tilde{\kappa}$	H_{rms} (km)	κ_{rms}
SQB	62.5	1.85	2.90	0.047	60.3~64.4	1.845~1.853	2.91	0.045
BNS	66.9	1.83	3.99	0.052	64.4~68.2	1.801~1.845	3.83	0.050
LB	69.8	1.78	5.13	0.039	67.7~70.3	1.771~1.799	4.71	0.044
YZS	65.8	1.81	3.55	0.081	63.3~67.7	1.792~1.813	3.67	0.080
HB	54.2	1.75	5.76	0.066	49.8~63.0	1.732~1.811	3.30	0.076
MBT	47.8	1.75	3.40	0.051	46.6~49.8	1.738~1.750	3.57	0.057

*The compartments are shown in Figure S3. Compartments are named by the main geological structure in it (SQB: central-southern QB). Before calculating mean and standard deviation (STD) for each compartment, measurements at each station was first processed by blockmean module in GMT to compromise the unevenly distributed instrumentation. The calculation of the range and root-mean-square (RMS) of fitting in Figures 2e-f is done under raw data without any spatial pretreatment.

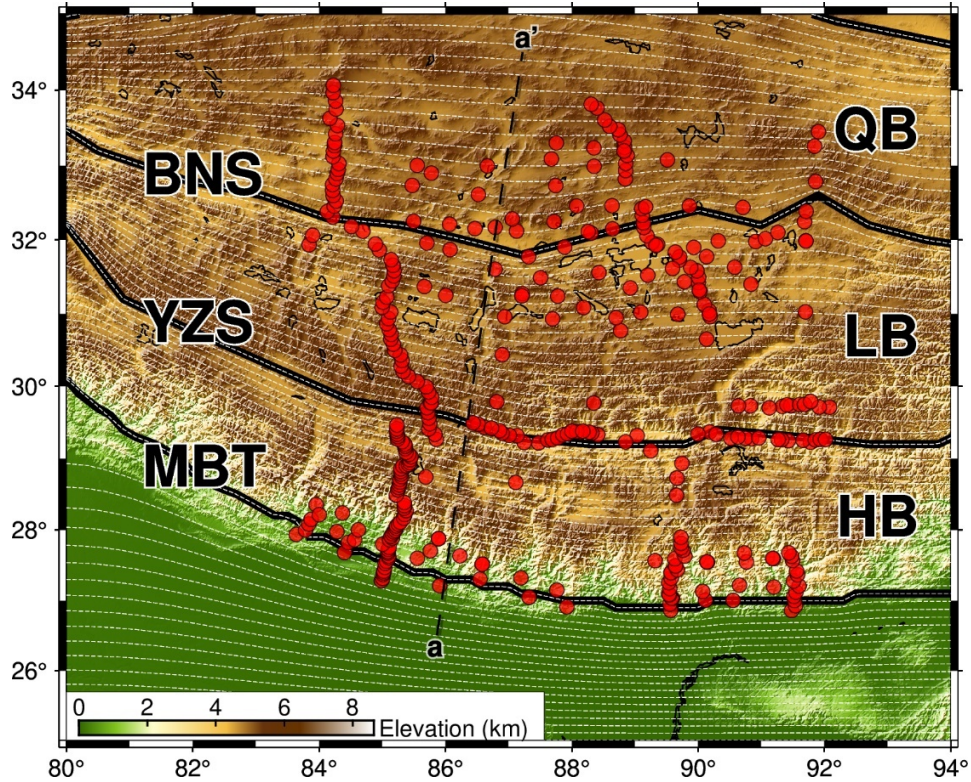


Figure S1. General view of the projection of H - κ - c results onto the reference profile aa' . The white dashed isolines are derived from body-fitting grid, which is generated by

gridgen (<https://github.com/sakov/gridgen-c>). Each station is projected onto the intersection point of aa' and the isoline that passes through it exactly.

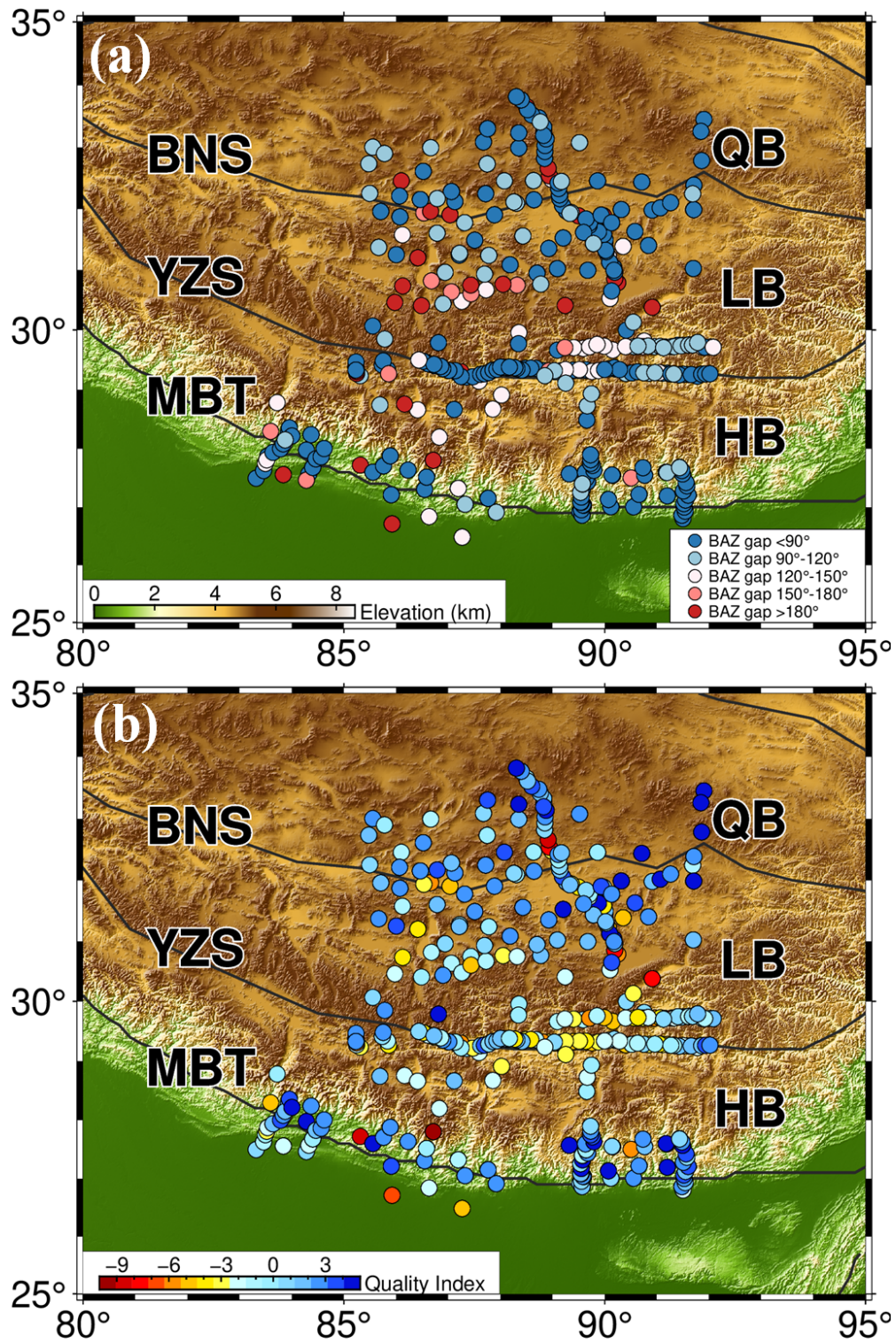


Figure S2. Two quality control indices for H - κ - c results. (a) Maximum BAZ deficiency for RFs. (b) Experiential H - κ - c quality index. Larger index represents it's more likely to obtain ideal H - κ - c results considering the RF quality and deviation from the posit of H - κ - c method. Detailed criteria for calculating this index can be found at Data Set S1.

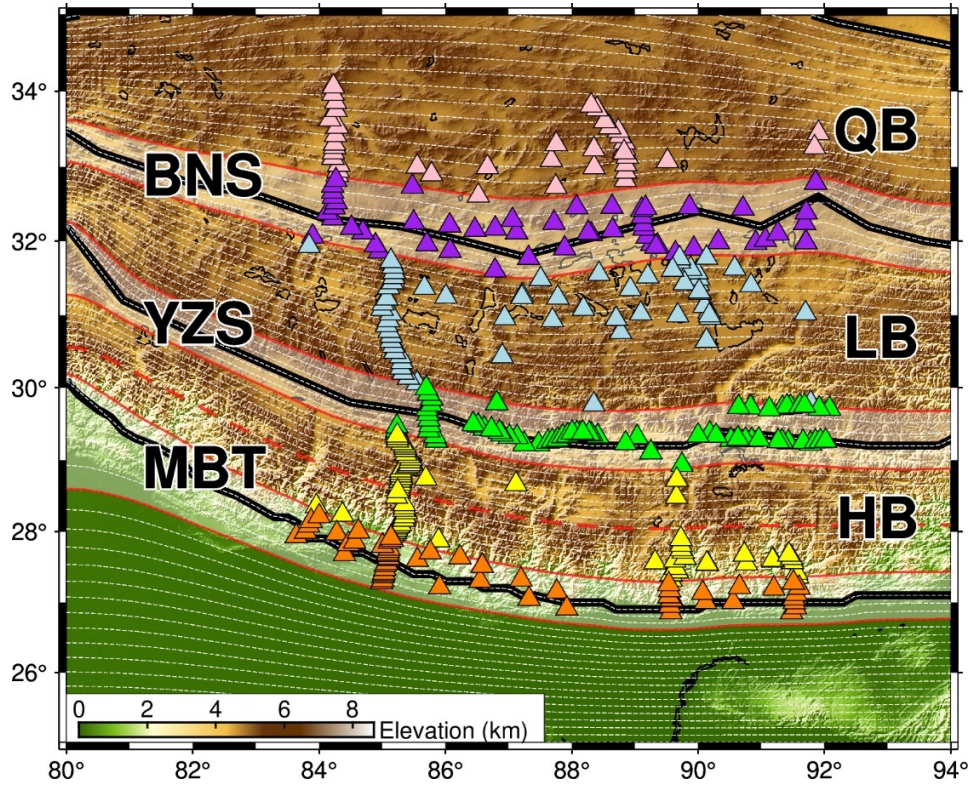


Figure S3. Division of blocks and boundaries for Table S2. We consider the transition zones, which possesses certain width, as separate blocks. The widths of transition zones (white shaded area) are roughly estimated by certain isoline (red solid lines) in the body-fitting grid. Colors demonstrate comparting of the stations. Red dashed line represents the division of southern and northern part of HB.

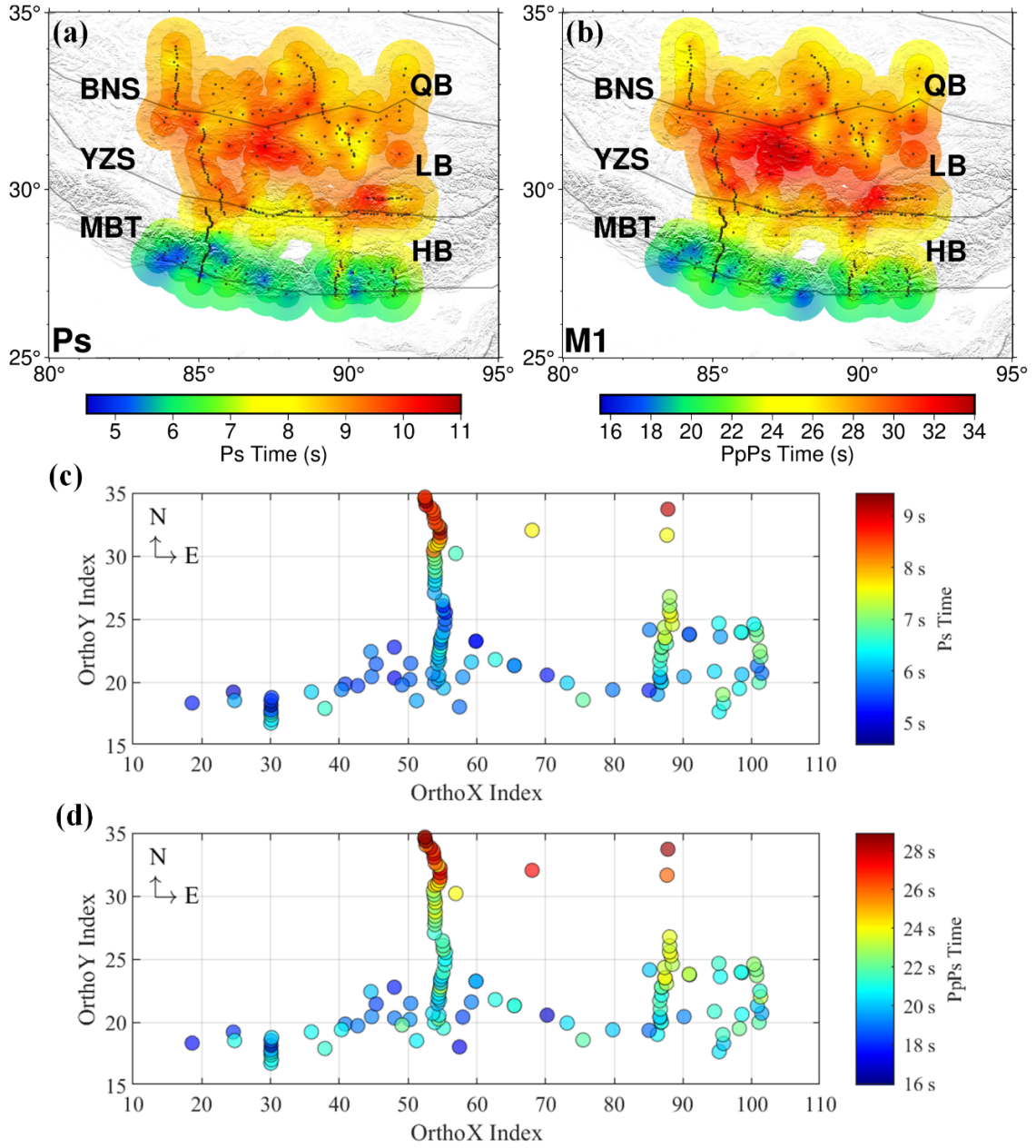


Figure S4. Spatial variation of time separation for (a) Ps-P and (b) PpPs-P. The time separations are obtained by performing a grid search of harmonic fitting curve. The black dots represent stations used for interpolation. Panels (c) and (d) are Ps-P and PpPs-P time separation in HB and YZS compartments (see Figure S3) in an arc-parallel & arc-perpendicular view, respectively. The abscissa and ordinate for (c) and (d) are X and Y index in the body-fitting grid (Figure S1) accordingly.

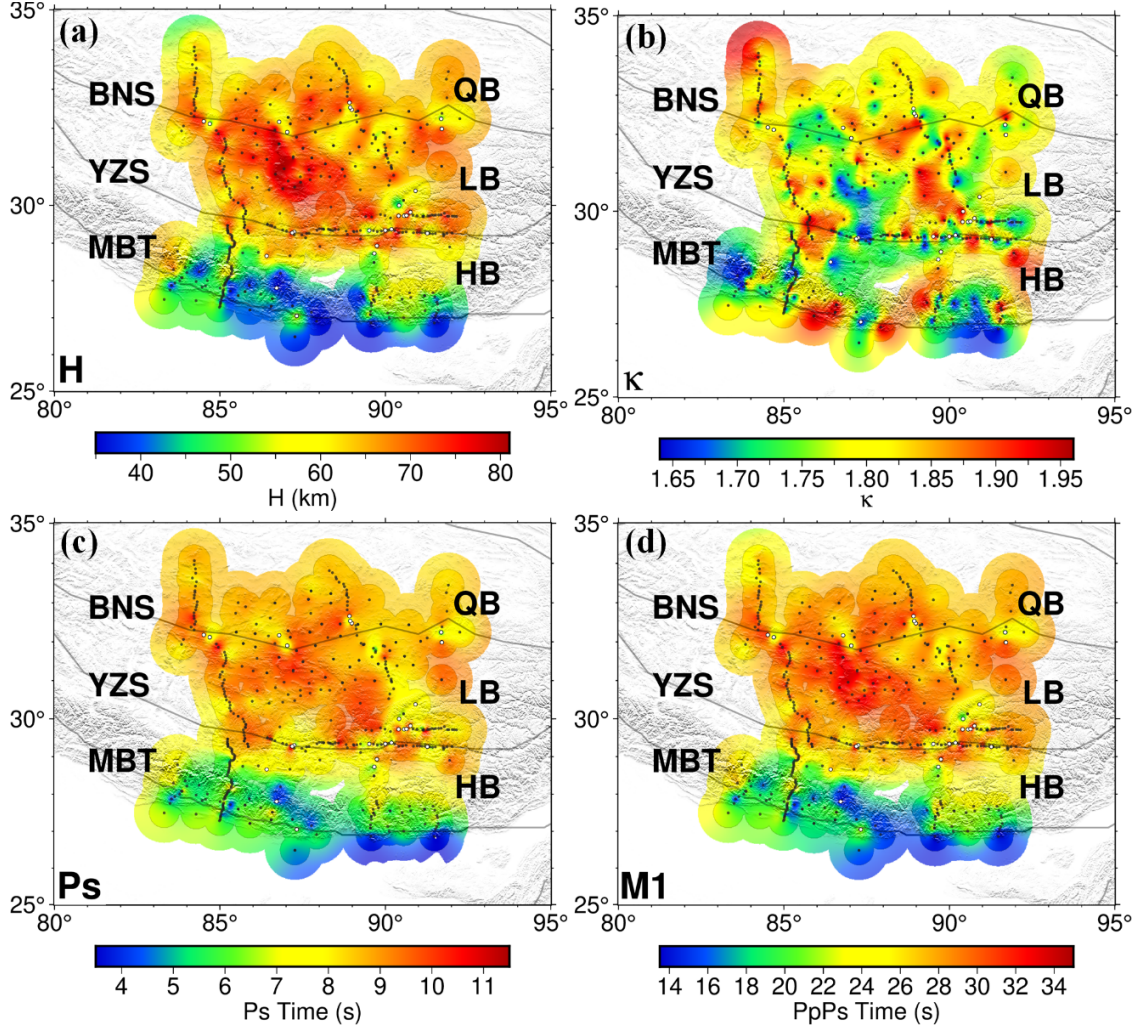


Figure S5. Spatial variation of H - κ stacking results for uncorrected RFs. (a) crustal thickness H . (b) V_p/V_s ratio κ . (c) Ps-P time separation. (d) PpPs-P time separation. Time separations are calculated using the H - κ formula (Zhu & Kanamori, 2000). The dots represent stations used for interpolation, with hollow dots indicating stations detected as Ps-P or PpPs-P time separation outliers. These outliers are obtained by subtracting the time separation calculated using the H - κ formula for a single station, from the time separation obtained by interpolating from nearby stations, and then sorting these difference levels. Panels (e)-(h) correspond to (a)-(d) respectively, but exclude stations detected as Ps-P or PpPs-P time separation outliers before interpolation. (to be continued).

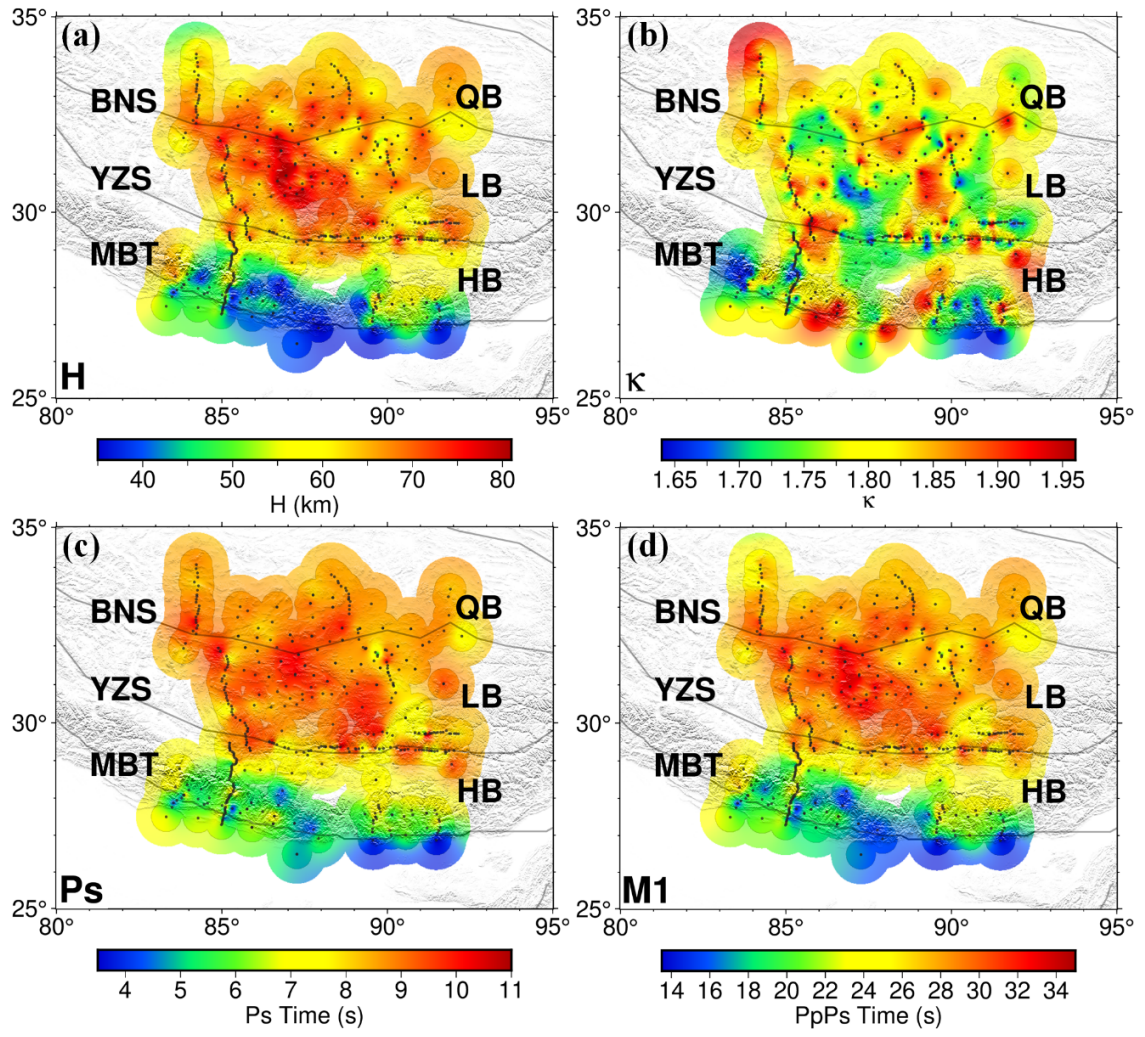


Figure S5. (Continued)

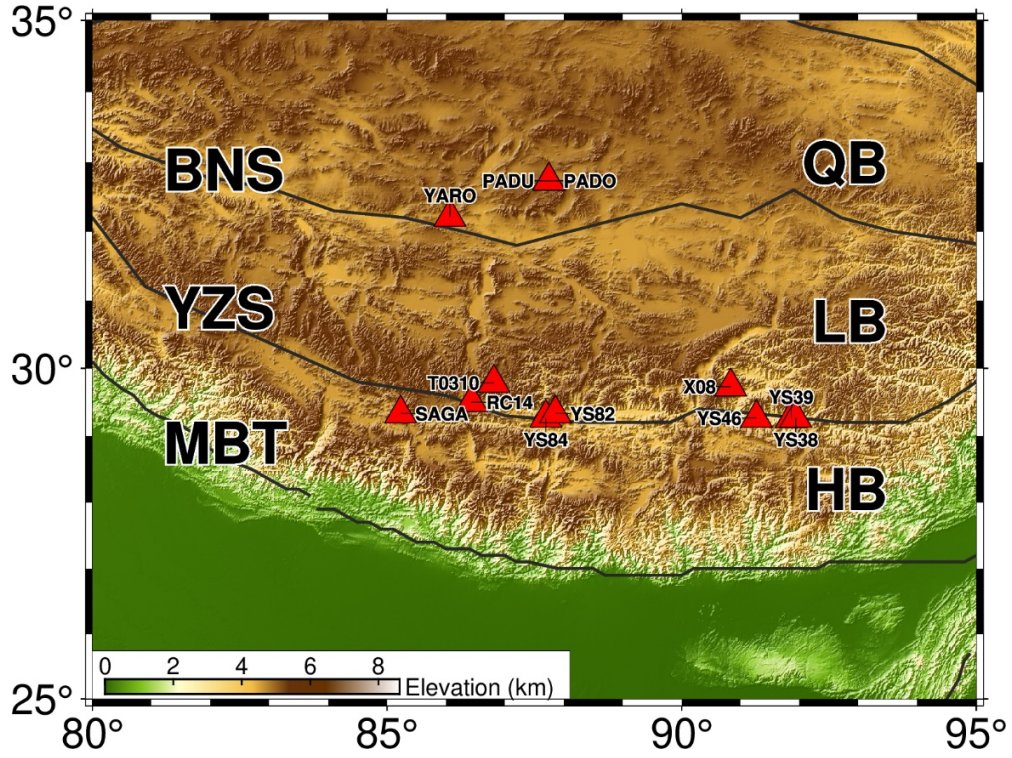


Figure S6. Exposition of stations used for further discussing and their H - κ - c results. The first panel shows the spatial distribution of these stations, and the following panels present their H - κ - c results. For each station, subpanels (a)-(c) illustrate harmonic correction for Ps, PpPs (M1), and PpSs+PsPs (M2), respectively. Subpanel (d) shows H - κ stacking of uncorrected receiver functions, while subpanel (e) shows H - κ stacking of harmonically corrected receiver functions. (to be continued)

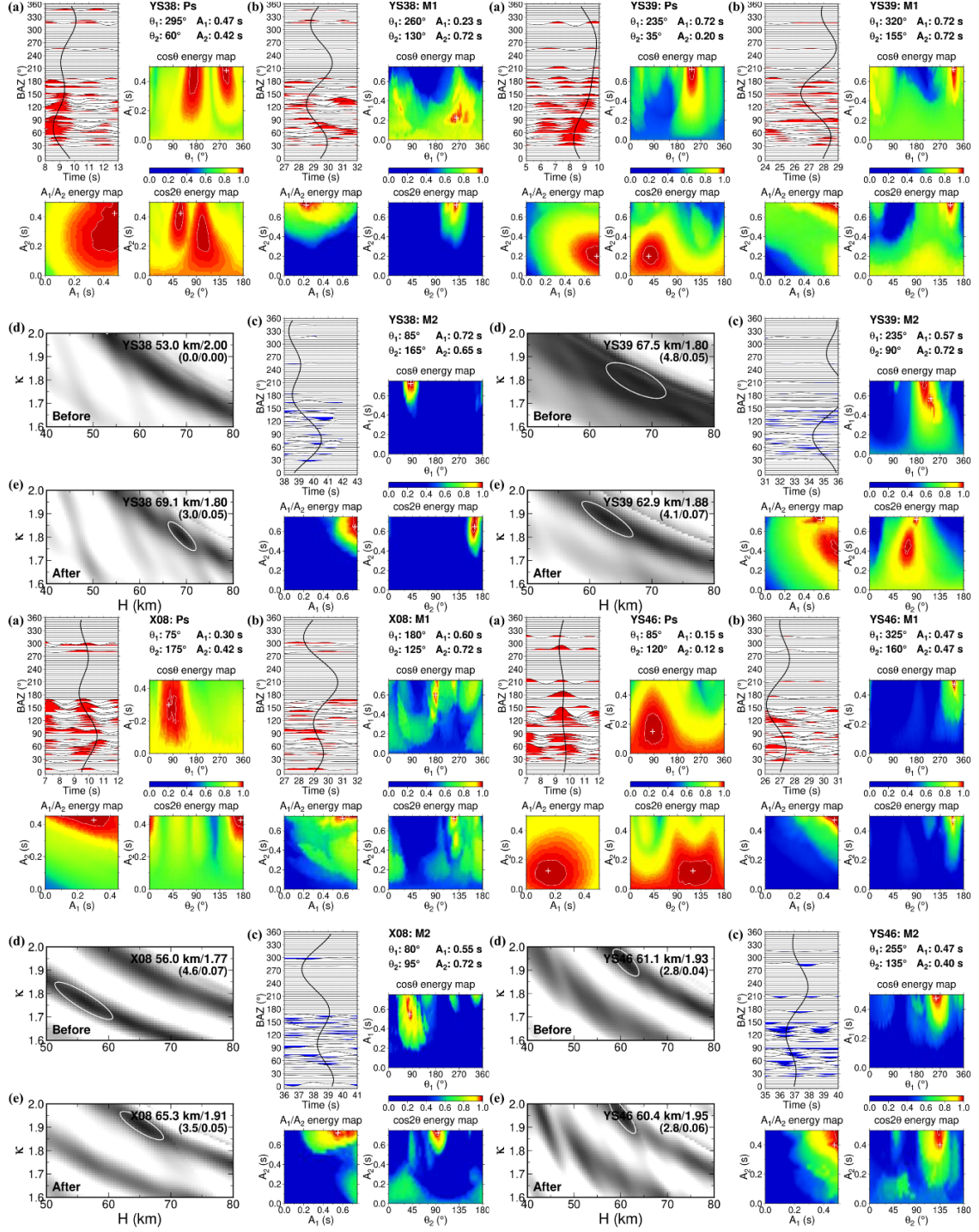


Figure S6. Four example stations in eastern high- κ region of YZS. The station codes are YS38, YS39, YS46 and X08 clockwise from the top left corner (Continued).

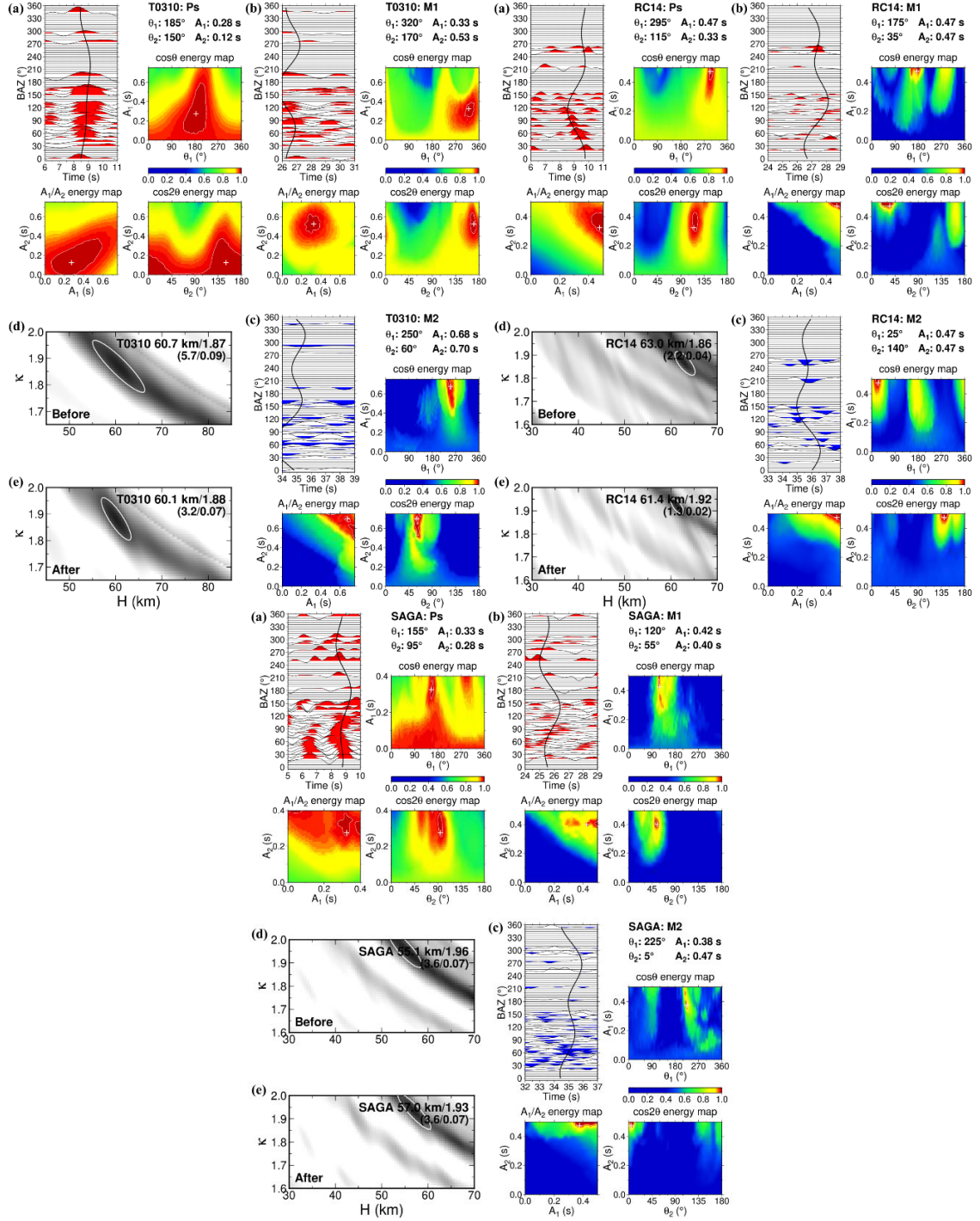


Figure S6. Three example stations near western high- κ region of YZS. The station codes are T0310, RC14 and SAGA. (Continued).

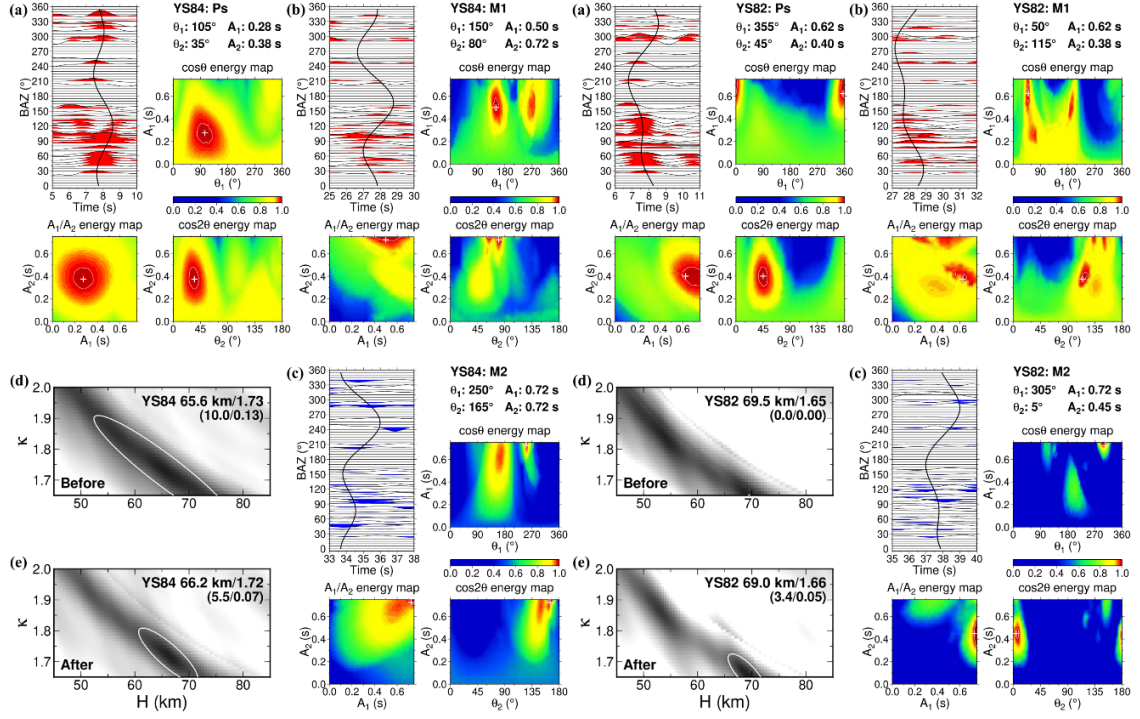


Figure S6. Two example stations in the low- κ region of YZS. The station codes are YS84 and YS82. (Continued).

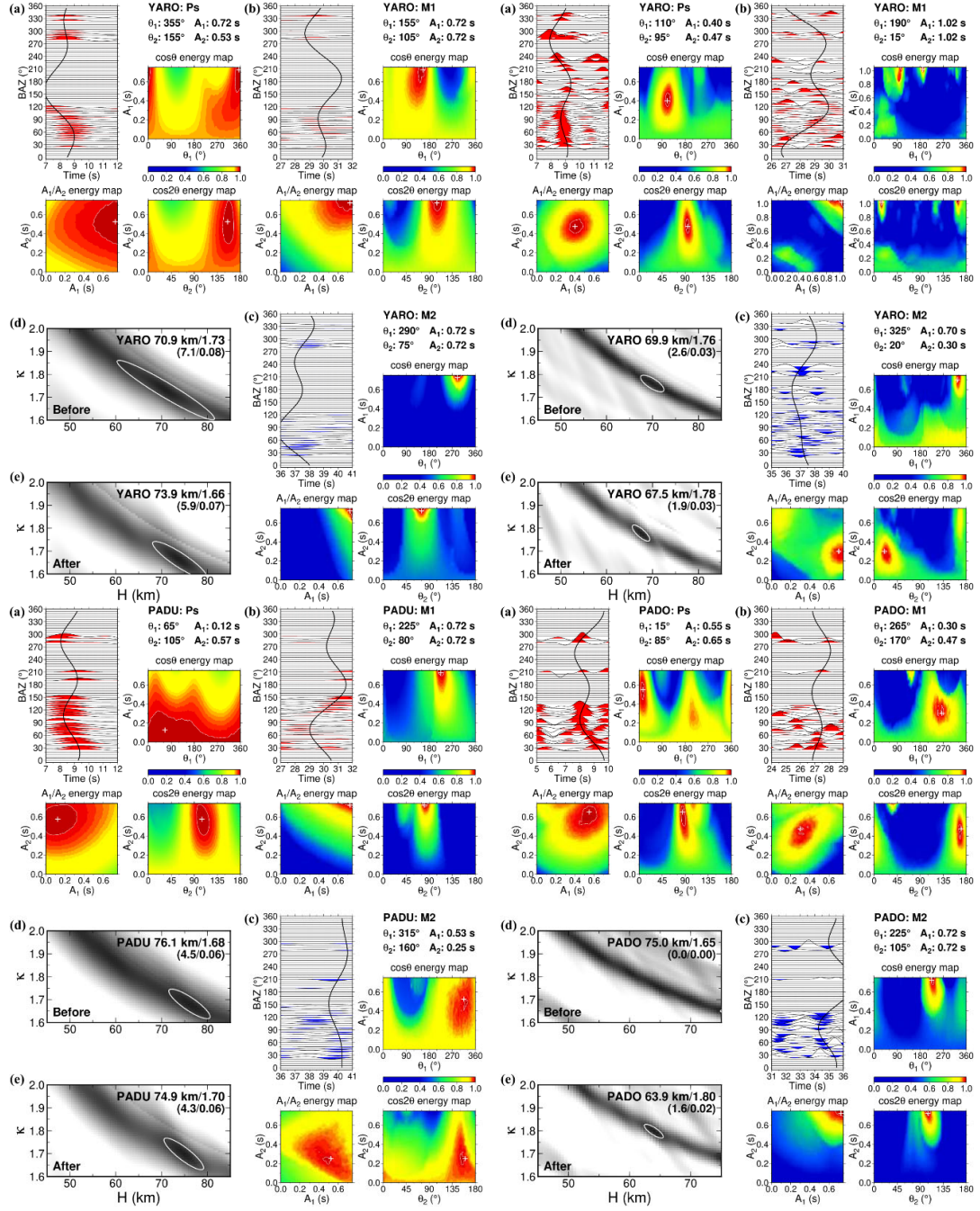


Figure S6. Two demonstration stations of H - κ - c results under RFs with different Gaussian parameters (1.0 for low frequency RFs and 2.5 for high frequency RFs). The station codes are YARO and PADU/PADO (PADU and PADO are at exactly the same location). (Continued).

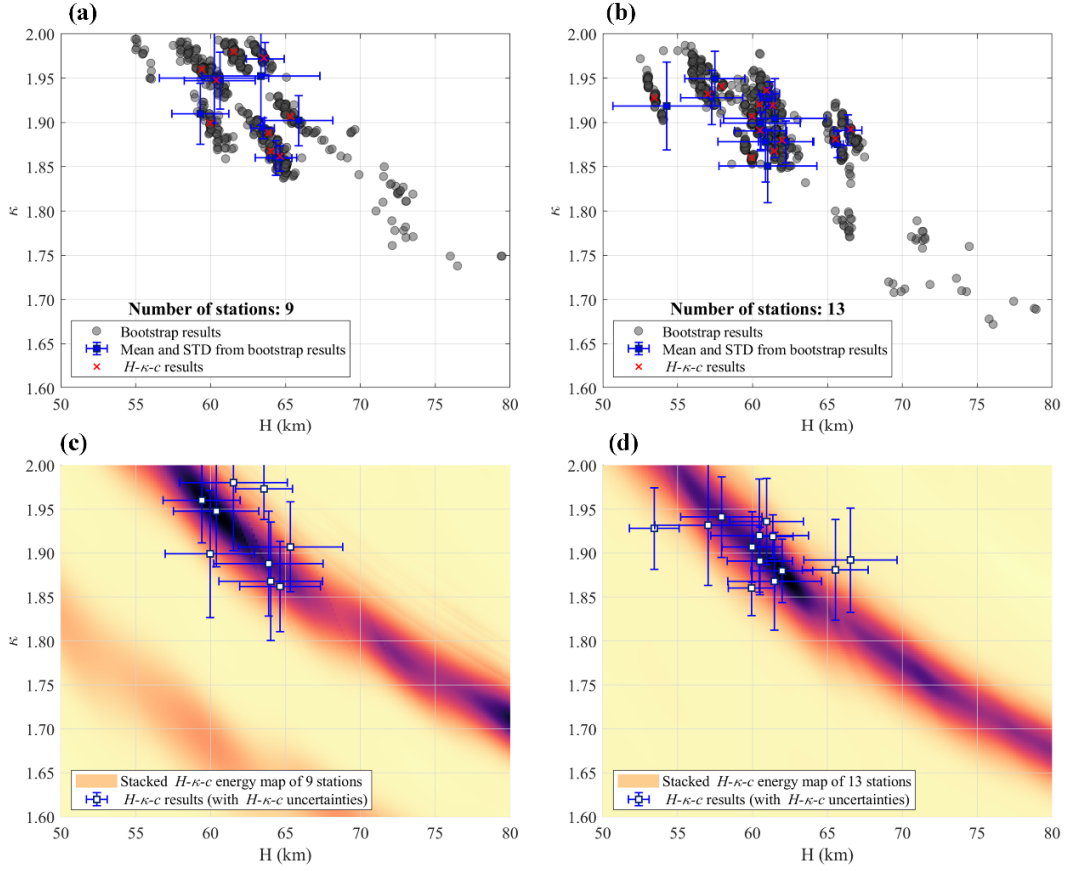


Figure S7. Bootstrap results of high κ stations ($\kappa > 1.85$) near YZS and the comparisons with H - κ - c results. (a) Bootstrap results for stations at P1. (b) Bootstrap results for stations at P2. (c) H - κ - c results for stations at P1. (d) H - κ - c results for stations at P2. The location for P1 and P2 can be found at Figure 3. Every station is bootstrapped with 100 samples. The size of one bootstrap sample is identical to the total number of RFs at corresponding station. The stacked H - κ - c energy maps in figures (c-d) are computed by stacking the H - κ - c energy maps of corresponding stations in P1 or P2. To mitigate the opacity in the stacked energy map arising from the inconformity between the single-station energy maps, a cubic power sharpening is applied to every single-station energy map before inter-station stacking.

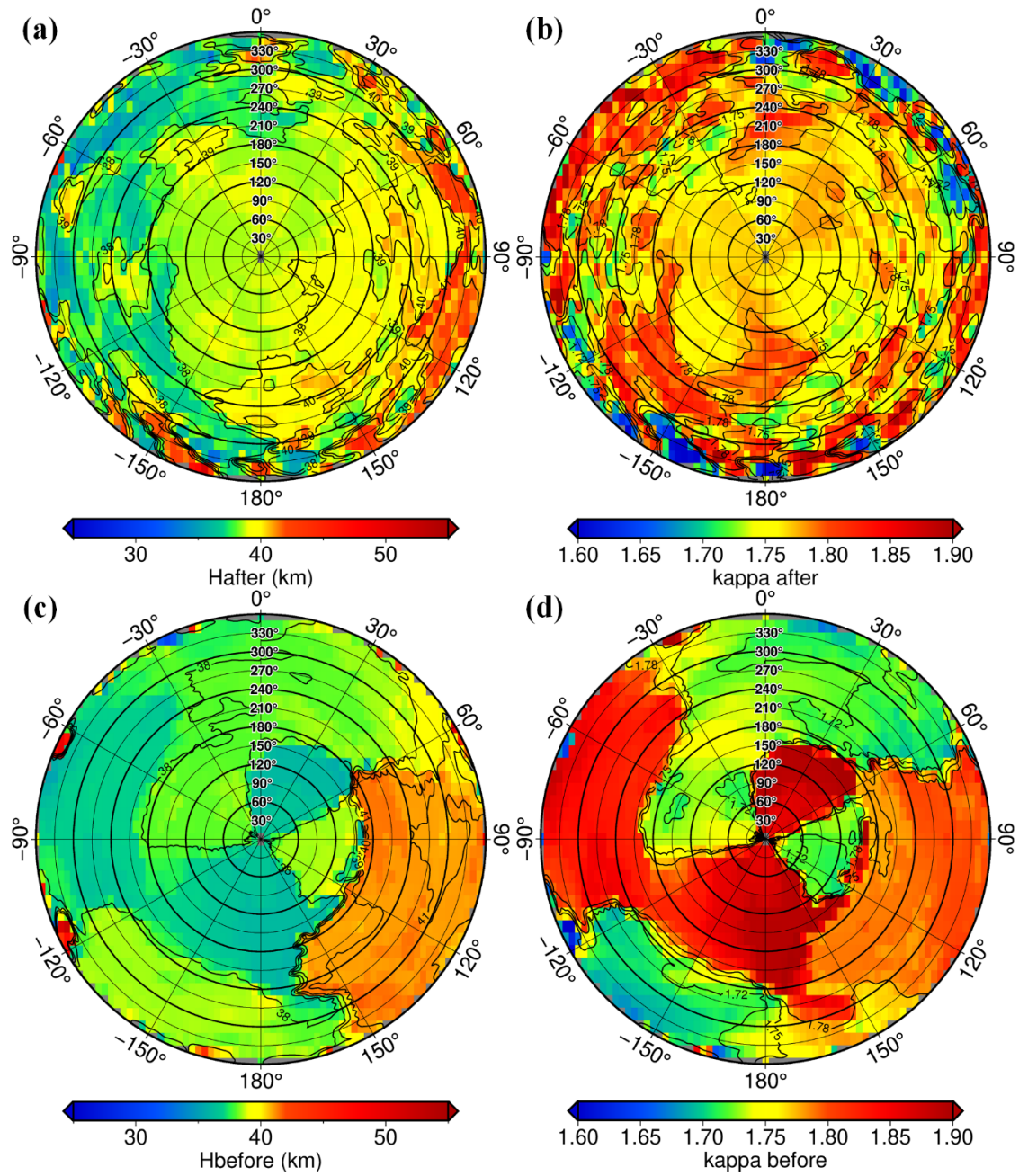


Figure S8. Forward modeling test examining the effect of BAZ deficiency on H - κ - c (or H - κ) results using the SYN8 model from Li et al. (2019). Full-BAZ-coverage RFs were simulated using the Raysum code (Frederiksen & Bostock, 2000). BAZ gaps of varying sizes were then created and centered at different BAZs to assess the impact of BAZ deficiency on the resulting H - κ - c (or H - κ) values. The results are plotted in polar coordinate system, where radius presents the BAZ gap size, and the azimuth presents the

center of BAZ gap. Panels (a) and (b) show the H and κ results, respectively, obtained using the H - κ - c method, while panels (c) and (d) show the H and κ results, respectively, obtained using the traditional H - κ method.

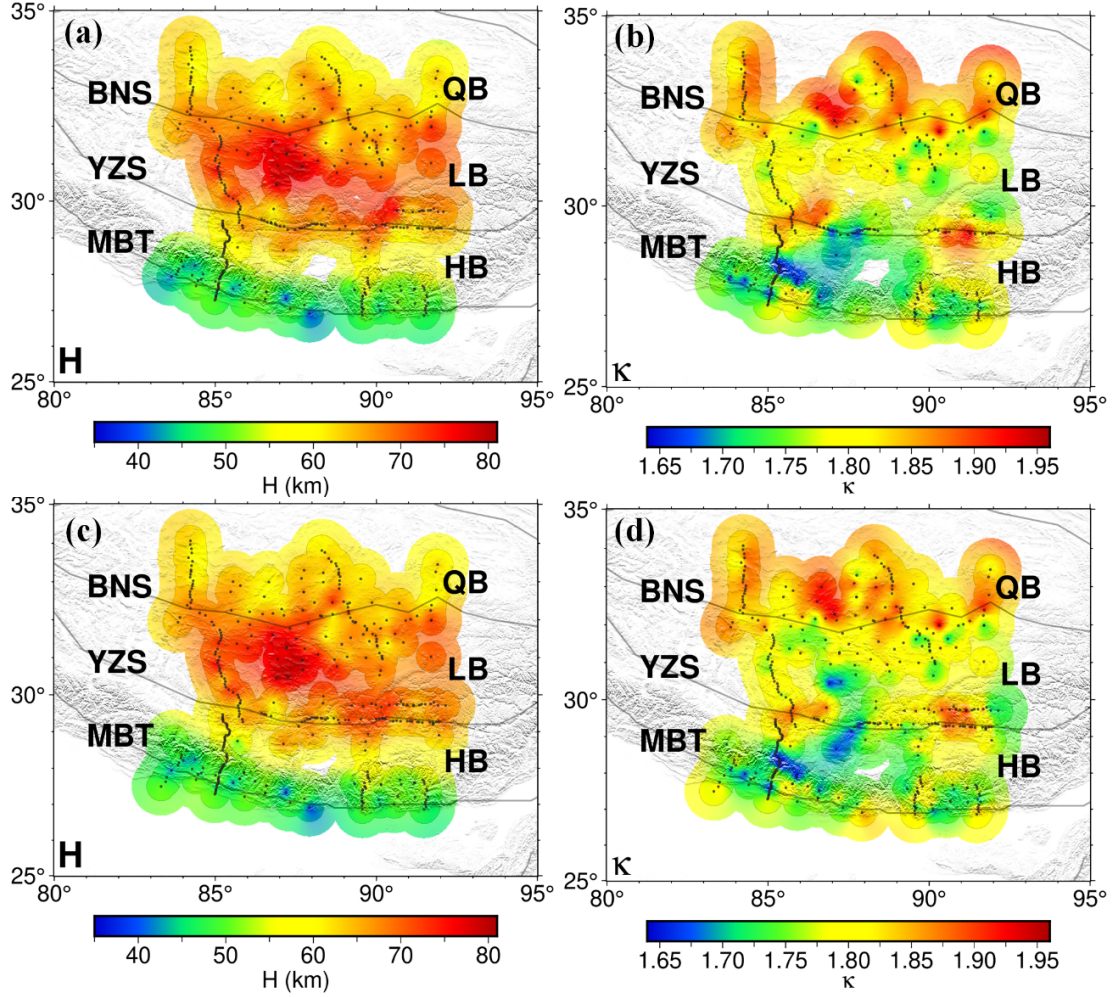


Figure S9. Comparison of H - κ - c results obtained using strict or looser threshold for BAZ gap. Panels (a) and (b) are the H and κ results, respectively, obtained by applying 90° BAZ threshold on the data to construct Figure 2. Panels (c) and (d) are the H and κ results, respectively, from an older quality control version of H - κ - c results, which utilized 150° BAZ threshold.

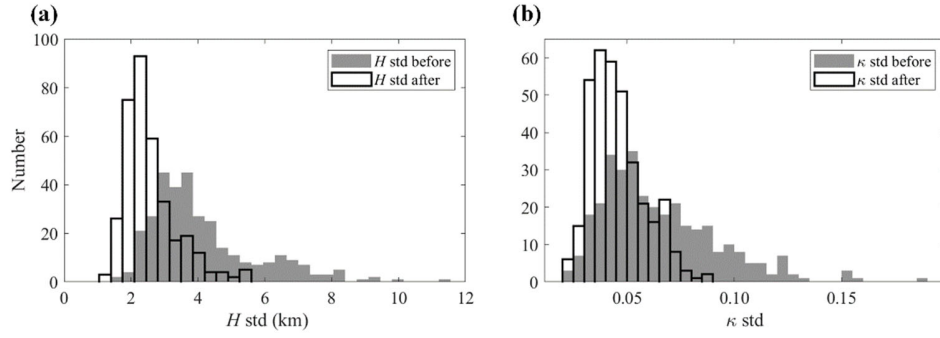


Figure S10. Histograms of H - κ standard deviations for (a) H and (b) κ before (grey) and after (black) the harmonic correction.

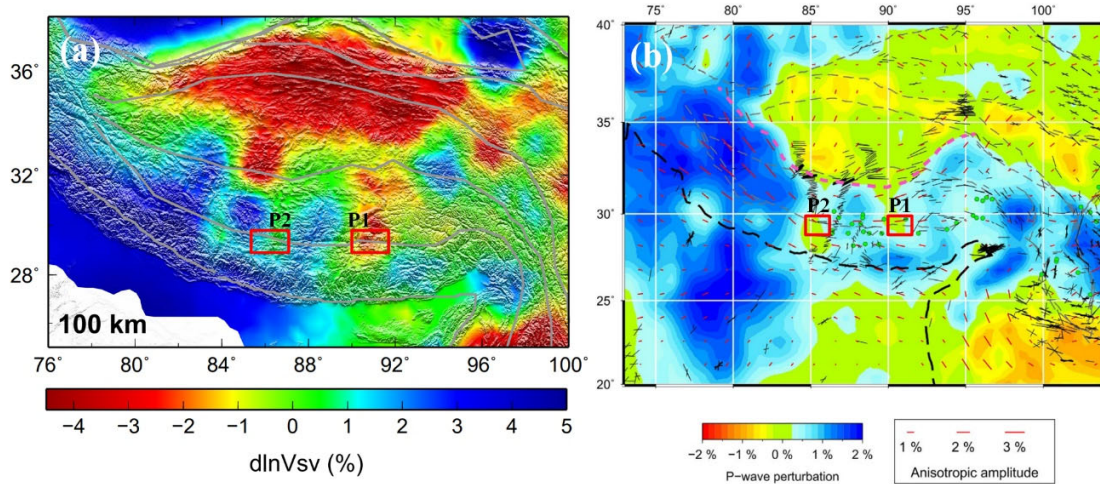


Figure S11. Comparison between isolated high- κ patches (P1 & P2) and mantle velocity. (a) V_{SV} anomalies at 100 km (replotted from Chen et al., 2015) and (b) V_p perturbations at 100 km (sourced from Figure 4 of Wei et al., 2016).

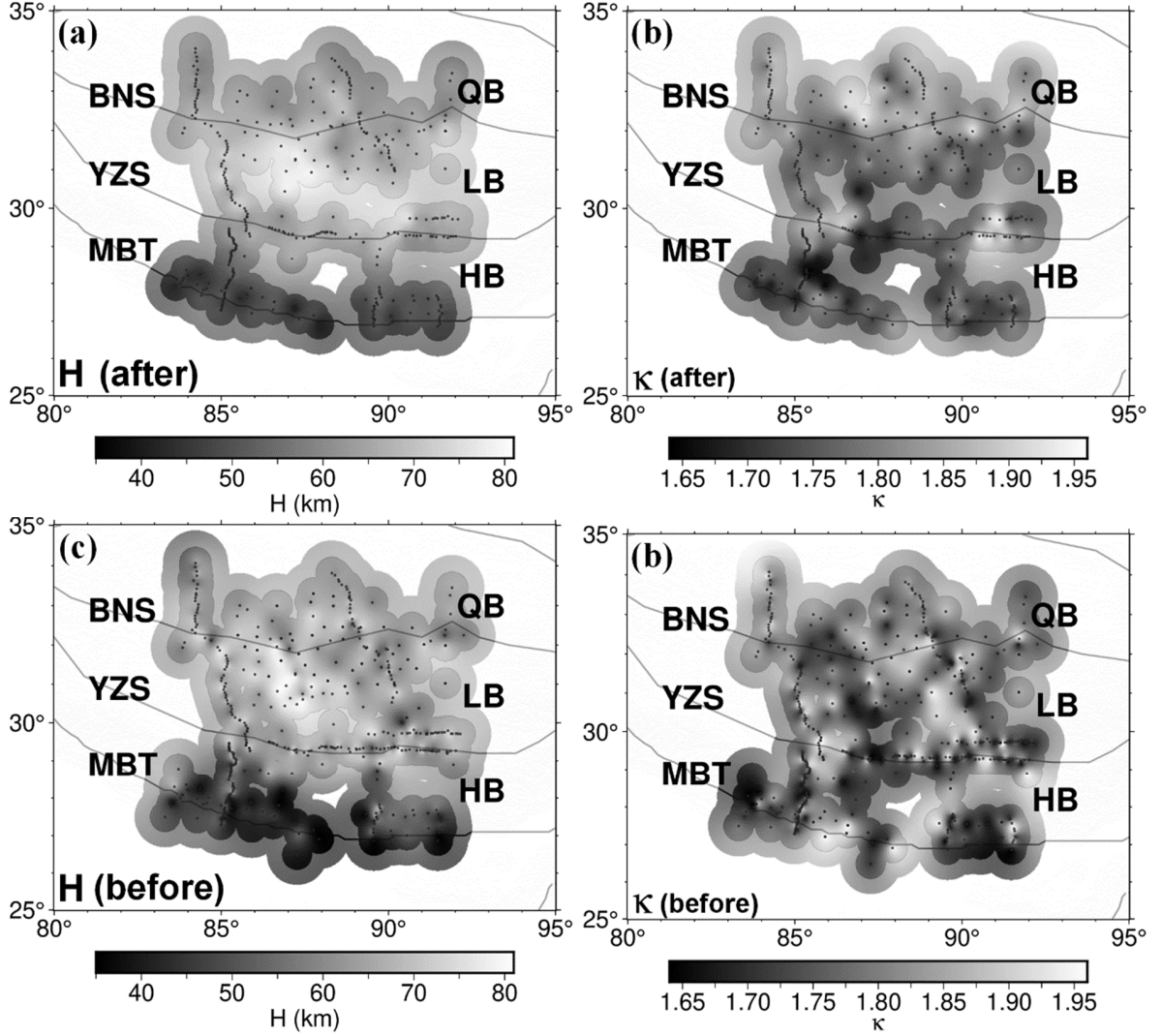


Figure S12. Color-blind friendly version for spatial variation maps. Panels (a) and (b): spatial variation map of H - κ - c results (i.e., H - κ stacking of harmonic corrected RFs) for crustal thickness (H) and V_p/V_s ratio (κ), respectively. Panels (c) and (d): spatial variation map of H - κ results (i.e., H - κ stacking of uncorrected RFs) for H and κ , respectively. Panels (e-h) are the same as panels (a-d) accordingly but using another color map. Dots represent stations used for interpolation. The opaque colored regions indicate areas within 45 km from the stations. The translucent colored regions indicate areas within 45-90 km from the stations. (to be continued)

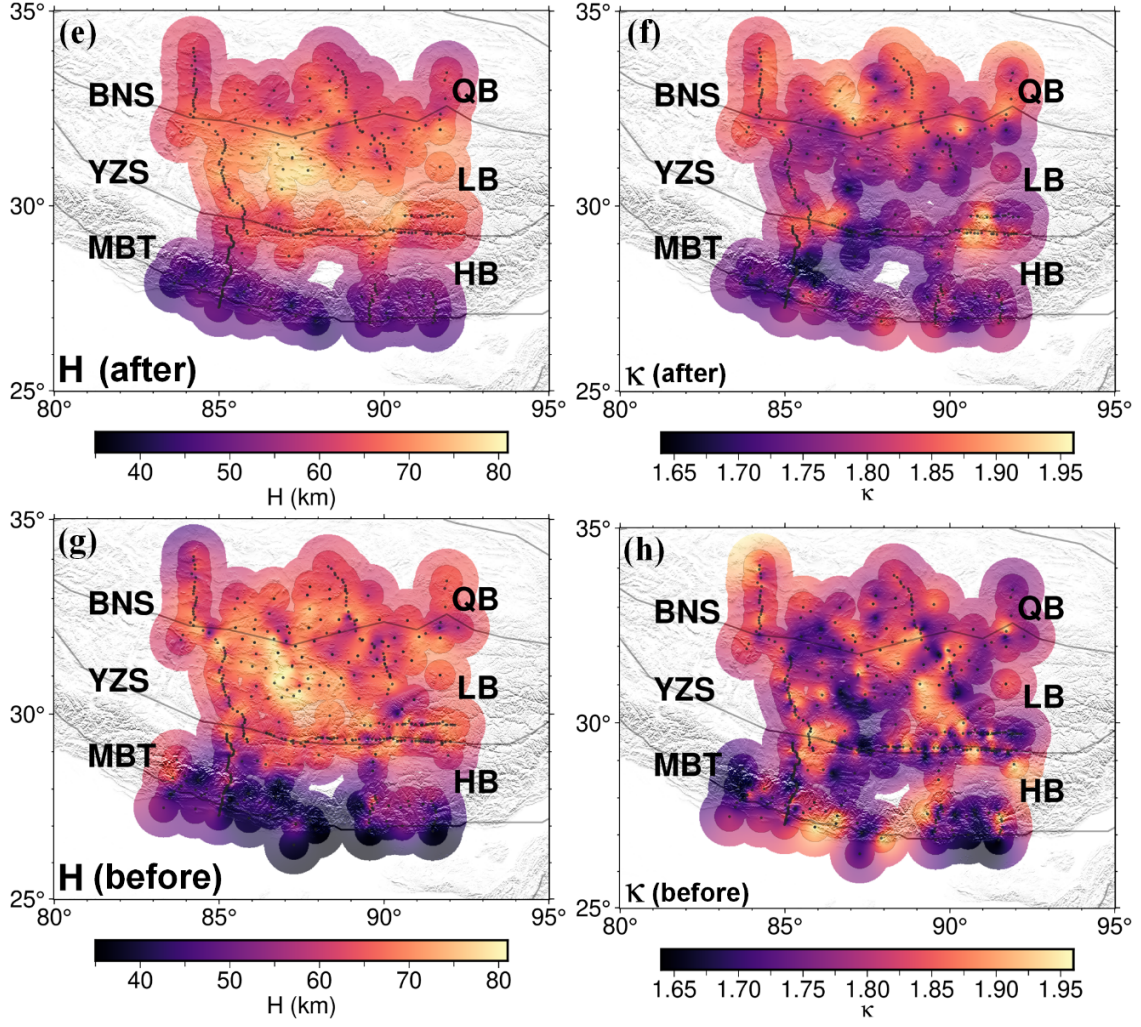


Figure S12. (Continued)

Data Set S1. The H - κ - c results in central-southern Tibetan Plateau. The data file contains two text file and a xlsx-formatted Excel sheet. One text file summarizes adopted H - κ - c solutions, containing columns for station code, longitude, latitude, H result and κ result, while the other text file describes the criteria to calculate quality index. The xlsx-formatted Excel sheet containing information on quality indices and data quality evaluations is also provided. The context for the information in the Excel sheet can be found in the column headers. A directory containing figures of stability tests and H - κ - c

plots for every station is uploaded separately at <https://doi.org/10.5281/zenodo.8317789>, due to the limit for file size.

Data Set S2. Radial and transvers receiver functions (RFs) of GANSSER, Bhutan Pilot, and 5 stations of INDEPTH IV. The RFs waveform data are in SAC (Seismic Analysis Code) format. The longitude and latitude of stations are also provided in the text files.

References of Supporting Information

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