Comment on "An Evaluation of the Timing Accuracy of Global and Regional Seismic Stations and Networks" by Yang *et al.* (2021)

Xin Zhang*[1] and Lianxing Wen[2]

Abstract

Yang *et al.* (2021; hereafter, YSR21) reported widespread clock errors at global and regional stations by measuring travel-time residuals of repeating earthquakes (doublets) after the corrections for relative event parameters and claimed that the reported temporal changes in the inner core boundary (ICB) in Wen (2006; hereafter, Wen06) were a "misidentification" after correcting the clock errors and instrumental changes of the seismic stations. Here, we examine their claims with a focus on the reported "problematic" stations AAK and OBN and the two associated doublets they emphasized in the inner core study. Forward calculations show that: (1) YSR21's doublet relocation results contain large errors, generating large travel-time residuals in the individual stations and in the depth-sensitive phases, (2) YSR21's selection of "problematic stations" is not supported by the travel-time residuals predicted from their relocation results, and (3) YSR21's reported clock errors of the two stations are not reproducible based on their relocation results. Our reanalysis of the doublet data, which yields a much better fit to the observations, indicates no clock error at OBN and no justifiable claim of a clock error at AAK. Accordingly, YSR21's manual shifts by clock errors to the OBN and AAK observations of Wen06 are not justified, and their resultant claim of "misidentification" of the temporal ICB change in Wen06 is unfounded. We further show that the effect of instrument changes can be simply corrected by the deconvolution of instrument responses, and the temporal change of *PKiKP* at station ARU in Wen06 is evident after the correction. Our study confirms the reported ICB temporal change in Wen06. The inaccurate relocation and unreproducible results in YSR21 raise questions on their claim of prevailing clock errors in the global stations and the validity of the past inner core studies by the two leading authors.

Introduction

Recently, Yang *et al.* (2021, hereafter, YSR21) estimated potential clock error in a seismic station based on the residual of the relative time shift of *P* waves among repeating earthquakes (doublets) and reported over 5000 probable clock errors ranging from tens of milliseconds to over 10 s at the global and regional stations from the Incorporated Research Institutions for Seismology (IRIS) Data Management Center. They claimed that the clock errors seemed to be prevailing in moderate seismic stations even for those being tagged with high timing quality by the IRIS timing quality and the Global Seismographic Network (GSN) timing metrics. To illustrate the importance of time error correction, they made an example of the reported temporal changes of the inner core boundary (ICB) based on a doublet SSI_1993-2003 by Wen (2006; hereafter, Wen06) and corrected for the clock errors on the stations AAK and OBN that were derived from the residuals of the two doublets D1_1995–2003 and D2_1993–2004, respectively, and presented a procedure to correct for the instrument change at the station ARU. They claimed that "We further demonstrate that the original observations of the temporal change by Wen (2006) can be explained entirely by correcting for the instrument response and timing errors" and that the reported temporal changes of the ICB in Wen06 were a "misidentification".

Such a claim of widespread clock errors of seismic instruments, if it were true, would be a great warning to the network operators and raise doubts on the integrity of many studies in the literature, especially those that relied on an accurate timing to tens of milliseconds (e.g., the study of Wen06). To place this claim in the broad context of inner core studies, this is the second time the clock errors in AAK and OBN are raised between doublet SSI_1993–2003 by the two leading authors. Yang and Song (2020a) first claimed clock errors at those stations based on the differential travel times of *SKP*–*PKiKP* of the doublet with a claim that *SKP*–*PKiKP* differential travel times could be used to detect clock errors without consideration of the relative difference of doublet locations. Yao *et al.* (2021) pointed out that the claim was erroneous because the *SKP*–*PKiKP* differential travel times were significantly affected by the relative depth difference between the doublet, and that their reported clock errors were

Supplemental Material

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[1] Laboratory of Seismology and Physics of Earth's Interior; School of Earth and Space Sciences, University of Science and Technology of China, Hefei, China, https://orcid.org/0000-0002-5891-0344 (XZ); [2] Department of Geosciences, State University of New York at Stony Brook, Stony Brook, New York, U.S.A.

*Corresponding author: zx2019@mail.ustc.edu.cn

artifacts, that is, exactly the effects of the relative depth difference of the doublet reported in Wen06. Although the concerned stations and the doublet are only a subset of the reported data for the temporal change of ICB (we refer the readers to Yao *et al.*, 2015, 2019), the results in YSR21 were also used as a major source for a repeated claim of "misidentification of temporal change of inner core surface" by two of the authors (Yang and Song, 2023), when they responded to a comment (Tian and Wen, 2023) that there were no validities for the claim of existence of seismic evidence for inner core differential rotation and the postulation of a local gradient in the top of the inner core made in the study of Yang and Song (2022), and as a major reference against temporal change of inner core surface in a recent exchange on the correct interpretation of the observed temporal change of inner core phases (peer review information in Wang *et al.*, 2024; see Data and Resources).

In this comment, we focus our analysis on the best example of clock errors of the two "problematic" stations AAK and OBN reported by YSR21. We show that YSR21's relocation results of doublets contain large errors, their selection of "problematic stations" is questionable, and their reported clock errors are not reproducible from their relocation results. After reanalysis of the doublet data they used to estimate the clock errors at AAK and OBN, we show that there is no clock error at OBN and no justifiable claim of clock error at AAK. With the correction for instrument changes at ARU, we confirm the conclusion of the reported temporal changes of the ICB observations in Wen06.

Evaluation of YSR21's Results

We agree with YSR21's proposal that analyzing the doublet data could potentially provide a powerful means to detect possible clock errors in the seismic stations to the precisions of tens of milliseconds. However, the task can only be accomplished if the relocation is performed accurately and doublets are selected with care. We examine YSR21's relocation results of the two doublets, their selection of "problematic stations" with clock errors and the reproducibility of their claimed color errors at AAK and OBN.

Large errors in YSR21's relocation of doublets

It is evident from the predicted residuals at individual stations and waveform alignments of depth-sensitive phase pairs that the relocation results of YSR21 contain large errors (Figs. 1–4). A straightforward way to evaluate the accuracy of a doublet relocation result is to forward calculate the relative time difference of the seismic phases between the doublet at individual stations based on the relocation result and check the residuals between the calculated and observed relative time difference of the seismic phase between the doublet at each station. One can also check the doublet waveform alignments of the seismic phases after corrections for the relative travel-time difference between the doublet predicted by the relocation result. A good relocation result should generate little residuals and excellent waveform alignments between the doublet in the individual stations. We calculate the relative travel-time residuals (termed as *dt* residuals, following the definition in YSR21) of noninner core (non-IC) phases including *P*, *pP*, and *PKPbc* at global stations based on YSR21's relocation results of two doublets and align the doublet waveforms of the seismic phases based on the predicted arrivals (Figs. 1–4). We calculate $T^{\mathrm{theor}}_{\mathrm{doublet},k,p}$, the theoretical relative travel time of seismic phase p at station k for a doublet that has a source location difference and a time difference in the relative origin time $\Delta O_{\mathrm{doublet}}$, by a simple formula (1) (Wen, 2006):

$$T^{\mathrm{theor}}_{\mathrm{doublet},k,p} = \Delta O_{\mathrm{doublet}} + \Delta t^{\mathrm{theor}}_{\mathrm{doublet},k,p} = \Delta O_{\mathrm{doublet}} + dD_k \times \frac{dt}{dD}(k,p,D,h) + dh \times \frac{dt}{dh}(k,p,D,h), \tag{1}$$

in which dD_k represents the difference between epicentral distances of the two events at station k; dh represents the difference between the two event depths; $\frac{dt}{dD}(k,p,D,h)$ represents the derivative of travel time with respect to epicentral distance D, and $\frac{dt}{dh}(k,p,D,h)$ represents the derivative of travel time with respect to source depth h (following the definitions in Wen06). The accuracy of formula (1) is verified by various open-source codes like "TauP" (Crotwell *et al.*, 1999) and "ttimes" (Buland and Chapman, 1983) to the computation precision of 1 ms of those codes.

Using the same reference model IASP91 (Kennett and Engdahl, 1991) used by YSR21, a large range of *dt* residuals (i.e., $T^{\mathrm{obs}}_{\mathrm{doublet},k,p} - T^{\mathrm{theor}}_{\mathrm{doublet},k,p}$, in which $T^{\mathrm{obs}}_{\mathrm{doublet},k,p}$ is the observed relative travel time between the doublet for phase p at station k measured by cross correlation and is also the "*dt* measurement" named in YSR21) is predicted in the seismic stations for doublet D1_1995–2003 based on YSR21's relocation results ranging from −76 to 138 ms (Fig. 1a). The location of event 1995 deviates from the location of the minimal root mean square (rms) by 828 m and generates an rms residual of 55 ms as opposed to the minimal value of 30 ms observed in the region (Fig. 1c,d). For D2_1993–2004, a large range of *dt* residuals of non-IC phases is also predicted based on YSR21's relocation ranging from −65 to 66 ms (Fig. 3a). The location of event 1993 deviates from the minimal rms location by 606 m and generates an rms residual of 39 ms as opposed to the minimal value of 6 ms observed in the region (Fig. 3c,d).

The inaccuracy of YSR21's relative depth determination is evident in the prediction of relative travel times of *pP*–*P* phases. *pP*–*P* relative travel times of a doublet are mostly sensitive to the depth separation of the doublet and are not affected by any potential clock errors. A horizontal separation of 1000 m would produce a difference of about 0.5 ms for *pP*–*P* relative arrival time, whereas a depth separation of 100 m would generate a difference of ∼23 ms for *pP*–*P* relative arrival time. Clear *P* and *pP* phases are observed in D1_1995–2003

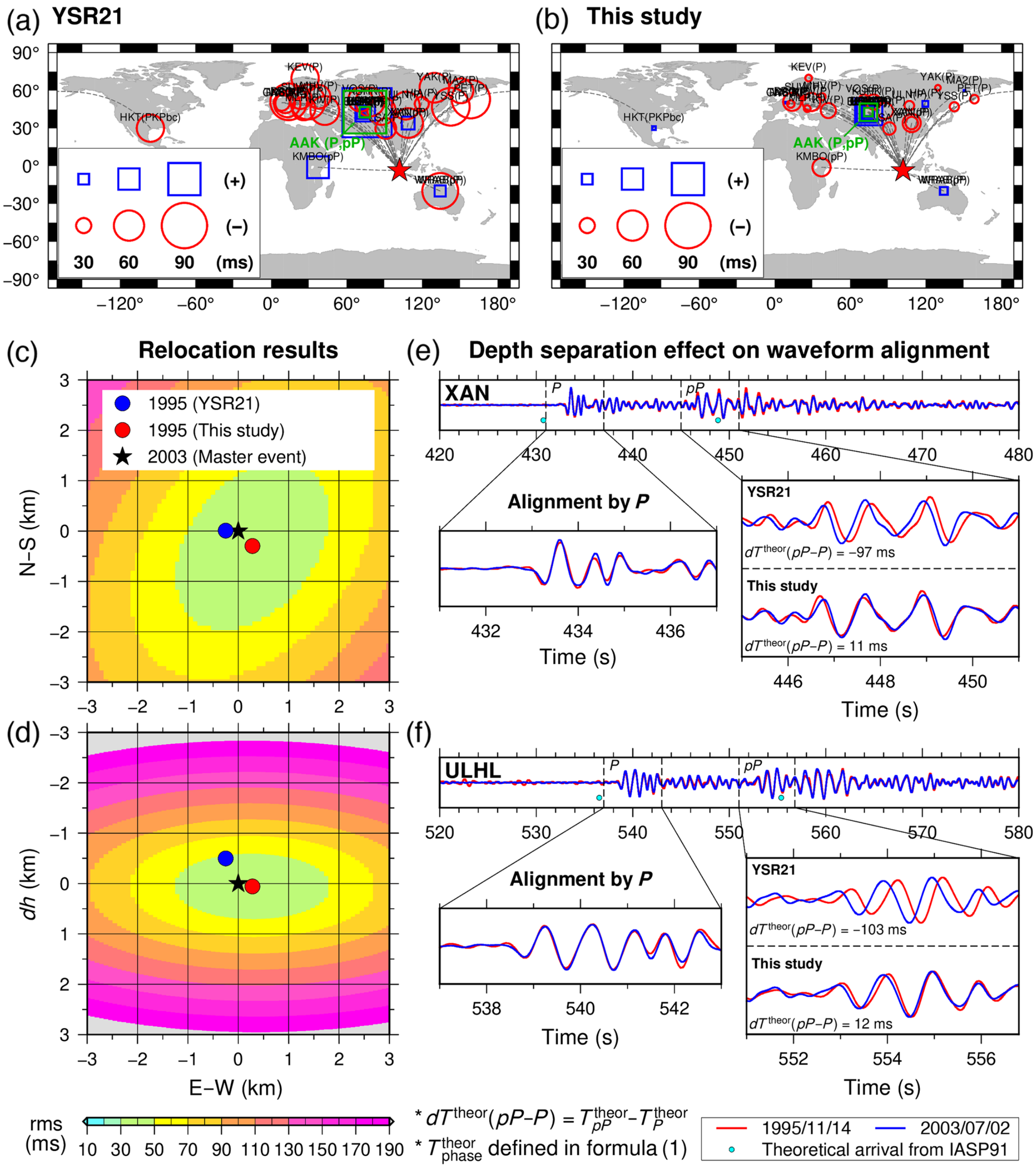

Figure 1. Inaccurate relocation result of D1_1995–2003 by YSR21 and relocation result of this study. (a,b) *dt* residuals at global seismic stations computed based on relocation results of (a) YSR21 and (b) this study. Residuals are plotted in symbols, with blue squares representing positive values (early event arriving relatively later), red circles representing negative values (early event arriving relatively earlier), and magnitudes proportional to the symbol sizes. The "problematic" station AAK claimed by YSR21 is not used in the relocation of this study, but its *P*- and *pP*-wave residuals are calculated based on the relocation results and marked in green in both panels. (c,d) Comparison of relocation results between YSR21 (blue) and this study (red) in the maps of root mean square (rms) of *dt* residuals as a function of the potential event location (background color map). The later event (2003) (black stars) is fixed in the relocation procedure following YSR21. (e,f) Predictions of *pP–P* travel times based on the relocation results of YSR21 and this study at two example stations: (e) IC.XAN and (f) KN.ULHL. Waveforms are aligned by *P* phases based on cross-correlation, and *pP* waveforms are aligned according to the predicted relative travel-time residuals between *pP* and *P* (marked as dT^{theor} (*pP–P*)) using the relocation results of YSR21 and this study. The top panel shows the doublet waveforms in a long time window. The bottom left panel shows the waveform alignment of direct *P*. The bottom right panel shows the alignments of *pP* waveforms of the doublet of two relocation results. Theoretical arrival times in the later event for *pP* and *P* are marked by cyan circles in the top panel. Waveforms of the earlier event and the later event are presented in red and blue traces, respectively. The color version of this figure is available only in the electronic edition.

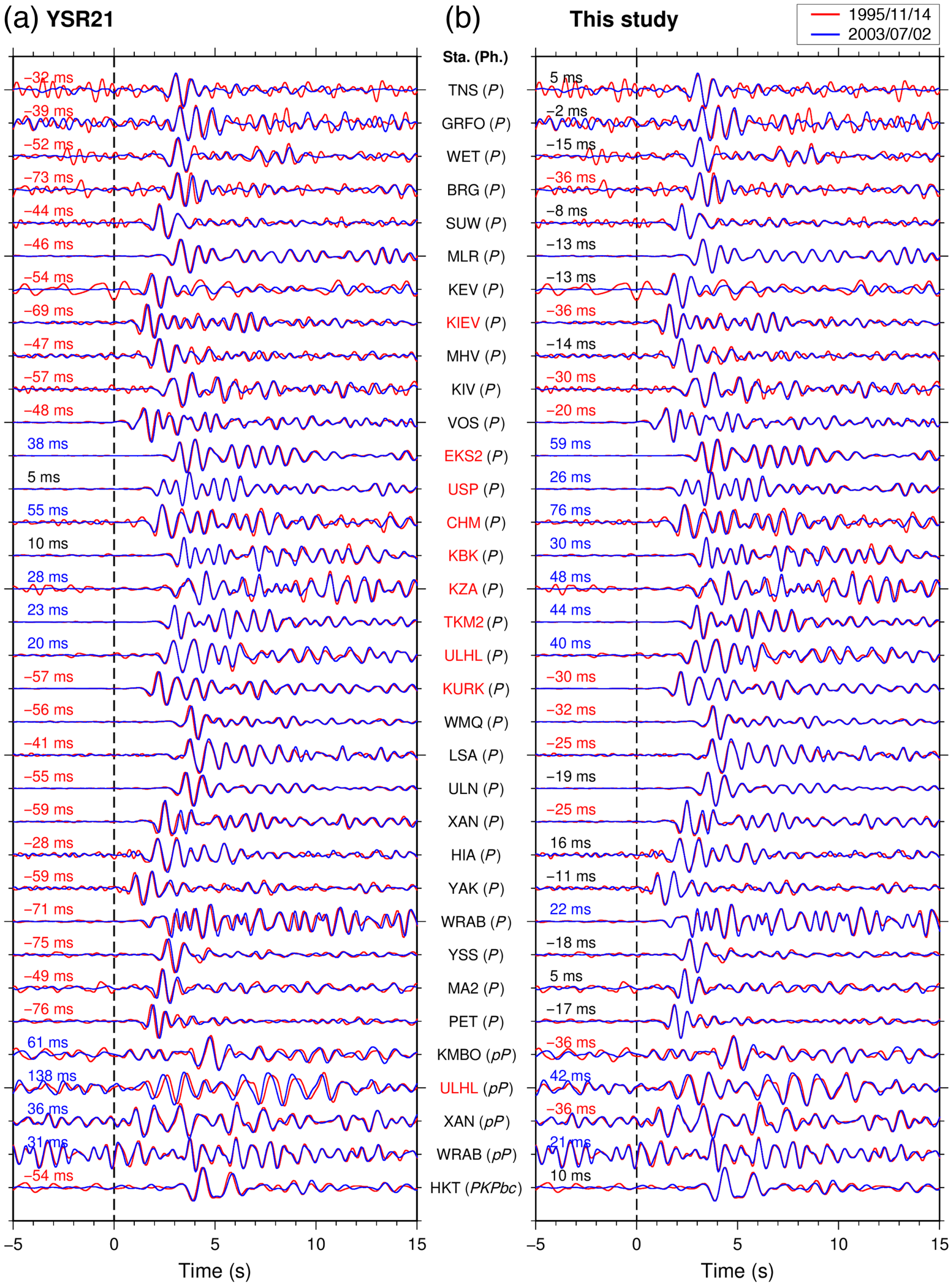

Figure 2. Waveform alignments based on two relocation results for D1_1995–2003. (a) For YSR21 and (b) for this study. Station names and seismic phases used for relocation are marked between the panels, with "problematic" stations with "large clock errors" listed in YSR21 marked in red. *dt* residuals are marked on the top left of the corresponding traces, with red representing values smaller than −20 ms, blue for values larger than +20 ms, and black within −20 and +20 ms. A negative *dt* residual value indicates that the signal of the earlier event (red traces) offsets earlier than that of the later event (blue traces) after correcting for effects of the relocation event parameters, and vice versa. Relative time offsets are computed by cross-correlation in a 20 s time window containing the seismic phase. The color version of this figure is available only in the electronic edition.

and D2_1993–2004 (examples in the top panels of Figs. 1e,f and 3e). When the doublet observations are aligned along *P* waveforms, the *pP* waveforms aligned based on the predictions of YSR21's relocation results exhibit a time offset of ~100 ms between the observations of doublet D1_1995–2003 (Fig. 1e–f), indicating an error of more than 400 m in their reported relative depth separation of the doublet, and a time offset of more than 70 ms between the observations of D2_1993–2004 (Fig. 3e), indicating an error of more than 300 m in their reported relative depth separation of the doublet. The inaccuracy of their relocated relative depths of two doublets is also evident in *dt* the residuals of another depth-sensitive phase *PKPbc*, with a depth separation of 100 m generating a *dt* residual of about 12 ms. YSR21's relocation results predict *PKPbc* residuals of −54 ms at station HKT for D1_1995–2003 (Fig. 2a) and 39 ms at HRV for D2_1993–2004 (Fig. 3f), indicating the same magnitudes of error in their determination of relative depths of the doublets.

Questionable selection of "problematic stations" of clock errors

The reported "problematic" stations with clock errors in YSR21 are not supported by their relocation results. Note that the reported "problematic stations" (those labeled in red in Figs. 2 and 4) exhibit no larger *P*-wave *dt* residuals than other stations (Figs. 2a and 4a). In fact, they have overall smaller *P*-wave *dt* residuals than the "normal stations" YSR21 reported. The "problematic stations" USP, KBK, and ULHL have the smallest *P*-wave *dt* residuals (5, 10, and 20 ms, respectively) among all the stations in D1_1995–2003 (Fig. 2a), and the "problematic station" CHTO has the smallest *P*-wave *dt* residual of 7 ms

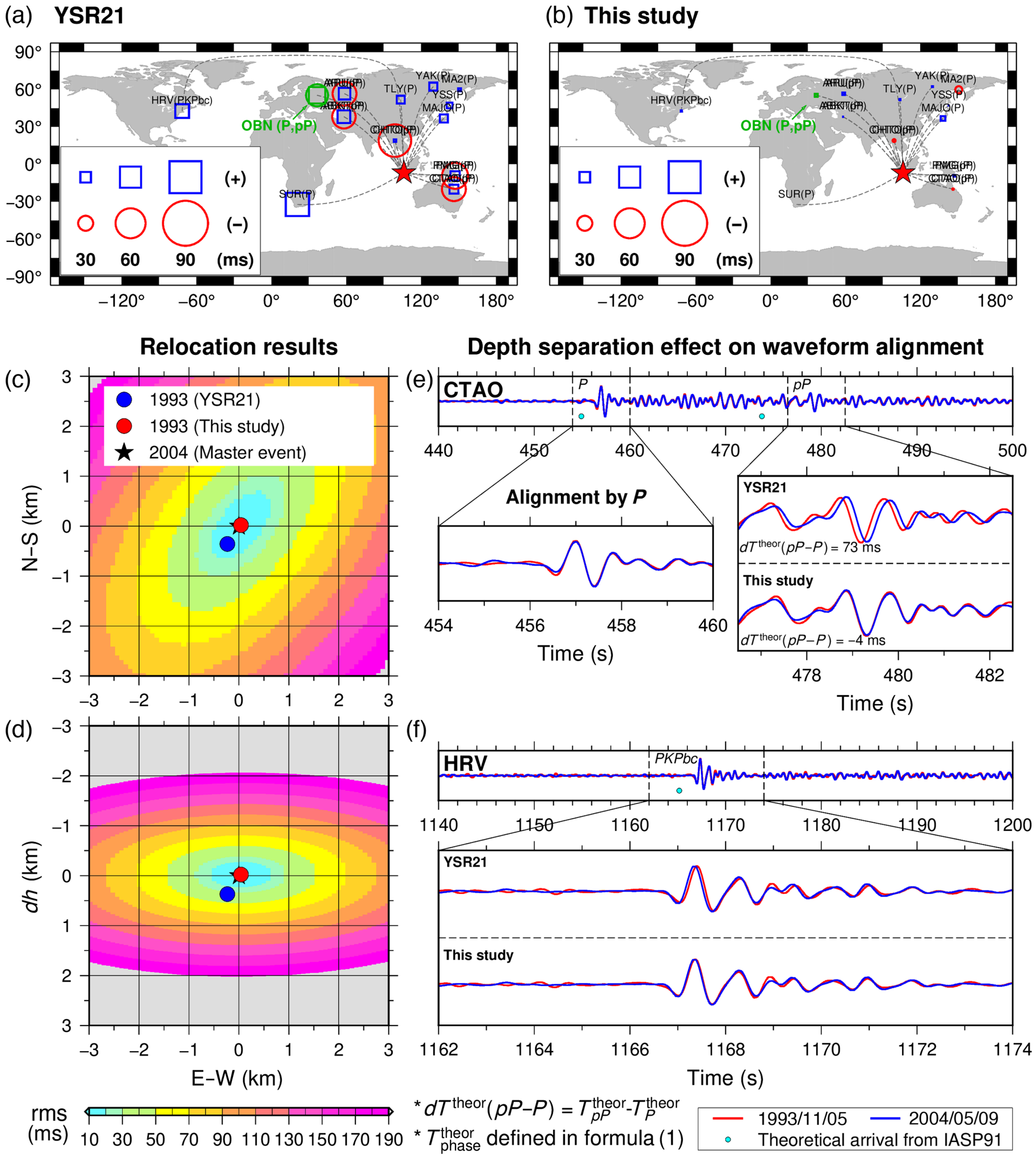

Figure 3. The same as Figure 1, except for doublet D2_1993–2004 with the "problematic" station OBN (not used in the relocation of this study). Panel (f) presents the predicted alignment of *PKPbc* at station IU.HRV based on two relocation results. The color version of this figure is available only in the electronic edition.

in D2_1993–2004 (Fig. 4a). All those *dt* residuals are also much smaller than the error bound of ±30 ms set for the selection of "problematic stations" in YSR21 (the large *dt* residual of 138 ms for the *pP* phase at ULHL in D1_1995–2003 and that of −65 ms for *pP* at CHTO in D2_1993–2004 are due to the errors of their relative source depths as discussed before).

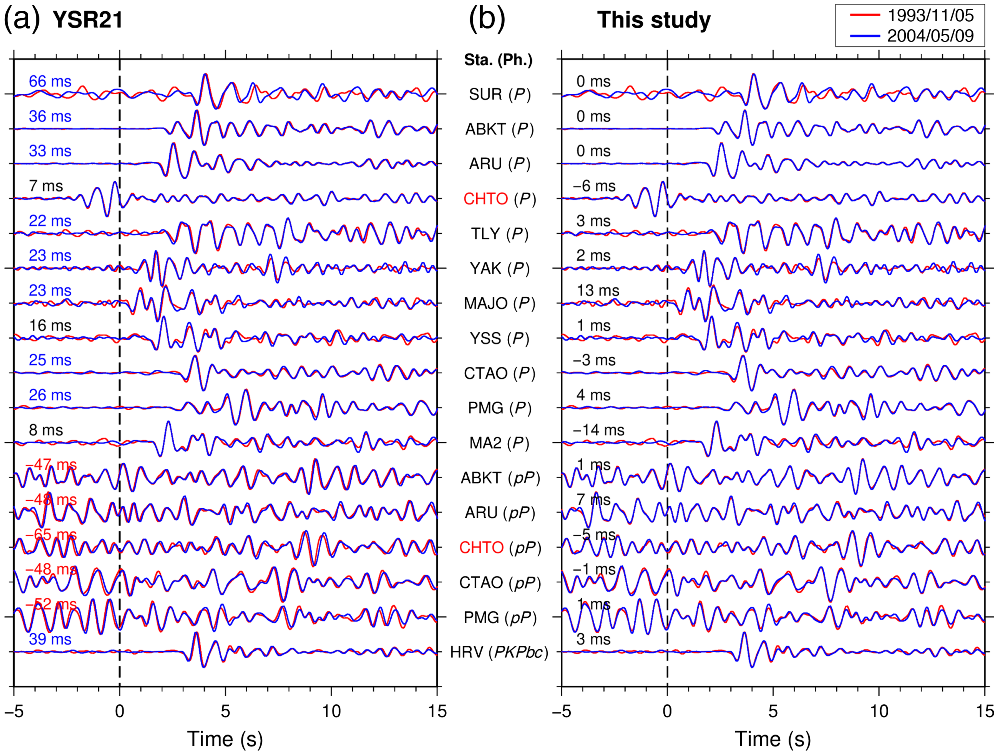

Figure 4. The same as Figure 2, except for doublet D2_1993–2004. The color version of this figure is available only in the electronic edition.

Unreproducible clock errors at AAK and OBN based on YSR21's relocation results

The YSR21's claimed clock errors at stations AAK and OBN are not reproducible based on their relocation results (Table 1). The calculated *P*-wave *dt* residual at AAK is 23 ms based on YSR21's relocation results of D1_1995–2003, different from the clock error of 65 ms that YSR21 claimed at that station. The calculated *P*-wave *dt* residual at OBN is 132 ms based on YSR21's relocation results of D2_1993–2004, different from the clock error of 92.5 ms that YSR21 claimed at that station. Note that the *dt* residuals at these two stations are calculated with respect to the *dt* measurements reported by YSR21 and computed using the same reference model IASP91 as in YSR21. The calculations are verified with the two open-source codes, that is, TauP and ttimes.

Reanalysis of Doublet Data and Clock Errors at AAK and OBN

We relocate the two doublets based on the master event approach (Wen, 2006), using global seismic data with high-quality non-IC phases *P*, *pP*, and *PKPbc* from IRIS (see Data and Resources). We remove the instrument response from the data, convolve the data with the WWSSN short-period response, filter the data from 0.6 to 3.0 Hz, and interpolate the seismic data to 1 ms sampling rate. To examine possible clock errors in the stations AAK and OBN, these two stations are not used for event relocation of the two doublets discussed subsequently. The selection of the stations used for the relocation is objective, solely based on the data quality of the station. We do not exclude any stations otherwise in the relocations, including some "problematic stations" claimed by YSR21 if their data have good quality, because none of those "problematic stations" can be objectively regarded as "problematic" as we discussed in the previous section. The *dt* residuals of our results range from −36 to 76 ms for D1_1995–2003 and from −14 to 13 ms for D2_1993–2004 (Figs. 1b and 3b), with the maximum values of 76 and 14 ms as opposed to 138 and 66 ms from YSR21's results. The rms residuals of our relocations are 30 and 6 ms for D1_1995–2003 and D2_1993–2004, respectively, as opposed to 55 and 39 ms from YSR21 for the two doublets (Figs. 1a versus 1b and 3a versus 3b). The relative doublet depths of our relocations yield excellent fits to *pP*–*P* relative travel times of the two doublets and the travel time of *PKPbc* at HKT for D1_1995–2003 and HRV for D2_1993–2004. Note that waveforms of *pP* and *PKPbc* phases overlay each other between the events of the doublets with no discernable time offset (Figs. 1e,f, 2b, and 3e,f).

Our relocation results differ from those of YSR21 for both doublets, in both the relative horizontal locations and relative depths (Table 2). For D1_1995–2003, event 1995 is located at a horizontal distance of 407 m away along an azimuth of 137° in our relocation, as opposed to a horizontal distance of 251 m away along an azimuth of 272° in YSR21. For D2_1993–2004, event 1993 is located at a horizontal distance of 49 m away along an azimuth of 63° in our relocation, as opposed to a horizontal distance of 424 m away along an azimuth of 213° in YSR21 (Figs. 1c,d and 3c,d). The depth separations of the two doublets of our relocation results are +58 m and −22 m for doublets D1_1995–2003 and D2_1993–2004, respectively, as opposed to YSR21's reported relative depths of −499 m and +370 m in an opposite direction.

Our relocation results are affected little by the reference models used for relocation, the omission of AAK/OBN data in the relocations, or the accuracy of the *dt* measurements by the cross-correlation method. For example, the relocations using the preliminary reference Earth model (PREM) (Dziewonski

TABLE 1
dt Residuals of AAK for D1_1995–2003 and OBN for D2_1993–2004

Station	Reported by YSR21 (ms)	Recalculated (Based on YSR21's Relocation) (ms)	This Study (ms)
AAK	65	23	47
OBN	93	132	8

and Anderson, 1981) and another standard model ak135 (Kennett *et al.*, 1995) have a difference of no more than 1.1 m in the relative horizontal location of the doublets and a difference of no more than 0.1 m in the relative depth of the doublets, with respect to those from IASP91. The inclusion and exclusion of the "problematic" station AAK data result in a difference of 47 m in the relative horizontal location and 0.2° in the azimuth of event 1995 with respect to the master event 2003 for D1_1995–2003 and a difference of 15 m in the relative depth of D1_1995–2003. The inclusion and exclusion of the "problematic" station OBN data result in a difference of 22 m in the relative horizontal location and 0.9° in the azimuth of event 1993 with respect to the master event 2004 for D2_1993–2004 and a difference of 3 m in the relative depth of D2_1993–2004. The relative travel times measured by the cross-correlation method have an uncertainty of 10 ms (Wen, 2006; Yao *et al.*, 2019; Lythgoe *et al.*, 2020). Such an uncertainty may have probably to a large extent been reflected in the dt residuals of the individual stations in the relocation results, but bootstrap tests for the two doublet data indicate that an uncertainty of 10 ms would generate a horizontal location difference of 66 m or a depth difference of 18 m in the relocation results. The bootstrap results are estimated from 1000 relocation tests for the two doublets with an error within ±10 ms randomly added to the observed dt measurements of the individual stations.

The residuals at AAK and OBN computed from our relocation results are 47 and 8 ms, respectively (Fig. 5b,d). Based on our relocation results, no clock error can be found at station OBN, as the magnitude of residual is within the relocation error and the specification of the accuracy of the clocks of the GSN station. One can argue that AAK may have some clock errors based on its relatively large travel-time residual. However, the doublet used to evaluate AAK clock error has a relatively large relocation error, with an rms residual of 30 ms and the largest residual in the individual stations reaching 76 ms possibly due to some potential temporal changes of shallow structures near the source region of the doublet (e.g., similar to those reported in Yu *et al.*, 2013). Because of those large residuals, the doublet is not a good candidate event pair to use to detect clock errors, and it is not appropriate to attribute the travel-time residual of 47 ms observed at AAK for the doublet to a clock error.

TABLE 2
Relocation Results of Two Doublets of YSR21 and This Study

	PDE Catalog*					Relocation Results†					
ID	Date	Origin Time	Latitude (°)	Longitude (°)	Depth (km)	Latitude (°)	Longitude (°)	Depth Correction (m)	Origin Time Correction (s)	dt(rms) (ms)	dt(max) (ms)
D1_1995–2003	1995/11/14	06:32:55.750	−3.682	101.924	57.0	(−3.6429)	(102.0577)	(−499)	(1.9186)	(55)	(138)
						−3.6457	102.0625	58	1.9227	30	76
	2003/07/02	00:47:11.860	−3.643	102.060	75.2						
D2_1993–2004	1993/11/05	07:02:06.110	−7.033	106.101	74.8	(−6.9472)	(106.1759)	(370)	(2.1537)	(39)	(66)
						−6.9438	106.1784	−22	2.1538	6	14
	2004/05/09	22:25:31.130	−6.944	106.178	78.3						

*Event parameters from Preliminary Determination of Epicenters (PDE) catalog.

†Event parameters from relocation results of two studies, with those shown within parentheses in the upper row for each doublet from YSR21 and those in the lower row for each doublet from this study.

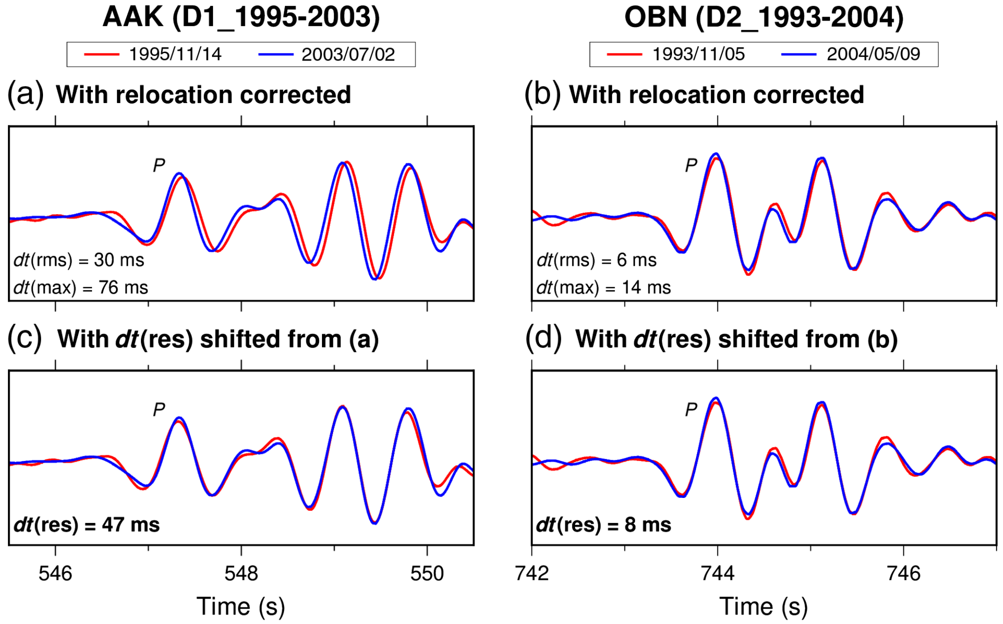

Figure 5. Waveform alignments for AAK and OBN based on this study. (a,c) *P* waveform alignments of doublet D1_1995–2003 at station AAK based on the relocation result of this study, with (a) the relocation source parameters corrected and (c) an additional time shift of *dt* residual (termed *dt*(res) and marked on the bottom left) from panel (a) to illustrate the accuracy of the residual estimated in panel (a). (b,d) *P* waveform alignments of doublet D2_1993–2004 at station OBN based on the relocation result of this study, with (b) the relocation source parameters corrected and (d) an additional time shift of *dt*(res) (marked on the bottom left) from panel (b) to illustrate the accuracy of the residual estimated in (b). The rms and maximum of *dt* residuals of all stations of the relocation for the two associated doublets are marked on the bottom-left in panels (a) and (b). Waveforms of the earlier event are shown in red while those of the later event are in blue. The color version of this figure is available only in the electronic edition.

Unfounded Claim of “Misidentification of the Temporal Change of the ICB”

We now examine YSR21’s claim that the temporal changes of *PKiKP* (a *P* wave reflecting at the ICB) observed in doublet SSI_1993–2003 by Wen06 were a “misidentification of the temporal change of the ICB”. YSR21 made such a claim by making time corrections to the *PKiKP* or *PKiKP*/*PKIKP* observations of doublet SSI_1993–2003 at three stations (AAK, OBN, and ARU) that were reported by Wen06 to exhibit *PKiKP* temporal changes between the events of the doublet. After those time corrections, they claimed that *PKiKP* phases do not exhibit an obvious time shift for the doublet. For AAK and OBN observations, they manually shifted the waveforms of the corresponding event by clock errors of 65 and 93 ms, respectively. The claim was repeated in Yang and Song (2023) with the same procedures applying the same clock errors. As we show in our reanalysis of the doublet data in the previous section, none of those clock errors are justified because the relocation results of the associated doublets exhibit large errors and those clock errors cannot be reproduced based on the relocation results of the doublets. Our reanalysis of doublet data shows no clock error at OBN and a residual of 47 ms at AAK. No justifiable claim of the AAK residual can be made as a clock error, as the doublet that was used to estimate the residual cannot be located within the accuracy of the residual level of 30 ms. That 47 ms residual at AAK is also less than the *PKiKP* time shift observed in doublet SSI_1993-2003. For ARU observations, we show that the apparent time shift between the responses of different seismic instruments can be simply corrected by removing the respective instrument responses (Fig. 6a–c). After the removal of the effect of different instrument responses at ARU, a 50 ms time offset of *PKiKP* phases is evident in the waveform alignments of the corrected data of the doublet (Fig. 6e). We conclude that YSR21 and Yang and Song (2023) have made an unfounded claim that the reported temporal changes of the ICB in Wen06 were a “misidentification.” Our analysis confirms the reported temporal changes of the ICB in Wen06.

Implications to the Past Inner Core Studies by Yang and Song

The significant relocation errors and unreproducible results in YSR21 raise questions about the validity of the reported doublets and the accuracies of the analyses in their past inner core studies (Yang and Song, 2020a,b, 2021, 2023). We note that this is the only study from their group that the detailed source parameters of the studied doublets were reported. In all the other publications (Yang and Song, 2020a,b, 2021, 2023), the doublets were presented without any information on relocated source parameters. The significant depth errors of the doublets in YSR21 may also explain why Yang and Song (2021) failed to recover the relative depth of doublet SSI_1993–2003 reported by Wen06. The validity of the doublets should be verified by their relative location and the accuracy of the reported temporal changes is intimately related to the accuracy of the doublet relocation. Regardless of the correctness of the interpretation therein, we urge a revisit of those studies with detailed and accurate relocation analyses of the reported doublets therein.

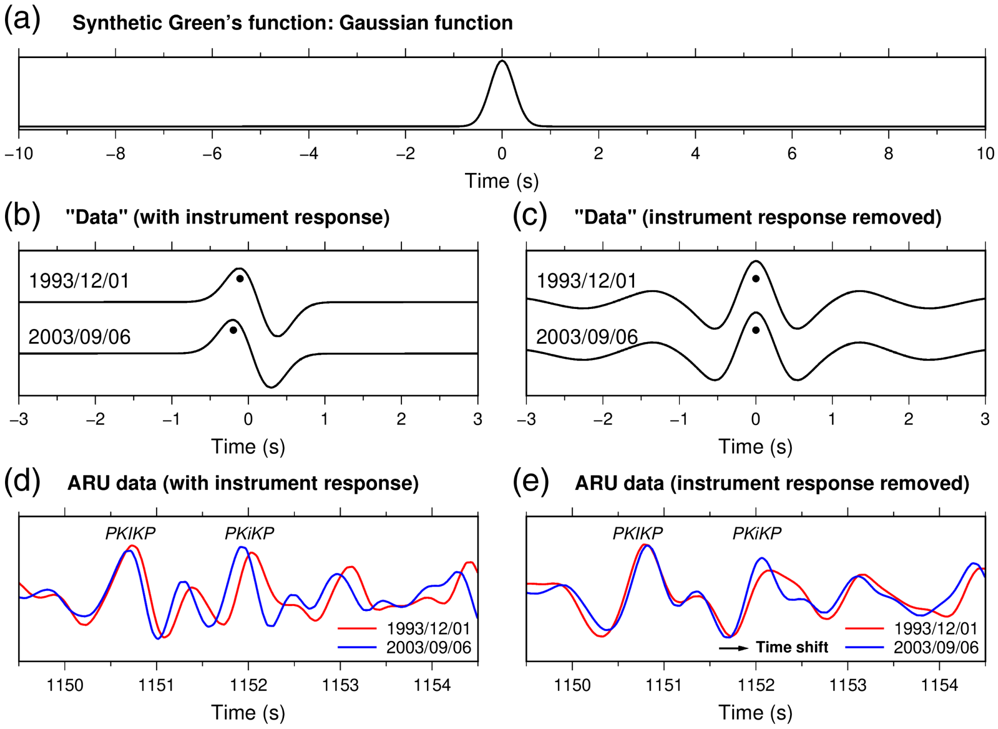

Figure 6. Effect of different instrument responses at station ARU between 1993 and 2003 and its correction. (a–c) Synthetic tests using a simple source with a Gaussian source time function. (a) Synthetic Green's function used as the seismic input to ARU, represented by a Gaussian function with a width of 0.25 s. (b) "Data" generated by convolving ARU instrument responses at the different epochs of event occurrences with the synthetic Green's function in panel (a). The main energy peaks (marked by black dots) present an apparent time shift during the occurrence of the doublet. (c) "Data" from panel (b) but with their respective instrument responses removed. "Data" are filtered with the same frequency band of 0.5–0.6 and 1.5–2.0 Hz following YSR21. Note that the removal of the instrument response corrects the apparent time shift due to differences in the sensor responses and yields a zero shift on ARU data with the respective instrument responses removed. (d,e) Observed waveforms of doublet SSI_1993-2003 at ARU displayed (d) with instrument response and (e) with their respective instrument responses removed. The waveforms are aligned based on the time shift due to differences in relative origin time and source separation between two events of the doublet following Wen06, with those of the early event shown in red traces and those of the later event shown in blue traces. Note that *PKiKP* waveforms present an evident time shift of 50 ms between the events (marked as the black arrow). The color version of this figure is available only in the electronic edition.

Concluding Remarks

Using the two stations AAK and OBN that YSR21 extensively discussed and the associated doublets YSR21 used to estimate the clock errors of the seismic stations, we show that (1) the relocation results of YSR21 contain large errors as evident from the large predicted relative travel-time residuals at the individual stations (reaching 138 and 66 ms, respectively, for the two doublets) and the obvious waveform misalignments between events of the two doublets for the depth-sensitive phases, with the predicted surface-reflected *pP* waveforms exhibiting time offsets by ~100 ms and the predicted *PKPbc* waveforms exhibiting time offsets ranging from −54 to 39 ms; (2) the selection of "problematic stations" in YSR21 is not supported by their relocation results as the reported "problematic stations" overall have smaller relative travel-time residuals of *P* phase than the reported "normal stations" and some "problematic stations" have minimal values of relative travel-time residual among all the seismic stations; and (3) the clock errors reported by YSR21 are not reproducible from their relocation results with a difference as large as ~40 ms between their reported values and the recalculated values based on their relocation results.

Our reanalysis of the two doublet data yields relative travel-time residuals of 8 ms at OBN and 47 ms at AAK from the associated doublets D2_1993–2004 and D1_1995–2003, as opposed to the reported clock errors of 93 and 65 ms claimed in YSR21. Our study indicates no clock error at station OBN and no justifiable claim of a clock error at AAK. The relatively large residuals at AAK and other individual stations for the doublet D1_1995–2003, along with an rms residual of 30 ms in the relocation, indicate that the doublet is not a good candidate event pair used to detect clock errors at seismic stations, and it is not justifiable to attribute the 47 ms residual at AAK to a clock error at the station. We conclude that the reported large and prevailing clock errors at global and regional seismic stations in YSR21 are problematic because of their inaccurate relocation results, questionable selection of "problematic stations" and unreproducible time estimations.

Our relocation analysis and correction for the effect of changing instruments confirm the observed temporal changes of the ICB in Wen06 and refute YSR21's claim of "misidentification of the temporal changes of the ICB in Wen06". The significant relocation errors and unreproducible results in YSR21 raise questions on the validity of the reported doublets and the accuracies of the analyses in the past inner core studies from the two leading authors. Regardless of the correctness of the interpretation therein, we urge a revisit of those studies with detailed and accurate relocation analyses of the reported doublets therein.

Data and Resources

The original seismic datasets used in this study were obtained from the Incorporated Research Institutions for Seismology (IRIS) Data Manage Center (DMC) (https://ds.iris.edu/ds/nodes/dmc/) through the IRIS Wilber 3 system (https://ds.iris.edu/wilber3/) and were processed using Seismic Analysis Code (SAC) (Goldstein *et al.*, 2003). To be specific, the original seismic datasets for doublets D1_1995-2003 and D2_1993-2004, and the original datasets for doublet SSI_1993-2003 were last accessed in May 2023. The instrument responses, original data and processed data of station AAK in doublet D1_1995-2003 and station OBN in doublet D2_1993-2004 and all the other original data used in this comment, the list of calculated clock errors of stations of doublets listed in YSR21 (Table S2 therein, available in the supplemental material to this comment) based on the relocation results in the correction *YSR23-errata* (available at doi: 10.1785/0220230360) and the differences between YSR21's reported clock errors and the calculated clock errors, and a duplication of the archive in the commented authors' reply (https://github.com/yiyanguiuc/Data-used-in-Reply-to-Zhang-and-Wen, last accessed and duplicated in April 2024) are available at https://github.com/Geoxin/Comment_on_YSR21-SRL_by_Zhang-and-Wen (last accessed April 2024). The four instrument responses of station II.OBN for doublet D2_1993-2004 used in this comment and in YSR21 accessed in the commented authors' reply are also documented in the supplemental material of this comment. All plots were made using the Generic Mapping Tools (GMT) (Wessel *et al.*, 2013). The peer review information mentioned in the introduction are available at https://static-content.springer.com/esm/art%3A10.1038%2Fs41586-024-07536-4/MediaObjects/41586_2024_7536_MOESM2_ESM.pdf (last accessed July 2024).

Declaration of Competing Interests

The authors acknowledge that there are no conflicts of interest recorded.

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Appendix

Additional notes on the correction and reply of the commented authors

After the above comment had gone through the peer review process, it was sent to the commented authors around 21 September 2023 for their reply. The commented authors have since published a correction on 6 December 2023 (*YSR23-errata*, see Data and Resources) and submitted a reply that was transmitted to us on 10 April 2024 for this final round of exchange. In the reply (Yang *et al.*, 2024), the commented authors stated that the unreproducible YSR21's reported clock errors we pointed out in this comment were due to "an accidental error when we exported our original data to Table S1". They further stated "Our original results are now reproducible with the corrected Table S1, and the original conclusions are not affected". The commented authors also published the instrument responses of station OBN used in YSR21 in accompany with figure 2 in the reply (see Data and Resources; archived in a duplication mentioned in Data and Resources and documented in the supplemental material of this comment). We feel a need to add these additional comments on the correction and the reply from the commented authors.

On the correction *YSR23-errata*

A comment is warranted on the commented authors' statement of their correction: "The only corrections are in the 5th column and the footnotes of Table S1." That statement is accurate. However, the footnote change switched the reference event of the doublets from the later event stated in YSR21 to the earlier event stated in the correction. Note that we obtained event locations that were in the opposite directions of the YSR21 results in this comment (Figs. 1c,d and 3c,d). The footnote change essentially reversed all their initial location results in an opposite direction and made their corrected locations closer to ours. Note also that their reported doublet relative locations in *YSR23-errata* and the reported relative travel-time measurements in YSR21 are now referenced to opposite earthquakes in the doublets. The 5th column is for the inferred relative origin time corrections between the doublets (with respect to the catalog origin times). In the correction *YSR23-errata*, all (450 in total) but one in that column have a different value from YSR21.

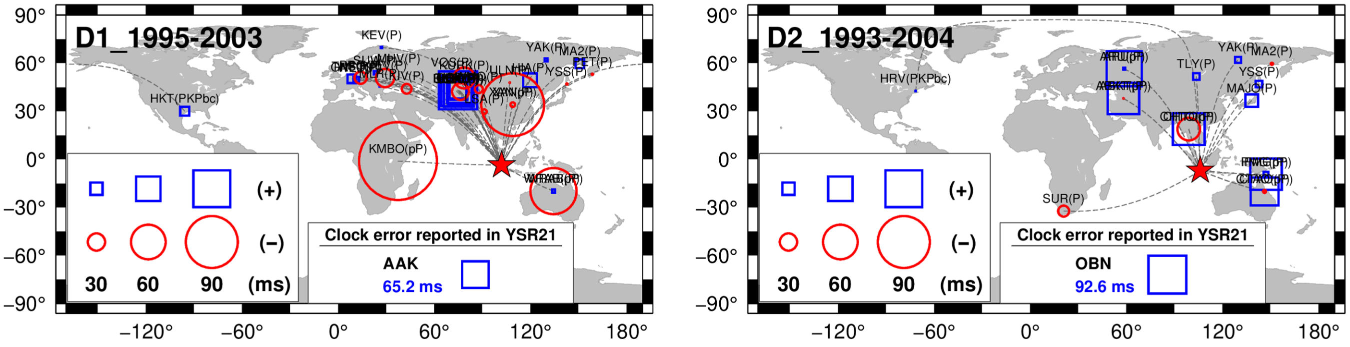
Several points can be made after analysis of their correction and the instrument responses they published:

1. With their corrected relocation results (*YSR23-errata*), YSR21's reported AAK clock error based on doublet D1_1995–2003 and OBN clock error based on doublet D2_1993–2004 are now reproduced within ±0.5 ms—an amount smaller than the computation precision of 1 ms (see the main text for the discussion on the computation precision).
2. Forward calculations show that their corrected relocation results predict large differential travel-time residuals at the individual stations for both doublet observations (Fig. A1a, compared with Figs. 1b and 3b), indicating that the corrected relocation results still contain significant errors, and the claimed clock errors are unreliable.
3. For the instrument responses published with the reply, we confirm no difference between the instrument responses used in YSR21 and this comment. We reprocess the data with the instrument responses used in YSR21 and obtain identical results with this comment. An example is shown in Figure A1b, in which we exactly reproduce Figure 5d in this comment with the instrument responses used by YSR21. The reason for this outcome is that the instrument responses used in the two studies are identical. The commented authors could have easily performed this kind of test on the results in this comment using the instrument responses they had and confirmed no changes in instrument responses between the studies.

Several irregularities emerge upon further analysis of the correction *YSR23-errata*:

1. A significant portion of YSR21's reported clock errors can still not be reproduced with their corrected doublet parameters. We check the reproducibility of all the clock errors reported in YSR21 with their corrected relocation results by examining the differences between the reported clock errors in YSR21 and the clock errors calculated based on their corrected doublet relocation results (Fig. A2a). Note that many clock errors listed in Table S2 of YSR21 are still unreproducible (blue dots and green dots with values beyond ±1 ms, Fig. A2a). We should note that this reproducibility test is not affected by any claims of "instrument changes" or "time changes" in the EarthScope archives and the unreproducible amounts in Figure A2a should not be viewed as uncertainties of the clock error studies. The calculated clock errors are measured against the *dt* measurements reported in YSR21 (columns 5th and 6th of Table S2

(a) *dt*(res) based on corrected relocation results in YSR23-errata



(b) *P* waveforms processed with instrument responses used in this comment and YSR21

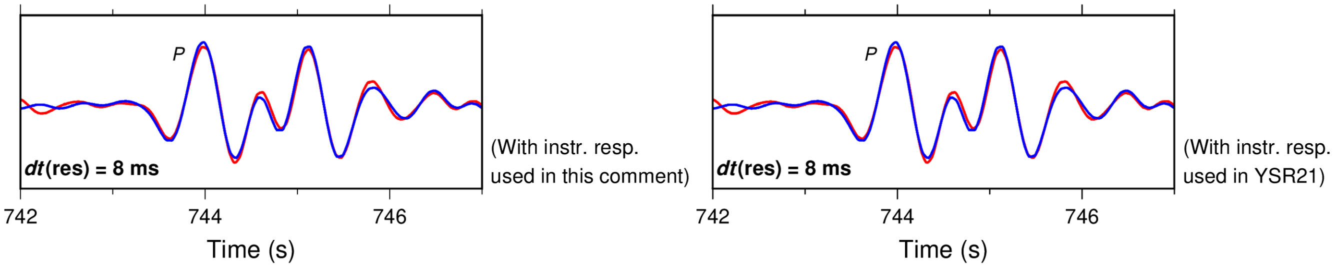
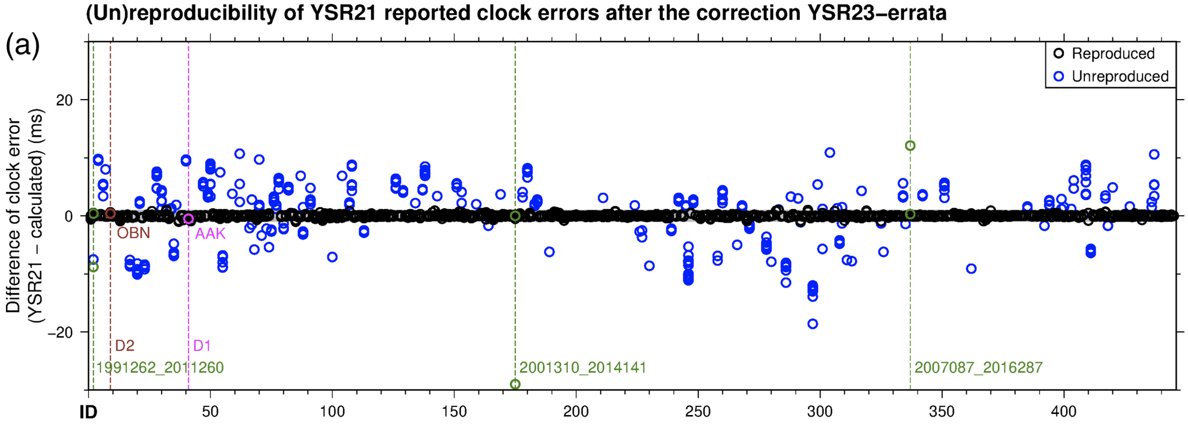


Figure A1. Residuals (*dt*(res)) based on the correction *YSR23-errata* and no effect of the instrument responses used between YSR21 and this comment. (a) *dt*(res) at individual stations computed based on the corrected relocation results of doublets D1_1995–2003 and D2_1993–2004 in *YSR23-errata* (see Data and Resources), respectively. Residuals are plotted in symbols, with blue squares representing positive values (early event arriving relatively later), red circles representing negative values (early event arriving relatively earlier), and magnitudes proportional to the symbol sizes. YSR21's reported clock errors at stations AAK and OBN are marked inside the panels for reference. Note the large residuals in both doublets after the correction *YSR23-errata*, indicating inaccurate doublet relocation parameters after the correction *YSR23-errata*. (b) Alignment of *P* waveforms of OBN of D2_1993–2004 processed with the instrument responses used in this comment (archived in the website mentioned in Data and Resources) (left) and the instrument responses used by YSR21 (as published in their reply; see Data and Resources) (right). Note that the left panel is just a copy of Figure 5d in this comment. Note also the left and right panels are identical because both studies used the same instrument responses. The color version of this figure is available only in the electronic edition.

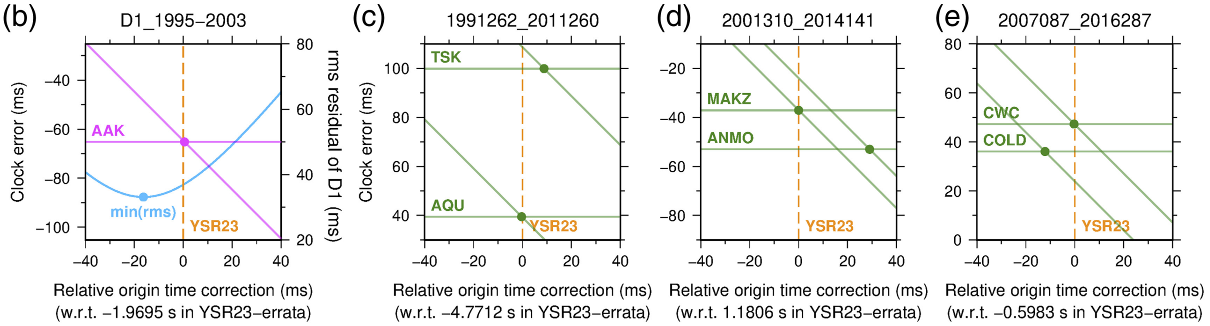
in YSR21), so there is no error involved on the part of the measurements in this reproducibility analysis. The only error is the computation precision of 1 ms in the forward calculations, and that precision marks the criterion for checking the integrity of the reproducibility of a doublet relocation result. The fact that the corrected doublet parameters in *YSR23-errata* can reproduce 87.82% of the reported clock errors in YSR21 and the OBN and AAK clock errors being questioned up to 0.5 ms indicates that the program the commented authors used has the same computation precision, and the above unreproducibility is not due to the computational precision.

2. Close inspections of those unreproducible results raise concerns about the integrity of the correction process in *YSR23-errata*. We show some irregularities using four doublet examples in their reproducibility of the reported clock errors. All discussions will be based on the corrected locations in *YSR23-errata* and be focused on how the change of the relative doublet origin time correction (i.e., the 5th column change from YSR21 to *YSR23-errata* in Table S1 therein) affects the calculated clock errors. Note that, for an individual station, the calculated clock error is linearly proportional to the assumed relative doublet origin time correction, so any reported clock error of an individual station can be reproduced with a particular doublet relative origin time correction if one disregards the accuracy of the relocation result. We present the reported clock error of AAK in D1_1995–2003 as an example (Fig. A2b). The corrected relative origin time correction in *YSR23-errata* reproduces YSR21's reported clock error at the station.

   However, the corrected relative origin time correction does not generate the minimal rms differential residual among all possible relative origin time corrections. The problem of *YSR23-errata* becomes more apparent in the doublets with reported clock errors in multiple stations. More than 26% of the 436 doublets with multiple "problematic stations" have some reported clock errors unreproduced. As we show in the three doublet examples in Figures A2c–e, no single



(Un)reproducibility of YSR21 reported clock errors after the correction YSR23−errata



(b–e) Examples of some irregularities in the correction YSR23−errata

Figure A2. (Un)reproducibility of YSR21's clock errors after the correction *YSR23-errata* and examples of some irregularities in the correction *YSR23-errata*. (a) Differences between the clock errors reported in YSR21 (Table S2 therein) and the clock errors computed based on the corrected doublet relocation results in *YSR23-errata*. Each circle corresponds to the difference of a reported clock error in YSR21 and is plotted along the associated doublet ID in the horizontal axis. Circles that fall within the shaded region (within ±1 ms, the computation precision) are considered to be reproduced (black), and those outside the shaded region are not reproduced by their corrected doublet relocation results (blue). Symbols of five labeled doublets are not color-coded with the (un)reproducibility but with the doublets. Note the significant number of the reported clock errors in YSR21 that are not reproduced after the correction *YSR23-errata*. The pink and brown circles correspond to stations AAK in doublet D1_1995–2003 and OBN in doublet D2_1993–2004, respectively. The green circles correspond to some example "problematic" stations in three example doublets (green dashed lines) reported in YSR21 for the plots of panels (c–e). (b) Calculated AAK clock error (−45° slopped pink line) and rms differential travel-time residual (light blue curve) as a function of assumed relative origin time correction to the catalog origin times in doublet D1_1995–2003 based on the corrected doublet location in *YSR23-errata*, the reported AAK clock error in YSR21 (pink horizontal solid line), and the corrected value of relative origin time correction in *YSR23-errata* (i.e., 5th column of Table S1 therein) (orange vertical dashed line). Note that changing the relative origin time correction can reproduce any reported clock error of a station. Note also that the corrected relative origin time correction in *YSR23-errata* that reproduces the reported AAK clock error does not generate the minimal rms residual (marked by the light blue dot). (c) Calculated clock errors at two example stations (−45° slopped green lines) as a function of assumed relative origin time correction to the catalog origin time of doublet 1991262-2011260 based on the corrected doublet location in *YSR23-errata*, reported clock errors of the two stations in YSR21 (green horizontal solid lines with station names labeled), and the corrected value of relative origin time correction in *YSR23-errata* (i.e., 5th column of Table S1 therein) (orange vertical dashed line). (d,e) Same as panel (c), except for doublets 2001310-2014141 and 2007087-2016287, respectively. In each bottom panel, the relative origin time correction in the horizontal axis is plotted with respect to the corrected value of the doublet in *YSR23-errata* (note the labeled values are in an opposite sign to those in *YSR23-errata* due to the reference event switch in *YSR23-errata* from YSR21 and this comment). Note that no single relative origin time correction can simultaneously reproduce the reported clock errors in (c–e). Note for panel (a) calculations: YSR21 stated that YSR21's reported clock errors were calculated with respect to "the first mantle *P* arrivals if the distance is smaller than 104°, or the inner core *PKP* arrivals if between 104° and 145°, or the outer core *PKP* arrivals if greater than 145°". The exact phase of use for each station was not stated in YSR21. We compute the clock error of a station with respect to all possible phases of firstly arrived *P*, *Pn*, P_{diff}, PKP_{ab}, PKP_{bc}, *PKiKP*, PKP_{df}, and choose the calculated clock error that has the minimal difference from YSR21's reported clock error in the reproducibility test. In addition following YSR21, the "Correction for instrument change" due to "gradual deterioration in the instrument phase response reported of the Streckeisen STS-1" reported by U.S. Geological Survey researchers (i.e., 6th column of Table S2 therein) of a station is corrected from its "*dt* measurement" value (i.e., 5th column of Table S2 therein) in our computation procedure. The color version of this figure is available only in the electronic edition.

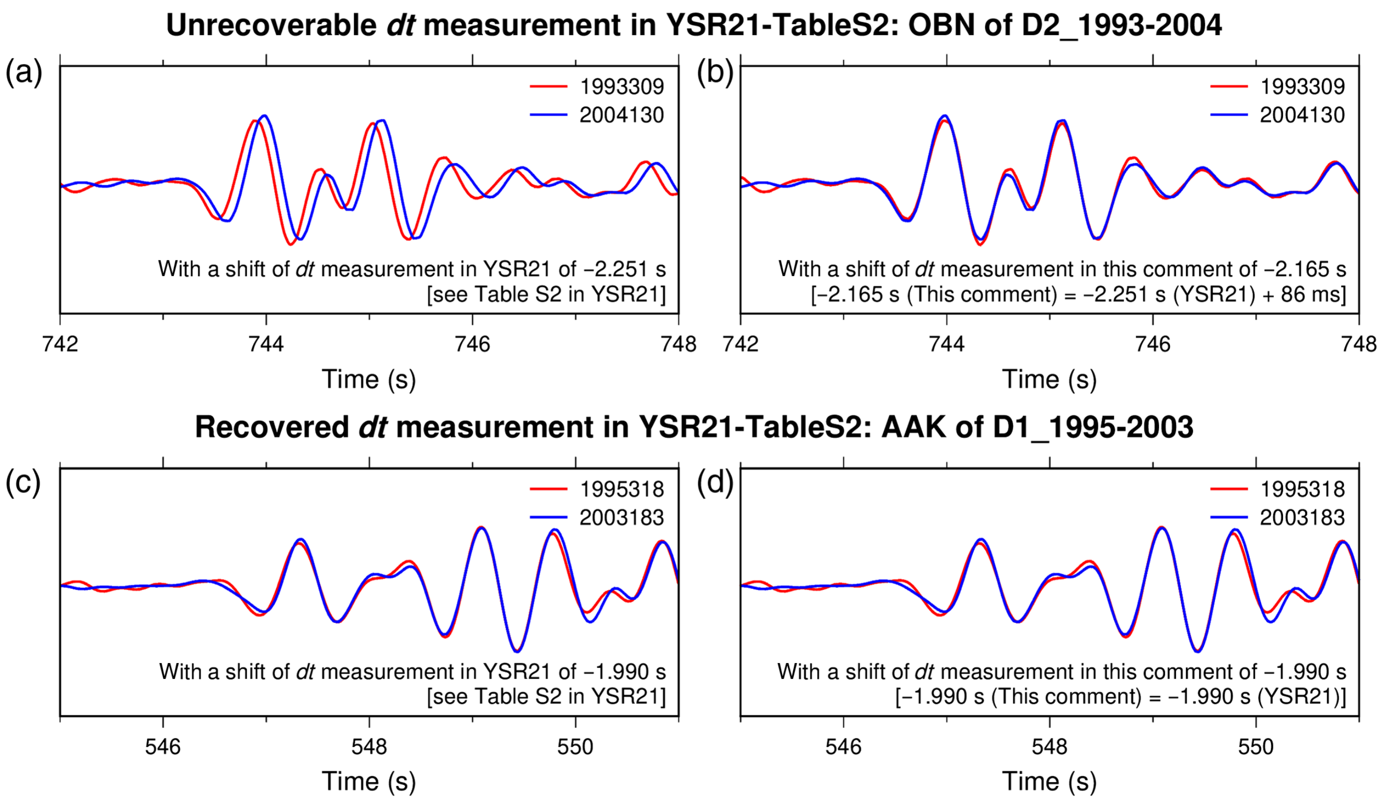


Figure A3. Unrecoverable *dt* measurement in YSR21 for station OBN of doublet D2_1993–2004 and recovered *dt* measurement in YSR21 for station AAK of doublet D1_1995–2003. (a,b) *P* waveform alignment for station OBN of doublet D2_1993–2004 with a shift of *dt* measurement of (a) −2.251 s listed in YSR21 (Table S2 therein) and (b) −2.165 s measured in this comment. The evident waveform misalignment in panel (a) indicates a mysterious erroneous measurement in YSR21. Note that the unrecoverable *dt* measurement in YSR21 is about 86 ms (i.e., the absolute value of (−2.251 s) − (−2.165 s)) off from the correct measurement. Waveforms are processed with the removal of the instrument responses published by the commented authors' reply and are filtered in a frequency range of 0.6–3.0 Hz following YSR21. (c,d) *P* waveform alignment for station AAK of doublet D1_1995–2003 with a shift of *dt* measurement of (c) −1.990 s listed in YSR21 (Table S2 therein) and (d) −1.990 s measured in this comment. Waveforms are processed in the same way as panels (a) and (b), except that the instrument responses used in this comment are used. Note that YSR21's *dt* measurement of AAK is recovered using the data and instrument responses used in this comment, indicating no time change in the data of the station in the EarthScope archives between YSR21 and this comment. All shifts in panels (a–d) are performed with respect to the catalog origin times of the doublets. The top right labels indicate dates and they are shown in the same style as the mentioned Table S2 of the commented article YSR21. The color version of this figure is available only in the electronic edition.

relative origin time correction can simultaneously reproduce the reported clock errors in those doublets. In those cases, the correction performed in *YSR23-errata*, that is, by reversing the direction of the reported relative doublet location and changing the value of the relative origin time correction, may not reproduce all the reported clock errors on multiple stations when the reported clock errors are intrinsically unreproducible.

3. Processing the OBN data with the instrument responses the commented authors published, we discover that YSR21's reported value of measured differential travel-time residual at OBN of D2_1993–2004 is questionable. We check *P* waveform alignment of OBN with a shift of the *dt* measurement of −2.251 s reported in YSR21 (Table S2, therein) with respect to the catalog origin times of the doublet (following the same reference of YSR21's measurements). The alignment shows an evident time shift between the doublet (Fig. A3a), indicating an erroneous measurement in YSR21 of differential travel time at OBN. Note that the alignment based on our measurement of −2.165 s in this comment yields an excellent waveform fit between the doublet (Fig. A3b). Quantitatively, the reported *dt* measurement in YSR21 is about 86 ms off from the accurate measurement. Accordingly, the YSR21's reported OBN clock error (i.e., *dt* measurement minus *dt* prediction based on the doublet parameters) of 93 ms contains an amount of about 86 ms due to the erroneous *dt* measurement. Yet, the reported clock error of 93 ms was exactly reproduced after the correction *YSR23-errata* (Fig. A2a).

We still do not have any information about how the relocation was performed in YRS21. However, with the availability of the instrument responses they used and the correction they published, our further analysis affirms the conclusions we made in this comment and reaches the following additional conclusions. YSR21's reported 65 ms AAK clock error was obtained from a mysterious pick of a doublet relocation result that is neither accurate nor located in the minimal rms in their own event location parameters. YSR21's reported 93 ms OBN clock error is a result of a combination of a similar mysterious pick of a questionable doublet relocation result and a mysterious data measurement of differential travel-time residual that is 86 ms off the accurate measurement.

More concerningly, the unreproducibility of a significant number of the reported clock errors after the correction *YSR23-errata*, many irregularities in the correction listed earlier, and the reproducibility of YSR21's original claims of OBN and AAK clock errors even when one contains a significant error due to the erroneous measurement, suggest a likelihood that the initial YSR21 reported clock errors may be intrinsically unreproducible and raise concerns on the integrity of the correction process of *YSR23-errata*.

We should also add a cautionary note to the reader that those reproduced clock errors in Figure A2 are just reproduced by the corrected doublet results in *YSR23-errata*. They likely have large errors because of the inaccurate doublet results in both YSR21 and their correction *YSR23-errata*, as we show in the detailed analyses of doublets D1_1995–2003 and D2_1993–2004 in this comment.

On the data update in the EarthScope archives as the commented authors' explanation of the unreproducible identification of their reported "problematic stations" and dismissal of this comment

The commented authors state in their reply that "… some [problematic] stations now "have minimal values of relative travel time residual" simply because the issue has been fixed by the data and metadata updates at EarthScope", and cite Davis *et al.* (2023) (which was published on 8 September 2023 after the submission of this comment on 28 August 2023) as "The timing issues related to the stations of the II (Scripps Institution of Oceanography, 1986) network reported by YSR21 have been recognized by station operators and have been partially corrected by the International Deployment of Accelerometers (IDA) (Davis *et al.*, 2023). ZW23 [referring to this comment] did not reference this critical article." This is what is stated in Davis *et al.* (2023): "Accordingly, the timing of the data for the four stations earlier have been repaired, and as of June 2023, these data should be correct in the EarthScope archive (as stated earlier, AAK was repaired and replaced in 2020)." The four stations are II.AAK, II.ABKT, II.KAPI, and II.MBAR (fig. 5 in Davis *et al.*, 2023) and the repaired value is 1 s, "a class of clock failure modes, including leap second misplacement, mishandling or corruption of the time string or incorrect wiring of the cable connecting the external clock to the DAS, that can lead to timing errors close to, or precisely at, 1 s" (Davis *et al.*, 2023). Their repaired values have no association with the relative travel-time residuals in the discussion, which are in the order of tens of milliseconds, and those stations are different from the "problematic stations" USP, KPK, ULHL, CHTO we questioned in this comment (Figs. 2 and 4).

The commented authors' reply states "ZW23 was apparently not aware of the database update in the data center. Some data in the EarthScope (formerly Incorporated Research Institutions for Seismology; IRIS) archives, including timing as well as instrument response metadata, have been updated following the report by YSR21, which is clearly not accounted for by ZW23". We find no record that the EarthScope archives have responded to YSR21's claims of clock error and made corresponding time changes. Contrary to the commented authors' claim, we recover YSR21's reported AAK *dt* measurement in D1_1995–2003 indicating no time change for the station in the EarthScope archives between YSR21 and this comment (Fig. A3c,d). In fact, no actionable time correction can be made to the seismic recording, even if one obtains a correct clock error from the doublet analysis like YSR21. A clock error found in a doublet analysis could be caused by a time error any time before (or at) the earlier event of the doublet or an opposite-valued time error any time between the doublet. The YSR21 results are being questioned to be unreproducible. YSR21 possesses the original data downloaded at the time of the publication and is in the position to identify and verify with the EarthScope archives which stations and what amounts were time changed in the EarthScope archives. The obligation falls on the commented authors. In the absence of evidence supporting the commented authors' claim and the presence of evidence on the contrary, we do not believe the commented authors make a credible claim of the related time changes in the EarthScope archives in response to YSR21's claims of clock error.

On the rest of the reply of the commented authors

We find no need to respond to the comment of the commented authors using the current data availability in the EarthScope archives to criticize Wen06 for not mentioning clock errors in some stations for which data were not available in the archives at the time. We also find no need to respond to the comments that our inner core studies and this comment used different data processing procedures. This comment is to understand the results in YSR21. It simply adopts the data processing procedure in YSR21 so that the comparisons of the results and waveforms between the studies are performed in the same frequencies. The actual data processing, the detailed relocation results of the doublets, and the uncertainties of various data processing in our inner core studies were all presented in detail in our previous publications (Wen, 2006; Yao *et al.*, 2015, 2019, 2021). A straightforward way of accounting for the effect of the continuingly updated information of changing instrument responses in the EarthScope archives is well illustrated in the ARU example of this comment (Fig. 6e). Rather than responding to the comments from the commented authors on those articles and our previous comments, we refer readers to those original publications. None of our previous publications and this comment denied the possible existence of clock errors of seismic stations, and it has been our common practice to discard outliers of stations that have evident time errors of more than 1 s (e.g., II.ABKT, IU.CHTO, and US.MIAR for some doublets) in our doublet studies. The statement that "The data that contradict their conclusions are not included" in the reply is simply not true. Regarding the comment in the reply claiming small effects on the predicted *P* or *PKPbc* differential travel-time residuals because of the inaccuracy of the relative depth of a doublet, we refer the readers to the Large errors in YSR21's relocation of doublets section for example numbers. We decide not to comment further on the other (main) issues in the reply (i.e., all the figures and related conclusions therein) that are distractive to the topic being discussed, but we urge readers to examine the original data and perform their own data processing before referencing those results in the reply. The discrepancy from their results could arise even in the simple discussions such as the effect of instrument responses on the *PKiKP* differential time (e.g., fig. 7g in YSR21 versus Fig. 6e in this comment).

We do not comment others' work in a subjective way. Nor do we respond to the comments such as "that any such comment or reply should adhere to professional standards" or "the presentation and the tone of the new comment, like the previous two comments (Yao *et al.*, 2021; Tian and Wen, 2023), are unfortunate". We believe the judgment of the appropriateness and professionalism of a publication belongs to its readers. We should point out that not a single example of relocation results (e.g., station coverage, residual, resolution, or error bar) was presented in YSR21—an article that has a sole focus on using the relocation results to detect clock errors. The same remains true in their reply when the relocation results were being questioned. No processing procedures were presented in the correction of the effects of the instrument responses of ARU in the presentation of fig. 7g in YSR21, a result that was used repeatedly to discredit the temporal PKiKP change at ARU; and no explanation was provided to why that figure was different from Figure 6e in this comment after the same, simple, and reproducible procedure of instrument correction, which shows a clear *PKiKP* temporal change after the correction. Finally, there was no communication to our team from the commented authors prior to the publication of YSR21 that was directed to discredit our inner core results. The statement in their reply "Our attempts to work with the comment authors to examine each other's works directly were not successful" is simply misleading.

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