Reply on RC 2:

The manuscript presents a potentially useful methodological assessment of high-resolution δ234U measurements in annually banded tropical corals. The combination of analytical replicates, full procedural replicates, intra-skeletal comparisons, different sampling strategies, multiple coral taxa, and neighboring colonies provides a valuable dataset for evaluating the applicability of coral δ234U as a proxy for seawater uranium isotope variability. However, several important issues need to be resolved before the manuscript can support its main conclusions. In particular, the analytical framework needs to be more carefully reconciled with the recent methodological advances of Hu et al. (2025). This is especially important because the manuscript aims to interpret δ234U variations at the ~0.5–1‰ level, whereas Hu et al. demonstrated that choices in tailing correction and decay constants can introduce systematic offsets of approximately 0.2‰. In addition, the current manuscript does not consistently distinguish analytical precision, external reproducibility, procedural reproducibility, and natural skeletal heterogeneity. Consequently, some statements concerning the detection of sub-permil environmental variability and the absence of species effects appear stronger than warranted by the data. I therefore recommend major revision before acceptance, given that the authors can address my comments below:

Major points:

1) The analytical accuracy and tailing correction need to be quantitatively reconciled with Hu et al. (2025). This is, in my view, the most important issue. The manuscript states that the low-mass tail of 238U is reconstructed using a PCHIP interpolation based on half-mass measurements and explicitly contrasts this approach with Hu et al. (2025). However, Hu et al. demonstrated that the shape of the uranium tail in the vicinity of mass 234 cannot necessarily be inferred accurately from conventional interpolation between adjacent half masses. Their Th-analog approach directly constrained the tail at the position corresponding to 234U and showed that an inappropriate half-mass correction can bias measured 234U/238U ratios by approximately 0.22‰ near secular equilibrium and ~0.20‰ for modern seawater. The PCHIP approach may indeed reproduce the true tail better than a simple exponential interpolation, but this is currently asserted rather than demonstrated at the precision relevant to this manuscript. Because the environmental signals discussed here are commonly only ~0.5–1‰, a potential systematic bias of ~0.2‰ is not negligible. I strongly recommend that the authors quantitatively demonstrate that the PCHIP correction provides an unbiased estimate of the tail specifically at m/z ~ 234. This could be achieved, for example, by directly comparing PCHIP-derived corrections with the Th-analog approach of Hu et al., or by analyzing an independent secular-equilibrium material and/or reference solutions spanning substantially different δ234U values. At minimum, the manuscript should quantify the difference expected between the PCHIP and Th-analog approaches and propagate this uncertainty into the environmental interpretations.

We thank the reviewer for highlighting the importance of quantitatively evaluating the ^{238}U tailing correction at m/z 234. The ^{238}U tail is an instrumental feature of the mass spectrometer, and its magnitude and shape depend on the detector, amplifier configuration, ion beam intensity, and other instrumental conditions. It therefore needs to be characterized for the specific analytical setup.

Our correction follows the approach described in detail by Kerber et al. (2023), which builds on extensive methodological work in our laboratory since 2016, including the PhD thesis of Arps (2017; DOI: 10.11588/heidok.00023313). Briefly, the ^{238}U tail is characterized at the beginning of each analytical sequence using an unspiked CRM-112A solution measured at multiple off-mass positions. The nonlinear tailing behaviour is then reconstructed using a shape-preserving piecewise cubic Hermite interpolating polynomial (PCHIP), which is subsequently extrapolated to the masses of interest. This approach was selected by Kerber et al. (2023) because it provided a better representation of the measured ^{238}U tail than an exponential fit, particularly at lower masses.

We retain this established PCHIP-based correction because it is based on direct characterization of the ^{238}U tail under our specific instrumental conditions and has been investigated in previous methodological work in our laboratory (Arps, 2017; Kerber et al., 2023). We acknowledge that a direct quantitative comparison between the PCHIP correction and the Th-analog approach presented by Hu et al. (2025) would provide further insight into potential systematic differences between the two methods. However, a detailed methodological comparison is beyond the scope of the present study and will be addressed in subsequent work.

The objective of this study is not to establish a new tailing correction procedure or to achieve the highest possible analytical precision, but to assess the applicability of coral $\delta^{234}U$ measurements for resolving natural variability in coral archives. This will be subject of a subsequent publication. Our interpretations primarily focus on $\delta^{234}U$ variations of approximately 1‰ and larger, which are clearly distinguishable from the external analytical reproducibility of ±0.4‰ (2 SD) demonstrated by our reference-material measurements. We will therefore revise the manuscript to ensure that the analytical limitations are appropriately acknowledged and that smaller variations are not overinterpreted.

2) The normalization strategy and the claim of absolute accuracy are currently unclear and potentially circular. The manuscript appears to use two reference materials in different roles. The Methods state that measurements were bracketed using HU-1, whereas later the authors state that “all isotope measurements were normalized to NBS-CRM-112A.” This needs to be described much more explicitly. In particular, if CRM-112A is used to define the normalization of the measured isotope ratios, then the observation that 66 analyses of CRM-112A yield a mean of −38.5‰ cannot independently demonstrate analytical accuracy. It would mainly demonstrate precision/reproducibility around the assigned normalization value. Yet the Discussion currently uses these 66 measurements as the principal evidence for accuracy. The HU-1 results may provide an especially useful independent check. The manuscript states that its HU-1 corresponds to approximately −0.9‰ relative to secular equilibrium. Hu et al., however, obtained approximately −1.25 to −1.27‰ for HU-1 using the revised method. The ~0.3–0.4‰ difference is comparable to the entire external reproducibility claimed in this manuscript and should therefore be reported and discussed rather than overlooked.

We thank the reviewer for pointing out that the roles of HU-1 and NBS-CRM-112A in our normalization procedure were not sufficiently clearly described. We will revise the Methods section to clarify the two-step normalization procedure.

Measurements were conducted using the standard bracketing method with the Harwell Uraninite 1 (HU-1) standard to ensure measurement stability and correct for instrumental drift. HU-1 was used as an internal bracketing standard for instrumental normalization, and its measured $^{234}U/^{238}U$ ratio was fixed to a constant reference value during data reduction ($\delta^{234}U$ = 0‰). This step serves purely as an instrumental correction and does not imply a physical assumption of secular equilibrium.

Following this instrumental correction, all measurements were normalized to NBS-CRM-112A, using its reference $\delta^{234}U$ value of −38.5‰. After this two-step normalization, the 66 CRM-112A measurements yielded a mean value of −38.5‰ with an external reproducibility of ±0.4‰ (2 SD).

We agree with the reviewer that the CRM-112A measurements cannot independently establish absolute accuracy because this reference material was used to define the final normalization. They primarily demonstrate the external reproducibility of the normalized measurements.

Regarding the difference between the HU-1 value obtained in our laboratory (approximately −0.9‰ relative to secular equilibrium) and that reported by Hu et al. (2025; approximately −1.25 to −1.27‰), we note that the analyses were performed using HU-1 materials in different laboratories. Potential differences between individual material batches or their preparation cannot be excluded, although the available data do not allow us to identify the cause of this discrepancy. HU-1 is used in our procedure for instrumental bracketing and drift correction, rather than as the reference material defining the final $\delta^{234}U$ scale. A further investigation of the standard materials against a secular equilibrium is in the works already, and will be subject of a following publication.

The manuscript will be changed accordingly: “Measurements were performed using the standard bracketing method with HU-1 to monitor measurement stability and correct for instrumental drift. For data reduction, the measured $^{234}U/^{238}U$ ratio of HU-1 was assigned a constant reference value ($\delta^{234}U$ = 0‰). This step serves as an instrumental normalization and does not imply that HU-1 is assumed to be in secular equilibrium. Following this correction, all measurements were normalized to NBS-CRM-112A using its reference $\delta^{234}U$ value of −38.5‰.

The 66 measurements of CRM-112A yielded a mean value of −38.5‰ with an external reproducibility of ±0.4‰ (2 SD). As CRM-112A was used to define the final normalization, these measurements demonstrate the external reproducibility of the method but do not provide an independent assessment of its absolute accuracy.”

The objective of this study is to investigate relative $\delta^{234}U$ variability recorded in coral skeletons rather than to establish an independently validated absolute seawater $\delta^{234}U$ reference value. The environmental interpretations presented here are primarily based on $\delta^{234}U$ variations of approximately 1‰ and larger. We therefore distinguish between the external reproducibility of our measurements and the absolute accuracy of the isotope scale, and will revise the manuscript to make this distinction explicit.

3) The use of the Cheng et al. (2013) λ234 value should be reconsidered after Hu et al. (2025). The manuscript calculates δ234U using λ234 = 2.82206 × 10-6 yr-1 from Cheng et al. (2013). Hu et al. (2025), however, revised the 234U half-life and corresponding decay constant after identifying a systematic bias in previous 234U tail corrections. Given

that Hu et al. is already cited throughout this manuscript, it is difficult to justify retaining the previous λ234 without discussion. The difference between the old and revised λ234 corresponds to approximately 0.2‰ on the activity-ratio scale, which is small for traditional U-series applications but not small relative to the <1‰ variations emphasized here.

We thank the reviewer for raising this point. We will recalculate the δ^234U values using the revised 234U decay constant reported by Hu et al. (2025; $\lambda 234 = 2.82147 \times 10^{-6}\ yr^{-1}$), instead of the value from Cheng et al. (2013). The recalculated values are on average 0.16‰ higher than those obtained using the previously applied decay constant. This change does not affect the observed variability or any of the conclusions of the study. The revised decay constant will be applied consistently throughout the data evaluation and manuscript.

4) Analytical precision, external reproducibility, procedural reproducibility, and natural heterogeneity are not consistently distinguished in the current manuscript. For example, internal uncertainties are reported as 2σ standard errors, whereas CRM-112A reproducibility is described using a standard deviation of ±0.4‰; Figure 2 additionally reports a 2σM of ±0.06‰. These quantities represent fundamentally different aspects of uncertainty and should not be compared interchangeably. The manuscript concludes that δ234U variations exceeding 1‰ can safely be interpreted as seawater variability, and elsewhere states that variations <1‰ can be detected. These statements are difficult to reconcile quantitatively with the reported replicate variability.

We thank the reviewer for highlighting this important distinction. We agree that the different components of uncertainty and variability were not sufficiently clearly distinguished in the original manuscript. We will therefore revise the terminology throughout the manuscript to distinguish between internal analytical uncertainty, external analytical reproducibility, procedural/sample reproducibility, and natural skeletal heterogeneity.

In particular, the standard deviation of ±0.4‰ obtained from the repeated CRM-112A measurements represents the external reproducibility of individual measurements, whereas the 2σM value of ±0.06‰ shown in Figure 2 represents the uncertainty of the mean of the repeated CRM measurements. These quantities are therefore not directly comparable, and this distinction is now made explicit in the text and Figure 2 caption.

We will also revise our interpretation of sub-permil variations in coral δ234U. We will now state that differences substantially larger than the external analytical reproducibility can be more readily distinguished from analytical variability, while their interpretation as environmental signals requires consideration of procedural variability, sampling strategy, and natural intra-skeletal heterogeneity.

Similarly, we now distinguish between the analytical resolution of a difference and the ability to attribute that difference to environmental variability. The revised Conclusions will emphasize that sub-permil differences can be analytically resolved, but that variations at this scale require careful consideration of analytical reproducibility and sample heterogeneity.

Minor points

We thank the reviewer for these helpful comments. We will address all of the minor comments in the revised manuscript, including the corrections to terminology, section

numbering, figure captions, error notation, statistical reporting, temporal-resolution statements, species-related interpretation, TriSpike description, and typographical errors.

1. Abstract, “238U/234U ratios” should be “234U/238U ratios”

done

2. Two sections are labeled 2.4, “ICP-MS concentration and calcium assessment” and “MC-ICP-MS U isotope measurements”. The latter should be Section 2.5.

done

3. Figure 1, the text reports a maximum measured concentration of 174.4 ppb, whereas the figure caption states 128.40 ppb. These numbers should be reconciled.

done

4. The statement that analytical error “decreases exponentially” with uranium concentration should either be supported by an explicit fitted exponential relationship or replaced with a more descriptive formulation such as “decreases strongly/nonlinearly.”

done

5. Please define consistently whether reported uncertainties represent 2SD or 2SEM. Every figure caption should explicitly specify the uncertainty represented by error bars.

done

6. Figure 2 should clearly distinguish the “standard deviation of individual analyses (external reproducibility)” from the uncertainty of the mean (2σM = ±0.06‰). The very small uncertainty on the mean should not be described as the analytical reproducibility of an individual coral measurement.

done

7. Table 3 should report not only Pearson correlation coefficients, but also the number of paired observations and exact p values for each comparison. Because the time series are autocorrelated, the authors should also consider whether nominal Pearson p values overestimate significance.

We will add the number of paired observations and exact p values for each comparison to Table 3. We also evaluated the lag-1 autocorrelation of the records used for these comparisons. The records did not show consistently strong lag-1 autocorrelation, although some showed low to moderate autocorrelation. Given the small number of paired observations, higher-lag autocorrelation estimates would be highly uncertain. We therefore retained the Pearson correlations and nominal p values, but will revise the text to avoid overinterpreting statistical significance.

8. The statement that “the temporal resolution is limited solely by sample availability” is too strong. Temporal resolution is also limited by growth rate/band thickness, sampling geometry, age-model uncertainty, U concentration, required U mass, and analytical precision.

done

9. The statement that concordant δ234U among species “confirms the lack of fractionation observed using the 238U/235U ratios” should be softened. Agreement in 234U/238U does not directly constitute confirmation of observations made using a different uranium isotope ratio.

done

10. Please clarify the exact role of the 233U–236U TriSpike. The Methods describe the spike composition but later state that instrumental mass bias was corrected using natural 235U/238U. It would be useful to state explicitly which isotope ratios are used for concentration determination, spike correction, and mass-fractionation correction.

We thank the reviewer for pointing out the need for clarification. We will revise the Methods to state explicitly that the 233U–236U TriSpike is used for uranium concentration determination, whereas instrumental mass bias of the natural uranium isotope ratios is corrected independently using the 235U/238U ratio. The corrected 234U/238U ratio is subsequently used to calculate δ234U. The detailed measurement and data-reduction procedure is described in Kerber et al. (2023, 2025).

11. The manuscript would benefit from explicitly reporting the “234U signal intensity”, rather than only total U concentration. Hu et al. show that uncertainty in the 10to13 Ω amplifier baseline and tail correction directly controls the achievable precision of the small 234U beam. This would make the analytical comparison much more meaningful than solution concentration alone.

done

12. There are several typographical and grammatical issues that should be corrected, such as duplicated words (“the theca”), “corals species,” “reproducability,”, etc.

done