Response to Anonymous Referee #2

Below, we provide a point-by-point response to each comment. The reviewer's comments are shown in black italics, our responses in blue, and the proposed revised text in red (*Reviewer comment*, Response, Revised text).

Anonymous Referee #2:

This study by Lin et al. presents three tree-ring cellulose oxygen-isotope chronologies developed along a latitudinal gradient and evaluates their potential for reconstructing hydroclimatic variability across the East European Plain, a region where this proxy remains comparatively understudied.

The main finding from this study is that δ18OTRC retains stronger sensitivity to atmospheric moisture conditions than TRW at the wetter, temperature-limited northern and central sites, whereas TRW more directly reflects soil-moisture limitation at the drier southern site.

Overall, the study is well-organised and shows a clear main objective, consistently developed throughout the manuscript. The methods used for sample preparation and the general analytical framework are appropriate. The manuscript is generally well grounded in the relevant literature and the discussion includes topics which are of great interest within this research field.

I found the manuscript scientifically interesting and generally well prepared. My comments mainly concern methodological transparency, statistical interpretation and the clarity of some passages. The following comments should help improve the methodological transparency, clarity and interpretation of the results.

We thank the reviewer for the careful and constructive assessment of our manuscript. The comments have helped us improve the methodological transparency, statistical interpretation, and clarity of the study. We have carefully considered each comment and will revise the manuscript accordingly, as detailed below.

Comments 1: *Lines 43–54: The paragraph provides a useful broad overview of the latitudinal transition from temperature- to moisture-limited TRW. However, it would benefit from a more explicit summary of the principal seasonal climate controls reported in previous studies, for example, which temperature and moisture variables dominate, during which months or seasons and in which parts of the region. This would provide a clearer basis for evaluating the additional information supplied by δ18OTRC.*

Response 1: Thank you for this comment. We have revised this paragraph to more clearly describe the dominant climatic variables, seasonal response windows, and their spatial distribution for TRW across the East European Plain. The revised text clarifies that TRW in the northern region responds primarily to June–July temperature, the central transitional region is influenced jointly by summer temperature and moisture conditions, whereas TRW in the southern region is primarily limited by warm-season moisture availability. These additions provide a clearer background for evaluating the complementary hydroclimatic information provided by $\delta^{18}O_{TRC}$. The corresponding revision is provided below.

Revised text in the Introduction (original Lines 45–47): First, TRW–climate relationships show pronounced regional differences across the East European Plain, with a transition from temperature limitation to moisture limitation around 55–60° N (Matskovsky, 2016). North of approximately 60°

N, conifer TRW generally responds positively to summer temperature, with the strongest responses occurring mainly in June and July (Dolgova et al., 2022; Matskovsky, 2016; Semenyak and Dolgova, 2023). In the central transitional region at approximately 54–56° N, TRW is jointly influenced by summer temperature and moisture conditions, with the main moisture-related variables including precipitation, PDSI, and soil moisture (Matskovsky, 2016). Farther south, in the southern Middle Volga region and the forest-steppe zone of Voronezh, pine growth is primarily limited by warm-season moisture availability (Kuznetsova and Solomina, 2022; Matveev et al., 2019).

Comments 2: *Line 72: Including some comments about the cited spatial heterogeneity would give important context on how the dominant controls and seasonal response windows of δ18OTRC are expected to vary with moisture source, transport pathway and local hydroclimatic regime. Now it is only mentioned that the dominant controls "can shift with changes in moisture sources…", but it is not specified how those shifts actually are.*

Response 2: Thank you for this comment. We have revised this paragraph to further explain the mechanisms underlying the spatial heterogeneity in the climate sensitivity of $\delta^{18}O_{TRC}$. The revised text clarifies that moisture sources and transport pathways influence the isotopic composition of precipitation and tree source water; local relative humidity and evaporative demand regulate leaf-water evaporative enrichment; and soil-water storage and the mixing of precipitation from different seasons alter the seasonal contribution of precipitation to tree source water. These processes may cause the dominant controls, response strength, and seasonal windows of $\delta^{18}O_{TRC}$ to vary under different hydroclimatic settings. This spatial heterogeneity motivated our regional, multi-site assessment across the East European Plain. The corresponding revision is provided below.

Revised text in the Introduction (original Lines 69–72): Moisture sources and transport pathways influence the isotopic composition of precipitation and tree source water, whereas local relative humidity and evaporative demand regulate leaf-water evaporative enrichment (Gat, 1996; McCarroll and Loader, 2004; Roden et al., 2000). Soil-water storage and seasonal mixing can further alter the contribution of precipitation from different seasons to tree source water, potentially extending the $\delta^{18}O$ climate response beyond the period of cellulose formation (Treydte et al., 2014). Consequently, the dominant controls, response strength, and seasonal response windows of $\delta^{18}O_{TRC}$ may differ among hydroclimatic settings (Freund et al., 2023; Treydte et al., 2007).

Comments 3: *Lines 101-106: The description of summer temperature is potentially confusing because "temperatures decreased from the south to the central region" may be read as implying a temporal change rather than a spatial gradient. Please rephrase the sentence to state the site values directly or describe an increase in summer temperature from north to south.*

Response 3: Thank you for this comment. We have revised the sentence to report the mean summer temperature at each of the three sites directly and to clearly describe the north–south spatial gradient. The corresponding revision is provided below.

Revised text in the Material and methods (original Lines 103–105): Mean summer (June–August) temperature increased from 12.86 °C at the northern site to 16.73 °C at the central site and 19.66 °C at the southern site.

Comments 4: *Lines 131–132: Please explain and justify the criteria used to select cores for δ18O analysis. How many candidate trees and cores were available at each site, how many met the* *eligibility criteria and how were the four analysed trees selected from that eligible set? In particular, please clarify why cores containing missing or extremely narrow rings were excluded and whether these criteria were defined a priori and applied consistently across sites. Extremely narrow rings may record biologically and climatically meaningful growth-suppression events; excluding them could therefore introduce selection bias unless exclusion was analytically necessary, for example because they provided insufficient cellulose for reliable isotope measurement. The methodological justification should be supported with relevant literature. Please also explain why replication was increased only at the northern site and discuss the resulting imbalance among sites.*

Response 4: Thank you for this comment. We have added the selection criteria for cores used in the $\delta^{18}O_{TRC}$ analysis to the Methods section, and Supplementary Table S1 now lists the numbers of candidate trees, candidate cores, and cores finally selected for isotope analysis at each site.

Regarding core selection, although the three sites were sampled at different times, our laboratory has long applied the same selection criteria, which were used consistently across all three sites. These criteria included preferentially selecting the oldest cores to minimize potential juvenile effects; reliable cross-dating and continuous coverage of the target period; clearly identifiable ring boundaries; the ability to separate individual rings without contamination from adjacent rings; and sufficient α-cellulose for isotope measurements (Xu et al., 2011, 2013b). Narrow rings were not excluded simply because of their small width; they were retained as long as they could be reliably separated and provided sufficient material for isotope analysis. Cores containing missing rings were not selected because they could not provide a continuous annual isotope series. Based on these criteria, four cores from four different trees were selected directly from all candidate cores at each site.

Regarding sample size, four cores from four different trees were initially analyzed at each of the three sites. Additional sampling at the northern site in 2021 allowed us to extend the isotope chronology to 2021, whereas no comparable additional material was available for the central and southern sites. Because the three additional northern cores cover only approximately 20 years (2000–2021), the long-term Rbar and EPS for the northern site were still calculated from the original four long cores, yielding values of 0.67 and 0.89, respectively. During the overlapping period, the original four-tree chronology and the expanded seven-tree chronology showed similar interannual variability (Fig. S2a), and their climate-response patterns were also broadly consistent, particularly for summer hydroclimatic variables (Fig. S2b, c). Therefore, the increased recent replication at the northern site did not substantially alter the dominant climate signals identified in this study or the main conclusions. Accordingly, we have expanded the description of core selection, added the corresponding comparison results, and added Table S1 and Fig. S2 to the Supplementary Material, as detailed below.

Table S1. Numbers of candidate trees and cores available, and cores selected for $\delta^{18}O_{TRC}$ analysis at each study site.

Site	Candidate trees	Candidate cores	Selected cores
Northern—B75S	21	42	4
Northern—B93S	18	36	3
Central—A22S	16	30	4
Southern—T03S	21	36	4

B75S, B93S, A22S, and T03S are sample codes. B93S denotes the additional samples collected during the 2021 resampling campaign at the northern site.

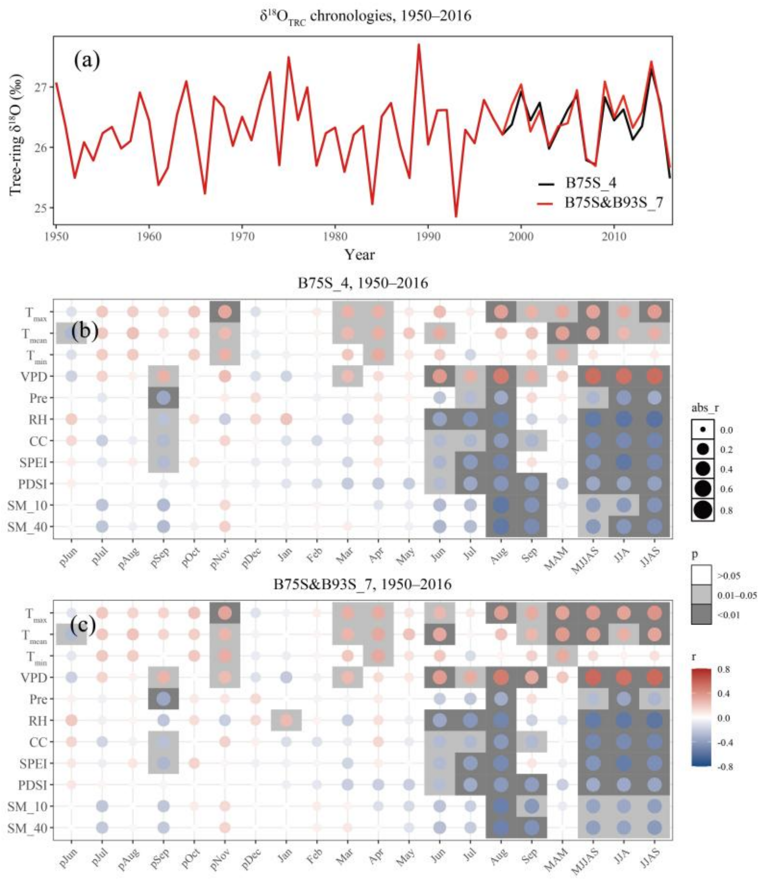

Figure S2. Comparison of the original and expanded northern $\delta^{18}O_{TRC}$ chronologies and their climate responses. (a) Comparison between the original four-tree chronology (B75S_4) and the expanded seven-tree chronology (B75S&B93S_7); correlations between climate variables and (b) the original four-tree $\delta^{18}O_{TRC}$ chronology and (c) the expanded seven-tree $\delta^{18}O_{TRC}$ chronology.

Revised text in the Material and methods (original Lines 131–134): The numbers of candidate samples and the results of core selection for $\delta^{18}O_{TRC}$ analysis are summarized in Table S1. The same selection criteria were applied at all three sites, including preferentially selecting the oldest cores to minimize potential juvenile effects, reliable cross-dating and continuous temporal coverage, clearly identifiable ring boundaries, and the ability to isolate individual rings without contamination from adjacent rings while obtaining sufficient α-cellulose for isotope measurement (Xu et al., 2011, 2013b). Narrow rings were retained as long as they could be reliably separated and provided sufficient material, whereas cores containing missing rings or rings that could not be reliably separated and measured were not selected. Based on these criteria, four cores from four different trees were initially selected from all candidate cores at each site. Additional sampling at the northern site in 2021 provided three further cores covering 2000–2021, allowing the isotope chronology to be extended to 2021.

Added text in the Results (after original Line 218): The original four-tree and expanded seven-tree chronologies at the northern site showed similar interannual variability over their overlapping period (Fig. S2a).

Added text in the Results (after original Line 257): Notably, at the northern site, the original four-tree and expanded seven-tree chronologies also showed broadly consistent climate-response patterns, particularly for summer hydroclimatic variables (Fig. S2b, c).

Comments 5: *Lines 187–190 and 213–219: The central and southern isotope chronologies are based on only four trees and have EPS values of 0.84. Although these values indicate appreciable common signal strength, the statement that the chronologies "effectively capture a common environmental signal" may be too categorical, particularly because 0.85 is frequently used as a conventional benchmark and because EPS does not by itself eliminate the uncertainty associated with low replication. Please provide the precise calculation procedure and clarify whether EPS and Rbar vary through time. If available, time-varying sample depth, Rbar and EPS should be shown. The conclusions concerning regional representativeness and reconstruction potential should also acknowledge this limitation.*

Response 5: Thank you for this comment. We agree that the EPS values at the central and southern sites (0.84) are slightly below the commonly used reference threshold of 0.85. Therefore, the original statement that "these chronologies effectively capture a common environmental signal" was too definitive. We have revised this statement to indicate that "EPS ≥ 0.84 suggests overall coherent inter-tree signals within each site," and we have also acknowledged the uncertainty associated with low sample replication when discussing the regional representativeness and reconstruction potential of the chronologies.

We have further added details on the calculation of Rbar and EPS in the Methods section. At each site, pairwise Pearson correlations were calculated among the four individual-tree $\delta^{18}O_{TRC}$ series, and the arithmetic mean of the six pairwise correlation coefficients was used as Rbar. EPS was then calculated from Rbar and a fixed sample replication of N = 4, following Wigley et al. (1984). The three additional series collected at the northern site in 2021 cover only approximately 2000–2021 and were therefore not included in the calculation of the long-term Rbar and EPS. Because the isotope chronologies span only approximately 65–72 years and have relatively low sample replication, Rbar and EPS were used as summary measures of inter-tree coherence over the common period of the four original core series at each site rather than being calculated using moving windows. Annual sample replication at each site has now been added to Fig. 2. Accordingly, we have clarified the Rbar and EPS calculations, revised the interpretation of EPS, acknowledged the limitation associated with low replication, and added annual sample depth to Fig. 2, as detailed below.

Added text in the Material and methods (after original Line 191): Rbar was calculated as the mean of all pairwise Pearson correlations among the four original core series at each site, and EPS was derived from Rbar using a fixed sample replication of N = 4. Because the isotope chronologies span only approximately 65–72 years, Rbar and EPS were calculated over the common period of the four original core series at each site rather than using moving-window analyses. The three additional northern series cover only approximately 2000–2021 and were therefore excluded from these calculations.

Revised text in the Results (original Lines 218–219): EPS was ≥ 0.84 at all three sites, suggesting overall coherent inter-tree signals within each site.

Added text in the Discussion (after original Line 418): However, the low replication and EPS values of 0.84 at the central and southern sites introduce uncertainty into chronology representativeness and should be considered when evaluating their regional applicability and reconstruction potential.

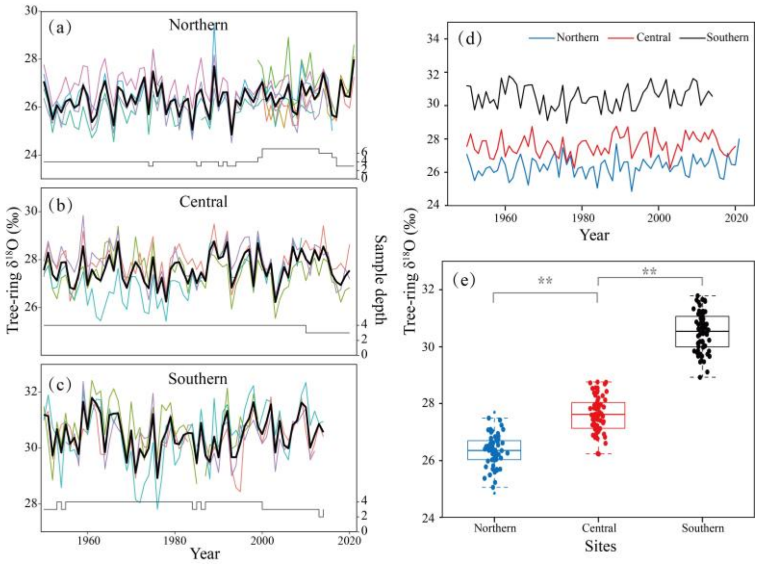

Figure 2. $\delta^{18}O_{TRC}$ chronologies for the northern (a), central (b), and southern (c) East European Plain. Individual $\delta^{18}O_{TRC}$ series are shown as thin colored lines; the site mean chronologies are shown as thick black lines. Annual sample depth is shown by the gray step lines in panels (a–c). Time-series plots (d) and box-and-whisker plots (e; 1950–2014) show the $\delta^{18}O_{TRC}$ chronologies at the three sites. In panel (e), the line within each box denotes the median; box limits indicate the 25th and 75th percentiles; and filled circles denote outliers. Asterisks indicate statistical significance (**, $p < 0.01$).

Comments 6: *Lines 411–417 and 440–451, particularly lines 445-446: The conclusion that the northern chronology is sufficiently strong and stable to support a "reliable climate reconstruction" appears stronger than the analyses presented. The study demonstrates a statistically significant climate–proxy association and explores its temporal stability, but it does not perform a reconstruction or report calibration–verification statistics. I suggest consistently referring to "reconstruction potential" unless predictive skill is evaluated using an appropriate calibration and validation framework.*

Response 6: Thank you for this comment. We have revised "reliable climate reconstruction" and similar statements throughout the manuscript to "climate reconstruction potential." The corresponding revisions are provided below.

Revised text in the Discussion (original Lines 413–415): The northern $\delta^{18}O_{TRC}$ chronology exhibits a strong and stable growing-season VPD signal (Fig. 3; Fig. S3; Fig. S7), indicating particularly strong potential for high-latitude hydroclimate reconstruction.

Revised text in the Conclusions (original Lines 444–446): The $\delta^{18}O_{TRC}$ chronologies at three sites record a coherent signal of regional summer hydroclimate variability, but the northern chronology shows the strongest and most stable climate response, indicating the greatest reconstruction potential.

Revised text in the Conclusions (original Lines 450–452): Overall, our study demonstrates that $\delta^{18}O_{TRC}$ contains valuable information on the spatiotemporal patterns of hydroclimate variability across the East European Plain and highlights its potential for future hydroclimate reconstruction.

References cited in our response

Xu, C., Sano, M., and Nakatsuka, T.: Tree ring cellulose $\delta^{18}O$ of *Fokienia hodginsii* in northern Laos: A promising proxy to reconstruct ENSO?, J. Geophys. Res.-Atmos., 116, D24109, https://doi.org/10.1029/2011JD016694, 2011.

Xu, C., Zheng, H., Nakatsuka, T., and Sano, M.: Oxygen isotope signatures preserved in tree ring cellulose as a proxy for April–September precipitation in Fujian, the subtropical region of southeast China, J. Geophys. Res.-Atmos., 118, 12805–12815, https://doi.org/10.1002/2013JD019803, 2013b.
Wigley, T. M. L., Briffa, K. R., and Jones, P. D.: On the Average Value of Correlated Time Series, with Applications in Dendroclimatology and Hydrometeorology, J. Clim. Appl. Meteorol., 23, 201–213, https://doi.org/10.1175/1520-0450(1984)023%3C0201:OTAVOC%3E2.0.CO;2, 1984.