

RC2: 'Comment on egusphere-2025-952', Anonymous Referee #2, 16 Apr 2025

General comments

*This manuscript examines the long-term physiological and growth responses of *Abies spectabilis* across elevational gradients in wet and dry regions of the Tibetan Plateau, using tree-ring width, basal area increment (BAI), and ^{13}C -derived intrinsic water-use efficiency (iWUE). The authors aim to disentangle the relative roles of climate warming and atmospheric CO_2 in modulating tree growth. The study addresses timely questions in forest ecophysiology and uses standard dendrochronological and isotope techniques. However, the manuscript suffers from several significant conceptual, methodological, and shortcomings. The analysis relies heavily on correlative patterns/scenarios with limited mechanistic interpretation. Basic sample metadata is omitted and critical information on detrending and sample replication is lacking. Moreover, while the Tibetan Plateau is an understudied region, the manuscript largely reproduces well-established findings regarding iWUE trends, growth–climate relationships, and physiological strategies under CO_2 enrichment. The analysis does not introduce new mechanisms, theory, or methods. Thus, its novelty lies primarily in applying standard approaches to a geographically distinct context—which is of regional interest, but not a substantial conceptual advancement for the field.*

[Response]: We sincerely appreciate the time and effort taken to evaluate our manuscript, and we are grateful for the constructive feedback that will undoubtedly strengthen our work. Below we address each of the main concerns raised:

Conceptual Advancements: Our study advances current understanding by revealing how the interplay between elevational and moisture gradients generates divergent physiological responses in high-elevation forests dominated by a single species (*Abies spectabilis*). Importantly, we identified critical moisture-dependent thresholds in CO_2 response, demonstrating that even within the same species, trees exhibit fundamentally different physiological strategies depending on their local environmental context. These findings provide compelling empirical evidence from a climate-sensitive yet understudied region that challenges prevailing assumptions

about uniform species-level responses to climate change in ecosystem models.

Methodological Concerns: We have substantially revised the Methods section to provide comprehensive information on the samples, including detailed descriptions of detrending approaches and sample statistics (Table S1-S2). In terms of mechanistic interpretation, we have provided a table to detail the parameters and stats of the SEMs (Table S3).

Below, please see a detailed point-by-point response to your concerns.

Major concerns

1. The authors fail to report key information about the sampled trees, such as sample sizes per site, tree ages (range and mean), diameter at breast height (DBH), or inter-individual variability. Given the long temporal scope, this omission undermines the interpretation of growth trends. Tree age can confound long-term growth patterns and sensitivity to climate or CO₂. This basic metadata must be included in a table or appendix.

[Response]: Thanks for your comment. We fully agree that these basic metadata are important for the interpretation on the results. Therefore, we have added more information on the tree ages and DBH in the Table S1. Moreover, we have also provided the specific information on the tree cores that were used for isotope analysis in the Table S2.

Table S1. Information for the tree-ring samples on the southern Tibetan Plateau.

Position	Site	Species	Latitude (°N)	Longitude (°E)	Altitude (m)	Trees	DBH (cm)	Mean age	No. of stems/ha	TRW time span	rbar	MS
Treeline	SYDU	ABSP	27.506	88.99	4152	70	31.0±21.5	68	146	1784- 2014	0.41	0.18
Middle altitude	SYDM	ABSP	27.515	88.99	3872	31	28.5±10.0	47	840	1837- 2014	0.34	0.19
Lower altitude	SYDD	ABSP	27.516	88.99	3680	28	27.4±10.1	34	873	1938- 2014	0.25	0.2

Treeline	DJU	<i>ABSP</i>	27.837	87.47	3918	19	25.0±5.8	132	344	1780-2006	0.40	0.17
Middle altitude	DJM	<i>ABSP</i>	27.838	87.46	3657	19	40.1±9.5	129	450	1774-2006	0.43	0.16
Lower altitude	DJD	<i>ABSP</i>	27.84	87.46	3378	13	28.3±6.6	85	556	1893-2006	0.37	0.18

ABSP, *Abies spectabilis*; rbar, the mean inter-series correlation; MS, mean sensitivity; DBH, diameter at breast height.

Table S2. Information for the tree-ring samples for isotope measurement on the southern Tibetan Plateau.

Position	Site	Species	Trees	TRW time span	Isotope data time span	Mean age	DBH (cm)	rbar	MS
Treeline	SYDU	<i>ABSP</i>	6	1784-2014	1901-2014	160	25.7±2.9	0.25	0.23
Middle altitude	SYDM	<i>ABSP</i>	5	1837-2014	1949-2014	90	28.7±4.9	0.25	0.24
Lower altitude	SYDD	<i>ABSP</i>	5	1938-2014	1973-2014	51	25.4±2.9	0.35	0.22
Treeline	DJU	<i>ABSP</i>	7	1780-2006	1888-2006	155	31.5±4.2	0.47	0.15
Middle altitude	DJM	<i>ABSP</i>	5	1774-2006	1869-2006	207	55.5±8.4	0.31	0.18
Lower altitude	DJD	<i>ABSP</i>	5	1893-2006	1897-2006	107	39.9±2.0	0.54	0.15

ABSP, *Abies spectabilis*; rbar, the mean inter-series correlation; MS, mean sensitivity; DBH, diameter at breast height.

2. While the authors use ARSTAN with negative exponential or linear detrending, they do not explain how this affects long-term trends—the central focus of the paper. Detrending can remove real long-term growth signals (e.g., due to CO₂ fertilization). Were raw BAI series analyzed? Were alternative detrending methods tested (e.g., Regional Curve Standardization)? This needs clarification and discussion.

[Response]: We appreciate the reviewer's valuable comment regarding the potential influence of detrending methods on growth trend detection. In this study, we used raw basal area increment (BAI) series to assess long-term growth trends, as BAI is less susceptible to biological trends and provides a more direct measure of stem biomass compared to tree-ring width data (Franco and Fares, 2008; Yang et al., 2022b;

Martinez-Sancho et al., 2018). To further minimize age-related effects, we excluded the early growth period from both trend analysis and isotope measurements ([Table S2](#)).

For climate-growth relationship analysis, we applied standard detrending procedures to BAI series using both negative exponential/linear and spline function approaches (Conover, 2012; Van Der Sleen et al., 2015). Importantly, our results revealed consistent climate-growth relationships across different detrending methods for all major climate variables.

To enhance clarity, we have revised the Methods section to: (1) explicitly state that detrended data were used exclusively for climate-growth analysis; (2) clearly distinguish between the applications of raw BAI (for growth trends) and standardized BAI chronologies (for climate responses); (3) provide more detailed documentation of our detrending procedures.

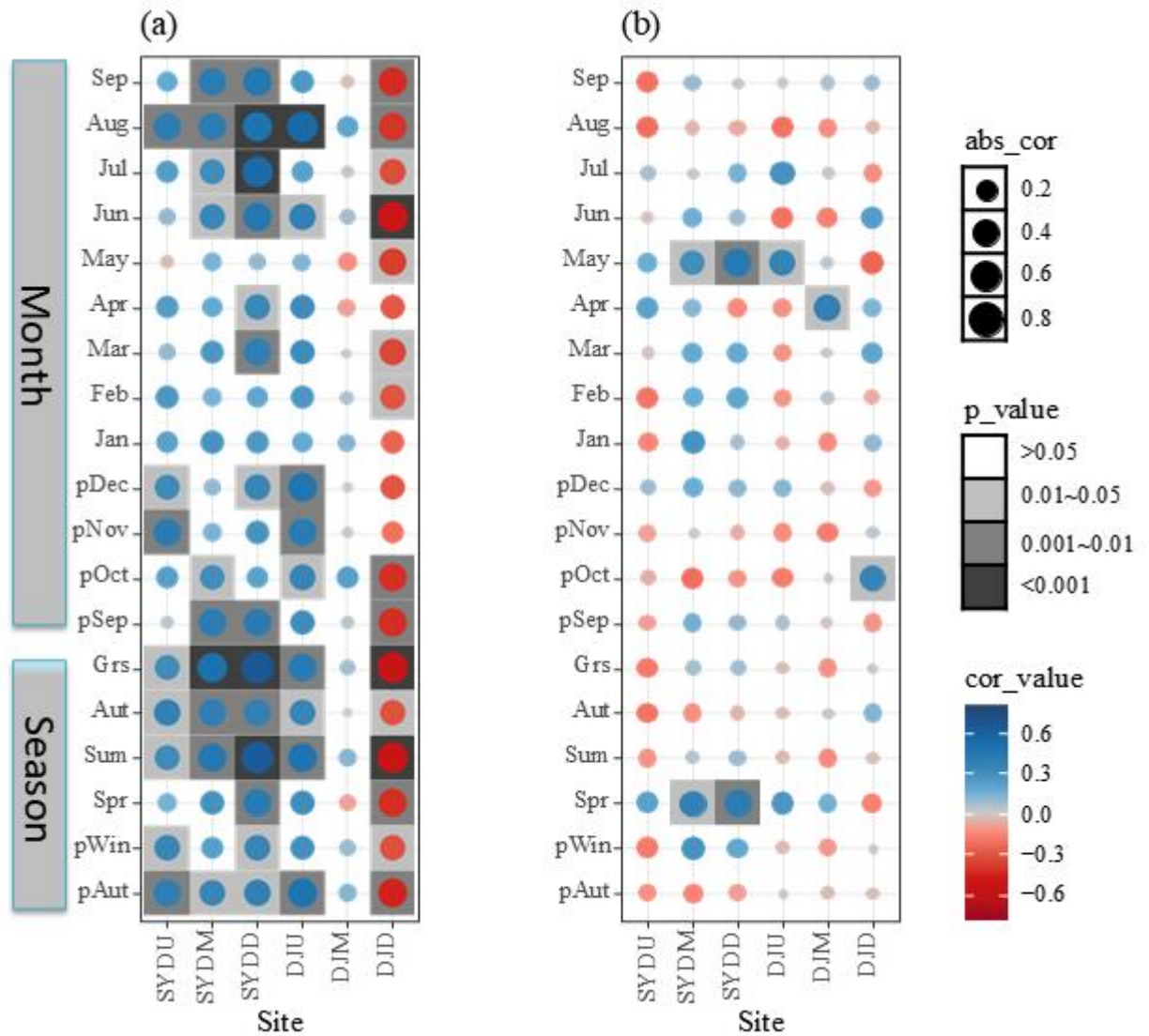
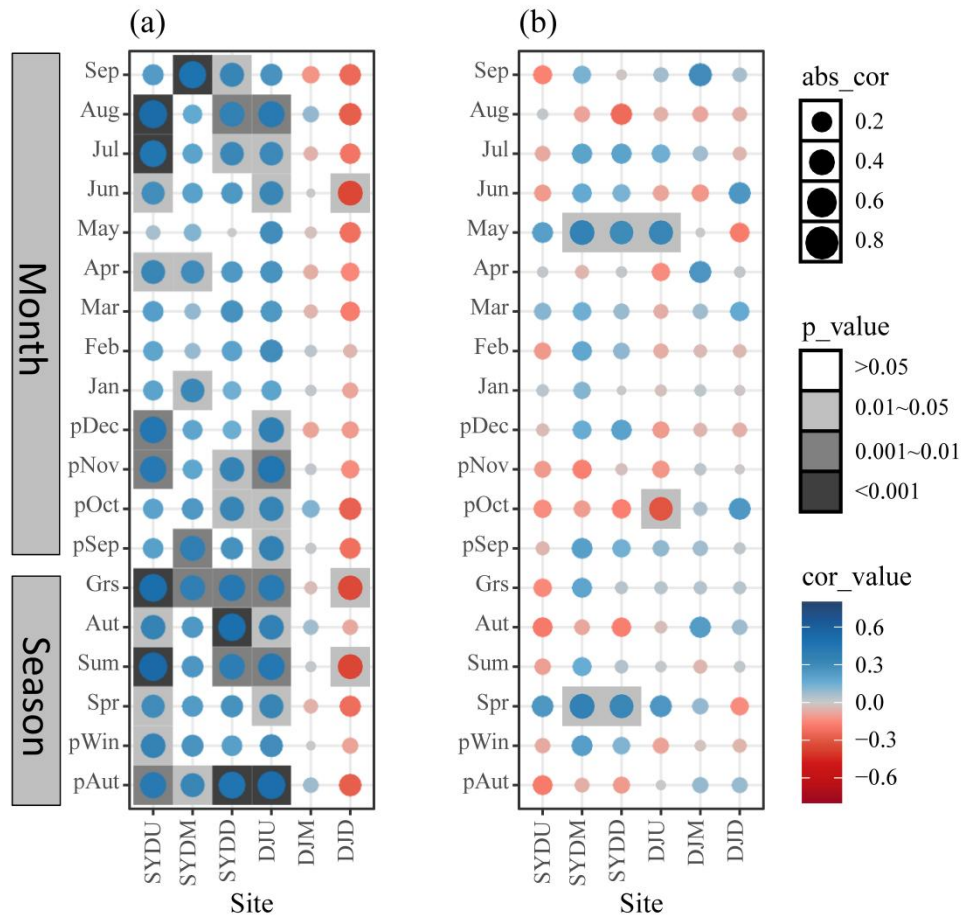


Figure 6. Pearson correlation coefficients between **detrended** basal area increment and climatic variables, including (a) mean temperature and (b) total precipitation, on both monthly and seasonal scales for Himalayan fir during the period 1965–2013. **Note that the BAI series were detrended using negative exponential or linear curves.** "Grs" denotes the growing season (June to September). "Cor_value" and "abs_value" represent the correlation coefficient value and the absolute value of the correlation, respectively.

The results using a smoothing spline function with 50% variance cutoff at two thirds of the series length are as follows:



3. The use of theoretical C_i/C_a trajectories (Scenarios 1 – 3) is oversimplified. These scenarios assume fixed relationships that rarely hold across environmental gradients or time. The authors treat alignment with Scenario 1 (" $C_i = \text{constant}$ ") as evidence of physiological strategy but offer no underlying reasoning in terms of stomatal control, leaf traits, or drought response. This needs much deeper physiological interpretation.

[Response]: We sincerely appreciate the reviewer's insightful comment. We fully acknowledge that the theoretical scenarios of C_i/C_a changes presented in our initial analysis were overly simplistic and did not provide meaningful mechanistic explanations for our core findings. In response to this valuable feedback, we have removed both the C_i/C_a analysis and related discussion from the revised manuscript.

4. The authors repeatedly attribute growth changes to rising C_a or warming based on correlations, without ruling out confounding variables (e.g., age, stand density, soil

conditions). The SEM framework is promising but underdeveloped, and the model structure, diagnostics, and assumptions are not detailed.

[Response]: Thank you for your valuable comment. We fully acknowledge that factors such as tree age, stand density, and soil conditions can influence tree growth. To minimize age-related effects, particularly in the early growth stages, we excluded tree rings from initial years showing strong growth trends, thus the shorter temporal coverage of isotope data compared to tree-ring width chronologies (Table S2). While other stand characteristics (e.g., density and soil conditions) may indeed affect growth-climate-CO₂ relationships - and we have now included this information in the revised manuscript (Tables S1-S2) - these factors remain relatively stable over time and are unlikely to explain the observed temporal growth changes in recent decades. Rather, the pronounced climate change and rising atmospheric CO₂ concentrations appear to be the dominant drivers of interannual growth variations of trees in the high-altitude forests of this study (Panthi et al., 2020; Yang et al., 2022a).

To enhance the robustness of our structural equation modeling (SEM) approach, we have: (1) expanded the methodological description regarding factor selection in model construction; (2) clarified the interpretation of statistical outputs and model diagnostics; and (3) provided comprehensive piecewise SEM results in the supplemental materials (Table S3).

Table S3. Summary of the piecewise structural equation meta-model (pSEM) for testing the influences of climatic factors on basal area increment (BAI) and intrinsic water-use efficiency (iWUE) of Himalayan fir during the period 1965 – 2010s at different altitudes. β is the standardized regression coefficient, and S.E. is the standard error. Abbreviations: Tpaut = previous autumn mean temperature; Tsum = summer mean temperature; Tspr = spring mean temperature; Tgrs = growing season mean temperature (June to September); RHspr = spring relative humidity; RHgrs = growing season relative humidity (June to September); RHwin = winter relative humidity; SPEIspr = spring standardized precipitation-evapotranspiration index; SPEIgrs = growing season standardized precipitation-evapotranspiration index (June to September).

Site	Response variable	Predictor variable	β	S.E.	Critical value	P-value
SYDU	BAI	iWUE	0.1166	0.0309	0.7472	0.4589
	BAI	Tgrs	0.1435	0.7033	0.8961	0.3751
	BAI	Tpaut	0.3777	0.2276	2.8362	<0.01
	BAI	Pgrs	-0.2081	0.0046	-1.556	0.1269
	iWUE	Tgrs	0.5308	2.7814	4.2362	<0.001

SYDM	iWUE	Tpaut	-0.0738	1.1135	-0.5724	0.5699
	iWUE	SPEIspr	0.1567	1.8069	1.2155	0.2305
	BAI	iWUE	0.2137	0.0703	1.4584	0.152
	BAI	Tgrs	0.2994	2.354	2.0129	<0.1
	BAI	Tpaut	0.1949	0.758	1.5834	0.1207
	BAI	Pgrs	0.1959	0.0156	1.5546	0.1274
	BAI	RHgrs	-0.2499	0.5443	-1.9459	<0.1
	iWUE	Tgrs	0.5562	4.2002	4.3683	<0.001
	iWUE	Tpaut	0.1356	1.5725	1.1065	0.2744
	iWUE	RHgrs	0.0315	1.1155	0.2491	0.8044
SYDD	BAI	iWUE	0.4527	0.0997	3.0971	<0.01
	BAI	Tgrs	0.2431	2.8764	1.7251	<0.1
	BAI	Tspr	0.161	1.1319	1.4095	0.1673
	BAI	Pspr	0.2083	0.0215	1.8744	<0.1
	iWUE	Tgrs	0.5507	3.7033	4.4483	<0.001
	iWUE	Tspr	0.2051	1.7453	1.7063	<0.1
	iWUE	RHgrs	-0.2113	0.9069	-1.7321	<0.1
	BAI	iWUE	0.0256	0.0323	0.174	0.8628
	BAI	Tgrs	0.2596	0.379	1.659	0.1056
	BAI	Tspr	0.1989	0.2468	1.2472	0.2202
DJU	BAI	RHspr	0.4223	0.0459	2.906	<0.01
	iWUE	Tgrs	-0.0401	2.0466	-0.216	0.8302
	iWUE	Tspr	0.3189	1.2732	1.7613	<0.1
	iWUE	RHspr	0.3172	0.2197	2.0745	<0.05
	iWUE	SPEIspr	0.2289	1.9737	1.363	0.1811
	BAI	iWUE	0.4975	0.0532	2.8913	<0.01
	BAI	Tgrs	-0.0034	0.8131	-0.0197	0.9844
	BAI	Tspr	-0.4129	0.4904	-2.5119	<0.05
	BAI	RHspr	-0.5529	0.0866	-3.8923	<0.001
	BAI	Pspr	0.2686	0.0585	1.919	<0.1
DJM	iWUE	Tgrs	0.442	2.2004	3.0331	<0.01
	iWUE	Tspr	0.271	1.4057	1.8595	<0.1
	BAI	iWUE	-0.1942	0.063	-1.5072	0.14
	BAI	Tgrs	-0.5024	0.7402	-3.9003	<0.001
	BAI	RHwin	-0.2553	0.0577	-2.0357	<0.05
	iWUE	Tpaut	0.2125	1.3755	1.1598	0.2532
	iWUE	Tgrs	0.1124	2.1529	0.6132	0.5433
DJD						

5. Many of the main findings—that iWUE increased, growth responded positively to warming in wet regions, and drought limits growth at lower elevations—are well established in the literature. The manuscript would benefit from a clearer articulation

of what is truly new.

[Response]: Thank you for your comment. Our study advances current understanding of tree-growth responses to environmental changes by examining a unique combination of two key gradients—altitude and moisture—in forests dominated by a single species (*Abies spectabilis*).

Specifically, our study provides novel insights in two key ways:

(1) Spatial Heterogeneity of CO₂ Fertilization Effects: By comparing wet and dry regions, we demonstrate that both temperature and water availability acts as critical thresholds, determining whether elevated CO₂ enhances growth. This finding underscores that growth responses in high-altitude forests depend on the interplay between elevational gradients and regional moisture conditions.

(2) Dual Effects of Temperature on Growth: Using piecewise structural equation modeling (pSEM), we quantify contrasting roles of the increased temperatures in growth dynamics. At lower altitudes with water deficits, conservative stomatal regulation likely explains why improved intrinsic water-use efficiency (iWUE) did not consistently translate into growth benefits.

6. The manuscript references nutrient availability as a potentially limiting factor (e.g., lines 54–56, 238), citing literature that suggests it can constrain the CO₂ fertilization effect. However, no nutrient data (e.g., soil N or P) are presented or analyzed. This creates a mismatch between the framing and execution of the study. Either include relevant data or remove unsupported speculation.

[Response]: Thank you for your insightful comment. We agree that our original discussion regarding the effects of nutrient availability may have been overly speculative, particularly given the lack of direct evidence in our current study. Accordingly, we have removed this section and the associated references to better focus on our actual findings in the revised manuscript.

7. While I believe that using AI to assist with scientific writing is acceptable, the

manuscript shows clear signs of overreliance, including inconsistent use of abbreviations, redundancy of abbreviations, and occasional lapses in technical accuracy. The dataset presented is valuable, but the manuscript requires substantial revision to improve clarity, coherence, and scientific precision before it can be considered for publication.

[Response]: Thanks for the comment. We have carefully examined the whole manuscript to cure the issues regarding the inconsistent use of abbreviations and the technical inaccuracies to ensure the precision and coherence of the text.

Minor comments

1. Use species name in italic.

[Response]: Sure. Done as suggested.

2. More information on the ice core data are needed

[Response]: Thanks for your comment. We have added more information on the source of the CO₂ data in the revised manuscript: “CO₂ concentration data was derived from a combination of the reconstructed values (period 1900-2003) using ice cores (Mccarroll and Loader, 2004; Boucher et al., 2014) and the direct observations of CO₂ concentration for the period 2004-2013, which were obtained from the Mauna Loa Observatory of America (<http://www.esrl.noaa.gov/gmd/obop/mlo/>).”

3. Figures: Captions are too brief (especially in Figs. 2, 3, 4, 5) (also, there are no legend for coloring in figures).

[Response]: Thanks for your comment. We have added the color legends in the figures and supplied more information in the captions for the figures 2-4. Note that the original Fig. 5 was removed in the revised manuscript.

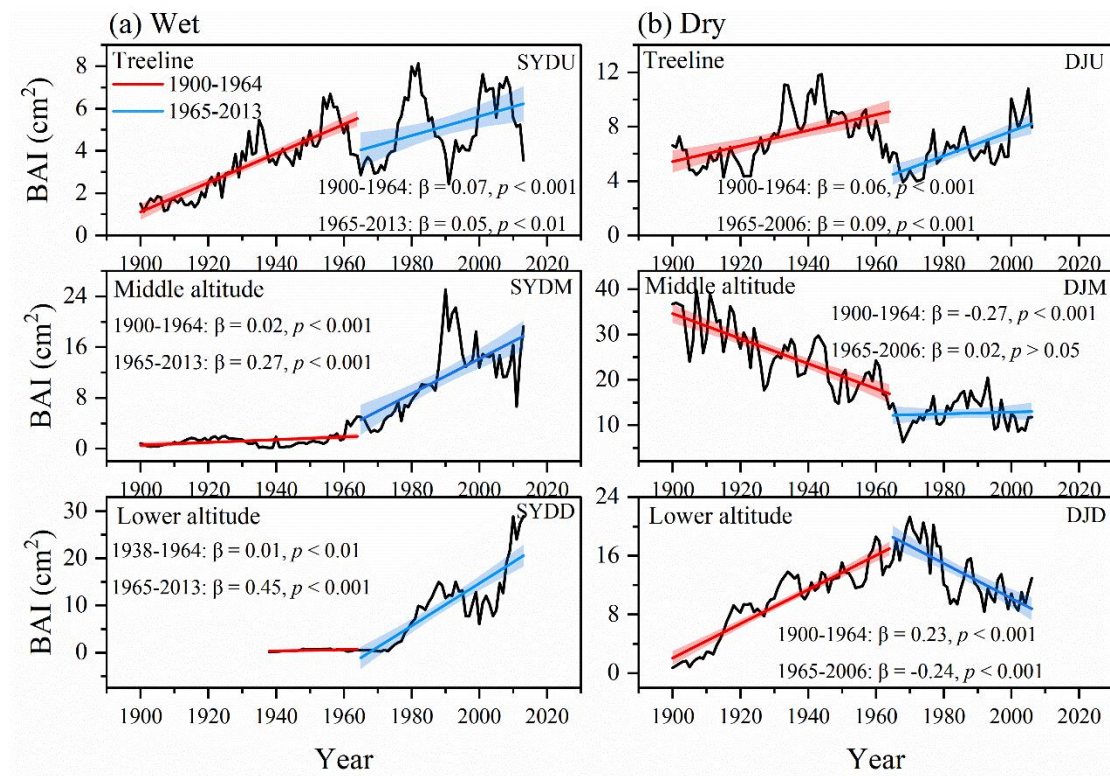


Figure 2. Temporal trends of basal area increment (BAI) for Himalayan fir at different altitudes during the period 1900–2010s. The symbol " β " represents the slope of BAI ($\text{cm}^2 \text{ year}^{-1}$). The linear regression results of each period are attached. It also provides explanatory variance and significance levels, with the shaded area presenting a 95% confidence interval.

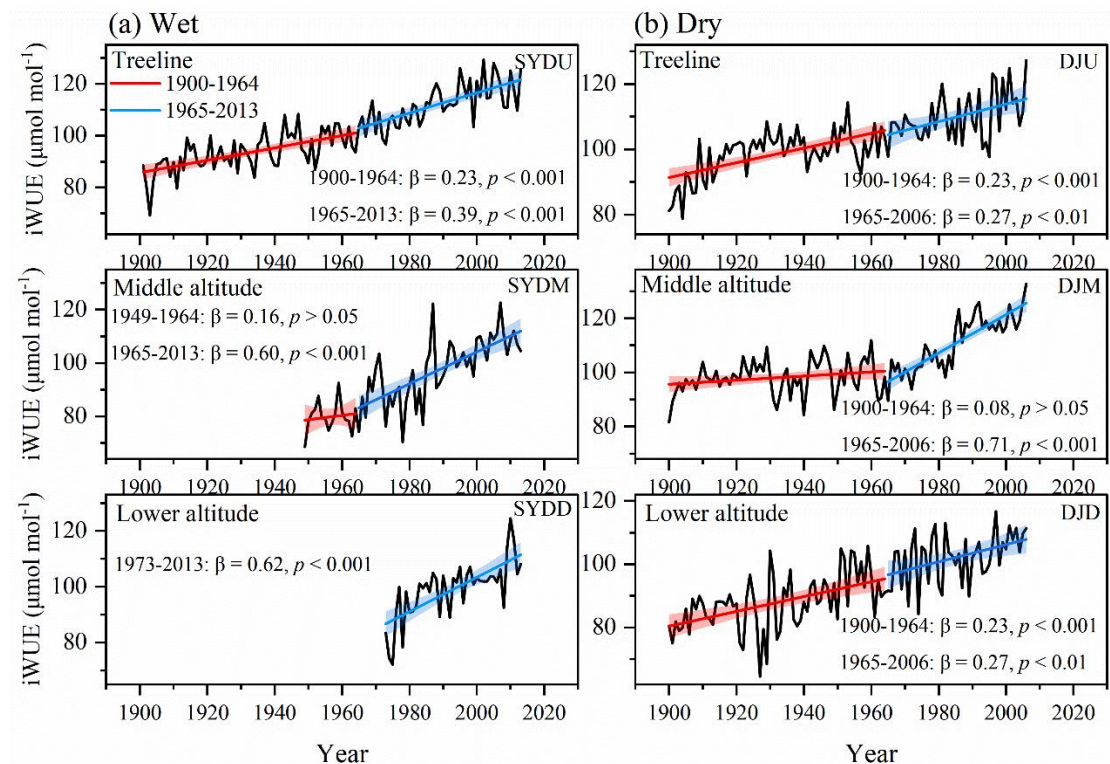


Figure 3. Temporal trends of intrinsic water-use efficiency (iWUE) during 1900-2010s for Himalayan fir at different altitudes. The symbol “ β ” represents the slope of iWUE ($\mu\text{mol mol}^{-1}$). The linear regression results of each period are attached. It also provides explanatory variance and significance levels, with the shaded area presenting a 95% confidence interval.

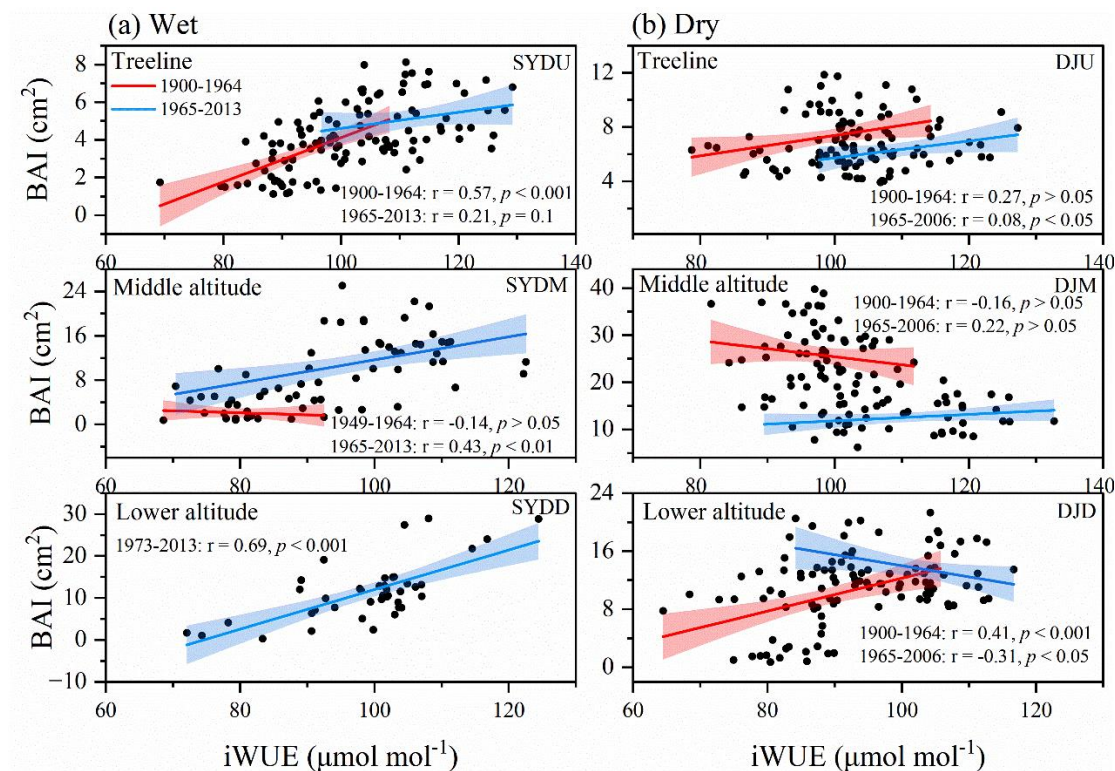


Figure 4. Long-term relationships between intrinsic water-use efficiency (iWUE) and basal area increment (BAI) of Himalayan fir at different altitudes across two hydrologically distinct sites. The linear regression results of each period are attached. It also provides explanatory variance and significance levels, with the shaded area presenting a 95% confidence interval.

4. Figure 4, it is hard to believe the results about iWUE since a lot of p-values show no significance of trends.

[Response]: Thank you for your comment. Indeed, non-significant correlations were observed prior to 1965 for most sites, with the exception of the treeline site in the wet region (SYD) and the lower-altitude site in the dry region (DJ). However, we note gradual shifts in the correlations between iWUE and BAI across the two altitudinal gradients under differing hydrological conditions. Specifically, post-1965, the iWUE-BAI correlations transitioned from negative to positive with increasing altitude in the drier site (DJ), while the BAI-iWUE slope exhibited a progressive decline as

altitude rose.

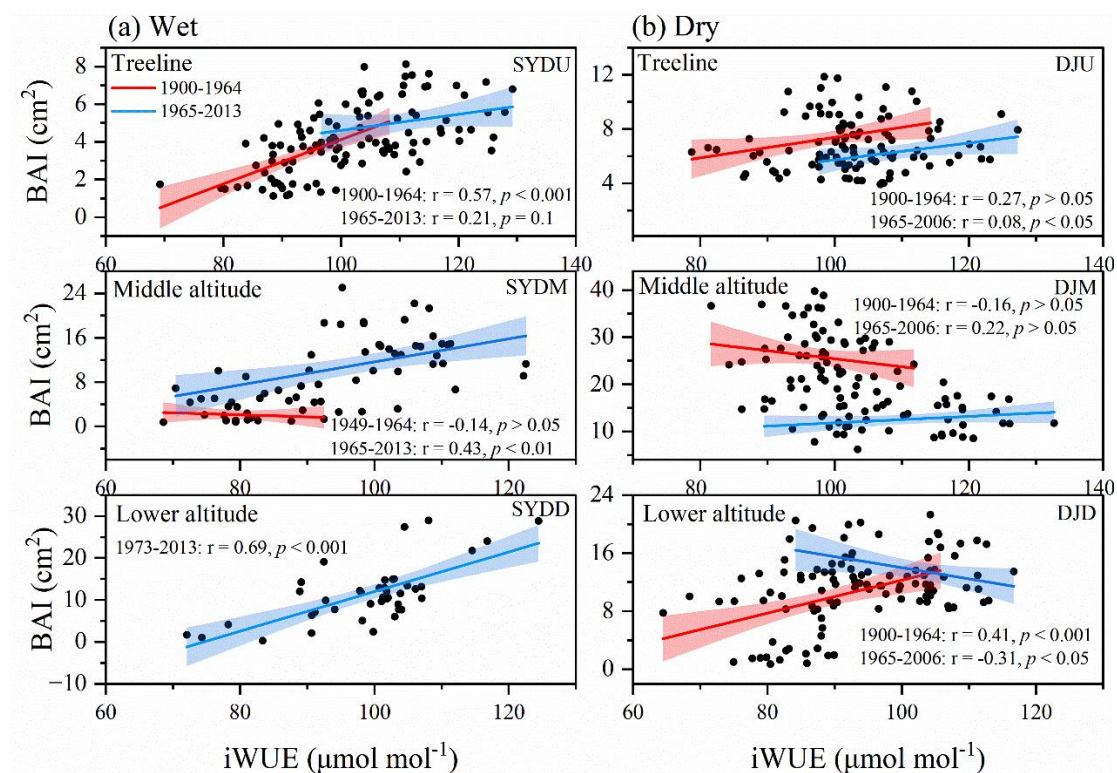


Figure 4. Long-term relationships between intrinsic water-use efficiency (iWUE) and basal area increment (BAI) of Himalayan fir at different altitudes across two hydrologically distinct sites. The linear regression results of each period are attached. It also provides explanatory variance and significance levels, with the shaded area presenting a 95% confidence interval.

5. Any more information on the SPEI data? How were the data collected? Where they gridded data? Were the data extracted at specific locations?

[Response]: Thanks for your comment. We have extracted the standardized precipitation evapotranspiration index (SPEI) data from the climate explorer (<http://climexp.knmi.nl>). The SPEI were calculated based on the climate data from the Climate Research Unit (CRU, University of East Anglia) TS Version 4.01 with a spatial resolution of $0.5^{\circ} \times 0.5^{\circ}$ over the period from 1900 to 2014. The region mean values of SPEI calculated over the grids within the region $27.75^{\circ} - 28.25^{\circ} \text{ N}$, $88.75^{\circ} - 89.25^{\circ} \text{ E}$ for SYD, and the region $27.95^{\circ} - 28.45^{\circ} \text{ N}$, $86.75^{\circ} - 87.25^{\circ} \text{ E}$ for DJ, respectively.

Reference

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Again, thank you very much for your insightful comments. We believe these revisions have substantially elevated the quality of our work. Should any additional clarifications be needed, we would be happy to address them.