Response to Reviewer 3 :

We sincerely appreciate your thorough and constructive comments, which have significantly strengthened the conceptual clarity, methodological rigor, and scientific contribution of our manuscript. We have addressed all comments point-by-point below:

Major comments:

1. **Q:** The Abstract contains several interesting findings, but key points remain unclear. In particular, it is not sufficiently clear how the reported SOS and EOS responses are linked to the proposed "saturation effect." The abstract should explain whether saturation refers to phenological timing itself, to temperature sensitivity, or to the urban warming effect. The biological meaning of negative and positive values such as negative ΔSOS and positive ΔEOS should also be stated explicitly. In addition, the rationale for replacing T with LST is not clear in the abstract, and the broader ecological significance of the study is not clearly highlighted. At present, the abstract reports many numbers and relationships, but the main take-home message remains diffuse.

R: We sincerely thank you for this insightful and constructive comment. We completely agree that the original Abstract was dense with numerical results but lacked clarity on several foundational concepts and the overall take-home message. Following your specific suggestions, we have thoroughly revised the Abstract to highlight the main ecological implication and core findings. Meanwhile, relevant conceptual explanations have been clearly supplemented and elaborated in the main text:

(1) Clarification of the "Saturation Effect": We have explicitly defined the nonlinear saturation effect in the discussion section, clarifying that it refers to the weakened and plateauing trend of urban warming’s promoting influence on phenology under warmer background conditions.

(2) Biological Meaning of Metrics: The biological connotation of negative ΔSOS and positive ΔEOS has been clearly interpreted in the methodology section, clarifying urban-rural phenological differences.

(3) Distinct roles of T and LST: We have systematically elaborated the complementary roles of preseason temperature (T) and land surface temperature (LST) in our analytical framework, explaining their respective application rationales and high correlation in urban environments.

(4) Broader Ecological Significance: The revised Abstract further refines and highlights the generalized ecological implication and key take-home message of this study.

2. **Q:** The manuscript introduces a potentially interesting central idea, namely that the response of vegetation phenology to urban warming may weaken or approach saturation under warmer background conditions. However, the scientific gap is not yet articulated clearly enough, and the novelty relative to previous urban phenology studies remains insufficiently developed. The Introduction should explain more explicitly what previous studies have already established and what remains unresolved, especially regarding nonlinear responses, threshold behavior, and the combined role of background temperature and aridity. At present, the logic from literature review to study objectives is not fully convincing.

R: We deeply appreciate your insightful critique regarding the conceptual framing of our Introduction. We completely agree that the scientific gap and the specific novelty of our study—particularly concerning non-linear responses, threshold behaviors, and the compounding role of aridity—were not sufficiently developed. The transition from the literature review to our study objectives was indeed abrupt. To address this, we have substantially restructured the Introduction to build a more convincing logical flow:

(1) Highlighting the Non-linear Gap (L56 - 57): "Vegetation phenology, a critical aspect of ecosystem dynamics, exhibits significant sensitivity to the coupling of thermal and moisture variations (Badeck et al., 2004; Yu et al., 2003). While recent investigations have highlighted how urban warming precipitates an earlier start of the growing season (SOS) and a delayed end of the growing season (EOS), it is increasingly recognized that these responses are not solely temperature-driven but are fundamentally constrained by the background aridity of the locale. Thus, the phenological 'benefits' of the Urban Heat Island (UHI) effect must be evaluated through a dual lens of heat and water availability from the outset (Jeong et al., 2019). The cascading effects of these shifts extend beyond mere phenological alterations, contributing to a spectrum of ecological and environmental challenges (Zhou et al., 2016; Qiu et al., 2017; Ding et al., 2020).

However, the degree to which warming benefits phenological changes has been widely debated (Chmielewski & Rötzer, 2001; Ding et al., 2020; Yao et al., 2017). Urban environments offer a unique 'natural laboratory' for testing these phenological theories. Unlike experimental warming plots, the urban heat island (UHI) effect represents a sustained, large-scale warming scenario that has persisted for decades (Grimm et al., 2008). This allows researchers to observe long-term vegetation adaptation and identify thresholds that are difficult to capture in short-term manipulative experiments. Moreover, the vast geographic distribution of cities across climatic gradients provides a natural experimental framework to test how identical warming magnitudes (UHI) interact with varying background climates (Figure 1). Empirical evidence from the Northern Hemisphere consistently shows that cities in cold high-latitude regions exhibit more advanced SOS and delayed EOS in response to urban warming (Dallimer et al., 2016; Gazal et al., 2008; Jia et al., 2021; Li et al., 2021; Meng et al., 2020). While these studies offer valuable evidence regarding spatial heterogeneity, the non-linear dynamics of these responses—specifically, the saturation thresholds where urban warming benefits diminish, and how background aridity modulates these thresholds—remain inadequately quantified across climatic gradients. Identifying such thresholds is critical for predicting urban ecosystem stability under continuous global warming scenarios."

(2) Integrating Aridity into the Warming Context (L66 - 80): "It is noteworthy that drought conditions adversely disrupt temperature-driven phenological responses (Peng et al., 2019; Yuan et al., 2020). Urban vegetation is more vulnerable to moisture deficits due to the 'Urban Dry Island' effect (reduced soil moisture and elevated evaporation in built environments) and impervious surfaces (Zhang et al., 2019). UHI warming combined with high aridity elevates vapor pressure deficit and water demand, triggering defensive mechanisms (e.g., ABA accumulation (McAdam, 2013), protein degradation) that offset thermal advancements. Drought delays spring SOS and advances autumn EOS by inducing water stress and early dormancy (McAdam, 2013; Čehulić et al., 2019). However, in urban environments, this drought effect is compounded by the Urban Dry Island and impervious surfaces, further attenuating phenological sensitivity to extra warming, diminishing the positive impacts of UHI; this effect is stronger in warmer cities where plants approach thermal limits."

(3) Smooth Transition to Objectives (L90 - 94): "Thus, an investigation into the phenological response of plants to urbanization in China would enhance our understanding of their ability to acclimate to climate changes across various environments. However, how background temperature

and aridity interactively determine the thresholds and 'saturation' of phenological sensitivity to urban warming remains largely unquantified at a macro-scale. Addressing this gap is essential for predicting the stability of urban carbon sinks under future climate scenarios. To this end, the primary objectives of this study encompassed the following:"

3. **Q:** One of the most confusing aspects of the manuscript is the use of multiple temperature-related variables. The manuscript uses preseason air temperature (T), land surface temperature (LST), and urban warming-related differences, but their ecological meanings and analytical roles are not clearly distinguished. T appears to be used to quantify phenological sensitivity, while LST is treated as background climate and later used to derive thresholds. The rationale for replacing or translating T into LST is not explained clearly enough. The manuscript should clarify why T is used in one part of the analysis, why LST is used in another, how these variables differ ecologically, and how directly comparable they are. This issue affects not only the Methods, but also the interpretation of the Results and the conclusions.

R: We sincerely thank you for pointing out this confusing aspect. Your concern perfectly highlights a section where we omitted our detailed analytical rationale, causing the transition from T to LST to appear abrupt and their ecological roles to seem blurred. To resolve this, we have revised the manuscript to explicitly clarify their distinct analytical roles: T is used to establish the biological mechanism, while LST is used to characterize the spatial urban environment. Furthermore, we explicitly detailed the rationale for translating between them, which is fundamentally a statistically driven empirical substitution. We have made the following specific revisions:

(1) Clarifying the Distinct Roles: We added explicit explanations for why both variables are required (Methods, Section 2.3):

Modified text: "In this study, T and LST serve strictly distinct analytical roles. Pre-season air temperature (T) is the direct biological driver of plant physiology (e.g., chilling requirements). Therefore, T is used exclusively to quantify the pure biological phenological sensitivity (Rt) and identify true physiological thresholds. Conversely, Land Surface Temperature (LST) is the standard metric for quantifying the Urban Heat Island (UHI) effect. Thus, LST is used to characterize the spatial 'background climate' of each city across the continent."

(2)**Explaining the Rationale for Translation (Section 2.3):** We clarified that substituting T with LST is an empirical translation designed to bridge the biological findings with the urban geographical context, while strictly controlling for data matching biases:

Modified text (Replacing L361-364): "Because pre-season air temperature (T) is the direct driver of phenological sensitivity, we first derived the biological thresholds using T (Figure 5). However, to address our core objective—understanding how the background temperature (LST) determines these phenological shifts—we needed to clarify the quantitative relationship between the background LST and T. We fitted the relationship curve between LST and T across all cities. To strictly prevent data matching biases during this conversion, we utilized the spatiotemporally aligned 10-year climatological means (2010–2020) for both variables at a unified 250-m resolution. We observed a highly robust linear correlation (Figure S4). Based on this high goodness-of-fit, we utilized the empirical conversion formula between the two variables to mathematically substitute T with LST in the sensitivity curves. This empirical translation allowed us to systematically convert the T-driven physiological thresholds into the specific

LST-determined background climate thresholds (12.5°C for SOS and 4°C for EOS), explicitly projecting pure biological limits onto the urban map. While T and LST represent different physical properties, they are highly correlated in urban settings ($R^2 = 0.93$ for monthly mean temperature), ensuring the reliability of this empirically driven translation between physiological response and climatic background."

4. **Q:** Several parts of the Introduction should be revised for logic and clarity. The statement in L57–58 that background temperature heterogeneity may disrupt phenology responses to urban warming is not adequately supported by the examples that follow. The subsequent sentence in L64–65 is largely repetitive of the same idea. In addition, the expectation stated in L9–83, namely that urban warming benefits in warmer regions will gradually approach saturation, is a central hypothesis of the study but is introduced too directly and without sufficient literature support. If this hypothesis is important, it should be built on a stronger review of relevant studies from warm regions and on more explicit evidence for nonlinear or weaker responses under warm conditions. Also, although the manuscript is centered on urban warming, the first several paragraphs devote relatively little space to why urban environments provide a distinct and useful context for testing phenological sensitivity.

R: Thank you very much for your valuable comments on the logical structure and clarity of the Introduction. We have carefully revised and reorganized the relevant content point by point as suggested, and the detailed revisions with the original revised text are presented below:

(1) The vague statement about background temperature heterogeneity and the repetitive expressions in the original manuscript have been fully revised and reorganized. We have rebuilt the logical chain between literature examples and research gaps, removing redundant repetition and making the argument better supported:

"Urban environments offer a unique 'natural laboratory' for testing these phenological theories. Unlike experimental warming plots, the urban heat island (UHI) effect represents a sustained, large-scale warming scenario that has persisted for decades (Grimm et al., 2008). This allows researchers to observe long-term vegetation adaptation and identify thresholds that are difficult to capture in short-term manipulative experiments. Moreover, the vast geographic distribution of cities across climatic gradients provides a natural experimental framework to test how identical warming magnitudes (UHI) interact with varying background climates (Figure 1). Empirical evidence from the Northern Hemisphere consistently shows that cities in cold high-latitude regions exhibit more advanced SOS and delayed EOS in response to urban warming (Dallimer et al., 2016; Gazal et al., 2008; Jia et al., 2021; Li et al., 2021; Meng et al., 2020). While these studies offer valuable evidence regarding spatial heterogeneity, the non-linear dynamics of these responses—specifically, the saturation thresholds where urban warming benefits diminish, and how background aridity modulates these thresholds—remain inadequately quantified across climatic gradients. Identifying such thresholds is critical for predicting urban ecosystem stability under continuous global warming scenarios."

(2) The central hypothesis of phenological saturation in warmer regions is no longer proposed abruptly. We have supplemented sufficient theoretical basis, physiological mechanism and literature evidence to support this hypothesis in the revised Introduction:

"The magnitude of urban-induced phenological shifts is not uniform. Background climate heterogeneity constrains vegetation responses to additional urban warming: phenological advancements are strong in cold regions but weaken as baseline temperatures rise, implying that phenological sensitivity is a variable state conditioned by local thermal conditions. In ecology, the "saturation effect" describes that stimulus efficacy declines beyond a threshold, rooted in tolerance curve theory (Angilletta, 2009): organismal physiological functions increase with environmental drivers until reaching physiological saturation, beyond which no further enhancement occurs (Ketola & Kristensen, 2017). Plant physiological processes (photosynthesis, respiration, transpiration) do not increase linearly with temperature; they slow down or even decrease beyond a thermal threshold (Sage & Kubien, 2007; Ge et al., 2021). A meta-analysis has proved greater positive growth responses to warming in colder ecosystems (Rustad et al., 2001; Büntgen et al., 2019). We therefore hypothesize that urban warming benefits for phenology (advanced SOS, delayed EOS) gradually approach saturation in warmer regions, and extra UHI warming will no longer promote phenological shifts. This theory remains to be verified in urban phenology systems."

(3) The original opening paragraphs only briefly described the general link between phenology and climate, without illustrating the unique advantages of urban environments for phenological research. We have newly added the full paragraph shown in Point 1 above to elaborate that cities serve as a unique natural laboratory, which makes the research motivation more sufficient and logical.

Overall, we have eliminated redundant statements, improved logical coherence, strengthened theoretical support for the central hypothesis, and supplemented the unique research value of urban environments as suggested.

5. **Q:** The drought/aridity paragraph in the Introduction is informative, but it reads somewhat as a parallel topic rather than a fully integrated part of the main conceptual framework. If aridity is one of the two key regulators in the study, then it should be tied more explicitly to the urban warming question from the outset. The final sentence of that paragraph is also rather broad and reads more like a conclusion than a hypothesis. The manuscript would benefit from stating more explicitly how and why aridity is expected to interact with warming-related phenological responses in urban versus rural settings.

R: We completely agree with your point that aridity, as one of the two core regulators in this study, should be integrated into the conceptual framework from the very beginning of the Introduction. We have restructured the opening of the manuscript to present temperature and moisture as coupled drivers of phenology from the outset. Additionally, we have clarified the mechanisms underlying the urban-rural differences and replaced the broad concluding statement with a specific, testable hypothesis. We have made the following revisions:

(1)Integrated Aridity from the Outset (L48–55): We modified the opening sentences of the Introduction to establish that vegetation phenology is sensitive to the coupling of thermal and moisture variations, rather than focusing solely on temperature:

"Vegetation phenology, a critical aspect of ecosystem dynamics, exhibits significant sensitivity to the coupling of thermal and moisture variations (Badeck et al., 2004; Yu et al., 2003). While recent investigations have highlighted how urban warming precipitates an earlier start of the growing season (SOS) and a delayed end of the growing season (EOS), it is increasingly recognized that these responses are not solely temperature-driven but are fundamentally constrained by the background aridity of the locale. Thus, the phenological 'benefits' of the Urban

Heat Island (UHI) effect must be evaluated through a dual lens of heat and water availability from the outset (Jeong et al., 2019). The cascading effects of these shifts extend beyond mere phenological alterations, contributing to a spectrum of ecological and environmental challenges (Zhou et al., 2016; Qiu et al., 2017; Ding et al., 2020)."

(2) Explicit Mechanisms and Urban vs. Rural Settings (L84–98): We revised the aridity section to explain how and why moisture stress acts as a "brake" on warming-induced phenological shifts specifically in urban versus rural settings, incorporating the "Urban Dry Island" effect:

"It is noteworthy that drought conditions adversely disrupt temperature-driven phenological responses (Peng et al., 2019; Yuan et al., 2020). Urban vegetation is more vulnerable to moisture deficits due to the 'Urban Dry Island' effect (reduced soil moisture and elevated evaporation in built environments) and impervious surfaces (Zhang et al., 2019). UHI warming combined with high aridity elevates vapor pressure deficit and water demand, triggering defensive mechanisms (e.g., ABA accumulation (McAdam, 2013), protein degradation) that offset thermal advancements. Drought delays spring SOS and advances autumn EOS by inducing water stress and early dormancy (McAdam, 2013; Čehulić et al., 2019). However, in urban environments, this drought effect is compounded by the Urban Dry Island and impervious surfaces, further attenuating phenological sensitivity to extra warming, diminishing the positive impacts of UHI; this effect is stronger in warmer cities where plants approach thermal limits."

(3) Refined the Interaction Hypothesis (L99–101): We replaced the broad concluding statement with a specific, testable hypothesis regarding the interactive effects of LST and AI on the saturation threshold:

"Consequently, we hypothesize that background aridity (AI) acts as a critical negative regulator of the thermal saturation threshold. Specifically, we predict that as background aridity increases, the 'saturation point' at which warming benefits (such as advanced SOS or delayed EOS) plateau will occur at lower LST values. This implies that the saturation effect is not a fixed thermal threshold but a dynamic state conditioned by water stress, leading to a more rapid decline in phenological sensitivity in arid urban environments."

6. **Q:** The notation for $\Delta R_{t\text{-SOS}}$ and $\Delta R_{t\text{-EOS}}$ is internally inconsistent: the text refers to the 10th buffer zone at 20 km, but the equations use notation such as Rt-SOS(20), which could be misread as a buffer index rather than a distance. This should be standardized and clarified.

R: We sincerely thank you for pointing out this notational inconsistency. We agree that mixing the buffer index with the distance in kilometers is confusing and could easily be misinterpreted. To address this, we have standardized all notations across the equations to strictly use the buffer index (where '0' represents the urban center and '10' represents the 10th buffer zone at 20 km), ensuring consistency with Equations (4) and (5). We have made the following revisions:

(1)Standardized Notation in Equations (L240–241): We have corrected Equations (6) and (7) to use the index '(10)' instead of the distance '(20)'.

"$\Delta R_{t\text{-SOS}} = R_{t\text{-SOS}(0)} - R_{t\text{-SOS}(10)}$ (6)

$\Delta R_{t\text{-EOS}} = R_{t\text{-EOS}(0)} - R_{t\text{-EOS}(10)}$ (7)"

(2) Clarified Variable Definitions (L242–244): We have updated the accompanying text to explicitly define the indices, leaving no room for ambiguity regarding the buffer zones versus

distance:

"Among which, $R_{t\text{-}SOS}(0)$ and $R_{t\text{-}SOS}(10)$ are the mean $R_{t\text{-}SOS}$ of the urban center (buffer index 0) and the 10-th buffer zone (located 20 km away), respectively. Similarly, $R_{t\text{-}EOS}(0)$ and $R_{t\text{-}EOS}(10)$ are the mean $R_{t\text{-}EOS}$ of the urban center and the 10-th buffer zone."

7. **Q:** Since the concept of "saturation effect" is central to the paper, the authors should explain why a logistic function is appropriate and compare it with other nonlinear alternatives, such as quadratic, segmented, or generalized additive models. At present, the fitted logistic relationships are treated as support for saturation, but this remains incomplete without comparative model testing.

R: We sincerely thank you for this rigorous methodological suggestion. We fully agree that relying solely on a predefined logistic function without comparative testing leaves the "saturation effect" hypothesis incomplete. To address this critical point, we have conducted comprehensive comparative model testing (including quadratic, segmented, and GAMs) and added theoretical justifications. We have made the following revisions:

(1) Theoretical Justification and Model Testing Framework (L261–266): We updated the "Validation of phenology 'Saturation effect'" section in the Methods to explicitly describe the comparative model testing. We also provided a strong physiological justification for prioritizing the logistic function over other nonlinear models:

"To determine if there was a temperature saturation effect on vegetation phenology, we conducted a comparative model testing. Rather than assuming a single relationship a priori, we evaluated the fit of phenology versus pre-season temperature using competing models: a linear model, a quadratic model, a segmented (piecewise) model, and a logistic growth model. We specifically selected the logistic function as our primary model because quadratic models biologically imply a symmetric reversal (a continuous steep decline) rather than a plateau, and segmented models assume an abrupt, angular change in biological rates (Pinheiro & Bates, 2000), which is less physiologically realistic than the smooth, asymptotic transition captured by the logistic curve (Pinheiro & Bates, 2000). The asymptote of the logistic function mathematically represents the biological 'saturation point'—the maximum physiological limit of thermal benefits."

(2) Results of Non-linear Response and Saturation Evidence in Discussion (L442–446): We supplemented the Discussion with clear empirical evidence for the non-linear logistic response and saturation effect, demonstrating why phenological responses to warming follow a bounded, non-linear pattern rather than a simple linear relationship:

"We then extracted phenological information from all vegetation pixels across the country and plotted scatter diagrams of phenology versus pre-season temperature. Next, we fitted logistic growth curves to these scatter plots and evaluated the assumption using the goodness-of-fit metrics p-value and R2. Subsequently, we applied the same logistic curve to constrain the phenology of urban and suburban vegetation in 293 different cities against their pre-season temperatures, testing whether the phenological response to temperature in urban areas also follows a logistic growth pattern. Subsequently, we replaced the pre-season temperature with the background temperature LST to determine how the phenological saturation effect is regulated by the background temperature."

8. **Q:** The Results section reports several threshold values, but the relationships among them

are unclear. For example, Section 3.2 suggests that urban-rural differences in SOS and EOS weaken or even reverse when LST exceeds 12°C or 18.5°C, whereas elsewhere thresholds such as 12.5°C and 4°C are emphasized for LST-regulated sensitivity. These thresholds may correspond to different response variables, but this is not made sufficiently clear. The manuscript should distinguish much more explicitly between thresholds for phenological dates, thresholds for urban-rural differences, and thresholds for phenological sensitivity.

R: We sincerely thank you for highlighting this source of confusion. We completely agree that presenting multiple threshold values without sufficiently distinguishing the underlying variables made the Results section difficult to follow. To address this, we have systematically reviewed all reported thresholds and explicitly categorized them into three distinct ecological dimensions in the revised manuscript:

(1) Clarifying Thresholds for Phenological Differences (Section 3.2): We revised the text to explicitly state that 18°C and 18.5°C are the thresholds where urban-rural divergence disappears.

"Conversely, when LST exceeded the specific thresholds for urban-rural differences (LST = 18°C for ΔSOS and LST = 18.5°C for ΔEOS), the phenological disparities between urban and rural areas were no longer significant and sometimes even reversed (Figure 4a, b)."

(2) Clarifying Thresholds for Phenological Sensitivity (Section 3.3): We added explicit qualifiers to distinguish the 12.5°C and 4°C thresholds as relating strictly to sensitivity (the rate of change), rather than the absolute dates.

"Based on the first-order derivatives, we identified the specific thresholds for phenological sensitivity. We observed that when background LST exceeded 12.5°C for spring and 4°C for autumn, the temperature sensitivity (Rt) began to significantly weaken. This indicates a saturation of the physiological response rate, even though the absolute urban-rural difference (ΔSOS/ΔEOS) might still persist until higher temperatures are reached."

9. **Q:** Section 4.4 attributes vegetation-type differences mainly to broad functional traits such as drought resistance and resource-use strategy. While these interpretations are reasonable in general ecological terms, they remain fairly generic given that the manuscript uses broad vegetation categories and does not directly measure traits. This subsection should therefore be written more cautiously and tied more closely to the actual scope and limitations of the dataset.

R: We sincerely thank you for pointing out this overinterpretation. To address this, we have carefully rewritten Section 4.4 to soften these mechanistic claims, explicitly linking our interpretations to the actual scope and limitations of our dataset. We have made the following revisions:

(1) Acknowledging Dataset Limitations from the Outset (L522–527): We corrected the typo in the subsection title and revised the opening statements to explicitly acknowledge that while we observe differing sensitivities, our broad categories preclude direct trait-level analysis.

"4.4 Phenological response variation among different vegetation types

The phenological response to LST and AI varies significantly across vegetation types, reflecting the influence of distinct ecological strategies. Our results (Figure 6 and 9) demonstrate that Shrublands are the most sensitive to both warming and aridity, likely due to their opportunistic resource utilization strategy and higher leaf turnover rates (Xiong et al., 2024). In contrast, Coniferous Forests exhibited a muted response to both drivers (Malla et al., 2023). While our analysis relies on broad land-cover categories and does not directly measure species-specific functional traits, these discrepancies likely reflect generalized divergent ecological strategies among the vegetation groups."

(2) Cautious Rephrasing of Trait-Based Interpretations (L533–539): We toned down the definitive mechanistic statements regarding coniferous species and shrubs, framing them as potential explanations supported by broader literature rather than direct observations from our data. We also added a concluding sentence to explicitly state this limitation.

"This insensitivity is substantiated by our AI-sensitivity analysis (Figure 9a), suggesting that the conservative hydraulic traits of conifers—such as needle morphology and lower stomatal conductance (Sperry et al., 2002; McAdam, 2013) —act as a buffer against the "aridity-driven inhibition" that more severely affects broad-leaf species. Based on generalized ecological principles, this might be associated with typical drought-resistant adaptations found in many conifers (e.g., needle morphology and stricter stomatal control), which could limit the potential positive impact of warming on their phenology. In contrast, the heightened sensitivity of shrublands observed in our dataset aligns with literature suggesting more opportunistic resource utilization strategies in shrubs (Xiong et al., 2024)."

10. **Q:** There are many grammatical problems, awkward expressions, unclear symbol definitions, and even some formatting or rendering issues. Examples include ambiguous wording, inconsistent notation, and sentences whose meaning is difficult to interpret. These are not merely stylistic concerns; in multiple places they reduce scientific precision and make the logic harder to follow. I strongly recommend careful language revision of the full manuscript, including clarification of all abbreviations, symbol definitions, equations, and units.

R: We have conducted a full manuscript language revision, corrected all grammatical/formatting issues, standardized all abbreviations, symbols, equations, and units, and ensured scientific precision.

Minor comments:

1. **Q:** The statement in L88–89 could be rephrased more clearly. A wording such as "A pronounced delayed SOS was documented on the Yungui Plateau under preceding drought conditions" would be more natural.

R: We sincerely appreciate your's kind language suggestion. During the comprehensive revision of the Introduction, we have deleted this sentence to streamline the narrative logic and better focus on the core conceptual framework of the coupled regulation of background temperature and aridity on the saturation effect of urban phenological sensitivity; thus, the previously noted expression issue is no longer present in the revised manuscript.

2. **Q:** The transition from the background review to the study objectives is abrupt and should be made smoother.

R: We sincerely thank you for the suggestion to improve the logical flow. We have made the following revisions: Smoothed Transition (L105–107): We revised the final sentences of the Introduction to serve as a logical bridge. We moved from the general significance of studying China's urbanization to the specific necessity of quantifying the interactive effects of baseline climate on phenological thresholds:

"Thus, an investigation into the phenological response of plants to urbanization in China would enhance our understanding of their ability to acclimate to climate changes across various environments. However, how background temperature and aridity interactively determine the thresholds and 'saturation' of phenological sensitivity to urban warming remains largely unquantified at a macro-scale. Addressing this gap is essential for predicting the stability of urban carbon sinks under future climate scenarios. To this end, the primary objectives of this study encompassed the following: ..."

3. **Q:** The AI equation is not displayed clearly enough, making it difficult to determine whether AI is defined as P/PET or PET/P. This should be corrected.

R: We have clarified the AI equation in Section 2.3 to explicitly show that AI = PET / P, eliminating any ambiguity.

4. **Q:** The authors should report how much data were excluded during phenology preprocessing and quality control.

R: We thank your for this comment. At the end of the "Vegetation phenology extraction" section (L166), we have added a sentence summarizing the proportion of excluded data after applying the EVI thresholds, realistic phenology constraints, and land-cover masking:

"After applying these quality control thresholds and land-cover filtering criteria, approximately 48.5% of the initial pixels within the study buffer zones were excluded.

5. **Q:** Figure 2 needs improvement in visual clarity. The inset panels are too small and the y-axis in the inset appears partially obscured or overlapped, making the embedded comparisons difficult to interpret. Since these inset plots support key claims regarding spatial contrasts, they should be enlarged and reformatted for readability.

R: We sincerely thank you for this constructive feedback regarding the visual clarity of Figure 2. We entirely agree that the original inset panels were too small and that the overlapping axes hindered the interpretation of our key spatial contrast findings.

To address this, we have completely redesigned Figure 2. Instead of embedding the scatter plots and bar charts as small insets within the maps, we have extracted them and reformatted them as separate, enlarged panels. We have updated the figure and its corresponding caption in the revised manuscript to reflect these visual improvements.

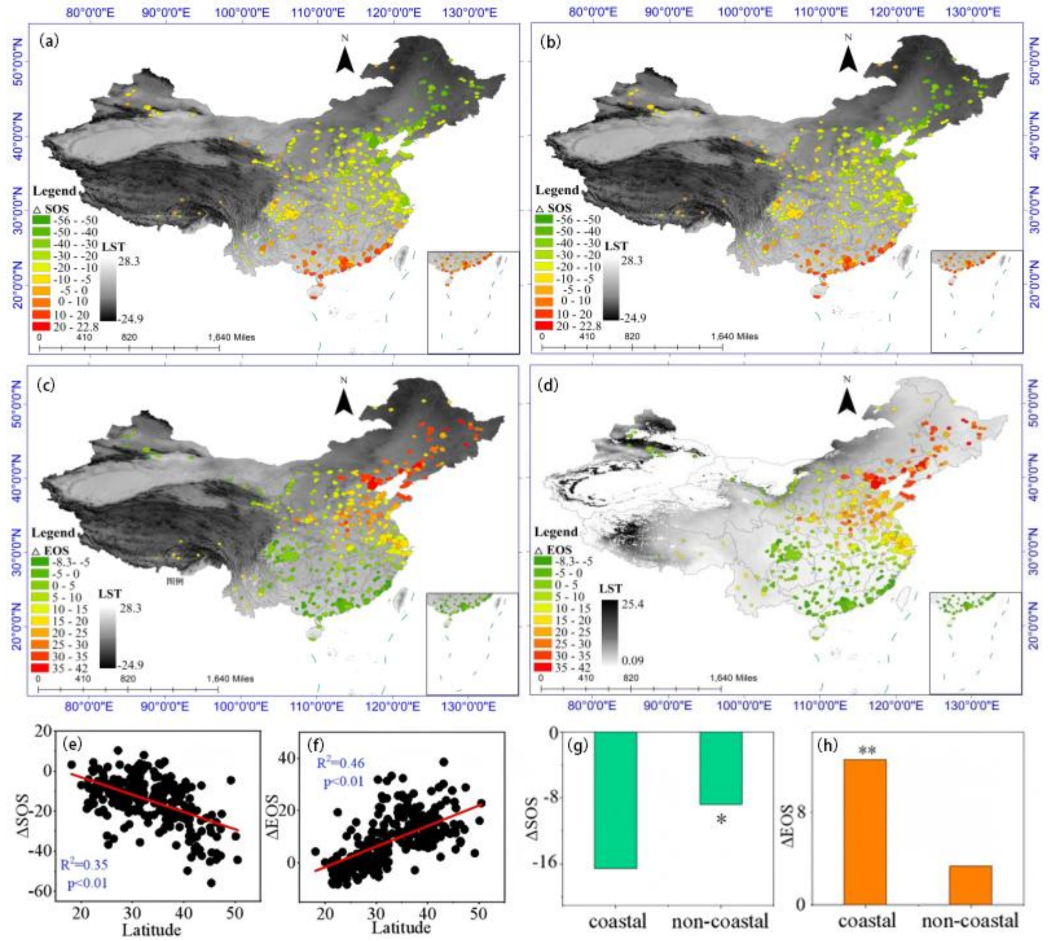

Figure 2. The spatial distribution of urban-rural disparities for SOS (ΔSOS) (a and b), EOS (ΔEOS) (c and d) was analyzed across mainland China. Mean land surface temperature (LST) was represented in black-and-white range for the entire continent, and the data in these figures reflected the 10-year mean from 2010 to 2020 for each city.

Panel (e) depicts the linear correlation between ΔSOS and latitude ($R^2=0.35$, $p<0.01$);

panel (f) depicts the linear correlation between ΔEOS and latitude ($R^2=0.46$, $p<0.01$); panel (g) compares ΔSOS between coastal and non-coastal provinces (*$p<0.05$);

panel (h) compares ΔEOS between coastal and non-coastal provinces (**$p<0.01$).

The map, generated using ArcGIS – version10.2, features administrative boundaries sourced from the Ministry of Civil Affairs of the People's Republic of China (http://xzqh.mca.gov.cn/map). Source: Esri, TomTom, FAO, USGS, and the GIS User Community; Ministry of Civil Affairs of the People's Republic of China | Powered by Esri.

6. **Q:** Several expressions in the Results reduce clarity and should be revised, for example "logistic trends was observed," "positive related," "the higher of AI," and "negative ΔEOS tended to appeared."

R: .We sincerely thank you for highlighting these grammatical errors and awkward phrasing. We apologize for the oversight, which indeed reduced the clarity of the Results section. We have carefully corrected these specific expressions to ensure grammatical accuracy, and we have further proofread the entire section to eliminate similar issues. We have made the following specific revisions:

(1) Revised "logistic trends was observed" (L320): We corrected the subject-verb agreement.Revision: "As we compared urban and rural regions, logistic trends were observed for both SOS and EOS in relation to LST (Figure 4)."

(2) Revised "positive related" (L381): We corrected the adverb form and the subject-verb agreement.Revision: "When the phenological responses were fitted to the AI, Rt-SOS and ΔSOS were positively related to AI (Figure 8)."

(3) Revised "the higher of AI" (L392): We rephrased this awkward translation to a more natural scientific expression.Revision: "When AI > 1.4, most cities shared a negative Rt-EOS, and higher AI values corresponded to more negative Rt-EOS."

(4) Revised "negative ΔEOS tended to appeared" (L394): We corrected the tense error after the infinitive "to".Revision: "It is noted that negative ΔEOS tended to appear when AI > 2.

7. **Q:** The manuscript should explicitly state the biological meaning of positive and negative ΔSOS and ΔEOS whenever these metrics are introduced and discussed.

R: We sincerely thank you for this constructive suggestion. We agree that constantly requiring readers to recall the mathematical definitions of positive and negative values for ΔSOS and ΔEOS can hinder the readability of the manuscript. To improve clarity, we have explicitly stated their biological meanings whenever these metrics are introduced and discussed throughout the text. We have made the following specific revisions:

(1) Explicit Definition in Methods (L235–237): Immediately after presenting the equations for ΔSOS and ΔEOS, we added a sentence to clarify their biological implications:

"Biologically, a negative ΔSOS value indicates an advanced start of the season (spring) in the urban center relative to the rural area, whereas a positive ΔEOS value signifies a delayed end of the season (autumn senescence) in the urban center."

(2) Contextual Reminders in Results (e.g., L291, L297): We inserted brief explanations in the Results section to ensure the biological meaning is immediately clear when discussing spatial patterns. For example:

"Spatially, cities located in high-latitude regions generally demonstrated more negative ΔSOS values than those in low-latitude regions (Figure 2), indicating more advanced spring phenology in urban areas of high-latitude cities, which suggests a stronger impact of urban warming on SOS in Northern and Western China (Figure 2a, b)."

(3) Clarifications in the Discussion: We similarly reviewed the Discussion section to ensure that terms like "negative ΔSOS" are consistently paired with phrases like "phenological advancement" to maintain biological clarity.

8. **Q:** The significance and ecological contribution of the study should be stated more explicitly in both the Abstract and the Discussion. At present, the manuscript reports many statistical relationships, but the main conceptual advance is not always clearly conveyed.

R: We sincerely thank you for this overarching and insightful critique. We completely agree that the original manuscript heavily emphasized statistical reporting and that the main conceptual advance and ecological contribution should be more organically woven into the interpretations.

To address this, we have systematically elevated the narrative in the Abstract and throughout each subsection of the Discussion. Rather than isolating the theoretical contribution, we have deeply integrated our conceptual framework (the "saturation effect" and "phenological compression") into the specific ecological interpretations of our findings. We have made the following specific revisions:

(1) Explicit Contribution in the Abstract: We revised the final sentences of the Abstract to concisely state our conceptual advance and ecological implications.

Modified text (Abstract, L24–26): "Conceptually, these findings challenge the linear paradigm of warming-driven phenological shifts by demonstrating finite physiological benefits of urban warming. Ecologically, this study highlights the coupled heat-aridity constraints on urban vegetation, providing key implications for climate-adaptive urban ecological planning."

(2) Theoretical Elevation in Section 4.1: We elevated the spatial findings (the 10-km footprint) to conceptualize urban areas as distinct "microclimatic islands" that require highly localized ecological management.

Modified text (Added to the end of Section 4.1): "Ecologically, the consistent 10-km effective footprint validates that urban environments function as distinct microclimatic 'islands.' This spatial boundary conceptually highlights that urban ecological engineering and greening strategies must account for highly localized, rather than regional, thermal forcings."

(3) Elevating the "Saturation Effect" in Section 4.2: We explicitly stated that our findings challenge the traditional linear "warming-driven advancement" paradigm, establishing that the physiological capacity of urban vegetation to capitalize on warming is strictly bounded.

Modified text (Added to the discussion of the saturation effect in Section 4.2): " Conceptually, these saturation thresholds challenge the traditional linear paradigm of ‘warming-driven phenological advancement’. By identifying explicit thermal boundaries, our framework establishes that the physiological capacity of urban vegetation to capitalize on UHI warming is strictly finite.

(4) Introducing "Phenological Compression" in Section 4.3: We elevated the Aridity Index results to highlight a profound ecological vulnerability: the compounding stress of UHI and drought may neutralize the anticipated carbon sequestration benefits.

Modified text (Added to the end of Section 4.3): "The overarching ecological implication here is a profound vulnerability: as background climates dry under global change, the compounding stress of UHI and background aridity may lead to 'phenological compression.' In arid urban ecosystems, this moisture deficit effectively neutralizes the anticipated carbon sequestration benefits of thermally extended growing seasons, rendering them highly sensitive to future climate extremes."

(5) Practical Ecological Application in Section 4.4: We linked vegetation type differences to trait-mediated resilience, providing practical implications for selecting appropriate tree species in urban greening programs.

Modified text (Added to the end of Section 4.4): "Recognizing these trait-mediated responses is a crucial conceptual step for urban forestry. It indicates that building climate-resilient urban ecosystems requires shifting from generic greening to deploying specific functional traits—such as the conservative hydraulic strategies of conifers—to buffer against the coupled heat-aridity saturation effects."