1st Reviewer

The manuscript investigates the spatial and temporal variations of ecosystem productivity sensitivity to the atmospheric CO2 growth rate (ACGR) across East Asia, utilizing the Global Carbon Budget and a subset of TRENDY v13 dynamic global vegetation models. While evaluating the regional divergence of carbon cycle feedback is an important pursuit, the manuscript currently suffers from critical methodological flaws. Specifically, concerns regarding the statistical definition of "sensitivity," unaddressed confounding climatic variables, and structural inconsistencies in the narrative must be thoroughly addressed. Extensive revisions are required to ensure the robustness of the proposed physical mechanisms.

→ Thank you for the reviewer's valuable and constructive comments, which greatly contributed to improve the quality of the earlier version of the manuscript. According to the reviewer's comments, the manuscript has been revised accordingly.

Major comments

1. The entire study hinges on defining sensitivity as the slope of a simple 20-year moving window linear regression between detrended GPP/NEP and detrended global ACGR. This approach is fundamentally problematic. Interannual variations in global ACGR are strongly driven by large-scale climate modes (e.g., ENSO) and tropical temperature anomalies, which concurrently impact regional climate parameters (such as temperature, precipitation, and vapor pressure deficit) in East Asia. Performing a bivariate regression without controlling for these dominating climatic covariates inevitably captures confounding climate-driven correlations rather than a true physiological or ecological sensitivity to CO2. The authors must adopt a multivariate statistical framework or factorial simulations to isolate the CO2 effect from background interannual climate variability.

→ Insightful comments! Indeed, global ACGR are influenced by large-scale climate variations such as ENSO and temperature anomalies on interannual timescales, and that these climate factors may also influence regional ecosystem processes. However, the purpose of this study is not to isolate the CO_2 effect from interannual climate variability, but to quantify the relationship between ecosystem productivity and ACGR in the Earth system where CO_2, climate and land use change are combined. Therefore, the sensitivity defined in this study can be interpreted as an integrated ecosystem response in the Earth system, rather than a CO_2-only effect. For this reason, this study used the TRENDY S3 scenario, which reflects CO_2, climate, and land-use change, along with a bivariate regression method to examine the relationship between ACGR and ecosystem productivity.

Responding to the reviewer's comments, we add the following sentences in the revised manuscript:

"The sensitivity defined in this study does not aim to isolate the direct effects of CO_2 only. Instead, we quantify the relationship between ecosystem productivity and the ACGR within the Earth system. In this context, the calculated sensitivity represents the combined ecosystem response to the coupled interactions of CO_2, climate variability, and land-use change."

"In conclusion, our findings demonstrate that ecosystem responses to ACGR reflect the compounding influences of atmospheric CO_2, interannual climate variability, and land-use change."

2. The manuscript does not clearly provide the exact regression formula, the units of the sensitivity, the detailed detrending procedure used in the main Methods, or how significance was assessed. At minimum, the authors should report the full equations and units explicitly.

→ Helpful comments! Responding to the reviewer's comments, we add the following sentences in the revised manuscript:

"SM is expressed in [kg m^{-2}], while transpiration was converted from [kg m^{-2} s^{-1}] to [mm day^{-1}] by multiplying by 86,400."

"A linear regression was then performed using a 20-year moving window, with the slope of each regression defined as the sensitivity of GPP to ACGR [g m^{-2} day^{-1} (GtC $yr^{-1})^{-1}$] (Fig. 1c)"

"Specifically, linear regression was performed between detrended variables, defined as follows:

$$Y' = \beta X' + \alpha \qquad (2)$$

,where Y' represents detrended ecosystem variables (e.g., GPP), X' represents detrended ACGR, and β indicates the regression slope; the slope β is defined as sensitivity."

"We apply the same method to calculate the GPP sensitivity to obtain the sensitivity of NEP, R_a, SM, transpiration in response to changes in ACGR. Note the sensitivity units of [g m^{-2} day^{-1} (GtC $yr^{-1})^{-1}$] for NEP and R_a, [kg m^{-2} (GtC $yr^{-1})^{-1}$] for SM, and [mm day^{-1} (GtC $yr^{-1})^{-1}$] for transpiration, respectively."

"We used the LOWESS method to remove a trend. This method differs from conventional linear trend removal and it captures nonlinear variations by fitting a smoothing curve through locally weighted regressions (smoothing span (f) = 0.25, robustness iterations = 3)."

"However, because statistical significance was not maintained across all moving windows, these results should be interpreted as a general temporal trend rather than a strictly significant one."

3. The manuscript's focus shifts abruptly between NEP, GPP, and Ra. The results initially focus on NEP to establish the baseline sensitivity , but Section 3.2 suddenly transitions to analyzing GPP, justifying this by stating GPP is more suitable for assessing changes in ecosystem productivity. This rationale is post-hoc and fragments the logical flow. The manuscript should clearly establish its primary target metric in the introduction and methods, and maintain a consistent analytical thread throughout.

→ Valuable comments! In the revised manuscript, we have clarified the distinct roles of NEP and GPP as key evaluation indices in the data and methods section, thereby improving the connection between sections 3.1 and 3.2 and enhancing the logical consistency of the transition from NEP-based model selection to GPP-based regional classification and mechanism analysis. We added the following sentence to the data and methods section:

"It is a noted that NEP was used as a criterion for model selection in this study because it reflects the overall carbon balance by integrating carbon uptake and loss through respiration. In contrast, GPP was used for regional classification and mechanism analysis. Since NEP is an indicator that reflects multiple ecosystem processes in carbon uptake and release; however, as it involves intricate and mutually offsetting reactions, interpreting the mechanisms related to productivity is complicated. Therefore, GPP, which directly represents photosynthetic carbon uptake, provides a more appropriate indicator for examining the impact of environmental factors on the sensitivity of ecosystem productivity."

In addition, we have improved the connection between sections 3.1 and 3.2 in the results section as follows:

"Following the model selection based on NEP sensitivity, we analyzed GPP sensitivity to elucidate the underlying mechanisms governing ecosystem productivity responses."

To assess the robustness of our result, in addition, we conducted model selection based on GPP sensitivity (Fig. R1). Of the 12 DGVM models in total, 9 were found to be significant based on NEP sensitivity (now Fig. 2a in the revised manuscript), and most of this model group was also retained under the GPP sensitivity criterion. Specifically, 8 of the original 9 models were found to be significant in both analyses, with only the SDGVM model being insignificant;

consequently, 8 models were ultimately selected. This difference was found to be very limited, and it can be seen that the overall main findings will remain consistent.

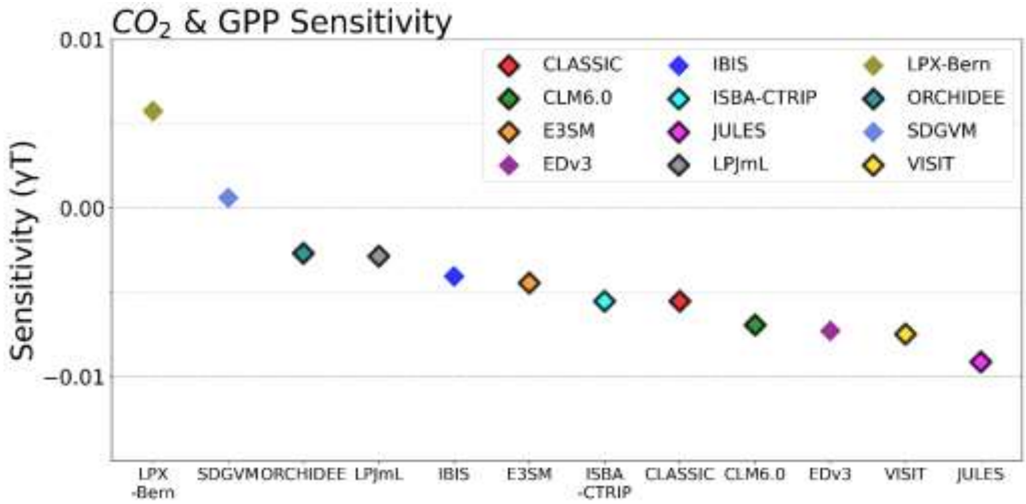

Figure R1. Scatter plot of the sensitivity between atmospheric CO_2 growth and GPP during 1959-2023, based on 12 models from TRENDY v13. Each scatter represents atmospheric CO_2 growth and GPP sensitivity of an individual model. Models with statistically significant relationships at the 95% confidence level (from the last 20-year window) are outlined in black.

4. In Section 3.3, the text abruptly diverges into an analysis of precipitation and cloud cover trends to explain variations in Photosynthetically Active Radiation (PAR). While PAR undeniably influences GPP, this sudden meteorological attribution distracts from the core focus of the paper. If the authors wish to retain this section, they must integrate it more cohesively, demonstrating mathematically how cloud cover-induced PAR anomalies specifically modulate the calculated CO2 sensitivity. Additionally, section 4 (Discussion) is conspicuously brief and fails to adequately synthesize or contextualize the study's findings within the broader scientific literature. Currently, it merely presents an additional result regarding land cover distribution (MODIS IGBP classification) to tentatively explain regional differences. A robust discussion should delve deeply into the results, rather than included a new finding.

→ Constructive comments! Following the reviewer's suggestion, we have removed the analysis of meteorological factors relating to cloud cover and precipitation from section 3.3 in order to clarify and focus the purpose of the paper. Accordingly, to maintain consistency with the results section, the description of data and methods section 2.3 cloud cover data of the original paper has also been removed. Regarding the MODIS IGBP land cover distribution, we acknowledge that positioning this within the discussion section was inappropriate, as it presented new findings rather than advancing the research results. We have therefore moved this analysis to end of the results section 3.3, where it now supports the explanation of regional variations in sensitivity from the perspective of vegetation types. Lastly, we have revised the discussion section and expanded its content as follows:

"The contrasting relationships between GPP sensitivity and environmental factors observed in this study indicate that the response of ecosystem productivity to ACGR in East Asia is regulated by distinct regional limiting factors. In the non-monsoon region, the positive correlation between GPP and SM sensitivities demonstrates that soil water availability closely modulates variations in the response of vegetation productivity to ACGR. Ultimately, these findings suggest that the response of ecosystem productivity to ACGR in the non-monsoon region is closely linked to water availability. By contrast, in the monsoon region, the phases of GPP sensitivity and SM sensitivity shifted to a contrasting relationship. This pattern suggests that changes in SM sensitivity do not directly lead to corresponding changes in GPP sensitivity. Although improved soil water availability generally supports vegetation productivity, the contrasting patterns between the two sensitivities indicate that soil water conditions alone are insufficient to explain the temporal variations in GPP sensitivity. Instead, the positive correlation between GPP sensitivity and PAR suggests that changes in radiation can be associated with the response of GPP sensitivity even under relatively favorable moisture conditions. Therefore, the response of ecosystem productivity to ACGR in the monsoon region appears to be regulated primarily by PAR, with radiation limitations contributing to variations in GPP sensitivity."

"Taken together, the regional differences in sensitivity identified in this study are driven by a complex interplay of environmental factors, including hydrometeorological conditions, available solar radiation, and land surface characteristics."

Minor comments

Lines 54-59. The definition of ACGR needs clarification. The text describes ACGR as the annual change in atmospheric CO2 concentration, but the unit is mass-based unit rather than a concentration-based unit.

→ Corrected as follows: "The ACGR was derived from atmospheric CO_2 concentration measurements and expressed as the annual change in atmospheric CO_2 burden [GtC yr^{-1}], defined as the year-to-year difference (Global Carbon Project, 2024; Friedlingstein et al., 2024)."

Lines 88-94. The exact regression framework is under-specified. Please provide the explicit regression equation used to define "sensitivity", the units of the regression slope, and how significance was assessed for each moving window.

→ Responding to the reviewer's comments, we clarified the relevant descriptions in the revised manuscript as follows:

"A linear regression was then performed using a 20-year moving window, with the slope of each regression defined as the sensitivity of GPP to ACGR [g m^{-2} day^{-1} (GtC $yr^{-1})^{-1}$] (Fig. 1c)."

"Specifically, linear regression was performed between detrended variables, defined as follows:

$$Y' = \beta X' + \alpha \quad (2)$$

,where Y' represents detrended ecosystem variables (e.g., GPP), X' represents detrended ACGR, and β indicates the regression slope; the slope β is defined as sensitivity. The calculation for the slope β is as follows:

$$\beta = \frac{\sum(X_i - \bar{X})(Y_i - \bar{Y})}{\sum(X_i - \bar{X})^2} \quad (3)$$

,where $\bar{X}$ and $\bar{Y}$ denote the mean values of variable X and Y, respectively."

"We apply the same method to calculate the GPP sensitivity to obtain the sensitivity of NEP, R_a, SM, transpiration in response to changes in ACGR. Note the sensitivity units of [g m^{-2} day^{-1} (GtC $yr^{-1})^{-1}$] for NEP and R_a, [kg m^{-2} (GtC $yr^{-1})^{-1}$] for SM, and [mm day^{-1} (GtC $yr^{-1})^{-1}$] for transpiration, respectively."

Lines 105-106 and 245-267. PAR is analyzed using "actual PAR values instead of ACGR sensitivity", whereas the other axes in Figs. 4-6 are sensitivity metrics. This mixes variables of different statistical meaning.

→ To avoid confusion, we have clarified this matter in the revised manuscript as follows:

"Also, PAR is an essential energy source for vegetation photosynthesis (Ren et al., 2018; Kalaji et al., 2014), and as it is not directly controlled by atmospheric CO_2 and can be considered an independent environmental variable."

"Unlike other variables shown as sensitivities to ACGR, PAR has no direct relationship with ACGR; therefore, actual PAR values are used to indicate radiation conditions that can influence ecosystem responses."

Lines 110-112. The sentence over-interprets the sign of the fitted slope. A negative NEP sensitivity does not, by itself, demonstrate a weakening of ecosystem carbon uptake ability.

→ Responding to the reviewer's comments, we revised the relevant sentence in the revised manuscript as follows:

"All models except LPX-Bern simulated negative NEP sensitivities, indicating an inverse relationship between ACGR and NEP in East Asia, which may reflect changes in ecosystem carbon uptake ability."

Lines 112-117. The model-selection criterion needs stronger justification. Retaining models based on sign consistency or significance only in the last 20-year window appears rather ad hoc, especially because the subsequent analyses cover the full 1959-2023 period.

→ In the present study, we calculated p-values for each window; however, we concluded that it is not statistically valid to sum or average p-values derived from different windows. The reason for this is that averaging p-values derived from different windows does not carry any statistically meaningful result. We therefore determined that a single window is appropriate for assessing statistical significance for model selection. Among the available time periods, we selected the most recent 20-year window, which represents current climate conditions and ecosystem responses. Responding to the reviewer's comments, we add the following sentences in the revised manuscript:

"Although statistical significance was assessed for each moving window, it was determined that summing or averaging the p-values calculated from different windows to represent a single index would not provide a statistically meaningful analysis. Consequently, the significance analysis was performed on a single window basis. The most recent 20-year period (2004-2023) was selected as the base window to reflect current climate conditions and ecosystem responses."

"Note that, because p-values cannot be meaningfully averaged into a single value, the statistical significance of NEP sensitivity was assessed using the last 20-year (2004-2023) moving window to reflect ecosystem changes in the recent decades."

Lines 121-127. The regional partition requires a stronger justification. The text itself acknowledges that the GPP sensitivity pattern does not perfectly align with the East Asian monsoon boundary, yet the main comparison is built on that mask. A sensitivity test with an alternative regional definition would strengthen the analysis.

→ The regional classification in this study was based on the monsoon region defined in previous study (10º-40º N, 110º-140º E) (Li and Zeng, 2002; Jianping and Qingcun, 2003), while the non-monsoon region was defined as the union of the remaining areas for comparison (41º-50º N, 90º-150º E and 10º-40º N, 90º-110º E). This classification provides a simplified analytical framework for comparing ecosystem responses under different hydroclimatic conditions based on GPP sensitivity patterns. As the reviewer noted, to distinctly separate regions based on GPP sensitivity patterns, a grid-level analysis could help identify more detailed mechanisms. However, we concluded that while this approach can identify regional variability, it is difficult to interpret the results in terms of physically meaningful, large-scale climate features. Therefore, as this study focused on analyzing large-scale differences in ecosystem responses, we divided the analysis into monsoon (based on previous research) and non-monsoon regions. This limitation has been noted in the revised manuscript as follows: "These regional distinctions, related to the monsoon system, provide a basis for understanding regional differences in ecosystem responses, reflecting the climatic influences of East Asia, and should be interpreted as a simplified framework representing regional scale hydroclimatic conditions rather than exact spatial boundaries."

Lines 140-146. Expressions such as "downward trend in negative NEP sensitivity" and "reduction in negative GPP sensitivity" are sign-ambiguous and hard to interpret. Please rewrite these passages using clearer language, for example by stating explicitly whether the values are becoming more negative or moving towards zero.

→ Detailed comments! To enhance clarity, we revised the relevant parts of the results section to indicate whether the values become more negative or converge to zero, thereby clearly describing the direction and sign of the sensitivity changes. Responding to the reviewer's comments, we clarified the relevant explanations in the revised manuscript:
"In Figure 3a, the sensitivity of NEP in the non-monsoon region remained negative throughout the entire period. It gradually approached zero by the late 1990s before shifting toward more negative values."

"Consequently, both regions exhibited a trend toward more negative NEP sensitivity, suggesting a strengthening inverse relationship between ACGR and ecosystem carbon uptake (i.e., increased ACGR corresponds to reduced carbon uptake capacity, and vice versa) in East Asia after the late 1990s, although the statistical significance varied among moving windows."

"In the non-monsoon region, GPP sensitivity remained negative for most of the period, briefly approaching zero and becoming slightly positive during the 1990s, before subsequently shifted back to negative values (Fig. 3b)."

"The convergence of GPP sensitivity toward more negative values over time indicates an intensifying inverse relationship between ACGR and GPP. This suggests that higher ACGR is increasingly associated with reduced photosynthetic carbon uptake, and vice versa; however, this pattern should be interpreted mainly as a temporal tendency rather than a consistently significant response across all moving windows."

"Regarding this relationship, R_a sensitivity showed a decreasing pattern similar to that of GPP, reflecting that R_a responded similarly to variations in ACGR."

Lines 156-158. The opening sentence of Section 3.2 is grammatically incomplete and conceptually abrupt.

→ We have revised the opening sentence of section 3.2 by replacing the previous sentence with clearer expression as follows:

"Following the model selection based on NEP sensitivity, we analyzed GPP sensitivity to elucidate the underlying mechanisms governing ecosystem productivity responses."

Regarding the concern that the sentence appeared conceptually abrupt, this has been addressed through the revisions detailed in the response to major comment 3. Specifically, we have clarified the distinct roles of NEP and GPP in the data and methods section and improved the logical connection between sections 3.1 and 3.2. This revision has resolved both the grammatical incomplete and conceptual abrupt of the previous sentence by more clearly presenting the transition from the NEP-based approach in section 3.1 to the GPP-based sensitivity analysis in section 3.2.

Lines 170-174. There are both language and presentation issues here.

→ Corrected as follows: "Although an SM sensitivity is generally associated with water availability and stomatal regulation, SM and GPP sensitivities show different temporal patterns. This suggests that in the monsoon region, where water availability is relatively high, increases in SM sensitivity play a less dominant role in modulating the GPP response to ACGR. Consistent with this interpretation, the explanatory power of the relationship between SM and GPP sensitivities was remarkably lower in the monsoon region (r^2 = 0.42) than in the non-monsoon region (r^2 = 0.72), indicating the compounding influence of other environmental factors."

Lines 190-191. There is a clear inconsistency between the text and Fig. 4f. The manuscript reports r = 0.66, but Fig. 4f shows a negative relationship and labels it as r = -0.66. Please correct either the text or the figure.

→ Corrected as follows: "In contrast, the monsoon region showed increasing SM sensitivity from negative to positive, whereas transpiration sensitivity exhibited a decreasing trend from positive to negative (r***=-0.66; Fig. 4f)."

Lines 239-242. The causal language is too strong. A coefficient of determination from a bivariate relationship is not sufficient to conclude that PAR is "the primary factor" weakening GPP sensitivity.

→ Responding to the reviewer's comments, we add the following sentences in the revised manuscript:
"In conclusion, the coefficient of determination for the entire period suggests that reductions in PAR are strongly associated with the weakening of GPP sensitivity."

In addition, in response to the reviewer's concern regarding overly strong causal language, we further reviewed the manuscript and revised related expressions throughout the results section: "This indicates that the sensitivities of both variables vary in the same direction over time. Additionally, the strong positive correlation suggests that the decline in SM sensitivity reflects reduced water availability that may limit vegetation activity, ultimately accompanying a decrease in GPP sensitivity. Conversely, an increase in sensitivity would also corresponds to an increase in GPP sensitivity."

"These opposing trends suggest that the ACGR related responses of transpiration and SM move in opposite directions and are closely linked. The decrease in stomatal conductance may be related to SM accumulation; conversely, changes in transpiration responses can also influence water availability conditions through changes in stomatal regulation. However, the increase in

SM sensitivity coincided with a decrease in transpiration sensitivity, showing that improved moisture conditions do not necessarily correspond to increased vegetation productivity."

"The relationship between transpiration sensitivity and SM sensitivity showed insignificant correlation during early period (r=0.13, p>0.1; Fig.6e), but became significantly negatively correlated during the later period (r^{**}=-0.50 and r^2=0.25; Fig. 6f), highlighting a pattern consistent with the full period analysis, in which changes in transpiration sensitivity are inversely associated with changes in SM sensitivity under ACGR related responses. Moreover, although no clear relationship emerged during the early period, the later period showed that improved moisture conditions during the later period do not necessarily correspond to increased vegetation productivity, which may partly explain the reduced sensitivity of GPP."

Lines 250-264. Trend slopes for precipitation, cloud cover, and PAR are reported without units.
→ Please see the reply for the reviewer's comment #4.

Lines 270-281. The land-cover discussion has a temporal mismatch. The manuscript uses mean MODIS land cover from 2001-2023 to interpret sensitivity behaviour over 1959-2023. This should be acknowledged more explicitly as a limitation.

→ Thoughtful comment! We acknowledge that the land cover analysis is based on the MODIS land cover dataset from 2001 to 2023, whereas the sensitivity analysis covers a longer period (1959-2023). This temporal inconsistency can lead to some uncertainty when interpreting long-term sensitivity patterns. Accordingly, a comparison of land cover between 2001 and 2023 reveals that, while changes were observed in some areas over time, the major patterns remain generally consistent (Fig. R2, R3 below). In particular, in the non-monsoon region, although the relative proportions of each vegetation type show minor variations, the same six dominant vegetation types are consistently identified. In the monsoon region, the four primary vegetation types also remain unchanged, with differences only observed in the fifth and sixth types. A comparison with Figure R4 further indicates that the dominant vegetation composition in each region remains largely stable. Therefore, although some caution is required when interpreting the relevant results, the overall impact on the results is considered to be limited. These limitations have been discussed in the revised manuscript's discussion section.

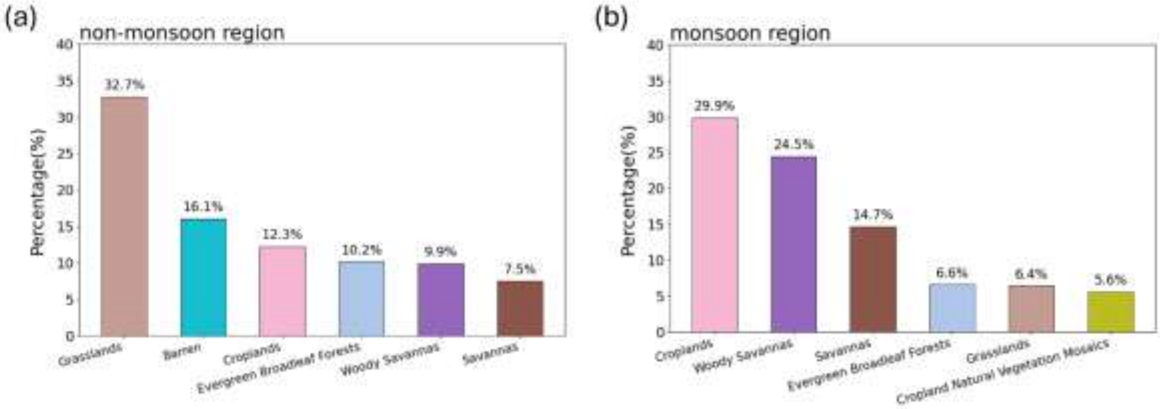

Figure R2 East Asian land cover distribution based on IGBP classification. MODIS land cover averaged in 2001, regridded to 0.5° × 0.5° spatial resolution, showing the percentage distribution of land cover types in (a) non-monsoon and (b) monsoon region.

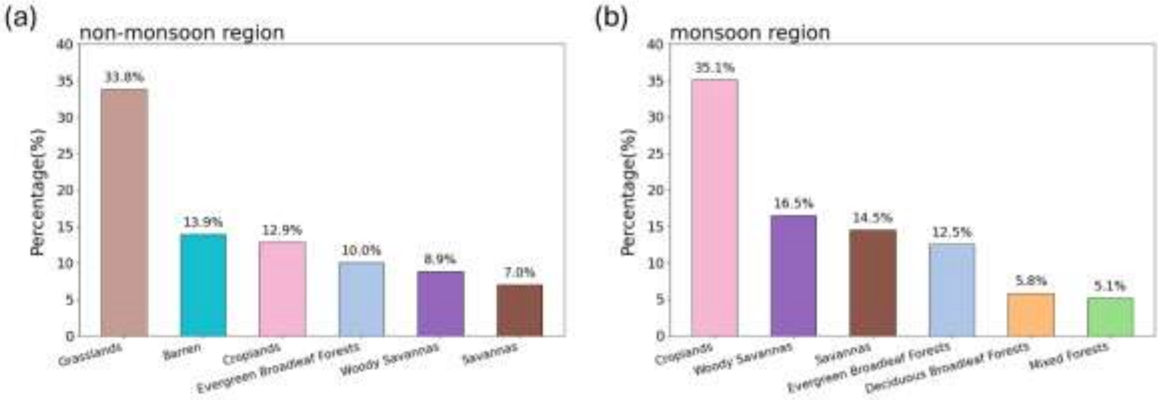

Figure R3 East Asian land cover distribution based on IGBP classification. MODIS land cover averaged in 2023, regridded to 0.5° × 0.5° spatial resolution, showing the percentage distribution of land cover types in (a) non-monsoon and (b) monsoon region.

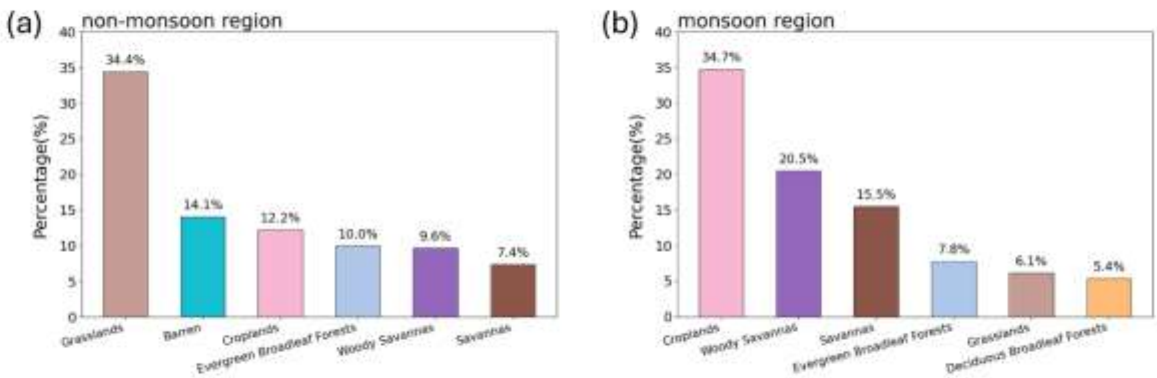

Figure R4. East Asian land cover distribution based on IGBP classification. MODIS land cover averaged during 2001-2023, regridded to 0.5° × 0.5° spatial resolution, showing the percentage distribution of land cover types in (a) non-monsoon and (b) monsoon region.

Responding to the reviewer's comments, we add the following sentences in the revised manuscript:

"However, as the MODIS dataset does not fully cover the longer sensitivity analysis period, careful consideration is required when analyzing long-term sensitivity patterns. A comparison of vegetation types between 2001 and 2023 reveals minor changes, but the patterns remain largely consistent. Although uncertainty exists due to this temporal mismatch, the impact on the overall analysis is expected to be limited."

Lines 295-306. The conclusion again goes beyond what the presented metric can directly support.

→ Responding to the reviewer's comments, we add the following sentences in the revised manuscript:

"GPP sensitivity was generally negative in the non-monsoon region and positive in the monsoon region."

"This downward trajectory was also observed in NEP sensitivity, indicating a strengthening inverse relationship between ACGR and both ecosystem productivity and carbon sequestration in East Asia."

"In the non-monsoon region, SM sensitivity displayed a stronger association with GPP sensitivity, whereas in the monsoon region, reductions in PAR were more closely linked to the weakening GPP response. These regional differences are likely associated not only with contrasting moisture and radiation conditions, but also with differences in vegetation structure between the two regions."

"Regional disparities in moisture regimes were also reflected in the relationship between transpiration and SM sensitivities. In the monsoon region, a negative correlation was observed between these two sensitivity metrics, suggesting that changes in transpiration responses may influence SM conditions through changes in stomatal conductance. Conversely, a positive correlation was observed in the non-monsoon region."