Reviewer 1

LUE quantifies the fraction of absorbed light used in photochemistry to produce chemical energy during photosynthesis and is essential for understanding ecosystem productivity and the global carbon cycle. Previous study have identified the key role of plant trait driving LUE variations, this study further advanced this topic by considering the climate-trait interactions. The manusript is well-written. The spatial resolution and time span is good. The logic and algorithm is clear and robust. After reviewing the manuscript, I have several issues that need to be addressed.

Response: We thank reviewer 1 (R1) for the positive comments regarding the manuscript. Please find below the responses to R1 comments.

1.Representation of Cropland or agricultural ecosystem in the flux tower upscaling. As we konw, Cropland usually showed large LUE. Currenly, this study overlooked the role of cropland sites. The spatial map also failed show the distribution over agricultural areas. I know, this might due the flux tower availability. At least, Sensitivity test should be incorpated. I doubt, whether the overall temporal trend is related to the cropland ecosystem.

Response: Thanks for this important comment. We agree that croplands generally have large LUE, and exclusion of cropland in this study may show data gaps to indicate the regional LUE variations. However, the gridded trait datasets used in this study have limited spatial coverage of plant functional traits over croplands across the entire study domain, particularly leaf nitrogen content (N) and specific leaf area (SLA), which are key predictors to map regional LUE variations (Line 132-133). Including croplands without consistent and enough trait information could introduce large uncertainties into model training and regional upscaling results. Additionally, exclusion of cropland into our analyses could also reduce the human management-related impacts (i.e. irrigation, fertilization) on vegetation LUE spatiotemporal variations in China, supporting straightforward linkages of LUE with environmental factors and plant functional traits. Nevertheless, we acknowledge that the exclusion of cropland in our study limits the representation of agricultural ecosystems in our regional estimates. We clarify this limitation and highlight the need for future studies incorporating enough cropland flux tower observations and spatially consistent trait data in the revised manuscript (Lines 379-384), which is also listed below.

"In addition, the trait datasets show limited spatial coverage of leaf nitrogen content (N) and specific leaf area (SLA) data over croplands, causing the exclusion of cropland LUE in the analyses of this study.

Such exclusion could induce limitations in the resulted regional LUE estimates as they do not fully represent LUE characteristics for agricultural ecosystems across China, and the extent to which croplands contribute to regional LUE variability and long-term trends remains uncertain. Future studies incorporating enough cropland flux tower observations and spatially consistent trait datasets are highly encouraged."

2. LUE product comparison. I know LUE could not directly derived, usually calculated by GPP and fapar. Maybe, checking the spatial consistency between normalized LUE and normalied SIF yield could partly address this issue.

Response: Thank you for this helpful suggestion. Following the reviewer's suggestion, we calculate the SIF yield as the ratio of SIF to APAR, with SIF obtained from the CSIF dataset. The data sources and the calculation method have been added to the Methods section (Lines 137–141). The comparison reveals the strong and significant positive spatial correlations between LUE and SIF yield over 2003–2020 (Pearson's r = 0.563, P < 0.001; Figure 8). Such complementary evidence of spatial consistency between LUE and Sif yield suggests that the LUE estimated in this study is robust. These results and their interpretation have been added to Section 3.3 (Lines 350-357).

Line 137-141: "Solar-induced fluorescence (SIF) data are obtained from the global spatially contiguous SIF (CSIF) dataset (Zhang et al., 2018), which covers the period 2000–2022. SIF yield is calculated as the ratio of SIF to absorbed photosynthetically active radiation (APAR), with APAR is estimated as the product of photosynthetically active radiation (PAR) and the fraction of absorbed photosynthetically active radiation (FPAR). FPAR is obtained from the MODIS MOD15A2H.061 product(Myneni et al., 2021), and PAR is obtained from the MODIS MCD18C2.062 product(Wang, 2025)."

Line 350-357: "To further address the robustness of the estimated LUE, we compare its multi-year mean spatial consistencies with SIF yield over 2003–2020. Since LUE and SIF yield have different units, the normalized values (Z-score) of these two variables are used for comparisons. The strong and significant positive spatial correlations are shown here (r = 0.563, P < 0.001; Fig.8), indicating broadly consistent spatial distributions between these two datasets, and implying the reliability of the estimated LUE in this study."

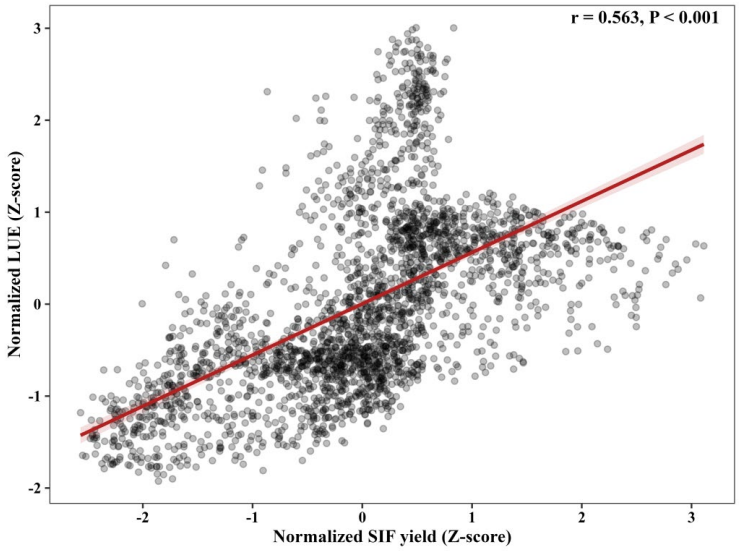

Figure 8: Spatial relationship between multi-year mean normalized LUE and SIF yield across China during 2003–2020. The red line represents the ordinary least squares (OLS) linear regression fit, and the shaded area indicates the 95% confidence interval.

3.Discussion. Large area of significantly decrease LUE are found in South China (Figure7). If this is robust, how to explain those decrease?

Response: Thank you for this valuable comment. To address this concern, we further examine the VPD conditions in areas exhibiting significant LUE declines across China and their relationships with the RF–SHAP results. Our analysis shows that these areas exhibit relatively low VPD, with a mean of 0.442 kPa and a 10th–90th percentile range of 0.177–0.614 kPa. These values largely fall within the range associated with negative VPD SHAP contributions (below approximately 1.2 kPa; Fig. 5d), suggesting that low-VPD conditions may be associated with lower model-predicted LUE. Previous studies also highlight the role of VPD in regulating photosynthetic processes and ecosystem LUE (Fei et al., 2019; Grossiord et al., 2020). In addition, widespread warming and spatially heterogeneous changes in soil water content (SWC) may further influence LUE through temperature and water limitations (Duffy et al., 2021; Zhou et al., 2015). We have revised the Discussion to incorporate these findings and clarify the potential roles of VPD, temperature, and SWC in the observed LUE declines (Lines 330-341), as detailed below.

"The significant LUE declines in parts of southern China may be associated with the nonlinear responses of LUE to atmospheric moisture conditions. Our additional analysis shows that areas exhibiting

significant LUE declines across China are characterized by relatively low VPD, with a mean of 0.442 kPa and a 10th–90th percentile range of 0.177–0.614 kPa. These values largely fall within the range associated with negative VPD SHAP contributions in our RF model (below approximately 1.2 kPa; Fig. 5d), suggesting that low-VPD conditions are associated with lower model-predicted LUE. Previous studies highlight the important role of VPD in regulating ecosystem LUE and photosynthetic processes (Fei et al., 2019; Grossiord et al., 2020). In addition, widespread warming occurs across southeastern China during 2003–2024, while SWC exhibits spatially heterogeneous changes, including decreases in some areas. Photosynthetic carbon uptake can be constrained when temperatures exceed ecosystem-specific optima (Duffy et al., 2021), whereas reduced soil water availability can limit photosynthesis through stomatal and non-stomatal processes (Zhou et al., 2015). Together, these findings suggest that the LUE declines may reflect the combined influence of atmospheric moisture conditions, temperature, and soil water availability, although the relative contributions of individual factors remain uncertain."

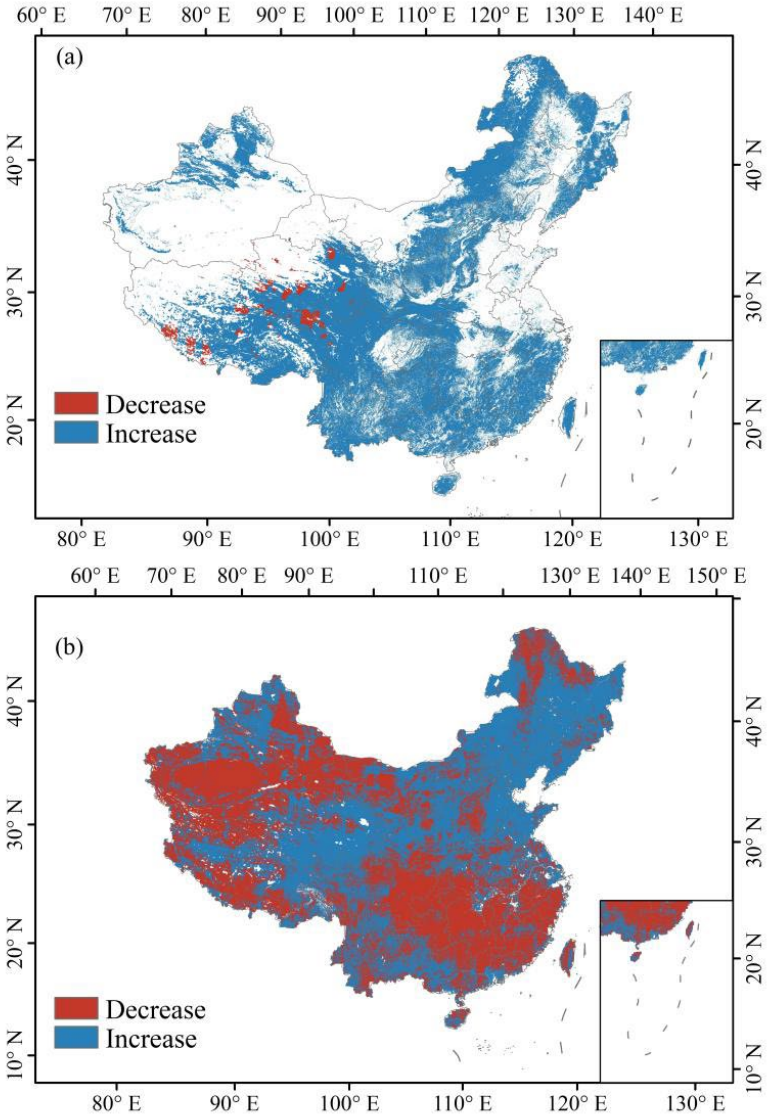

Figure R1. Spatial patterns of changes in air temperature (TA) and soil water content (SWC) across China during 2003–2024. (a) Spatial distribution of TA trends; (b) spatial distribution of SWC trends.