Dear Dr. Kato,
We have thoroughly revised our manuscript according to the suggestions of referee 2.

Our responses to each comment are detailed below, with the reviewer comments in italics and our responses in plain text. We thank the reviewers for their thoughtful comments, and the editor for considering our manuscript.

Best regards,
Ensheng Weng (on the behalf of all coauthors)

Response to referee 1

No response needed.

Response to referee 2

The authors have made significant improvements based on the reviewers' comments. I enjoyed reading the new manuscript version and am satisfied with their revisions. My major concerns about the previous version are solved. Below are some additional minor suggestions for the authors to further improve their manuscript:

Line 162: please add the reference for Beer's law.
Added:
Beer: Bestimmung der Absorption des rothen Lichts in farbigen Flüssigkeiten, Annalen der Physik, 162, 78–88, https://doi.org/10.1002/andp.18521620505, 1852.
Swinehart, D. F.: The Beer-Lambert Law, J. Chem. Educ., 39, 333, https://doi.org/10.1021/ed039p333, 1962.

P10, Line 208: although the authors briefly discussed cropland in the discussion, it would be better to mention or explain why they did not include cropland as a plant functional type in the BiomeE model.

We added one sentence to briefly explain why we didn't include the crop PFTs.

"Cropland is not included because the purpose of this paper is to describe the baseline processes of natural vegetation and soil biogeochemical cycle."

P16, Line 312: add a full stop.

Added.

Figure 5b: It is difficult to differentiate the NBC and TPJ sites.

We changed the schemes of line types and colors. Accordingly, we updated the figures 3 and 4 with the same color and line type scheme.

Section 4.2: There are several global data sets of LAI. A quick check on the modeled global pattern of LAI would be helpful in explaining the GPP results.

Following this suggestion, we added LAI figure for Figures 7 and 8 with the maximum LAI data from Ent vegetation dataset, where the LAI is from a Modis LAI product for the year 2004. We added LAI data sources in the method section, and discussed LAI discrepancies in discussion (5.2 Model predictions and performance).

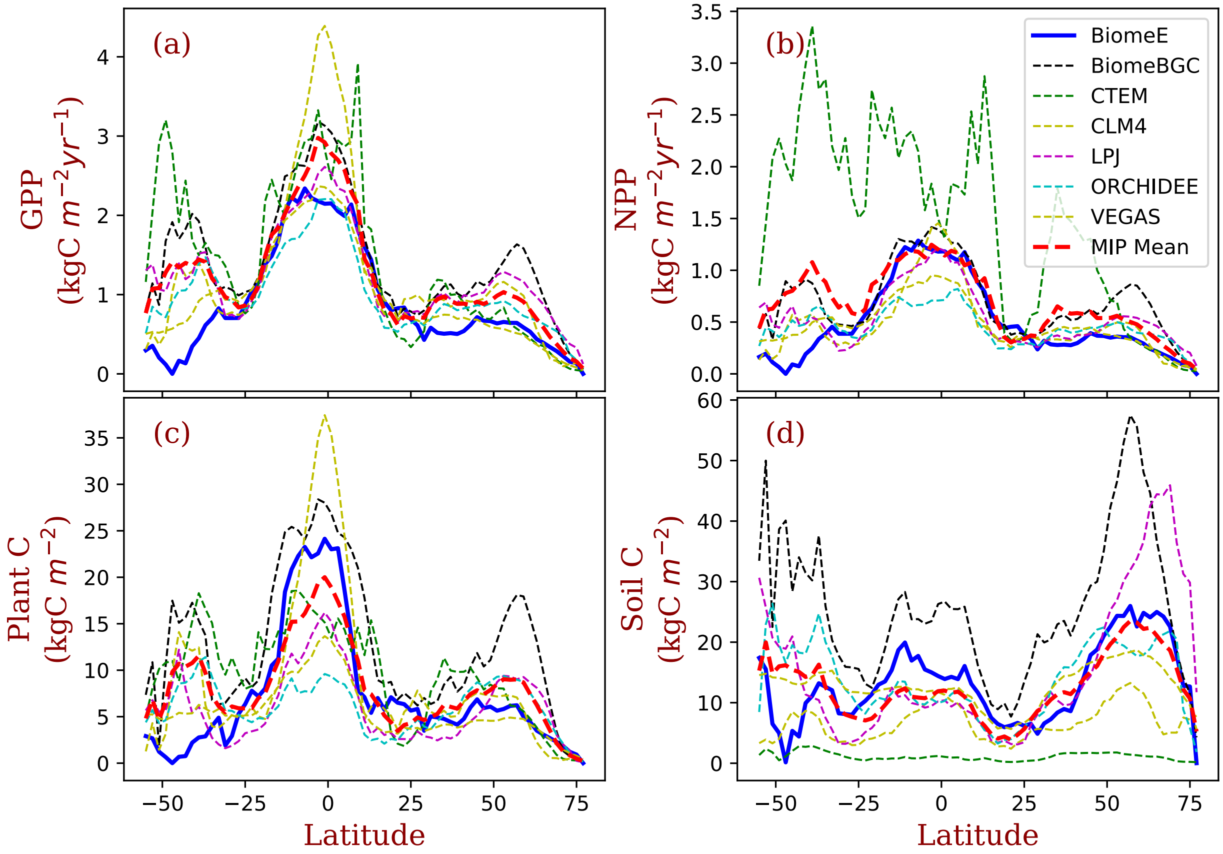
Copied below is the description of the LAI comparison with data in the result section (4.2 Global Comparisons with Observations):

"The simulated LAI roughly capture the spatial pattern of MODIS LAI (Figure 7: a and b), though there are high variations at each grid (Figure 8: a). Generally, the simulated LAI in well vegetated grids, e.g., boreal forest regions, is underestimated by our model because the crown LAI is calculated as a function of tree height and a parameter of maximum crown LAI (Table 1 and Eq. 6). The LAI in the grids that were converted to different land use types is overestimated because we assume all terrestrial grids are covered by potential vegetation in our test runs."

Figure 9: A curve of multi-model mean values across the MsTMIP model might be helpful for the comparison.

Figure 9 is intended to show the spread of MsTMIP model simulations and where BiomeE simulations are. Adding one more dot would complicate the figure.

We suppose the reviewer may refer to the Figure 10. After adding "*A curve of multi-model mean values*", it really looks better. See copied figure 10 below:



P39: Line 688: LMA has been defined.

Removed.

P41: Line 751: add a space after "competition".

Added.

P41-42: Some discussions in this paragraph lack references. For example, the "carbon negative leaves" is unclear to most readers. The "uniform leaf" needs more explanation.

Since we added LAI in the results section, we reorganized the discussion about LAI and crown leaf distribution, added related references, and changed the expressions of "uniform leaves" and "carbon negative leaves" to make them easier to understand (copied below).

"LAI is an illustrative variable for understanding why compromises are necessary when integrating ecological and demographic processes into an ESM. LAI, as a critical prognostic variable in vegetation models, links both plant physiology and biogeophysical interactions with climate systems (Richardson et al., 2012; Kelley et al., 2020; Park and Jeong, 2021). While LAI is usually simulated by a fixed allocation scheme, even if the allocation ratios are dynamic with vegetation productivity or environmental conditions (Montané et al., 2017; Xia et al., 2019), the prediction of LAI is often simplified as the balance between leaf growth and turnover.

In practice, for ESMs, modelers tend to tune the LAI to fit observations and get the required albedo and water fluxes whatever the parameters of photosynthesis and respirations are. The uniform leaves within a crown would make the lower layer leaves have a negative carbon gain if the LAI was tuned close to that observed in tropical and boreal evergreen forests (around 5~7). Therefore, the photosynthesis rate must be tuned to fit the canopy photosynthesis by keeping these carbon negative leaves. The crown with carbon negative leaves do not affect the ecosystem carbon dynamics in the "single-cohort" models because the whole canopy net carbon gain can be tuned to fit the observations.

However, for the demographic models, the trees with different sizes are explicitly represented and placed in different layers. The vegetation community can create an understory condition where seedlings cannot survive because of light limitation and negative carbon gains (Weng et al., 2015). Since the leaf traits in the crown profile are functions of light, water and nitrogen (Niinemets et al., 2015), a more complex crown development module is required to simulate branching and leaf development and deployment processes. A tree should be able to optimize its LAI to maximize its fitness as a result of interactions among crown structure, light interception, and community-level competition (Anten, 2002; Niinemets and Anten, 2009; Hikosaka and Anten, 2012). For balancing the model complexity and computing efficiency, we defined a much small target LAI in this model to avoid carbon negative leaves."

P46: Line 854: The MsTMIP models were analyzed by Cui et al. 2019 (GBC; 33, 668-689).

We appreciate the reviewer pointed out the missing reference of MsTMIP and added it in this section. This paper is supportive to what we discussed in this section.

Additional improvements:

We edited the whole text thoroughly.

We added a new parameter for PFTs in the table 1, $L_{\max,0}$, since we need this parameter to understand simulated patterns of LAI, which are included in this revised version.

We also updated the Figures S10 and S11 to add the simulated LAI by the single-cohort version of BiomeE.

We improved the discussion of phenology modeling section

"The phenological type is simulated as an emergent property of plant physiological processes and strategies of dealing with seasonal air temperature and soil water variations. Three parameters – growing degree days, running mean daily temperature, and critical soil moisture – are used to define all possible phenological types. These three parameters are widely used in a variety of phenology models (e.g., Prentice et al., 1992; Sitch et al., 2003; Arora and Boer, 2005). However, phenology is not just a physiological response to the seasonality of climate conditions. Evergreen plants are distributed in periodically cold or dry climates. It is a competitively optimal strategy in infertile soil conditions (Aerts, 1995; Givnish, 2002; Coomes et al., 2005). The benefits and costs of keeping different leaves in cold or dry periods should be realistically simulated based on eco-evolutionary theories for phenology modeling (e.g., Levine et al., 2022; Weng et al., 2017)."