Reply to Referee #1 on manuscript EGUSPHERE-2026-1335: “Integrating Ozone–vegetation Damage Schemes into SSiB4/TRIFFID: Evaluation of Six Parameterizations and Refinement of Ozone Decay Process Across Plant Functional Types”

Reply on RC1

We sincerely thank Referee #1 for the careful and constructive review. The comments were very helpful for improving the clarity, consistency, and presentation of the manuscript.

In response, we have substantially revised the Methods section to better distinguish the six O_3–vegetation damage parameterizations, including their ozone dose metrics, photosynthesis–stomatal treatments, and parameter settings. We have added a new summary table to provide a side-by-side comparison of the schemes. We have also clarified the distinction between instantaneous stomatal O_3 flux, POD_y, and CUO, and revised the description of schemes to more clearly distinguish formulation refinements from parameter updates.

In addition, we have revised the figures and captions to clarify the spatial and temporal information, sources of observational benchmarks, and meaning of plotted data points. Formatting issues, notation inconsistencies, figure labels, and technical errors have also been checked and corrected throughout the manuscript and supplementary materials.

A detailed point-by-point response to all general and specific comments is provided in the response PDF attached as a supplementary file. In the response PDF, the referee’s comments are shown in black, while our responses and the corresponding manuscript revisions are shown in blue. All changes are also shown in the revised manuscript using track changes.

General comments

1. First, the key characteristics and differences among the six ozone damage schemes are not clearly presented. The authors introduce L2015, L2024, S2007, CS2007, LMAgrid, and LMApft separately in the methods, but a side-by-side comparison is missing. For example, which metric (CUO, PODy, or instantaneous ozone uptake) does each scheme rely on? Are the effects on photosynthesis and stomatal conductance treated in a coupled or decoupled manner? Is CS2007 simply a recalibrated version of S2007 with lower ozone damage sensitivity coefficients and a simplified treatment for three PFTs? The distinction between LMAgrid and LMApft is also unclear. Including a summary table in the methods that highlights the essential features and differences of all six schemes would greatly improve clarity.

Response:

We agree with the referee that, although the six O_3–vegetation damage schemes were described separately in the original Methods section, their key structural differences were not sufficiently clear in a side-by-side manner. This could make it difficult for readers to distinguish the characteristics and key differences of each parameterization scheme. In the revised manuscript, we have therefore added a new summary table in Sect. 2.2 entitled "Key characteristics of the six ozone–vegetation damage parameterizations implemented in SSiB4/TRIFFID." This table compares the six schemes in terms of their O_3-damage metric, photosynthesis – stomatal treatment, and representation of ozone damage on photosynthesis. It should be noted that, following the suggestion of Referee #2, we have changed "L2024" to "Li2024" in both the response and the revised manuscript, to avoid confusion with "L2015".

Specifically, the new table clarifies that L2015 and Li2024 are CUO-based schemes, in which ozone damage is represented using cumulative uptake of ozone with prognostic uptake, decay, and healing processes. In contrast, S2007 and CS2007 are based on instantaneous stomatal ozone flux above a threshold. The two LMA-based schemes also follow an instantaneous-flux framework with mass-based O_3 flux calculated by leaf mass per area (LMA). In terms of the photosynthesis–stomatal treatment, L2015 and Li2024 are described as "decoupled", because O_3 damage is applied through separate response functions for photosynthesis and stomatal conductance. By contrast, the photosynthesis-stomatal treatment of S2007, CS2007, LMAgrid, and LMApft are described as "coupled". In these schemes, O_3 directly modifies photosynthesis, and stomatal conductance is then calculated through the Ball–Berry formulation.

As for the CS2007 scheme, although it is not structurally independent from the original S2007 formulation, Ma et al. (2023) recalibrated the O_3 sensitivity parameters using observational datasets compiled from a wide range of existing literature. Therefore, it represents a distinct parameterization with updated PFT-specific sensitivities. We have clarified this point in the revised manuscript and modified the original text to better explain the distinction of this scheme in our intercomparison.

Finally, we revised the text and clarified the distinction between LMAgrid and LMApft. These two schemes share the same trait-based mathematical formulation, but differ in the source of LMA data: LMAgrid uses a spatially varying gridded LMA dataset, whereas LMApft uses prescribed PFT-level LMA values. This distinction is now explicitly stated in both the new table and the text.

Manuscript revision:

We added a new Table 1 in Sect. 2.2, entitled "Key characteristics of the six O_3–vegetation damage parameterizations implemented in SSiB4/TRIFFID." The table compares the six schemes in terms of their O_3 damage metric, photosynthesis–stomatal treatment, and representation of O_3 damage on photosynthesis.

Line 129-147: In 2007, Sitch et al. (2007) proposed a semi-mechanistic parameterization to represent the transient O_3-induced damage to plants through the coupling between stomatal conductance and photosynthetic rate (S2007). The O_3 modification factor on photosynthesis (F) is formulated as a function of the excessive instantaneous stomatal O_3 flux above a PFT-specific threshold y:

$$F_{O3} = 1 - \alpha_{PFT} \times U \tag{3}$$

where U is the excessive instantaneous stomatal O_3 flux defined in Eq. (2), and α_{PFT} is the PFT-specific O_3 sensitivity coefficient derived from observations (Sitch et al., 2007). The coupled formulation of Eqs. (1)-(3) produces a quadratic in F_{O3} that can be solved analytically at each timestep. The resulting F_{O3} is then applied as a reduction factor on net photosynthetic rate, while stomatal conductance is subsequently calculated using the semi-empirical Ball-Berry formulation driven by the O_3-modified photosynthetic rate (Collatz et al., 1991; Zhan et al., 2003).

Within the same framework, Ma et al. (2023) further recalibrated the sensitivity parameters of S2007 using observed dose–response relationships compiled from a wide range of field and experimental studies. This recalibrated version is denoted as CS2007 in this study. Although CS2007 is not structurally independent from S2007, it differs in the updated PFT-specific coefficients and thresholds. This distinction allows us to evaluate how updated observational constraints on plant O_3 sensitivity influence simulated O_3 vegetation damage within the original S2007 framework. It should be noted that both S2007 and CS2007 provide low-, moderate-, and high-sensitivity parameter sets to represent uncertainty in plant O_3 responses. In this study, we used the moderate-sensitivity parameter sets as default configuration for both schemes to ensure a consistent comparison with the other parameterizations. The SSiB4/TRIFFID implementation of S2007 and CS2007 is summarized in Table S1, and the corresponding sensitivity parameters are shown in Table S2. More details of the two schemes are provided in Sitch et al. (2007) and Ma et al. (2023).

2. Second, the conceptual framework regarding ozone dose metrics is confusing, and the distinction between mechanistic use and analytical use is not properly addressed. The authors employ three concepts – PODy (Phytotoxic Ozone Dose over a threshold of y), CUO (Cumulative Uptake of Ozone), and instantaneous ozone uptake -- without clearly defining or differentiating them. The description confuses PODy with CUO, and the relationship between PODy and instantaneous uptake is not explained. In the results, the authors introduce a dose-response analysis between GPP and ozone, in which the simulated annual cumulative stomatal ozone uptake is directly defined as PODy. The authors should clarify the physical meaning of each metric and specify how each is used in the research.

Response:

We thank the referee for pointing out this conceptual confusion. We agree that the original manuscript did not clearly distinguish among the instantaneous stomatal O_3 flux, POD_y (Phytotoxic O_3 Dose over a threshold of y), and CUO (Cumulative Uptake of O_3). The use of these variables in analysis needs to be clarified.

In the revised manuscript, Sect. 2.2 has been reorganized to introduce the stomatal O_3 uptake metrics that are commonly used in the parameterizations before introducing the individual schemes. We define the instantaneous stomatal O_3 flux (f_{O3}) and the above-threshold excessive flux U, which is then used for calculating CUO and POD_y in the following sections.

In the revised version, CUO is defined as a model-internal O_3 stress state variable that evolves with O_3 uptake, decay, and healing process, which is used to represent O_3 damage state in the L2015 and Li2024 schemes. In contrast, POD_y is defined in this study as a cumulative flux-based dose metric, calculated by accumulating the above-threshold stomatal O_3 flux over a specific exposure period, without including decay or healing processes. In Sect. 2.5, we clarify that the annual POD_y is used only as a common diagnostic metric for the cross-scheme RGPP–POD_y dose–response analysis, which provides a consistent basis for comparing the simulated O_3 sensitivities across all parameterizations.

It should be noted that although Li et al. (2024) referred to the corresponding prognostic variable as POD_y in their original implementation, we use the term CUO in this study, following Lombardozzi et al. (2015), to represent the model-internal O_3 stress state that includes uptake, decay, and healing. This distinction clarifies the physical meaning and use of the two metrics: CUO is used mechanistically in the implementation of L2015 and Li2024 schemes to represent state of O_3 stress, whereas POD_y is used analytically as a common diagnostic metric for the dose–response comparison across schemes.

Manuscript revision:

Line 113-123: Although these schemes differ in their treatment of O_3 damage, they are all based on stomatal O_3 uptake. Therefore, we first define the instantaneous stomatal O_3 flux f_{O_3}, which represents the O_3 uptake through stomata at each modelling time step:

$$f_{O_3} = \frac{[O_3]}{r + k_{O_3} \times r_s} \tag{1}$$

where $[O_3]$ is the O_3 concentration at the top of the canopy, r denotes the aerodynamic and boundary layer resistance between leaf surface and the reference level, k_{O3} is the ratio of leaf resistance for O_3 relative to that for water vapor (1.67), and r_s refers to the stomatal conductance for H_2O (m s^{-1}). Based on f_{O3}, the excessive instantaneous O_3 flux above a threshold y (nmol m^{-2} s^{-1}) is defined as:

$$U = \max\left(f_{O_3} - y, 0\right) \tag{2}$$

where y is the area-based flux threshold. U represents the portion of instantaneous stomatal O_3 uptake that exceeds the critical threshold and is therefore assumed to trigger phytotoxic damage, and is used differently among parameterizations.

Line 148-184: Unlike S2007 and CS2007, which diagnose O_3 damage from instantaneous excessive stomatal O_3 uptake, L2015 and Li2024 calculate O_3 damage based on cumulative uptake of O_3 (CUO). According to Lombardozzi et al. (2015), CUO is calculated as a prognostic cumulative O_3 exposure metric that evolves with O_3 uptake, decay, and healing process.

$$CUO_t = CUO_{t-1}(1-D) + U(1-H) \tag{4}$$

$$D = \begin{cases} \dfrac{\Delta t}{l_{leaf} \times 3600 \times 24 \times 365}, & evergreen \\ 0, & else \end{cases} \tag{5}$$

$$H = \max\left(1 - \frac{LAI_{t-1}}{LAI_t}, 0\right), \quad for\ all\ PFTs \tag{6}$$

where CUO_t and CUO_{t-1} denote the cumulative O_3 stress at the current and previous model time steps, respectively. U is the excessive instantaneous stomatal O_3 flux defined in Eq. (2), representing the newly added O_3 uptake at current time step. D denotes the decay factor applied to the previously accumulated CUO, and is parameterized as a function of the leaf longevity l_{leaf} (year). H denotes the healing factor, which is derived from the change in leaf area index (LAI) between the current and previous time steps. It represents the attenuation of previously accumulated O_3 stress by new leaf growth, assuming that newly formed leaves are initially free of O_3 damage. Following Lombardozzi et al. (2015), CUO is accumulated only when LAI $\geqslant$ 0.5. When LAI falls below this threshold, CUO is reset to zero to represent the end of growing season and O_3 stress accumulation.

Based on the CUO formulation described above, Lombardozzi et al. (2015) developed separate empirical response functions for photosynthesis and stomatal conductance using experimental data compiled from the peer-reviewed literature. Accordingly, the O_3 modification factors for photosynthesis (F_{O3_A}) and stomatal conductance (F_{O3_g}) are expressed as linear functions of CUO:

$$F_{O3\_A} = a_p + b_p \times CUO \tag{7}$$

$$F_{O3\_g} = a_g + b_g \times CUO \tag{8}$$

where a_p and b_p are the intercept and slope coefficients for the photosynthetic response, and a_g and b_g are the corresponding coefficients for the stomatal conductance, respectively. The detailed response functions and PFT-specific parameter settings are shown in Table S2.

Building on the cumulative O_3 stress framework of L2015, Li2024 updates the response functions using a substantially expanded observational database. Using an expanded O_3 fumigation database compiled from the peer-reviewed literature, with a sample size approximately six times larger than that used in L2015, Li et al. (2024) developed PFT-specific response functions for photosynthesis and stomatal conductance. Unlike the linear or constant response functions that are used in L2015, Li2024 considers both linear and nonlinear functions to better capture the observed physiological responses across a wider range of vegetation types. Another difference between L2015 and Li2024 lies in the treatment of decay and healing process in the CUO calculation. In L2015, the healing factor is applied to the newly added uptake term. In contrast, following the logic of Li et al. (2024), both decay and healing are applied to the previously accumulated O_3 stress for different PFTs. In our implementation, CUO is calculated as:

$$CUO_t = CUO_{t-1}(1-D)(1-H)+U \tag{9}$$

$$D = \begin{cases} \frac{\Delta t}{l_{leaf}\times 3600\times 24\times 365} & evergreen \\ 0 & else \end{cases} \tag{10}$$

$$H = \begin{cases} 0 & evergreen \\ \max\left(1-\frac{LAI_{t-1}}{LAI_t},0\right) & else \end{cases} \tag{11}$$

The main difference between this formulation and L2015 is how the healing process is applied. In L2015, H modifies the newly added uptake term. In Li2024, however, it is applied to the previously accumulated CUO, representing the attenuation of existing O_3 stress by newly formed leaves. The key formulations and parameter settings for the L2015 and Li2024 schemes implemented in SSiB4/TRIFFID are provided in Table S1.

Line 289-299: To ensure a consistent intercomparison of vegetation responses across different O_3 damage parameterizations, we estimate PFT-specific O_3 sensitivities from the dose–response relationships (DRRs) between relative GPP change (RGPP) and POD_y. Here, POD_y refers to the phytotoxic O_3 dose over a flux threshold of y (nmol m^{-2} s^{-1}). As a flux-based diagnostic metric, POD_y directly links to biologically relevant stomatal O_3 uptake by accounting for O_3 concentration, stomatal conductance, and exposure duration (Mills et al., 2011; Pleijel et al., 2022). In this study, POD_y is calculated from the simulated stomatal O_3 flux as:

$$POD_y = \int \max(f_{O3}-y,0)\,dt \tag{14}$$

where f_{O3} is the instantaneous stomatal O_3 flux defined in Eq. (1), and y is the prescribed flux threshold. We obtain the annual POD_y by accumulating the above-threshold stomatal O_3 flux within each simulation year. Different from CUO, which represents O_3 stress after accounting for decay and healing, POD_y is used as a diagnostic dose metric to compare vegetation responses among different parameterizations on a consistent basis.

3. Third, the description of the original L2024 scheme is misleading, and the true contribution of the authors' proposed improvement remains unclear. Section 2.2 describes L2024 as a PODy-dependent scheme, but Section 2.3.2 introduces CUO when discussing the modification of the ozone decay process, creating an inconsistency. Moreover, the claim that extending the decay process to all PFTs is an improvement is problematic: in the original L2024 (Eq. 5 in Li et al., 2024), the decay process already applies to all PFTs (leaf longevity for evergreens, LAI change for deciduous plants). Thus, this is not an innovation of the present study. Similar issues appear in the description of the Ma et al. (2023) schemes (see specific comments). The authors should

clearly distinguish between parameter updates and structural improvements, and accurately restate their own contribution.

Response:

As is discussed in General Comment #2, we agree that the previous description did not clearly distinguish between POD_y and CUO. And our modification on $Li2024_{modify}$ experiment needs to be further clarified. We have revised Sect. 2.2 and Sect. 2.3.2 to make these distinctions explicit and to accurately clarify the treatment of decay and healing term in Li2024 and the refined $Li2024_{modify}$.

First, we clarified that POD_y and CUO are used for different purposes in the manuscript. POD_y is now described as a diagnostic dose metric used to compare vegetation O_3 sensitivity across parameterizations, whereas CUO is the prognostic cumulative O_3 stress variable used in L2015 and Li2024 after accounting for uptake, decay, and healing processes. This distinction is now explicitly stated in Sect. 2.5.

Second, we revised the description of the original Li2024 scheme to better reflect its actual formulation. To avoid confusion by implying that the original Li2024 lacks a decay/healing treatment, we now state that Li2024 applies the decay and healing terms differently among PFTs: the leaf-longevity-based decay term is applied to evergreen PFTs, whereas the LAI-related healing term is used for other PFTs. Therefore, our contribution is no longer described as "adding decay to all PFTs". Instead, we describe $Li2024_{modify}$ as a refined CUO treatment that applies decay and healing as complementary attenuation processes across PFTs. In this interpretation, the healing term represents rapid dilution of CUO when LAI increases, while the decay term represents gradual attenuation of accumulated O_3 stress when LAI is stable or declining. The manuscript now also explains that leaf longevity links the attenuation of CUO to the leaf life cycle, providing a trait-based constraint within the existing CUO framework.

We also clarified the distinction between the formulation refinement and the parameter update in $Li2024_{modify}$. In addition to the formulation refinement that applies both decay and healing terms across PFTs as complementary CUO attenuation pathways, we updated the leaf longevity parameter using observational data to constrain the characteristic timescale for the decay process. We now describe the formulation refinement and parameter update separately in Sect. 2.3.2 to clearly distinguish these two aspects.

Overall, we have revised the manuscript to restate our contribution and the scope of $Li2024_{modify}$. Specifically, the modification includes a formulation refinement that applies decay and healing as complementary CUO attenuation pathways across PFTs, together with a parameter update of leaf longevity that constrains the typical time for decay process. We have also clarified the distinction between POD_y, used as a diagnostic dose metric, and CUO, used as the prognostic cumulative O_3 stress variable in the L2015 and Li2024 schemes. These changes make the description of the original Li2024 formulation and our refinement more accurate and transparent.

Manuscript revision:

Line 297-299: Different from CUO, which represents O_3 stress after accounting for decay and healing, POD_y is used as a diagnostic dose metric to compare vegetation responses among different parameterizations on a consistent basis.

Line 242-267: In addition to the seven experiments described above, we performed an additional simulation, $Li2024_{modify}$, to examine a refined treatment of CUO attenuation within the Li2024 framework. In the original Li2024 implementation, the decay and healing terms are applied differently among PFTs: the decay term is applied for evergreen species while LAI-related healing term is used for other PFTs. In $Li2024_{modify}$, both processes are applied to all PFTs. This treatment is based on the interpretation that these two terms represent complementary pathways for attenuating CUO accumulation at different stages of canopy development. The LAI-related healing term represents a rapid attenuation of CUO when LAI is increasing, which reflects the assumption that newly formed leaves are initially undamaged by O_3 stress. In addition, the decay term represents a gradual attenuation of CUO when LAI is stable or declining. By using leaf longevity to describe how long leaves are exposed to O_3 before leaf fall or replacement, the decay term links the attenuation of CUO to the life cycle of leaves under a natural trait-based constraint.

This modification is conceptually aligned with the injury–recovery framework proposed by Felzer et al. (2009), in which O_3 damage is represented as a prognostic state variable governed by injury and recovery processes. In their framework, recovery comprises two components: (i) a characteristic healing rate indicating gradual physiological recovery due to cellular repair and leaf replacement when LAI is constant or decreasing, and (ii) a rapid healing associated with canopy growth, whereby newly formed leaves replace the damaged foliage as LAI increases. Following this concept, $Li2024_{modify}$ treats the decay and healing terms as complementary attenuation processes rather than separate treatments for different PFTs, which can be expressed as follows:

$$D = \frac{\Delta t}{l_{leaf} \times 3600 \times 24 \times 365} \quad for\ all\ PFTs \tag{12}$$

$$H = \max\left(1 - \frac{LAI_{t-1}}{LAI_t}, 0\right) \quad for\ all\ PFTs \tag{13}$$

Furthermore, we update the key parameter l_{leaf} using observed leaf longevity dataset to better constrain the decay process across PFTs (Wang et al., 2012). Leaf longevity is a key plant trait that reflects typical leaf life span of each PFT, and provides important physiological constraint for representing vegetation turnover in land surface models (Wang et al., 2012; Zhang et al., 2016). By linking the decay term to a measurable physiological trait, this refinement provides a trait-based constraint on the gradual attenuation of accumulated O_3 stress within the existing CUO framework. Therefore, the Li2024modify experiment was designed to evaluate how the refined treatment affects CUO accumulation and the O_3-induced vegetation damage in SSiB4/TRIFFID.

Specific comments

1. Throughout the abstract, main text, captions, and supplementary materials, there are multiple formatting errors: inconsistent terms for 'O_3' or 'ozone', and/or missing subscripts. Please check each instance carefully. In addition, please standardize the format of dashes '-' throughout the manuscript.

Response: All occurrences of O_3/ozone have been checked throughout the abstract, main text, captions, and supplementary materials. We have standardized the notation by using "O_3". Missing subscripts have been corrected. We also checked and standardized the use of hyphens and dashes throughout the manuscript.

2. Line 47: NO_x subscript.

Response: The formatting of NO_x has been corrected.

3. Lines 83-86: Reference format errors. Are the re-calibrated S2007 and LMA schemes from the same paper? The sentence is unclear.

Response: The citation format has been corrected, and the sentence has been revised for clarity. Both the CS2007 scheme and the LMA-based scheme are from Ma et al. (2023), but they represent different developments: the former retains the S2007 framework with recalibrated sensitivity parameters, whereas the latter reformulates O_3 sensitivity using LMA.

Line 83-86: Moreover, several recently developed parameterizations have not been comprehensively evaluated in regional simulations over China, including the new O_3-vegetation damage scheme in CLM proposed by Li et al. (2024), together with the recalibrated S2007 scheme and the LMA-based approach proposed by Ma et al. (2023).

4. Line 121: H_2O (m s^{-1}) font error. Please check similar issues throughout this section.

Response: The font of H_2O and the associated units has been correct. Similar formatting issues for variables and units throughout this section have also been checked and revised.

5. Line 122: Missing period '.'

Response: The missing period has been added.

6. Line 127: FO3_A and FO3_g do not match the formulas.

Response: The notation has been corrected to ensure consistency between text and formulas. These modification factors are now consistently denoted as F_{O3_A} and F_{O3_g}, respectively.

7. Line 146: Typo: 'O$_3$-modification'.

Response: The typo has been corrected and revised to "O$_3$ modification factor".

8. Line 157: Could be more explicit: 'stomatal flux-based O$_3$ damage framework'.

Response: The description has been revised to be more explicit. The LMA-based scheme is now described as following the stomatal flux-based O$_3$ damage framework of S2007, rather than simply as following the "S2007 framework".

Line 185-188: Following the stomatal flux-based O$_3$ damage framework of S2007, Ma et al. (2023) proposed a trait-based O$_3$ damage parameterization in which the plant O$_3$ sensitivity is represented using leaf mass per area. By using LMA to convert the area-based stomatal O$_3$ flux into a mass-based flux, this conversion allows a unified representation of O$_3$ sensitivity with a single PFT-independent parameter a across different plant species.

9. Line 164: Ambiguous wording. The sentence 'Following Feng et al. (2018), we set x = 0.019 based on the observations' is from the scheme setting of Ma et al. (2023). The distinction between LMAgrid and LMApft is unclear; they differ in LMA format and α.

Response: The description has been revised to clarify that the setting of x = 0.019 nmol g^{-1} s^{-1} follows both Feng et al. (2018) and the implementation of Ma et al. (2023). We also clarified that LMAgrid and LMApft share the same mathematical formulation but differ in both the source of LMA information and the prescribed mass-based sensitivity parameter a.

Line 191-200: Specifically, we set to $a = 3.5$ for LMAgrid and 2.82 for LMApft as suggested by Ma et al. (2023). x is the mass-based flux threshold. Following Feng et al. (2018) and Ma et al. (2023), we set $x = 0.019$ nmol g^{-1} s^{-1} based on the observations. In this study, we implement two versions of the LMA-based scheme with the same mathematical formulation but different sources of LMA information. The LMAgrid scheme uses a spatial explicit global LMA map from Moreno-Martinez et al. (2018), allowing O$_3$ sensitivity to vary among grid cells.

In contrast, the LMApft scheme uses prescribed PFT-specific LMA values, thereby keeping O_3 sensitivity spatially uniform within each PFT (Table S2). Details of the LMA dataset and processing are described in Sect. 2.3.2.

10. Line 170: Abbreviation not used (many such errors throughout; please check).

Response: We have replaced the "ozone" with the abbreviation "O_3". Unused abbreviations have been checked throughout the manuscript and corrected.

11. Line 172: Missing subscript (many such errors throughout).

Response: The missing subscript has been corrected. We have also checked the manuscript, figure captions, tables, and supplementary materials for similar formatting issues.

12. Table 2: The L2024modify scheme could also be included.

Response: The $\mathrm{Li2024}_{\mathrm{modify}}$ experiment has been added to the simulation summary table to make the experimental design complete and clear.

13. Line 262: The sentence 'Figure 1 shows... are shown in the supplementary materials (Fig. S4)' is unclear. Please rephrase.

Response: The sentence has been rephrased for clarity. In the revised version, we state that Fig. 1 presents the evaluation for US-Ha1 in 1998 and FI-Hyy in 2009, and that the corresponding results for US-Ha1 in 1999 and FI-Hyy in 2008 are provided in Fig. S4.

Line 318-320: Figure 1 presents the simulated O_3 flux and GPP for US-Ha1 in 1998 and FI-Hyy in 2009. The same evaluation for US-Ha1 in 1999 and FI-Hyy in 2008 is provided in Figure S4 as well.

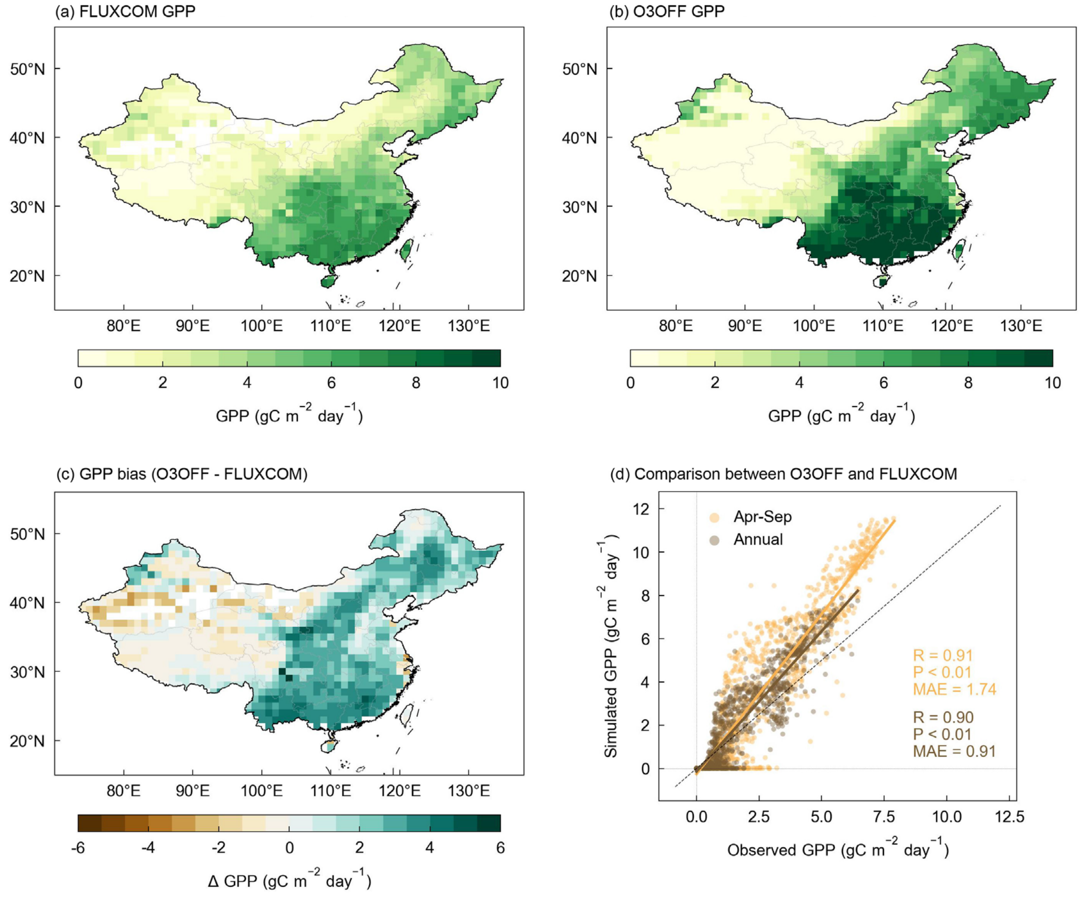
14. Figure 2: Why was GOSIF chosen for spatial validation but not FLUXCOM? Are panels (a), (b), (c) for the whole year or growing season? Experiment names in figures should match the main text (e.g., 'O3OFF' vs 'O3 OFF', 'O3ON' vs 'O3 ON'). Please check all figures.

Response: We have revised the caption of Fig. 2 to clarify that Panels (a), (b), (c) show growing-season mean GPP during April–September over China. Panel (d) presents grid-level comparisons between simulated and observed GPP for both growing-season mean values and annual mean values, as indicated by the two colors in the scatter plot.

We also checked the experiment names throughout all figures and captions and revised them to match the main text. Specifically, we now use "O3OFF" and "O3ON" consistently.

As for the model validation, we agree that both GOSIF and FLUXCOM are widely used benchmark datasets for GPP evaluation and model validation. In the revised manuscript, we clarify that GOSIF was selected for the main spatial validation because it provides continuous coverage for the full evaluation period of 2011–2020, whereas the FLUXCOM product used in this study is available only up to 2018. We therefore considered GOSIF more suitable for the primary validation of the decadal simulations.

To check whether this choice affects our conclusions, we also compared the simulations with FLUXCOM and found broadly consistent results with the GOSIF-based evaluation (Response Supplementary Figure 1). Specifically, the additional FLUXCOM-based evaluation confirms that the simulations capture the observed spatial variations in GPP, while O3OFF tends to overestimate both annual and growing-season GPP. FLUXCOM is also included in Fig. 3 as an additional benchmark for national annual GPP and the seasonal cycle. Therefore, using GOSIF as the primary dataset for Fig. 2 does not affect our main conclusions.



Response Supplementary Figure 1. Evaluation of simulated GPP against satellite-based observations over China. Panels (a) and (b) show growing-season mean GPP over China during April–September derived from FLUXCOM observations and O3OFF experiment, respectively. The difference between O3OFF simulation and FLUXCOM observation is shown in (c). Panel (d) presents grid-level comparisons between simulated and observed GPP over China for both growing-season (April–September) and annual values.

15. Figure 3: Why the inter-scheme difference have just one value instead of six?

Response: Figure 3 shows the overall inter-scheme spread, defined as the range between the maximum and minimum values among the six parameterizations. Therefore, only one value is shown for the inter-scheme difference in China. The purpose is to quantify the magnitude of uncertainty arising from parameterization selection and to compare this uncertainty with the magnitude of O_3-induced vegetation damage itself. We have clarified this definition in the caption of Fig. 3 to avoid confusion.

16. Figure 4: Why does L2024 show the strongest GPP damage in Fig. 4 but not the strongest LAI damage in Fig. S7? Similarly, why does LMApft show the strongest GPP damage in southeastern China (f) but no corresponding LAI damage? Is this related to how GPP and LAI are calculated in the model? Could absolute and relative damage values be marked on the figures? Figure caption is separated from the figure.

Response: We have revised Fig. 4 and Fig. S7 to make the quantitative comparison clearer. The area-weighted results show that Li2024 produces the largest national mean GPP reduction among the six schemes, with a growing-season mean of -1.204 gC m^{-2} day^{-1} relative to O3OFF. It also shows the largest national mean LAI reduction, with a change of -0.115 m^2 m^{-2}, followed by S2007 (-0.0963 m^2 m^{-2}) and LMApft (-0.0892 m^2 m^{-2}). Therefore, the quantified results are consistent between GPP and LAI at the national scale.

For southeastern China (110–122°E, 18–30°N), LMApft produces a relatively strong GPP reduction of -2.637 gC m^{-2} day^{-2}. However, this reduction is still smaller than Li2024 (-3.745 gC m^{-2} day^{-1}) and S2007 (-3.351 gC m^{-2} day^{-1}). The simulated LAI reduction of LMApft is also smaller, with a change of -0.214 m^2 m^{-2} compared with -0.320 m^2 m^{-2} for Li2024 and -0.324 m^2 m^{-2} for S2007.

Following the referee's suggestion, we have added the area-weighted national mean absolute and relative damage values to the panel titles of Fig. 4 and Fig. S7. We also corrected the color-bar unit in Fig. S7, and adjusted the layout so that the full caption of Fig. 4 appears together with the figure and is no longer split across pages.

17. Figure 5: Are these results for China or globally? Growing season or annual? Please clarify in each caption. The x-axis has errors.

Response: We have revised the caption of Fig. 5 to clarify that the results are derived from regional simulations over China and are based on annual values at the grid-cell scale. Specifically, each point represents the annual simulated POD_y and corresponding RGPP for one grid cell, and the colors denote the dominant PFT of that grid cell. We have also corrected the x-axis labels in Fig. 5 and added a legend to make the PFT classification clearer.

18. Figure 5 clearly shows the relationship between RGPP and PODy. Figures 6 and 7 discuss 'ozone sensitivity' based on this relationship. However, the captions of Figures 6 and 7 do not explicitly state that sensitivity refers to the slope in Figure 5. Please clarify to avoid confusion.

Response: The captions of Figs. 6 and 7 have been revised to explicitly state that O_3 sensitivity is quantified as the slope of the RGPP–PODy relationship shown in Fig. 5, as is indicated in the main text. This clarification has been added to avoid confusion in the interpretation of the sensitivity values.

Line 400-401: To quantify vegetation O_3 sensitivity at the PFT level, we used the slope of the RGPP–POD_y relationships in Fig. 5 as an indicator of O_3 sensitivity for each PFT.

19. Lines 319-326: Could the mismatch between stomatal ozone uptake and GPP damage across schemes be further explained? For example, L2015 decouples these two calculations.

Response: The text has been revised to better explain why stomatal O_3 uptake and GPP damage do not necessarily vary consistently across parameterizations. We clarified that the simulated GPP reduction depends on how each scheme converts O_3 uptake into photosynthetic reduction. This conversion differs among schemes mainly because of differences in response functions, phytotoxic thresholds, sensitivity coefficients, and the treatment of photosynthesis and stomatal conductance. We also added a brief explanation of L2015 for its separate treatment of photosynthesis and stomatal conductance. The weak or constant photosynthetic response functions of L2015 can lead to weak GPP responses. This revision helps motivate the subsequent RGPP–POD_y assessment of vegetation O_3 sensitivity.

Line 375-387: However, although higher O_3 flux generally correlates with increased photosynthetic and stomatal damage within a single scheme, this relationship is not consistent across different parameterizations (Figs. 4, S8 and S9). This mismatch occurs because stomatal O_3 uptake represents the amount of O_3 entering the leaf, whereas GPP damage depends on how stomatal O_3 uptake is converted into photosynthetic reduction within each parameterization. The conversion differs among schemes due to discrepancies in response functions, phytotoxic thresholds, sensitivity coefficient settings, and the treatment of photosynthesis–stomatal coupling. For example, L2015 applies separate response functions for photosynthesis and stomatal conductance, and the response functions are either constant or linear with relatively small coefficients for several PFTs. Therefore, high stomatal O_3 uptake does not necessarily lead to a strong GPP response. In contrast, the strong GPP reductions simulated by S2007 under relatively low O_3 uptake mainly reflect its parameter settings, including the prescribed sensitivity coefficients and flux thresholds. After recalibration, CS2007 yields weaker GPP reductions within the same stomatal flux-based framework. These variations indicate substantial differences in vegetation O_3 sensitivity among schemes and highlight the need for a systematic assessment of scheme-specific O_3 sensitivity. In the subsequent analysis, we quantify the vegetation O_3 sensitivity of the six schemes and evaluate their performance against observational constraints.

20. Line 328: The explanation of RGPP has already been given above.

Response: We have replaced the “relative change of GPP” by “RGPP”.

21. Line 418: Does the observational ozone sensitivity for each PFT attributed to Li et al. (2024) in Figure 6 correspond to the slopes calculated in Figure S3? This could be clarified.

Response: Yes, observed O_3 sensitivities attributed to Li et al. (2024) are the PFT-specific slopes derived from the An–POD_y relationships shown in Fig. S3. The detailed calculation procedure is described in Sect. 2.5. To make it clear, we have revised the caption of Fig. 6 caption to clarify this point.

22. Lines 425-426: The criticism of S2007 in the discussion is not accurate, as S2007 may have biases in sensitivity parameters instead of problems in the physical mechanisms.

Response: The discussion has been revised to avoid implying that the physical mechanism of S2007 is problematic. We agree that the discrepancy in S2007 can be largely affected by the selection of O_3 sensitivity parameters, rather than attribute to the stomatal flux-based framework itself. Since S2007 provides low-, moderate-, and high-sensitivity parameter sets to represent uncertainty in plant O_3 responses. Because the main purpose of this study is to compare multiple O_3 damage parameterizations under a consistent configuration, we used the medium-sensitivity parameter set as the default S2007 configuration rather than testing the full sensitivity range. Therefore, we have clarified this choice in the Methods and revised the Discussion to interpret the S2007 results more cautiously.

Line 142-145: It should be noted that both S2007 and CS2007 provide low-, moderate-, and high-sensitivity parameter sets to represent uncertainty in plant O_3 responses. In this study, we used the moderate-sensitivity parameter sets as default configuration for both schemes to ensure a consistent comparison with the other parameterizations.

Line 484-488: In contrast, S2007 and L2015 schemes exhibited larger deviations from the observational O_3 sensitivity for several PFTs. For S2007, this likely reflects the selected sensitivity parameter set rather than a deficiency in the stomatal flux-based framework. For L2015, the deviations are more closely related to its linear or constant response functions and the relatively limited observational basis available when the scheme was proposed (Li et al., 2024).