Response to the review comment 1 on gmd-2022-227

Review for GMD-2022-227 by Yimian Ma et al.

The authors present a submodel for ozone damage to different plant types inserted into an existing biosphere model (YIBs). This new ozone model calculates plant damage, expressed as GPP penalties, based on a unified sensitivity interacting with leaf mass per area. They conclude that approx. 5% of global GPP is not materialized due to ozone damage.

I perceive the study as a major advance over previous approaches to model ozone damage to plants, taking into account latest findings on leaf mass rather than area as defining factors for ozone sensitivity across plant types. The manuscript is well written and the steps taken to develop and integrate the ozone model into YIBs are sound. All conclusions are grounded on the presented evidence. Nonetheless, I see several places where the study could be amended; they are detailed in the following. While I strongly suggest to consider these, none of them questions the relevance and overall validity of the approach, though.

In conclusion, I recommend a major revision of the article. The 'major' is a sum of many 'minor' elements. If the authors are able to address my concerns, I clearly support a publication of this article.

Response: thank you very much for your helpful comments and constructive suggestions for further improving our manuscript. We have carefully considered all comments and revised our manuscript accordingly. We summarize our responses to each comment as follows. We believe that our responses have well addressed all concerns of the reviewer.

**** General comments ****

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-> While the new mass-based approach may prevail over area-based calculations, a crucial factor of ozone sensitivity is also the abiotic environment of growth, e.g. water availability, temperature or CO2 concentration. A change in these parameters, all others being equal, may strongly modify the ozone response of plants. It remains unclear how much these confounding factors are already considered in the model by shaping the actual LMA, since the global LMA data are prescribed from data sets. The authors are encouraged to discuss this and, if necessary, amend the model to also consider climatic parameters in their ozone module.

Response: we have added a new discussion section of 4.4 "Outlook for future modeling" to address this comment (***Lines 398-421***): "In nature, all aspects of plant physiochemical processes, such as growth, development, reproduction, and defense, are influenced by abiotic factors like water availability, temperature, CO_2 concentration, and light resources (Kochhar and Gujral, 2020). In our modeling, the cumulative O_3 fluxes are based on dynamic plant simulations with well-established DGVM to calculate the effects of these abiotic factors. LMA is considered as a factor representing the vulnerability of each species, by which divergent responses to the same O_3 stomatal dose can be further differentiated. In fact, many other key variables in DGVMs, for example, leaf photosynthetic traits (V_{cmax} and J_{max}), nutrient traits (leaf nitrogen and phosphorus), morphological traits (leaf thickness and size), and phenology-related traits (leaf life span) are all more or less interlinked with LMA (Walker et al., 2014). There are some generic regression relationships between them, which have not yet been fully validated by experimental studies. As a result, considerable improvements can be made in the direction of trait-flexible modeling within the existing DGVM frameworks. Our study demonstrates the validity of LMA-based approach for the O_3 plant damage modeling.

Although we used the most advanced LMA integrated from available observations, this dataset was developed based on static global grids and revealed the mean state for each pixel. In reality, LMA can vary with biotic/abiotic factors like leaf position in the canopy (Keenan and Niinemets, 2017), phenology, plant health, living environment (Fritz et al., 2018), and climate (Wright et al., 2005; Cui et al., 2020). Even long-term exposure to O_3 can alter leaf morphological characteristics and LMA (Li et al., 2017). In future studies, simulations from local to global scales could implement the spatiotemporal variations in LMA taking into account the demographic information and environmental forcings. We expect a breakthrough in the calculation of reliable LMA to achieve fully dynamic predictions of O_3 plant damage in Earth System Modeling, thus facilitating the research of plant response and adaption in changing environments."

-> There are several unclear points in the methods; these are detailed below in the specific comments. I mention them here as they sum up to a general comment.

Response: we have clarified the relevant expressions for each specific comment.

-> The calibration partly remains unclear (see below). Most importantly, though, an out-of-sample calibration is missing where each PFT is removed from calibration - for both the unified and the supporting PFT-specific calibration - and the resulting estimate compared particularly for this omitted PFT. This is relevant especially for crops, as they are well apart from the other plant types (e.g. in Figure 2), suggesting that this difference could largely drive calibration and thus the resulting performance be overly optimistic. The perfect fit of S_S to S_O for crops in Figure 6b corroborates this hypothesis.

Response: we have enclosed an additional test to address this concern as follows and updated the final uncertainty range accordingly. New results are on ***Lines 306-309***: "Finally, we tested a new calibration excluding CRO, the PFT that contributed the most to the calibration biases (shown as orange dashed lines in Fig. S8). The results gave an optimal *a* of 3.2, with global damage of 4.5%. All sensitivity experiments achieved consistent results as the YIBs-LMA simulation with damages ranging from 4.5% to 6.5% and spatial correlation coefficients larger than 0.94."

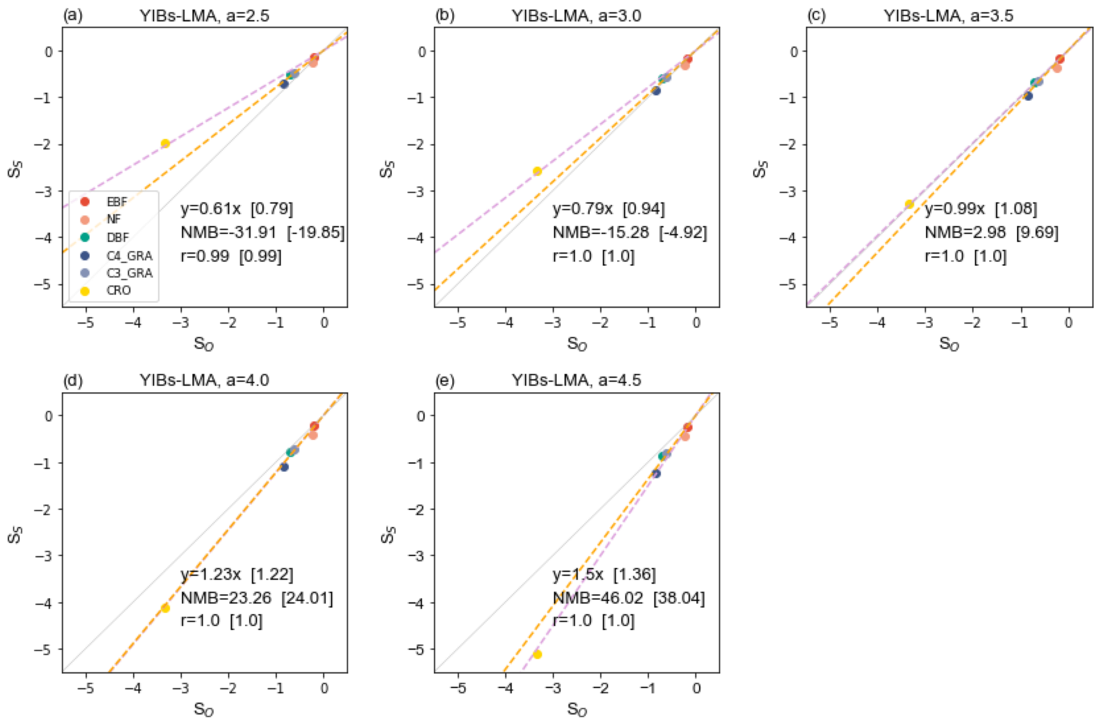

Figure S8. Supplementary calibrations excluding CRO are shown as orange dashed lines. Original calibration in Fig. 3 and 1:1 fitting are shown as dashed pink and light grey, respectively. The new slope, NMB, and r are recalculated and noted in square brackets.

-> An additional, similar exercise could include another year of ozone data. The current study only uses 2010, for calibration and validation. Another year will have another ozone distribution and thus would be useful to validate the findings.

Response: We have addressed this comment on ***Lines 264-265*** as "Notably, such calibration of *a* is robust under different O_3 field (see Fig. S2)." Fig. S2 is shown as follows.

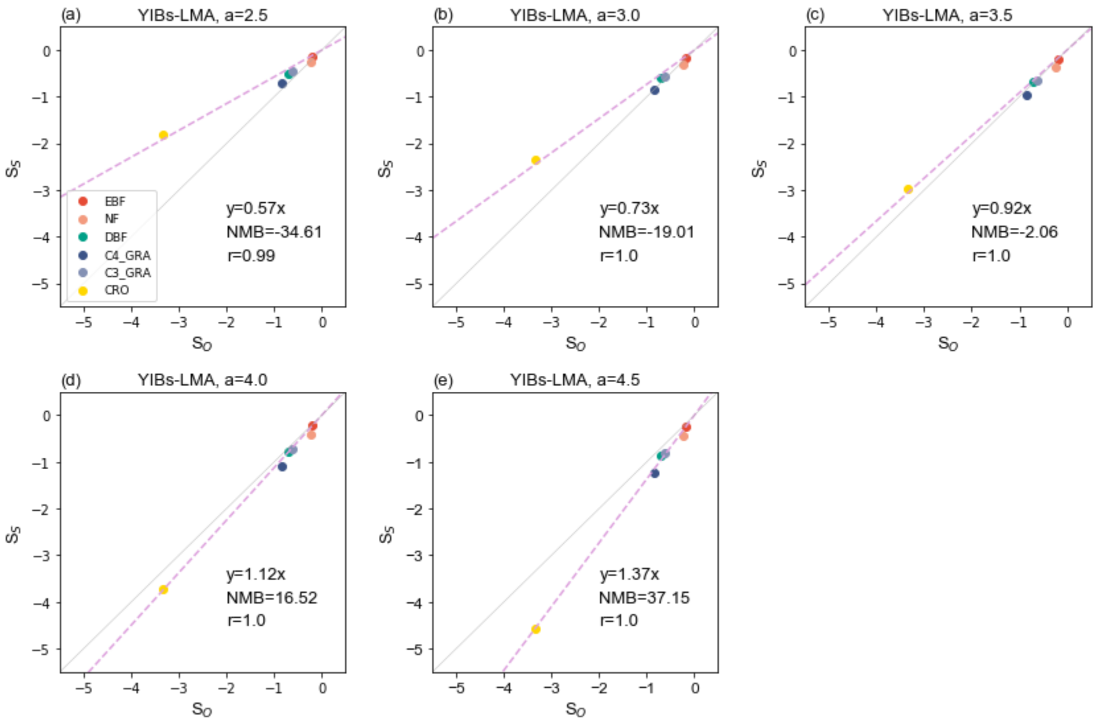

Figure S2. The calibration and validation with O_3 data in the year 2020 from CMIP6 SSP5-8.5 scenario. The forcing data remains the same as YIBs-LMA and calibration procedures are the same as in Fig 3. The new calibration achieved a minor shift of the optimal *a* from 3.5 to 3.6.

-> All of these new suggestions, once implemented, should then also be considered in the discussion section.

Response: We have implemented the new discussion section of 4.4 "Outlook for future modeling" (***Lines 398-421***) as suggested.

**** Specific comments ****

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-> Methods, 2.1: if F is the UNdamaged fraction, why is there a ozone penalty in equation 1?

Response: The damaged fraction should be expressed as $F = a_{PFT} \times max\{f_{O3} - y, 0\}$.
In our paper, we showed the UNdameged fraction $F = 1 - a_{PFT} \times max\{f_{O3} - y, 0\}$, which can be directly multiplied on net photosynthetic rate and stomata conductance to calculate the remaining part.

-> Methods, 2.1: explain f_O3 at first mention and add units to all variables

Response: we have added related information on ***Lines 149-150*** as "The stomatal O_3 flux f_{O3} (nmol m^{-2} s^{-1}) is calculated…"

-> Methods, 2.1, eq 2: f_O3 depends, in turn, on F. Please explain this circular dependence in the text and also what it means for calculation - do you need an optimizing routine?

Response: we have further explained it on ***Lines 165-166*** as "Equations (2) and (4) can form a quadratic equation. The F can be derived at each timestep (i.e. hourly) and applied to net photosynthetic rate and stomatal conductance to calculate the O_3-induced damages."

-> Methods, 2.1: how do water availability, temperature, CO2 et al. interact with the ozone uptake?
Response: The ozone uptake is regulated by stomatal conductance, which is dependent on environmental factors such as water availability, temperature, CO_2 and so on. In the revised paper, we clarified on ***Lines 221-223***: "In this study, all O_3 vegetation damage schemes are implemented in the YIBs model (Yue and Unger, 2015), which is a process-based dynamic global vegetation model incorporated with well-established carbon, energy, and water interactive schemes."

We have added the section 4.4 in discussion about abiotic factors. See ***the answers to the first general comment.***

-> Methods, 2.2, eq 6: what happens with negative values of f_O3 - y in the integral?
Response: In calculation, y is taken as a threshold, above which the f_{O3} are accumulated. We have modified ***Eqn. 6*** to be $POD_y = \int \max\{f_{O3} - y, 0\}$

-> Methods, 2.2: is every PFT dominant somewhere?
Response: Every PFT dominants some regions as ***Figure S1*** shows.

-> Methods, 2.3: the exact recipe for the calibration is missing. It remains partly elusive how you did the calibration - how many runs, which parameters were tuned, which step size, which algorithm, which target variables etc. Please augment, for all runs.
Response: We have modified this part on ***Lines 211-218*** as "For all supporting experiments, the parameter a for YIBs-LMA or the eight mean a_{PFT} for YIBs-S2007_adj are derived with the optimal 1:1 fitting between S_S and S_O to minimize the possible biases (Tables 2 and S3-S6). The basic method for calibration is feeding the model with series values of a or a_{PFT} until the predicted O_3 damage matches observations with the lowest normalized mean biases (NMB). For all LMA-based experiments, S_S from varied PFTs were grouped for the calibration of a, while for a_{PFT} in YIBs-S2007_adj, each a_{PFT} is determined individually by matching simulated S_S with S_O. Since S_O are available only for six out of the eight YIBs PFTs, including EBF, NF, DBF, C_3 grass, C_4 grass, and crop (Table S1), S_O of these PFTs are used for calibration. All runs are summarized in Table 1."

-> Methods, 2.3: a sensitivity towards environmental parameters would be useful to add
Response: As we explained in the answer to the first general comment, the plant responses to abiotic factors were accounted for in other well-established modules of the vegetation model.

-> Results, 3.1, l199+: is the higher agreement between observations and mass-based simulations (R2 = 0.77), when compared to area-based simulations (R2 = 0.54), expectable already in the uncalibrated version given the design towards mass-based traits?
Response: Yes, we reproduced the observed convergence in PFT-level O_3 damage in Fig. 2, in which all PFTs showed more consistency in DRRs with LMA-based sensitivity than the area-based approach.

-> Results, 3.2: can you justify the use of S2007 as a reference, i.e. why is the new model good if it agrees with the old?

Response: We have added discussion in ***Lines 368-378*** as: "…The similarity between YIBs-S2007 and YIBs-LMA shown in Fig. 5 revealed an advance in the modeling strategy. Simulated O_3 damage in YIBs-S2007 is based on the PFT-level calibrations that tuned sensitivity parameters of each PFT with observed DRRs. Such refinement is a data-driven approach without clear physical reasons. Instead, the YIBs-LMA framework converts the area-based responses to mass-based ones and achieves better unification in O_3 sensitivities among different PFTs. In this algorithm, the O_3 damage efficiency is inversely related to plant LMA, which influences both the O_3 uptake potential and the detoxification capability of the vegetation. The similarity in the global assessment of O_3 vegetation damage between YIBs-S2007 and YIBs-LMA further demonstrated the physical validity of LMA-based scheme in the Earth system modeling, because the independent LMA map was applied in the latter approach."

-> Results, 3.2, l232+: can you provide numbers on the difference components ([O3], LMA variation, land-use intensity etc.)?

Response: The information of all datasets is shown in section 2.4 ***between Lines 223-246*** as "…The model applies the same PFT classifications as the Community Land Model (Bonan et al., 2003) (Fig. S1). Eight PFTs are employed including evergreen broadleaf forest (EBF), needleleaf forest (NF), deciduous broadleaf forest (DBF), cold shrub (C_SHR), arid shrubland (A_SHR), C_3 grassland (C3_GRA), C4 grassland (C4_GRA), and cropland (CRO) (Fig. S1)…The gridded LMA required for the main mass-based simulation is derived from Moreno-Martinez et al. (2018) (M2018), which shows the highest value of >150 g m^{-2} for needleleaf forest at high latitudes while low values of ~40 g m^{-2} for grassland and cropland (Fig. 1a and Fig. S1). Grids with missing LMA data are filled with the mean of the corresponding PFT. Contemporary O_3 concentration fields in the year of 2010 from the multi-model mean in Task Force on Hemispheric Transport of Air Pollutants (TF-HTAP) experiments (Turnock et al., 2018) (Fig. 1b) are used as forcing data. The original monthly O_3 data are downscaled to hourly using the diurnal cycle predicted by the chemistry-climate-carbon fully coupled model ModelE2-YIBs (Yue and Unger, 2015). Generally, areas of severe O_3 pollution are found in the mid-latitudes of the Northern Hemisphere with highest annual average O_3 concentration of over 40 ppbv in East Asia…"

-> Figure 3h (crops): a linear fit does not seem to be the best choice here, in contrast to all other PFTs. How to account for that or interpret this levelling off?

Response: Croplands are greatly influenced by human manipulations. To achieve a better simulation, some widely-used DGVMs, like JULES, have their specialized model version for cropland modeling. In the YIBs model, we calculate crop GPP as natural PFTs, but with global map of crop phenology for field regulations (such as plantation and harvest). In future studies, we hope to improve the crop simulations with specific crop modules.

**** Technical corrections ****

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-> Methods, 2.2: explain POD at first mention (abbreviation & what does it mean)

Response: Corrected on Lines 67-68 as "POD_y (Phytotoxic O_3 Dose above a threshold flux of y (Buker et al., 2015))".

-> Methods, 2.2, l131: what do you mean with 'bio-indicators'?

Response: We changed the 'bio-indicator' to 'biotic indicator' for clarity.

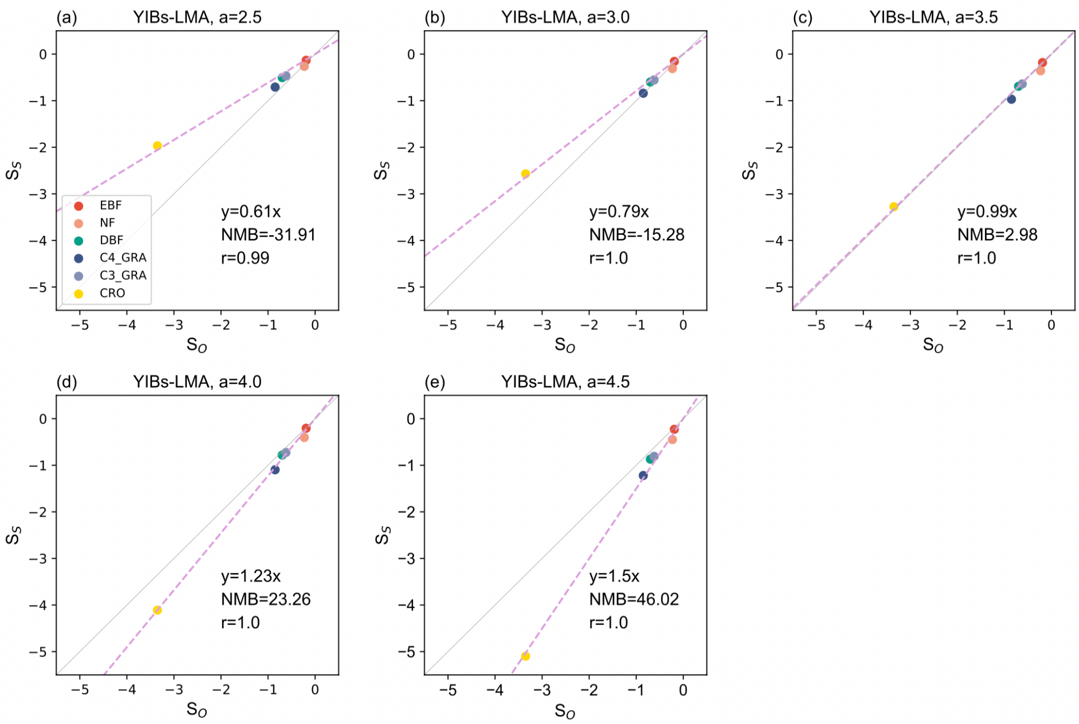
-> Results, 3.3: this section requires language proof-reading (Uncertainty section)

Response: We have proof-read and revised this section as suggested.

-> Results, 3.3, l250: the values (-0.2 and 1.7) are not %, but percentage points - the difference in % would be much larger

Response: we have changed the way to describe it on ***Lines 308-309*** as "All sensitivity experiments achieved consistent results as the YIBs-LMA simulation with damages ranging from 4.5% to 6.5% and spatial correlation coefficients larger than 0.94."

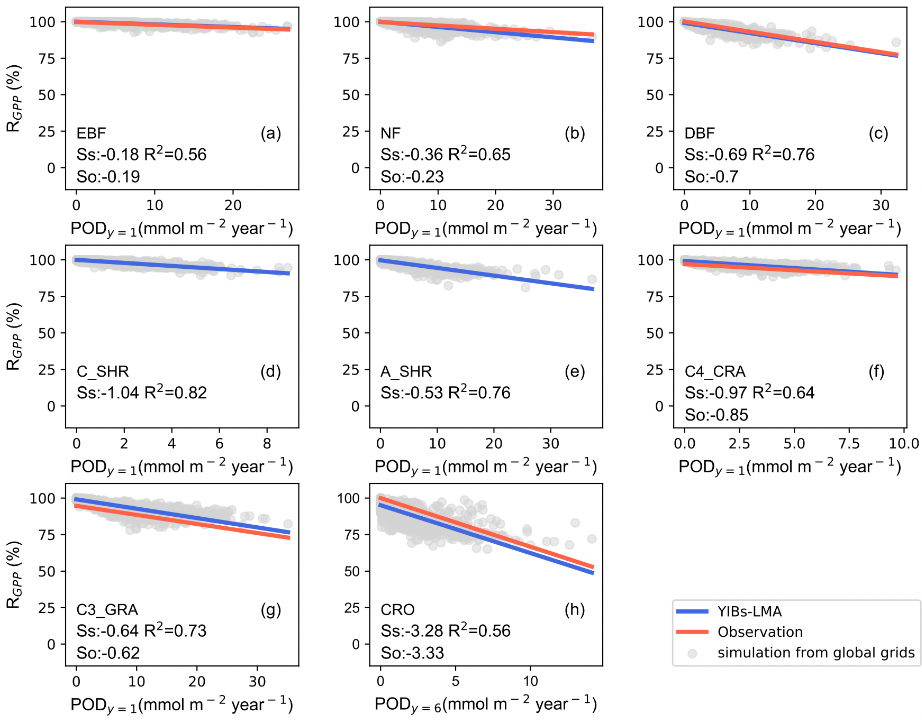
-> Figure 2: please add the 1:1 line and the out-of-sample line once it is calculated



Response: we have added 1:1 fitting (light grey lines) for each subplot (see new ***Fig. 3***). The recalibration excluding CRO was shown in the new Fig. S8.

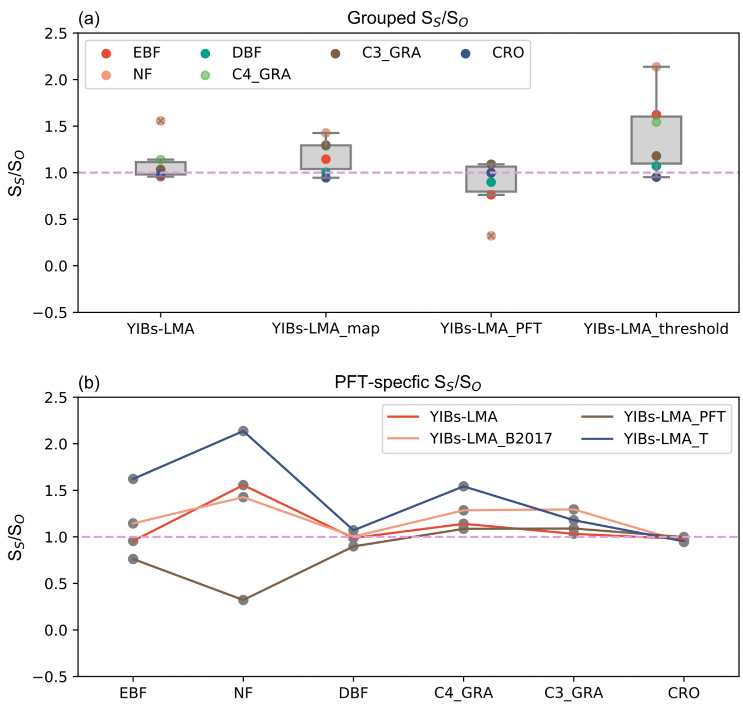
-> Figure 3: add the grey simulated dots to the legend

Response: we added this legend as suggested. See Fig. 4 as following:



-> Figure 6a: CRO is missing here?

Response: Results for CRO have been added to Fig. 7a in the revised paper:



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