Response to Comments of Reviewer #1

Manuscript number: egusphere-2024-365

Authors: Xinyi Zhou, Xu Yue, Chenguang Tian and Xiaofei Lu

Title: Global assessment of climatic responses to the ozone-vegetation interactions

The authors are grateful to the editor and reviewers for their time and energy in providing helpful comments that have improved the manuscript. In this document, we describe how we have addressed the reviewer's comments. Referee comments are shown in black italics and author responses are shown in blue regular text. A manuscript with tracking changes is attached separately.

Anonymous referee #1:

General comment

The paper presents a comprehensive array of feedbacks on climate variables resulting from O_3 -vegetation interaction during boreal summertime of the period 2005-2014. Utilizing the climate-vegetation-chemistry coupled ModelE2-YIBs model, this study compares a simulation assuming no damage to vegetation, with another incorporating high O_3 sensitivity. While some parts of methods and results need clarifications, some corrections, and further editing, the topic of this study is suitable for ACP and enriches the already existing literature.

Response:

Thank you for your positive evaluations.

Abstract

I think the abstract is good, presenting the scope of the paper concisely. I realize it's a matter of personal taste, but I'd only suggest a less "number-intensive" report of the results in this section. Furthermore, "2010s" appears for the first time here, indicating the "2005-2014" period, while, commonly, it indicates the 2010-2019 period. If possible, I would suggest finding a different label for this time window throughout the article.

Response:

Thank you for your suggestion. We chose a new label "the present day" for the "2005-2014" time window and limited the use of numbers as follows:

"The most significant responses are found in the eastern U.S. and eastern China, where surface air temperature increases by +0.33±0.87 °C and +0.56±0.38 °C, respectively. These temperature rises are accompanied by decreased latent heat and increased sensible heat in both regions." (Lines 19-22)

"Using a climate-vegetation-chemistry coupled model (the NASA GISS ModelE2 coupled with Yale Interactive terrestrial Biosphere, or ModelE2-YIBs), we assess the global climatic responses to O_3-vegetation interactions during boreal summer of the present day (2005-2014)." (Lines 15-18)

Introduction

In my opinion, the introduction provides the essential information to contextualize the paper, listing an adequately ample array of examples regarding ozone effects on vegetation and the possible types of feedback. Anyway, I believe it would be helpful to provide more details for the readers that are less familiar with this specific subject, and to improve the style for enhanced coherence.

Response:

Thank you for your rewarding advice.

Line 45: I believe that flux-based measurements are also statistical, at least to some extent, so I would avoid qualifying exposure-based indexes this way – I suggest either substituting or removing the adjective.

Response:

Thank you for your suggestions. In the revised paper, we removed this sentence and added descriptions of more exposure-based and flux-based indexes for the better clarity: "Several exposure-based indexes such as accumulated hourly O_3 concentrations over a threshold of 40 ppb (AOT40) and sum of all hourly average concentrations (SUM00) are used to assess O_3-induced vegetation damage (Fuhrer et al., 1997; Paoletti et al., 2007). In addition, the flux-related POD_y method (phytotoxic O_3 dose above a threshold flux of y) is also widely applied to consider the dynamic adjustment of stomatal conductance (Buker et al., 2015; Sicard et al., 2016)." (Lines 44-50)

Line 45-46: it might be good to specify what the "dynamic adjustment of vegetation physiological processes" depends on.

Response:

Thank you for the suggestion. Here, the 'vegetation physiological processes' are mainly referred to 'stomatal conductance'. We modified the sentences as follow:
"… the flux-related POD_y method (phytotoxic O_3 dose above a threshold flux of y) is also widely applied to consider the dynamic adjustment of stomatal conductance (Buker et al., 2015; Sicard et al., 2016)." (Lines 47-50)

Line 51: I'm not sure "inconsistent" is the appropriate adjective in this case. I'd reframe this in a different way.

Response:

We changed the word to "decoupled", and the revised sentence is as follow:
"In contrast, Lombardozzi et al. (2012) estimated the decoupled reductions in plant photosynthesis and stomatal conductance using different response relationships to the cumulative O_3 stomatal uptake." (Lines 55-57)

Line 63: "but" introduces a contrast, whereas "consistent but stronger" seems to convey an idea of enhancement. I'd suggest choosing a different wording. Throughout the paper, this adverb was used in the same way (i.e. introducing contrast without need) and I believe that substituting it with other words, or reframing these sentences could enhance clarity.

Response:

Thank you for pointing out the logical grammar issues in our writing. We adjusted this sentence as follows:
"As a comparison, Sadiq et al. (2017) found consistently stronger feedback on O3 concentrations in these polluted regions using the scheme of Lombardozzi et al (2012) embedded in the Community Earth System Model (CESM)." (Lines 67-70)

Line 65-67: The sentence "Inclusion of O_3-vegetation… surface O_3" feels disconnected from the rest on the text and, just by reading it, it is unclear if it is a consequence of what has been said earlier, if it's a claim lacking a reference, or if it's introducing the next sentence (in which case I'd suggest to improve the whole 65-72 lines).

Response:

We revised the sentence so that it clearly introduces the next content:
"Moreover, the inclusion of online O_3-vegetation interactions in numerical models will also result in a greater loss of simulated land carbon assimilation due to the feedbacks

of both ecosystems and surface O_3. This is attributable to several factors." (Lines 70-73)

Line 73-74: I believe "In addition to… between land and atmosphere" would be a direct consequence to ozone affecting stomatal conductance and I would mention this to improve logical coherence.

Response:

We revised the mentioned sentence to make it more logical:

"In addition to affecting surface O_3, the O_3-vegetation interaction can also alter the water and energy exchange between land and atmosphere through the modulation of stomatal conductance." (Lines 80-82)

Line 92: "aggregated" instead of "aggregate"? Anyway, the 91-93 sentence "which calculated… functional types" could be improved in clarity.

Response:

We revised the sentence as follow:

"This fully coupled framework was implemented with the semi-mechanistic O_3 damage scheme proposed by Sitch et al. (2007), which calculated aggregated O_3 damage to photosynthesis based on varied sensitivities to instantaneous stomatal O_3 uptake across eight plant functional types (PFTs)." (Lines 97-100)

Method

This section highlights adequately the general structure and workflow of the study. While it outlines the essential methods, I believe it would benefit with more details. Please add unit of measure when introducing some variable.

Response:

Thank you for your evaluation. We added unit of variables in the revised section following the suggestion.

To my understanding, surface O_3 within ESMs refers to the O_3 concentrations at the lowest model level, which might correspond to about 15-25 m above the ground, or even more depending on the vertical resolution. Do you think that this affects the O_3 evaluation part, since measuring stations are typically at a lower height (2-3 m above the ground)? In any case, I suggest providing more details about this matter, in the section 2.1 and/or in the section 2.4.

Response:

First, the vertical resolution of model affects near-surface O_3 simulation, as demonstrated by Shindell et al. (2003), who reduced bias in low-level ozone simulations from 31% to 8% by improving the model from 9 to 23 layers. Increasing the vertical resolution to 40 layers in our current model (Schmidt et al., 2014) significantly improves dry deposition simulation, consequently enhancing the accuracy of the model in simulating surface O_3 concentrations. Second, we think that the specific height difference of surface O_3 between the observations and the numerical model may affect the evaluation results to some extent, as O_3 concentrations near the surface vary with height (Fig. R1).

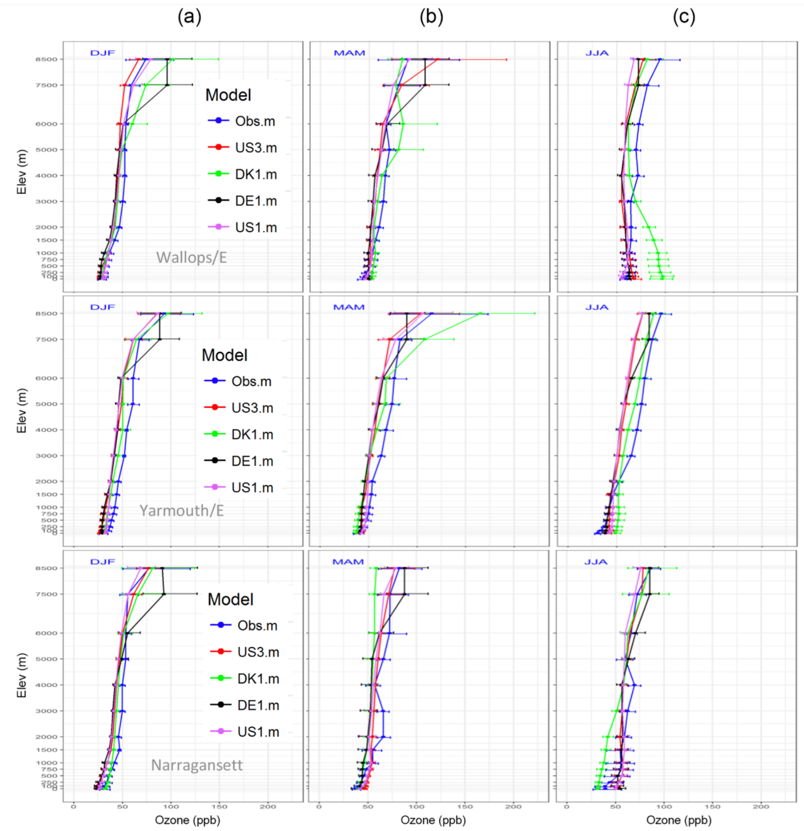

Figure R1. Seasonal vertical profiles of ozone mixing ratios for 2010 (a: winter; b: spring; c: summer), for stations located in the East America. The horizontal lines indicate the 95 % bootstrapped confidence interval for each vertical layer. (figure from Astitha, M., Kioutsioukis, I., Fisseha, G. A., Bianconi, R., Bieser, J., Christensen, J. H., Cooper, O. R., Galmarini, S., Hogrefe, C., Im, U., Johnson, B., Liu, P., Nopmongcol, U., Petropavlovskikh, I., Solazzo, E., Tarasick, D. W., and Yarwood, G.: Seasonal ozone vertical profiles over North America using the AQMEII3 group of air quality models: model inter-comparison and stratospheric intrusions, Atmos. Chem. Phys., 18, 13925–13945, https://doi.org/10.5194/acp-18-13925-2018, 2018.)

However, this bias will not affect the validation of the capacity of model for capturing the characteristics of the spatial distribution of the surface O_3. Moreover, daytime is the period when O_3-vegetation interactions usually occur. According to Zhang et al. (1999), the observed O_3 concentrations at different heights near the ground in summer do not vary much during the day (Fig. R2).

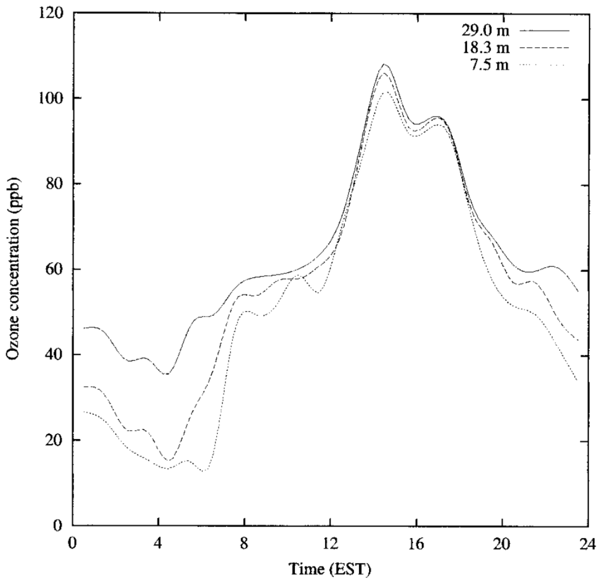

Figure R2. O_3 concentrations measured at the 29.0-m, 18.3-m, and 7.5-m levels above ground at the Harvard Forest on 10 August 1995 (figure from Zhang, J. and Rao, S. T.: The role of vertical mixing in the temporal evolution of ground- level ozone concentrations, J. Appl. Meteor. Climatol., 38, 1674-1691, https://doi.org/10.1175/1520-0450(1999)038<1674:TROVMI>2.0.CO;2, 1999.).

Finally, the gridded O_3 observational datasets utilized in this study are sourced from research aiming at providing datasets for model evaluation. For this, we provided more explanation in Section 2.4:

"The worldwide observations of the maximum daily 8-hour average O_3 (MDA8 O_3) concentrations were mainly collected from three regional networks: Air Quality Monitoring Network operated by Ministry of Ecology and Environment (AQMN-MEE) in China, the Clean Air Status and Trends Network (CASTNET) in the U.S., and the European Monitoring and Evaluation Programme (EMEP) in Europe. Observations used for validation beyond China, sourced from Sofen et al. (2016), are averaged over the period 2005-2014. This dataset encompasses 7288 station records worldwide and excludes the uncertainty associated with high mountain-top sites." (Lines 198-206)

2.1 Model descriptions

This section should mention the temporal resolution for the model.

Response:

Added as suggested.

"Both the physical and chemical processes are calculated every 0.5 h and the radiation module is called every 2.5 h." (Lines 112-114)

Line 115-116: It might be a good idea to offer more details about , , and

Response:

It seems that some information is missing in the comment. We guess that you suggest us to add some descriptions of modeling schemes for both photosynthesis and stomatal conductance. We revised this part as follows:

"Here, the total leaf photosynthesis, denoted as A_{tot} (unit: μmol m^{-2} [leaf] s^{-1}), is calculated considering both C_3 (Collatz et al., 1991) and C_4 plants (Collatz et al., 1992). The A_{tot} is derived from the minimum value of the constraints. The ribulose-1,5-bisphosphate carboxylase (Rubisco) limited rate of carboxylation is J_c:

$$J_c = \begin{cases} V_{cmax}\left(\dfrac{c_i - \Gamma_*}{c_i + K_c(1 + O_i/K_o)}\right) & \text{for } C_3 \text{ plant} \\ V_{cmax} & \text{for } C_4 \text{ plant} \end{cases} \quad (2)$$

The carboxylation rate restricted by the availability of light is J_e:

$$J_e = \begin{cases} a_{leaf} \times PAR \times \alpha \times \left(\dfrac{c_i - \Gamma_*}{c_i + 2\Gamma_*}\right) & \text{for } C_3 \text{ plant} \\ a_{leaf} \times PAR \times \alpha & \text{for } C_4 \text{ plant} \end{cases} \quad (3)$$

The export-limited rate for C_3 plants and the phosphoenolpyruvate carboxylase (PEPC) limited rate of carboxylation for C_4 plants are represented by J_s:

$$J_s = \begin{cases} 0.5\, V_{cmax} & \text{for } C_3 \text{ plant} \\ K_s \times V_{cmax} \times \dfrac{c_i}{P_{atm}} & \text{for } C_4 \text{ plant} \end{cases} \quad (4)$$

In these functions, V_{cmax} (μmol m^{-2} s^{-1}) is the maximum carboxylation capacity. c_i and O_i (Pa) represent the internal leaf CO_2 and oxygen partial pressure. Γ_* (Pa) denotes the CO_2 compensation point, while K_c and K_o (Pa) are Michaelis–Menten constants for the carboxylation and oxygenation of Rubisco, respectively. The parameters Γ_*, K_c, and K_o vary with temperature based on the sensitivity of the vegetation to temperature (Q_{10} coefficient). PAR (μmol m^{-2} s^{-1}) is the absorbed photosynthetically active radiation, a_{leaf} is leaf-specific light absorbance that considers sunlit and shaded leaves, and α is quantum efficiency. P_{atm} (Pa) represents the ambient pressure. K_s is set to 4000 as a constant following Oleson et al. (2010), to limit photosynthesis of C_4 plants get saturated at lower CO_2 concentrations." (Lines 123-139)

2.2 The O3-Vegetation damage scheme

Line 134: Calculation for should be detailed further.

Line 135: would need a reference.

Response:

We further clarified this part as follows:

"

$$F_{O3} = \frac{[O_3]}{R_a + [\frac{k_{O3}}{g_{sd}}]}, \qquad (9)$$

where $[O_3]$ represents surface O_3 concentrations, R_a (s m^{-1}) stands for aerodynamic resistance, which expresses turbulent transport efficiency in transferring sensible heat and water vapor between the land surface and a reference height. The constant k_{O3}=1.67 is the ratio of stomatal resistance for O_3, estimated based on the theoretical stomatal resistance to water (Laisk et al., 1989). When plants are exposed to $[O_3]$ (Eq. 9), A_{tot} and g_s will decrease (Eq. 6 and Eq. 7) if the excess O_3 enters leaves (Eq. 8). The increased stomatal resistance acts to protect plants by reducing the O_3 uptake of stomata. Consequently, the damage scheme describes both changes in photosynthetic rate and stomatal conductance." (Lines 161-169)

2.3 Experiments

Line 139: "two sets of simulations" are mentioned. Does it mean that each experiment contains more than one run, or that it's just "two simulations" (one run for each of the experiments)?

Response:

Corrected. It is "two simulations". (Lines 172)

Line 140-142: the simulation labels meaning could be made explicit.

Response:

Thank you for the suggestion. We changed the experiment names as follow:

"The control experiment "O3_offline" was conducted without the O_3 damages to vegetation. As a comparison, the sensitivity experiment "O3_online" contained online O_3-vegetation interaction with high O_3 sensitivity." (Lines 173-175)

Line 142: please be more explicit with "high O_3 sensitivity".

Response:

Thank you for the suggestion, we provided more explanations as follow in Section 2.2: "a_h (mmol m^{-2} $s^{-}1$) is the high O_3 sensitivity coefficient, calibrated by Sitch et al. (2007) on data from field observations by Karlsson et al. (2004) and Pleijel et al. (2004) to represent 'high' sensitivity of relative species of each PFT." (Lines 156-158)

2.4 Data for evaluations

I'd include in this section how each variable is evaluated specifically, at least when the evaluation is different than what expected – for instance, the evaluation carried out later refers to the surface daily maximum 8-hour ozone, whereas I expected ozone to be evaluated at the same time resolution of the model (or at least over a temporal scale that is more related to ozone vegetation fluxes). However, in general, specifying the temporal resolution of the dataset used for evaluation might help clarifying things.

Response:

We focused our validation efforts on the MDA8 O_3 variable, as O_3-vegetation interactions primarily occur during the daytime and our model can output monthly averaged MDA8 O_3 results.

Line 161: which simulation are you evaluating? It is not clear.

Response:

Clarified as follow:

"We evaluated the simulated air pollutants, carbon fluxes, and meteorological variables from 'O3_offline' run using observational and reanalysis datasets." (Lines 197-198)

Line 165-167: Was there any reason for picking the years 2009-2011, as opposite to including more years? Since the simulations you're using cover 10 years, it might be more adequate to compare them with more years.

Response:

The simulations in this study each run for 30 years, with the first 10 years dedicated to spin-up. Our primary focus is on the average data from the final 20 years, centered around 2010. In other words, using the average of observations from 2009 to 2011 is sufficient for model evaluation. However, in the revised version, we addressed this concern by using the period from 2005 to 2014 for validating the observed variables, except for GPP from Jung et al., (2011), for which only the latest data until 2011 were available. Given that the results indicate little variation in the evaluation effect between these two time periods, we did not change GPP observational data with longer time series.

"The worldwide observations of the maximum daily 8-hour average O_3 (MDA8 O_3) concentrations were mainly collected from three regional networks: Air Quality Monitoring Network operated by Ministry of Ecology and Environment (AQMN-MEE) in China, the Clean Air Status and Trends Network (CASTNET) in the U.S., and the European Monitoring and Evaluation Programme (EMEP) in Europe. Observations used for validation beyond China, sourced from Sofen et al. (2016), are averaged over the period 2005-2014. This dataset encompasses 7288 station records worldwide and excludes the uncertainty associated with high mountain-top sites. For AQMN-MEE, the mean value of 2014-2018 was used due to its establishment in 2013. The simulated aerosol optical depth (AOD) and LAI were validated using satellite-based data from the Moderate Resolution Imaging Spectroradiometer (MODIS) retrievals collection 5 (Remer et al., 2005) (http://modis.gsfc.nasa.gov/) averaged for the years 2005-2014. The simulated GPP was evaluated against the data product upscaled from the FLUXNET eddy covariance measurements for 2009-2011 (Jung et al., 2011). The daily temperature at 2m (T_{2m}) in 2005-2014 was obtained from the National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) reanalysis 1 (NCEP1) (Kalnay et al., 1996). For precipitation, we used the monthly data averaged in 2005-2014 from Global Precipitation Climatology Project (GPCP) (Huffman et al., 1997; Adler et al., 2018)." (Lines 198-217)

Line 170-171: could you be more specific about this data product? What do you mean by upscaled?

Response:

The "upscale" refers to the process of extrapolating or extending localized GPP datasets derived from eddy covariance measurements to a larger spatial scale. This involves using machine learning algorithms to scale up the observations from FLUXNET tower networks to generate global estimates of carbon and water fluxes in the study of Jung et al. (2011). We revised this sentence as follows:

"The simulated GPP was evaluated against the data product upscaled from the FLUXNET eddy covariance measurements for 2009-2011 (Jung et al., 2011)." (Lines 211-212)

Line 177-179: I believe NMB to be useful when comparing different quantities, but the non-normalized mean bias might convey a better quantification for some variables (such as ozone, or temperature), and I'd advocate for it either in place or siding the normalized version (for instance substituting the map of the observed data with the map of the non-normalized mean bias).

Response:

Thank you for the suggestion. We showed both normalized mean bias (NMB) and root mean square error (RMSE) in the revised paper:

"Root-mean-square-error (RMSE) and normalized mean biases (NMBs) were applied to quantify the deviations of simulations from observations:

$$RMSE = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(S_i - O_i)^2}$$

(10)

$$NMB = \sum_{i=1}^{n}(S_i - O_i)/\sum_{i=1}^{n}O_i \times 100\% \qquad (11)$$

Here, S_i and O_i represent the simulated and observed values, respectively. n denotes the total grid number used in the comparisons." (Lines 218-223)

We also replaced the scatter plots with the mean differences between simulations and observations in the validations. Please notice the slight changes in statistical metrics (such as r, NMB) due to the changes in the selected validation period.

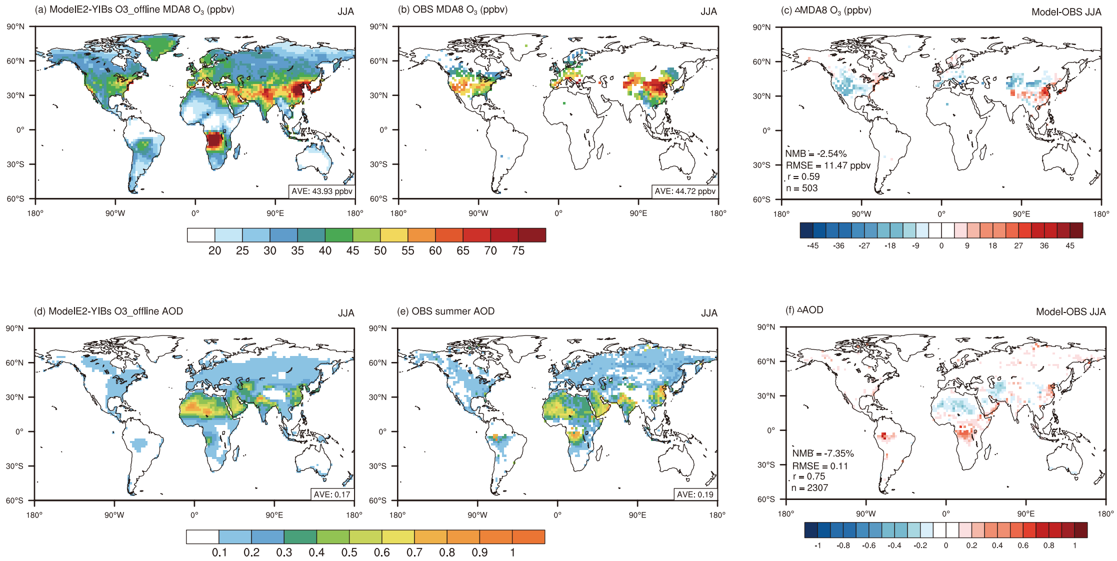

Figure 1. Evaluation of the boreal summertime (June-August) air pollutants at the present day simulated by the ModelE2-YIBs model. Surface daily maximum 8-hour ozone (MDA8 O_3; a-c) and aerosol optical depth (AOD; d-f) from the simulation O3_offline (a & d) and observations (b & e) are compared. The correlation coefficients (r), root mean square error (RMSE), normalized mean bias (NMB), and number of grid cells (n) for the comparisons are listed on the mean bias maps (c & f).

Results

3.1 Model evaluations

I believe that claiming a certain evaluation metric (such as correlation or NMB) to be high or low, or a certain variable to be adequately replicated, is a loose statement when not framed contextually. Any statement regarding the quality of an evaluation should reference a specific context. For instance, specifying if the evaluation is good compared to the literature, if the evaluated variable is the best among the ones being evaluated, or if the quality of the simulated variable meets the needs of the study. Furthermore, any proposition in this regard should be adequately motivated. If it is not possible to do so, I suggest leaving the numerical evaluation, without any qualitative remark. I signaled in the specific comments which are the lines that I found improper.

Response:

Thank you for your suggestion. We kept only the numerical assessment in the revised section and removed the qualitative description.

I think that this section does not cover strictly model evaluation, but also describes and contextualizes variables, so a different title might be more appropriate.

Response:

We changed the title to: "**3.1 The control simulation and model evaluations**". (Line 226)

Please be more specific as to which simulation you are evaluating. As far as I understand, it is "10NO3", but it should be made explicit throughout the text.

Response:

Clarified as follow:

"We first evaluated the air pollutants simulated by the control simulation O3_offline of ModelE2-YIBs model (Fig. 1)." (Lines 227-228)

"Simulated AOD at 550 nm by O3_offline (Fig. 1d) showed similar spatial pattern as the satellite retrievals (Fig. 1e) with R=0.75 and NMB of -7.35% globally (Fig. 1f)." (Lines 238-240)

"We then evaluated the simulated GPP and LAI by the control experiment for the boreal summer period (Fig. 2)." (Lines 243-244)

"We further validated the simulated meteorology from O3_offline (Fig. S2)." (Line 254)

Line 186: "adequately" (see general comment)

Response:

Deleted as suggested.

Line 191-192: Is this referred to the MDA8 average? Or just concentration averages? It would be better to refer always to the same quantity.

Response:

Sorry for the confusion, we changed the abbreviation '[O_3]' to 'MDA8 O_3'.

"Over a total of 503 grids with site-level O_3 measurements (Fig. 1b), the model replicated both the magnitude and spatial distribution of MDA8 O_3, with correlation coefficient (r) of 0.59 and NMB of -2.54% (Fig. 1c). Simulated summertime surface MDA8 O_3 was high in regions with large anthropogenic emissions, such as western Europe and eastern China (Ohara et al., 2007), as well as in central Africa with frequent fire emissions (van der Werf et al., 2017). On the global scale, the model yielded an average MDA8 O_3 of 43.93 ppbv and observations showed an average of 44.72 ppbv over the same grids." (Lines 228-235)

Line 195: "high R=0.77 and low NMB of -6.27%" (see general comment)

Response:

We revised the observational datasets from the period 2009-2011 to 2005-2014. Consequently, the relative correlation and NMB values may change for certain variables. Revised as follows:

"Simulated AOD at 550 nm by O3_offline (Fig. 1d) showed similar spatial pattern as the satellite retrievals (Fig. 1e) with R=0.75 and NMB of -7.35% globally (Fig. 1f)." (Lines 238-240)

Line 211: "low NMB of 8.49%" (see general comment)

Response:

Revised as follows:

"For surface air temperature, the model (Fig. S2a) reproduced observed (Fig. S2b) pattern with RMSE of 3.21 °C and r of 0.99 against observations (Fig. S2c)." (Lines 254-256)

Line 212-213: both simulations are referred to, but there's only one NMB value, and one correlation value, and the figure refers only to one of the simulations (10NO3).

Response:

We are sorry for the confusion. Here the word 'both' referred to 'simulations and observations' instead of 'two simulations'. We removed it and clarified as follows:

"For precipitation, the simulation (Fig. S2d) captures the observed spatial pattern (Fig. S2e) with NMB = 17.26% and r = 0.75 (Fig. S2f)." (Lines 256-258)

Line 213: could you provide any context to "high values in the tropical oceans"?

Response:

Sorry for the confusion. The main point we want to emphasize is that the model well captures the spatial distribution of precipitation. We removed this sentence in the revised paper.

Line 214-217: How do you define good performances? (see general comment)

Response:

Revised as follows:

"Overall, the model captures the spatial characteristics and magnitudes of air pollutants, biospheric parameters, and meteorological fields, making it a valuable tool for studying O_3-vegetation interactions." (Lines 258-260)

3.2 O_3 damage to terrestrial ecosystems

In this section, I would mention the fact that there are some areas of the globe that display higher GPP/stomatal conductance/LAI under "10HO3".

Response:

If only the effect of O_3 on vegetation (offline effect) is considered, GPP is negatively impacted on a global scale, with damage of -0.17 Pg[C] (-24.98%) and -0.52 Pg[C] (-16.71%) in eastern China and the eastern US, respectively (Fig. R3). Considering the feedback of O_3-vegetation interactions, the climate system is influenced and adjusted, resulting in both positive and negative impacts on ecosystem-related variables. Similar responses have been achieved in previous studies considering online O_3 vegetation damages (e.g., Sadiq et al., 2017). Overall, most of these positive changes are not statistically significant, especially when the confidence level is set to 95% (Fig. R4). And the changes in GPP due to O_3-vegetation interactions, primarily caused by O_3 damage on a global scale, predominantly show negative values, consistent with the spatial pattern observed in offline effect. We revised this section as follow to make the description clarified:

"We assessed the damaging effects of surface O_3 to ecosystems due to online O_3-vegetation interactions (Fig. 3)." (Lines 263-264)

"Though there are positive responses in some regions, they are not dominant and hardly significant." (Lines 273-274)

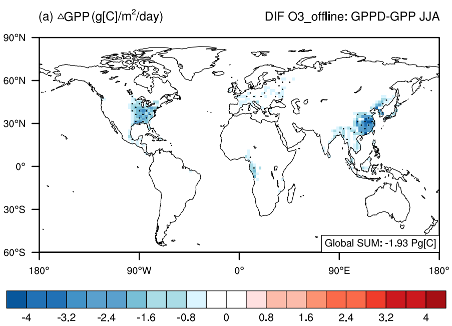

Figure R3. O_3-induced summer-time GPP loss simulated by the 'O3_offline' run.

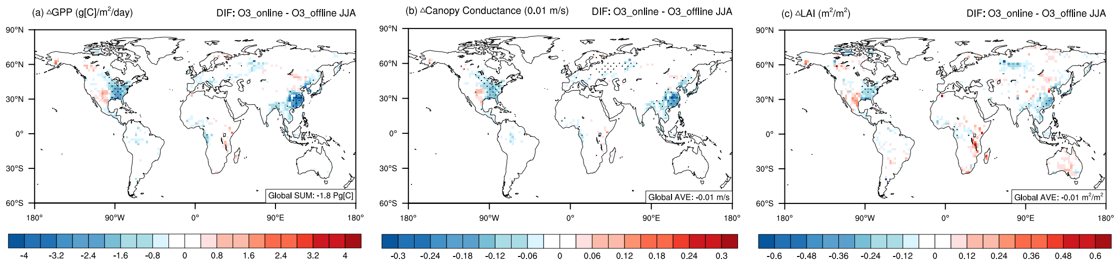

Figure R4. Same as fig. 3 but for significant changes with $p < 0.05$.

3.3 Global climatic responses to O_3-vegetation interactions

Line 249: could you be more specific about surface temperature? It is not clear what you're referring to, since it is then compared it with canopy temperature (line 251). I'd be more explicit.

Response:

Sorry for the confusion. In the new version, we've revised all the temperature-related variables to make them clearer. In this paper, the 'surface temperature' (Fig. 4a & Fig. S2a) refers to 'surface air temperature'. Here, we compare the increase in canopy temperature due to O_3-vegetation interactions observed in previous studies with the changes in surface air temperature simulated by our model. This comparison is valid because surface air temperature encompasses both vegetated and non-vegetated areas.

"Meanwhile, the reduction of latent heat flux promotes surface air temperature (Fig. 4a), resulting in the increase of sensible heat flux (Fig. 4f). Such warming was also reported in field experiments, where relatively high O_3 exposure resulted in noticeable increases of canopy temperature along with reductions of transpiration (Bernacchi et al., 2011; VanLoocke et al., 2012)." (Lines 293-298)

3.4 Changes of air pollution by O_3 -vegetation interactions

Line 285-286: "The enhancement of O_3 concentrations in polluted regions may exacerbate the warming effect of O_3 and cause additional damages to vegetation." Should be elaborated further.

Response:

Thank you for your suggestion, we elaborated further as follows:

"The enhancement of O_3 concentrations in polluted regions may exacerbate the warming effect of O_3 as a greenhouse gas and cause additional damages to vegetation. For instance, offline O_3 damages on GPP in eastern China and the eastern US are -

0.52±0.03 Pg[C] (-24.98±0.91%) and -0.17±0.02 Pg[C] (-16.71±1.16%), respectively, smaller than those induced by O_3-vegetation interactions (Table S2)." (Lines 332-337)

Line 296-297: there's a citation of the paper title instead of the authors.

Response:

Corrected.

Conclusions and discussion

Should it be "Discussion and conclusions?"

Response:

Revised as suggested.

Line 310: Does "surface warming" refers to air surface temperature?

Response:

Yes, it refers to the increase of surface air temperature.

Line 312: At first glance, the word "further" seems contradictory with the previous statements. For instance, I would suggest replacing the sentence with "However, the enhancement of cloudiness decreased surface temperature…". Ultimately, just from this sentence, it is unclear if the net effect is an increase or decrease in air temperature, or if these contrasting effects involve different regions.

Response:

Revised as suggested:

"However, the enhancement of cloudiness decreased surface temperature and promoted precipitation outside the key regions with intense O_3-vegetation interactions." (Lines 361-363)

Line 326: Does "surface warming" refers to air surface temperature?

Response:

Yes, it is.

Line 327-328: Would you be able to provide any explanation for this difference.

Response:

Revised as follow:

"The magnitude of these responses was much stronger than our predictions, likely because they considered the accumulation effect of O_3." (Lines 377-378)

Line 352-354: I suggest being more specific.

Response:

The differences between these works are discussed in details in the above context.

"For example, the simulations by Lombardozzi et al. (2015) revealed that surface O_3 reduces global GPP by 8%-12% and transpiration by 2-2.4% with regional reductions up to 20% for GPP and 15% for transpiration in eastern China and U.S. These changes were in general consistent with our results though we predicted larger reductions in transpiration than GPP due to O_3-vegetation interactions. Using the same scheme as Lombardozzi et al. (2015), Sadiq et al. (2017) showed that O_3-vegetation coupling induced the surface warming of 0.5-1° C and O_3 enhancement of 4-6 ppbv in eastern China and eastern U.S. The magnitude of these responses was much stronger than our predictions, likely because they considered the accumulation effect of O_3." (Lines 370-378)

Line 356-357: Most readers would recognize that a coarse resolution would be a limitation, but I would be more specific as to why with respect to O_3-vegetation interaction. For instance, later (line 360), it is mentioned that high-resolution improves simulation for extreme events: are extreme events relevant for O_3-vegetation interactions?

Response:

Severe O_3 pollution can occur under extreme conditions such as heat waves and droughts. Lin et al. (2020) found that during drought events, the O_3 removal capacity of water-stressed vegetation decreases, exacerbating severe O_3 pollution. Mills et al. (2016) noted that both extreme temperature and O_3 have impacts on critical growth stages of plants. We revised the related context as follow:

"However, high-resolution models exhibit improved simulations of extreme events (Chang et al., 2020; Ban et al., 2021), which have certain effect on O_3-vegetation interactions (Mills et al., 2016; Lin et al., 2020)." (Lines 408-410)

Line 357-359: this sentence is unclear – it seems like "Ito et al. (2020) shows… that the model results are involved in the CMIP6 Coupled Climate-Carbon Cycle MIP

(C4MIP)", as if being included in the CMIP6 guarantees by itself that carbon fluxes are well represented.

Response:

We removed this sentence in the revised paper for the better clarity.

Figures

Figure 1: there's a mistake in the panel letters.

Response:

Corrected.

Figure 1-2: it might be more useful to show the mean bias maps instead of the observed values, as it allows for easier comparisons.

Response:

Revised as suggested:

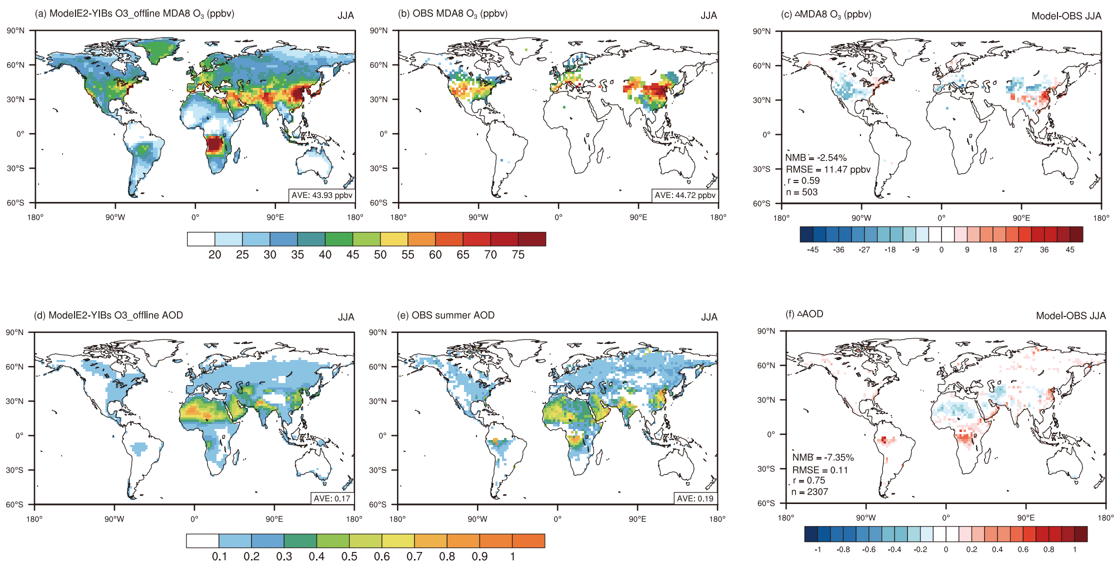

Figure 1. Evaluation of the boreal summertime (June-August) air pollutants at the present day simulated by the ModelE2-YIBs model. Surface daily maximum 8-hour ozone (MDA8 O_3; a-c) and aerosol optical depth (AOD; d-f) from the simulation O3_offline (a & d) and observations (b & e) are compared. The correlation coefficients (r), root mean square error (RMSE), normalized mean bias (NMB), and number of grid cells (n) for the comparisons are listed on the mean bias maps (c & f).

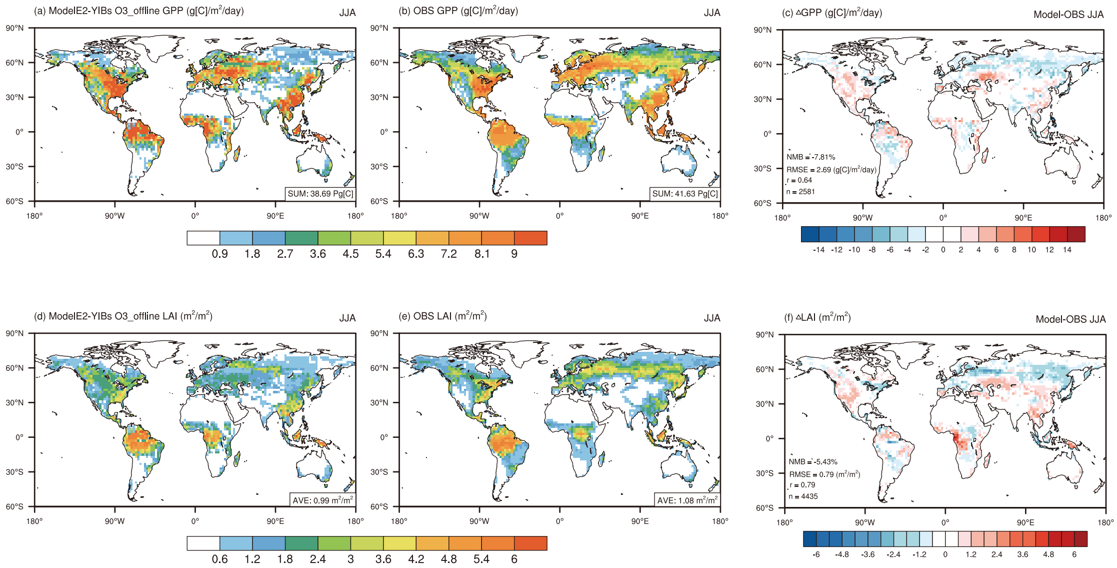

Figure 2. The same as Fig.1 but for gross primary productivity (GPP; a-c) and leaf area index (LAI; d-f).

Figure 3: have the p-values been corrected to account for the multiple repetitions in space in some ways? For instance, with Bonferroni, or false discovery rate.

Response:

No, we used the standard 't-test' function.

Figure 4a: you refer to this as "air surface temperature" in the text (line 241), but here you call it "Tsurf", which I think generates confusion with land surface temperature.

Response:

We revised the figure titles as follow:

“

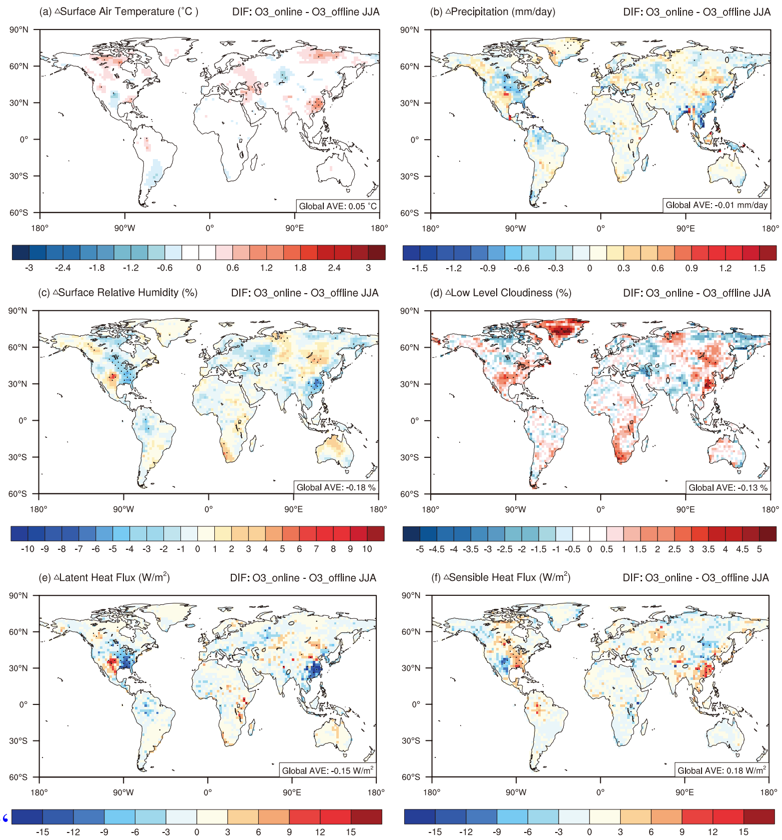

Figure 4. Changes of boreal summertime meteorological fields by O_3-vegetation interactions at the present day. Results shown are changes of (a) surface air temperature, (b) precipitation, (c) surface relative humidity, (d) low level cloudiness, (e) latent heat flux, and (f) sensible heat flux between simulations O3_online and O3_offline. For heat fluxes, positive values (shaded in red color) indicate the upward fluxes change. Black dots denote areas with significant changes ($p < 0.1$).”

Figure 3, 4, 6: I believe that the sentence “Please notice the differences in the color scales” is redundant when comparing quantities with different unit of measurement.

Response:

We deleted these sentences in the revised version.

References:

Astitha, M., Kioutsioukis, I., Fisseha, G. A., Bianconi, R., Bieser, J., Christensen, J. H., Cooper, O. R., Galmarini, S., Hogrefe, C., Im, U., Johnson, B., Liu, P., Nopmongcol, U., Petropavlovskikh, I., Solazzo, E., Tarasick, D. W., and Yarwood, G.: Seasonal ozone vertical profiles over North America using the AQMEII3 group of air quality models: model inter-comparison and stratospheric intrusions, Atmos. Chem. Phys., 18, 13925–13945, https://doi.org/10.5194/acp-18-13925-2018, 2018.

Buker, P., Feng, Z., Uddling, J., Briolat, A., Alonso, R., Braun, S., Elvira, S., Gerosa, G., Karlsson, P. E., Le Thiec, D., Marzuoli, R., Mills, G., Oksanen, E., Wieser, G., Wilkinson, M., and Emberson, L. D.: New flux based dose-response relationships for ozone for European forest tree species, Environ. Pollut., 206, 163–174, https://doi.org/10.1016/j.envpol.2015.06.033, 2015.

Collatz, G. J., Ball, J. T., Grivet, C., and Berry, J. A.: Physiological and Environmental-Regulation of Stomatal Conductance, Photosynthesis and Transpiration – a Model That Includes a Laminar Boundary-Layer, Agr. Forest Meteorol., 54, 107–136, doi:10.1016/0168-1923(91)90002-8, 1991.

Collatz, G. J., Ribas-Carbo, M., and Berry, J. A.: Coupled Photosynthesis-Stomatal Conductance Model for Leaves of C4 Plants, Aust. J. Plant Physiol., 19, 519–538, https://doi.org/10.1071/PP9920519, 1992.

Jung, M., Reichstein, M., Margolis, H.A., Cescatti, A., Richardson, A.D., Arain, M.A., Arneth, A., Bernhofer, C., Bonal, D., Chen, J. and Gianelle, D.: Global patterns of land-atmosphere fluxes of carbon dioxide, latent heat, and sensible heat derived from eddy covariance, satellite, and meteorological observations. J. Geophys. Res-Biogeosci., 116(G3), https://doi.org/10.1029/2010JG001566, 2011.

Laisk, A., Kull, O., & Moldau, H.: Ozone concentration in leaf intercellular air spaces is close to zero. Plant Physiol., 90(3), 1163-1167, https://doi.org/10.1104/pp.90.3.1163, 1989.

Lin, M., Horowitz, L.W., Xie, Y., Paulot, F., Malyshev, S., Shevliakova, E., Finco, A., Gerosa, G., Kubistin, D. and Pilegaard, K.: Vegetation feedbacks during drought exacerbate ozone air pollution extremes in Europe, Nat. Clim. Change., 10,444-451, https://doi.org/10.1038/s41558-020-0743-y, 2020.

Mills, G., Harmens, H., Wagg, S., Sharps, K., Hayes, F., Fowler, D., Sutton, M. and Davies, B.: Ozone impacts on vegetation in a nitrogen enriched and changing climate, Environ. Pollut., 208, 898-908, https://doi.org/10.1016/j.envpol.2015.09.038, 2016.

Oleson, K. W., Lawrence, D. M., Bonan, G. B., Flanne, M. G., Kluzek, E., Lawrence, P. J., Levis, S., Swenson, S. C., and Thornton, P. E.: Technical Description of version

4.0 of the Community Land Model (CLM), National Center for Atmospheric Research, Boulder, USA, CONCAR/TN-478+STR, 2010.

Paoletti, E., De Marco, A. and Racalbuto, S.: Why should we calculate complex indices of ozone exposure? Results from Mediterranean background sites. Environ. Monit. Assess., 128, pp.19-30, https://doi.org/10.1007/s10661-006-9412-5, 2007.

Shindell, D. T., Faluvegi, G., and Bell, N.: Preindustrial-to-present-day radiative forcing by tropospheric ozone from improved simulations with the GISS chemistry-climate GCM, Atmos. Chem. Phys., 3, 1675–1702, https://doi.org/10.5194/acp-3-1675-2003, 2003.

Sicard, P., De Marco, A., Dalstein-Richier, L., Tagliaferro, F., Renou, C., Paoletti, Elena, 2016. An epidemiological assessment of stomatal ozone flux-based critical levels for visible ozone injury in southern European forests. Sci. Total. Environ., 541, 729-741.

Sofen, E. D., Bowdalo, D., Evans, M. J., Apadula, F., Bonasoni, P., Cupeiro, M., Ellul, R., Galbally, I. E., Girgzdiene, R., Luppo, S., Mimouni, M., Nahas, A. C., Saliba, M., and Tørseth, K.: Gridded global surface ozone metrics for atmospheric chemistry model evaluation, Earth Syst. Sci. Data, 8, 41–59, https://doi.org/10.5194/essd-8-41-2016, 2016.

Zhang, J. and Rao, S. T.: The role of vertical mixing in the temporal evolution of ground-level ozone concentrations, J. Appl. Meteor. Climatol., 38, 1674-1691, https://doi.org/10.1175/1520-0450(1999)038<1674:TROVMI>2.0.CO;2, 1999.

Response to Comments of Reviewer #2

Manuscript number: egusphere-2024-365

Authors: Xinyi Zhou, Xu Yue, Chenguang Tian and Xiaofei Lu

Title: Global assessment of climatic responses to the ozone-vegetation interactions

The authors are grateful to the editor and reviewers for their time and energy in providing helpful comments that have improved the manuscript. In this document, we describe how we have addressed the reviewer's comments. Referee comments are shown in black italics and author responses are shown in blue regular text. A manuscript with tracking changes is attached separately.

Anonymous referee #2:

The authors use the coupled ModelE2-YIBs model to estimate climate and air pollution responses to ozone-vegetation interactions globally during boreal summers. This is an important and interesting topic that has been studied before by multiple researchers including some of the authors themselves, and surely falls within the scope of ACP.

Response:

Thank you for your positive evaluations.

While a lot of model evaluation work has been presented, as the authors noted, their results contradict with what have been reported previously and may be highly uncertain. It is also disappointing that, with multi-year long simulations, only period-mean results are shown. It'd be nice to see discussions on the temporal variability in their results, the drivers of that, and the (new) implications from temporally-varying sensitivities for estimating future environmental changes.

Response:

ModelE2-YIBs has been thoroughly validated in previous researches (Yue et al., 2017; Unger et al., 2020; Tian et al., 2021). For this study, we focused on the evaluations of carbon, air pollution, and climate variables related to O_3 vegetation feedback (Fig. 1, Fig. 2, and Fig. S2). We conducted time-slice experiments, in which the model years are not correspondent to the actual years. In addition, the long-term trend is limited because the fixed boundary conditions are applied. The simulated temporal variability may influence the significance of derived O_3 vegetation damages. As a result, we modified all the related global/regional values in the revised text to "mean/sum ±

standard deviation". Related context (other value-related sentences are not shown here, but the revised tables in the Supplementary are shown here):

"In order to show the uncertainty introduced by the internal variability of the model, all the related global/regional values are denoted as "mean/sum ± standard deviation of the last 20 model years"." (Lines 188-191)

Table S2. Relative changes of terrestrial ecosystems in two major geographic regions in response to O_3-vegetation interactions in model

Region	GPP	Stomatal Conductance	LAI
eastern China	-25.40±1.90%	-30.62±4.30%	-4.53±1.14%
eastern U.S.	-20.14±5.02%	-25.65±9.32%	-5.87±3.11%

Table S3. Changes of climatic variables in two major geographic regions in response to O_3-vegetation interactions in model

Region	Surface Air Temperature (unit: °C)	Precipitation (unit: mm day^{-1})	Sensible Heat Flux (W m^{-2})
eastern China	0.56±0.38°C	-0.79±1.05 (16.18±20.38%)	7.12±3.86 (25.46±14.71%)
eastern U.S.	0.33±0.87 °C	-0.45±1.33 (-9.82±14.20%)	6.3±5.4 (16.54±15.59%)

Table S4. Changes of air pollution in two major geographic regions in response to O_3-vegetation interactions in model

Region	MDA8 O_3 (ppbv)	$PM_{2.5}$ (unit: µg m^{-3})	AOD
eastern China	1.46±3.02	-1.94±1.67 (-8.52±6.88%)	-0.06±0.05 (-14.67±16.75%)
eastern U.S.	1.15±1.77	-0.27±0.36 (-6.01±7.9%)	-0.01±0.01 (-8.15±9.38%)

Specific comments:

L15: define ModelE2-YIBs

Response:

We revised the sentence as follows:

"Using a climate-vegetation-chemistry coupled model (the NASA GISS ModelE2 coupled with Yale Interactive terrestrial Biosphere, or ModelE2-YIBs), we assess the global climatic responses to O_3-vegetation interactions during boreal summer of the present day (2005-2014)." (Lines 15-18)

L18: delete "the"

Response:

Corrected as suggested.

"High O_3 pollution reduces stomatal conductance, resulting in warmer and drier conditions worldwide." (Lines 18-19)

L23: specify surface O_3 concentration metric used

Response:

Specified as follow:

"Surface maximum daily 8-hour average O_3 concentrations increase by +1.46±3.02 ppbv in eastern China and +1.15±1.77 ppbv in eastern U.S due to the O_3-induced inhibition of stomatal uptake." (Lines 23-25)

L25-27: quantitatively state the impact on aerosols, which is claimed as a highlight of this study

Response:

Add quantitatively state as suggested:

"With reduced atmospheric stability following the warmer climate, increased cloudiness but decreased relative humidity jointly reduce aerosol optical depth by -0.06±0.01 (-14.67±12.15%) over eastern China." (Lines 26-28)

L43: there are quite a few concentration-based metrics used to assess O_3 impact, not just AOT40

Response:

Thank you for indicating the deficiencies, we made the following revisions:

"Several exposure-based indexes such as accumulated hourly O_3 concentrations over a threshold of 40 ppb (AOT40) and sum of all hourly average concentrations (SUM00) are used to assess O_3-induced vegetation damage (Fuhrer et al., 1997; Paoletti et al., 2007). In addition, the flux-related POD_y method (phytotoxic O_3 dose above a threshold flux of y) is also widely applied to consider the dynamic adjustment of stomatal conductance (Buker et al., 2015; Sicard et al., 2016)." (Lines 44-50)

L60: please specify the study period by Gong et al.

Response:

Specified as suggested.

"Gong et al. (2020) revealed that O_3-vegetation interactions increased regional O_3 concentrations by 1.8 ppbv in the eastern U.S., 1.3 ppbv in Europe, and 2.1ppbv in eastern China for the year 2010." (Lines 65-67)

L63: please specify tool used by Sadiq et al.

Response:

Specified as suggested.

"As a comparison, Sadiq et al. (2017) found consistently stronger feedback on O_3 concentrations in these polluted regions using the scheme of Lombardozzi et al (2012) embedded in the Community Earth System Model (CESM)." (Lines 67-70)

L89: Why is YIBs spelled out here, after its first appearance at L60?

Response:

Corrected.

L100 and section 2.1: In general the approach applied in this work is old with no major updates from the authors' previous works on similar topics. ModelE now has version 4 (https://data.giss.nasa.gov/modelE/) that should address some of the deficits in previous versions of the model. The model was run at 2x2.5 deg/40 layer resolution which is far from sufficient to resolve processes that could impact weather states, chemical environments and feedbacks that are studied here. The accuracy of parameters in Table S1, based on Sitch et al., should also be extensively discussed. For example, the sensitivity parameters in Sitch et al. seem to be sensitive to life stages of trees and climatic conditions which is not accounted for/discussed in this study.

Response:

Model development is a very complex process, and we did a lot of work related to module coupling in the early stages. Although ModelE is now available in version 4, this version does not include the dynamic vegetation model YIBs that has been extensively validated for many biological processes (photosynthesis, stomatal conductance, phenology, biomass, soil carbon, carbon sink etc.) and ozone vegetation damages. Additionally, the development status of the atmospheric chemistry module in the new version of ModelE is not very clear. We recognize that modeling at a relatively coarse resolution has its limitations. However, within the scope of this study, this resolution is sufficient to discuss relevant issues and provide valuable insights, which has been well validated in previous work. In the discussion section, we acknowledged the limitations of model resolution, and will consider higher resolution models in future studies. Considering the effects of tree growth stages poses a common challenge in developing current models, and related efforts are in progress. In the discussion section, we also acknowledged the limits of the Sitch et al. (2007) scheme, which could be further improved with more available observations in the future:

"…, observations have shown large variability of plant sensitivities to O_3 damages. The Sitch et al. (2007) scheme employed the low to high ranges of sensitivity to indicate the inter-specific variabilities. In this study, we employed only the high O_3 sensitivity to explore the maximum responses. The possible uncertainties due to varied O_3 damage sensitivities deserved further investigations." (Lines 395-399)

L140/142: Can the authors please come up with new experiment names that are more self-explanatory?

Response:

Thank you for the suggestion. We change the experiment names as follow:

"The control experiment "O3_offline" was conducted without the O_3 damages to vegetation. As a comparison, the sensitivity experiment "O3_online" contained online O_3-vegetation interaction with high O_3 sensitivity." (Lines 173-175)

L143-154: The description on model configuration is very confusing. Was the 2010s anthropogenic/biomass burning emissions applied for 30 year simulations (including spin-up)? Does the model simulations include other natural emissions such as soil, lightning, BVOCs, etc, and if so, in later sections, could their sensitivities be shown? Was the PFT type input (shown in Fig. S1) temporally fixed throughout the simulation period and if so why would land use/land cover change not represented in the system?

Response:

For the first question: Yes, the 2010s emissions are applied for 30-year period of simulations. This is a method commonly used for time-slice simulations (e.g., Sadiq et al., 2017; Gong et al., 2020). The first 10 years are spin-up and only the results of the last 20 years are analyzed in order to ensure greater stability of the output data. We revised the text to clarify:

"For both experiments, the anthropogenic emissions of 2010 (the average of 2005-2014) for 8 species…" (Lines 175-177)

"The cover fraction of 8 PFTs (Fig. S1) fixed at 2010 were adopted from the land use harmonization (LUH2) dataset (Hurtt et al., 2020)." (Lines 183-184)

"For each time-slice simulation, the model was run for 30 years with all the input data fixed and the first 10 years are used as the spin up." (Lines 185-186)

For the second question: NO_x from soil in our model is fixed. NO_x from lighting (Fig. R1 b) changes following the relative humidity and precipitation patterns (Fig. 4b & 4c). In case of isoprene, the change in BVOC emissions is negligible (Fig. R2 a).

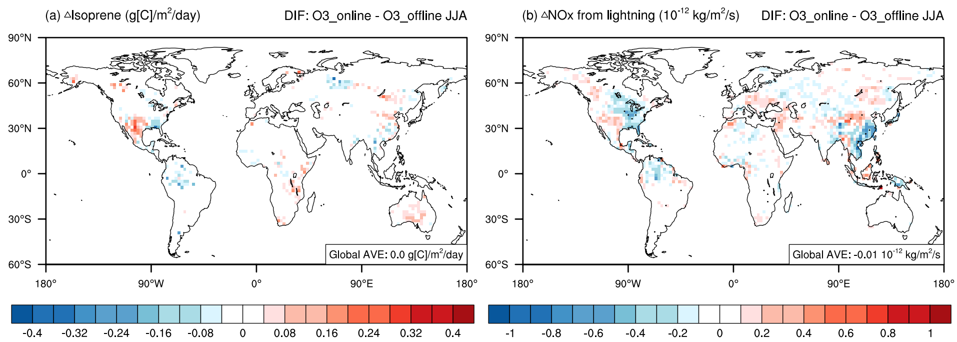

Figure R2. Changes of boreal summertime natural emissions induced by O_3-vegetation interactions at the present day. Results shown are changes of (a) isoprene (b) and NO_x from lightning between simulations O3_online and O3_offline. Black dots denote areas with significant changes ($p < 0.1$).

For the third question: The PFT types input are temporally fixed. We clarified in the revised paper as follows: "The cover fraction of 8 PFTs (Fig. S1) fixed at 2010 were adopted from the land use harmonization (LUH2) dataset (Hurtt et al., 2020)." (Lines 183-184)

L153: Why only boreal summers are focused on for a global (including the southern hemisphere) assessment? Also note that high O_3 days are not necessarily high O_3 flux days.

Response:

This is because boreal summer is the main growing season for most of the vegetation worldwide, and the main area of O_3 pollution is in the northern hemisphere. Previous studies also focused on the growing season (Lombardozzi et al., 2015) or boreal summer (Sadiq et al., 2017) period when most of photosynthesis and O_3 pollution reached the peak values. To make it clearer, we added more information as follows in the Supplementary and main context:

"We calculated the average of the last 20 years and focused on the boreal summer season (June-July-August, JJA) when the interaction of vegetation and surface O_3 reaches the maximum in one year (Fig. S3)." (Lines 186-188)

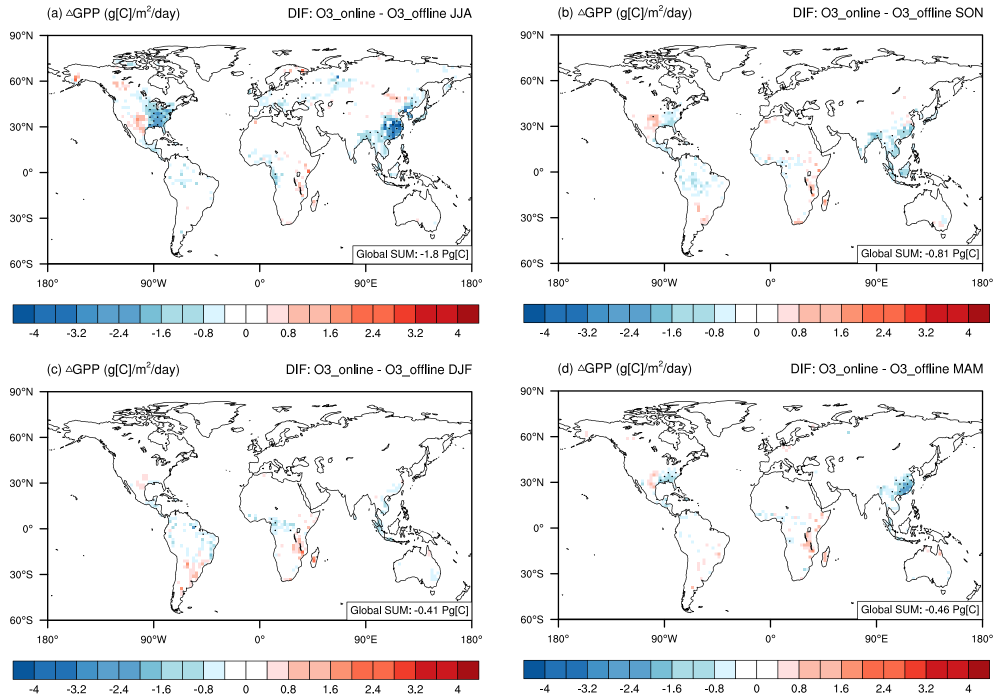

Fig. S3. Changes of GPP induced by O_3-vegetation interactions in different seasons at the present day. Results shown are changes of (a) JJA (June-July-August), (b) SON (September-October-November), (c) DJF (December-January-Feburary), and (d) MAM (March-April-May) between simulations O3_online and O3_offline. Black dots denote areas with significant changes ($p < 0.1$).

L156: no need to include "special"

Response:

Deleted as suggested.

L159: add model after "for"

Response:

Corrected as suggested.

Section 2.3: More descriptions on the used datasets and their respective accuracies (particularly for remote sensing and derived data) are needed. The different temporal coverages of these datasets are very confusing and hard to be linked to the results presented later.

Response:

We described the observational datasets as follow:

"The worldwide observations of the maximum daily 8-hour average O_3 (MDA8 O_3) concentrations were mainly collected from three regional networks: Air Quality Monitoring Network operated by Ministry of Ecology and Environment (AQMN-MEE) in China, the Clean Air Status and Trends Network (CASTNET) in the U.S., and the European Monitoring and Evaluation Programme (EMEP) in Europe. Observations used for validation beyond China, sourced from Sofen et al. (2016), are averaged over the period 2005-2014. This dataset encompasses 7288 station records worldwide and excludes the uncertainty associated with high mountain-top sites." (Lines 198-206)

"The simulated aerosol optical depth (AOD) and LAI were validated using satellite-based data from the Moderate Resolution Imaging Spectroradiometer (MODIS) retrievals collection 5 (Remer et al., 2005) (http://modis.gsfc.nasa.gov/) averaged for the years 2005-2014." (Lines 207-210)

L162-165: There are clearly O_3 observation data in Africa and South America in Fig 1b. What are their sources?

Response:

As we mentioned above, this dataset is obtained from Sofen et al. (2016), which compiled O_3 concentrations worldwide except for China. The data in Africa and South America is from World Data Center for Greenhouse Gases (WDCGG; http://ds.data.jma.go.jp/gmd/wdcgg/) from the World Meteorological Organization (WMO) Global Atmospheric Watch (GAW; http://www.wmo.int/pages/prog/arep/gaw/gaw_home_en.html).

L168: Which version of MODIS data? Does LAI data also come from MODIS?

Response:

Yes, LAI data is also from MODIS. We clarified as follows:

"The simulated aerosol optical depth (AOD) and LAI were validated using satellite-based data from the Moderate Resolution Imaging Spectroradiometer (MODIS) retrievals collection 5 (Remer et al., 2005) (http://modis.gsfc.nasa.gov/) averaged for the years 2005-2014." (Lines 207-210)

L187: MDA8 is not necessarily the best metric for evaluating ozone flux and vegetation impacts. It is worth noting that the poor coverage of O_3 observations can affect the global model evaluation.

Response:

We focus on the MDA8 O_3 variable because O_3-vegetation interactions occur mainly in the daytime. Indeed, sparse ozone observations present a challenge for both observational and modeling research nowadays. However, there are many observational sites in the areas where the majority O_3-vegetation interactions locate, which is sufficient to support the validity of our study.

Section 3.1: Evaluation is done on a global scale - this should also be done and summarized by various regions of the world (particularly, but not limited to the two hotspot regions). It is unclear why Case "10NO3" was evaluated and what the reported performance for this case means.

Response:

As can be seen from the spatial distribution of damage to GPP, we focused on these two key areas because this is where ozone-vegetation interactions are most significant. 10NO3 (now named O3_offline) was chosen as the reference experiment because this experiment was conducted as a baseline experiment (or normal state in which the model is developed). Validation results by comparison with observations show that our modeling experiments can be used in the following related studies. We made clarification as follow:

"We first evaluated the air pollutants simulated by the control simulation O3_offline of ModelE2-YIBs model (Fig. 1)." (Lines 227-228)

L198: There is no illustration of spatiotemporal variability in emissions that can support to this statement.

Response:

We added a reference to support this statement:

"Both the simulations and observations showed AOD hotspots over North Africa and the Middle East where dust emissions dominate, and in northern India and eastern China where anthropogenic emissions are large (Feng et al., 2020)." (Lines 240-242)

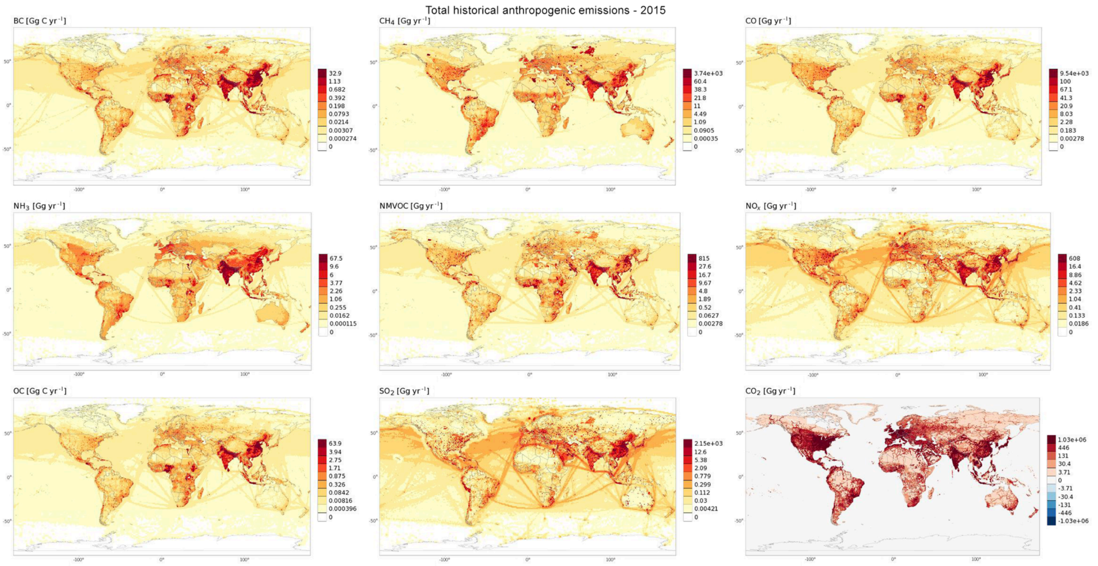

Figure R1. Total anthropogenic emissions in 2015 by species. (figure from Feng, L., Smith, S. J., Braun, C., Crippa, M., Gidden, M. J., Hoesly, R., Klimont, Z., van Marle, M., van den Berg, M., and van der Werf, G. R.: The generation of gridded emissions data for CMIP6, Geosci. Model Dev., 13, 461–482, https://doi.org/10.5194/gmd-13-461-2020, 2020.)

L265-269: Note that many of these processes discussed here may be well represented in models running at coarse resolutions.

Response: We recognize that modeling at a relatively coarse resolution has its limitations. However, within the scope of this study, this resolution is sufficient to discuss relevant issues and provide valuable insights, which has been well validated in previous work. In the discussion section, we acknowledged the limitations of model resolution, and will consider higher resolution models in future studies:

"Furthermore, the 2°×2.5° resolution of current ModelE2-YIBs has limitation due to the high computational demands. However, high-resolution models exhibit improved simulations of extreme events (Chang et al., 2020; Ban et al., 2021), which have certain effect on O_3-vegetation interactions (Mills et al., 2016; Lin et al., 2020). While chemical transport models with relatively coarse resolution can raise biases in simulated air pollutants, they still capture large-scale patterns similar to fine-resolution results and is reasonable compared to observational data (Wang et al., 2013; Li et al., 2016; Lei et al., 2020)." (Lines 406-413)

L287-302: What about aerosol climate impacts that feed back to ozone?

Response:

We did not isolate the impacts of aerosol climate effects, which can be considered in the future work. This paragraph focuses on the aerosol response to O_3-vegetation interactions and this work focuses primarily on the effects of O_3-vegetation interactions as well. Additionally, with relatively small changes in aerosols, the O_3 feedback from it may be even smaller.

L337-371: This long list of limitations make the interpretation of the reported model results harder. The authors may want to articulate what useful information can still be gained from this sensitivity analysis in spite of all these sources of uncertainty.

Response:

Thank you for your suggestions. We listed all the possible limitations of this study to inform the readers of modeling uncertainties. However, some of these limitations, such as O_3 damage scheme, O_3 damaging sensitivities, and missing of large-scale validations, are mainly related to the limitations in observations that are out of the scope of this study and capability of our efforts. In this study, we employed the standard deviation in numbers and 90% confidence tests in figures to indicate the significant and robust feedbacks from O_3-vegetation interactions. We also summarized in the last paragraph the key findings and the associated implications:

"Despite these uncertainties, our simulations revealed considerable changes of both climate and air pollutants in response to O_3-vegetation interactions. The most intense warming, dryness, and O_3 enhancement were predicted in eastern China and eastern U.S., affecting the regional climate and threatening public health for these top two economic centers. In contrast, we for the first time revealed the reduction of aerosol loading in those hotspot regions, suggesting both positive and negative effects to air pollutants by O_3-vegetation feedback. Such interactions should be considered in the Earth system models so as to better project future changes in climate and air pollutants following the anthropogenic interventions to both O_3 precursor emissions and ecosystem functions." (Lines 421-430)

Fig. 1 caption: replacing upper, left, bottom and middle with letter labels; add "the" before 2010s (and throughout the paper). Why did the model fail to capture high O_3 in the western US and the Middle East?

Response:

Revised as suggested. The model indeed underestimates surface ozone in the above-mentioned regions, especially in western U.S. This underestimation is likely attributed to the biases in emission inventories and simulated meteorology. The model employed fixed anthropogenic and biomass burning emissions averaged for 2005-2014. The biases in these emissions, especially the missing of interannually-varied wildfire emissions, may cause the underestimations of surface O_3 in western U.S. Moreover, simulated temperature by ModelE2-YIBs is much lower than observations in western U.S. (Fig. S2). Such biases in the simulated climate may reduce O_3 production by reducing the photochemical reaction rate in the specific regions. In the revised paper, we clarified as follows:

"However, the modeled result is overestimated over the North China Plain and slightly underestimated over the U.S., likely due to the biases in the emission inventories and predicted climate that drive the O_3 production." (Lines 235-238)

Fig. S2 caption: replacing upper, left, bottom and middle with letter labels

Response:

Revised as suggested.

Fig. S3-S4 colors are very hard to discern. Can the color schemes be adjusted?

Response:

Adjusted as follows:

"

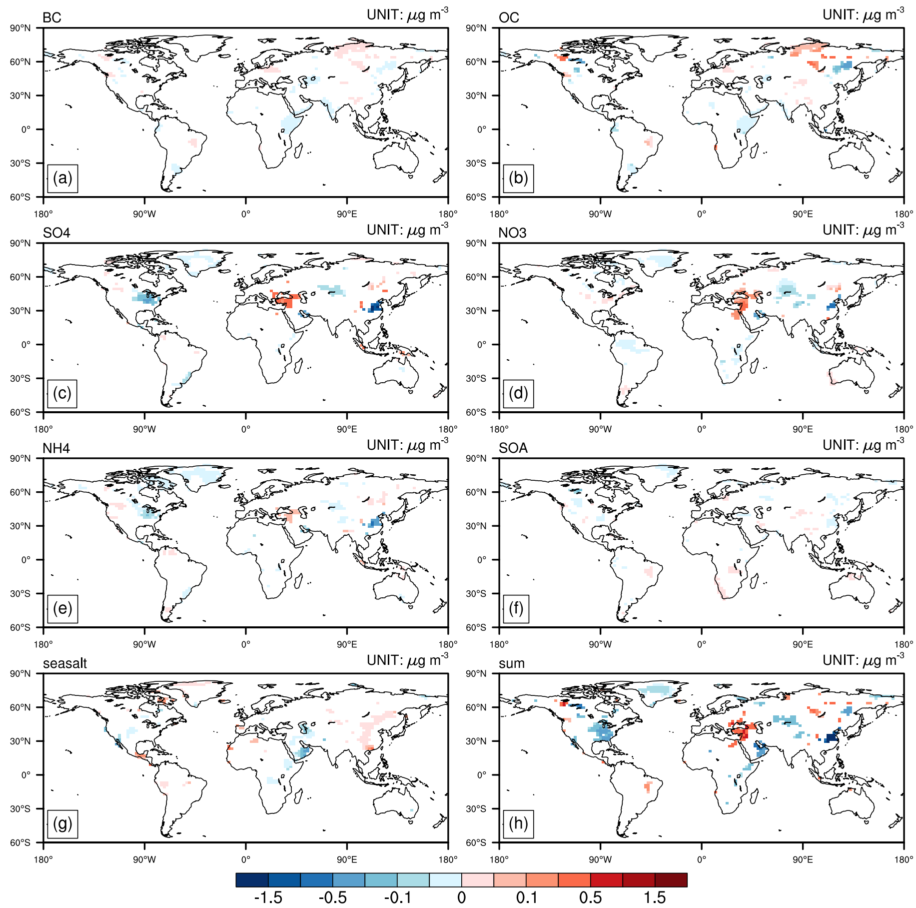

Fig. S4. Changes in 7 types (a-g) summer $PM_{2.5}$ (without silts) and their sum (h) at present day in the model by O_3-vegetation interactions. Results shown are the differences of $PM_{2.5}$ between O3_online and O3_offline. Only the significant changes ($p < 0.1$) are presented.

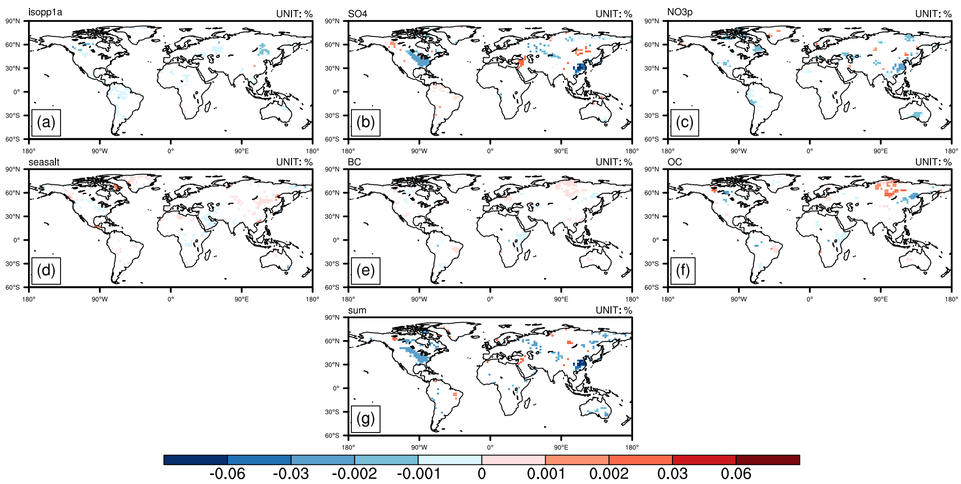

Fig. S5. Changes in 6 types (a-f) summer aerosol optical depth (AOD) and their sum (g) in at present day in the model by O_3-vegetation interactions. Results shown are the differences of AOD between O3_online and O3_offline. Only the significant changes ($p < 0.1$) are presented.

References:

Feng, L., Smith, S. J., Braun, C., Crippa, M., Gidden, M. J., Hoesly, R., Klimont, Z., van Marle, M., van den Berg, M., and van der Werf, G. R.: The generation of gridded emissions data for CMIP6, Geosci. Model Dev., 13, 461–482, https://doi.org/10.5194/gmd-13-461-2020, 2020.

Tian, C., Yue, X., Zhou, H., Lei, Y., Ma, Y. and Cao, Y.: Projections of changes in ecosystem productivity under 1.5° C and 2° C global warming, Glob. Planet. Change., 205, p.103588, https://doi.org/10.1016/j.gloplacha.2021.103588, 2021.

Unger, N., Zheng, Y., Yue, X. and Harper, K.L.: Mitigation of ozone damage to the world's land ecosystems by source sector, Nat. Clim. Change, 10, 134-137, https://doi.org/10.1038/s41558-019-0678-3, 2020.

Yue, X., Strada, S., Unger, N., and Wang, A.: Future inhibition of ecosystem productivity by increasing wildfire pollution over boreal North America, Atmos. Chem. Phys., 17, 13699–13719, https://doi.org/10.5194/acp-17-13699-2017, 2017.