

Responses to Comments and Suggestions of Reviewer #1

Ref. No.: egusphere-2026-361

Title: Ecosystem Climate Sensitivities Drive the Divergence in Aerosol-Induced Carbon Uptake Across CMIP6 Models

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This study develops a biophysical attribution framework to quantify the sources of divergence in aerosol-induced gross primary production (GPP) anomalies across five CMIP6 Earth System Models (ESMs). The results showed that ecosystem climate sensitivities drive the inter-model spread, rather than aerosol radiative and climatic effects alone. The finding is highly valuable. The manuscript's focus aligns perfectly with GMD's scope of model evaluation and diagnostics. However, there are still some problems with the Methodology and Discussion. Therefore, I recommend that the manuscript be accepted after a major revision.

Response: We sincerely thank the reviewer for the positive and encouraging evaluation of our manuscript. We also appreciate your highly constructive feedback. We have modified the manuscript according to the comments and suggestions. Changes in the revised manuscript are highlighted with **Yellow** color. Our responses are provided below (words in **Blue** is the responses and in **Red** is the context of revised paper).

Major comments:

1. The DFE varies significantly with vegetation type. However, the paper does not adequately consider the impacts of vegetation type on DFE. It would be better to show the model simulations influenced by plant functional types (PFTs) in the paper.

Response: Thanks for the comments and suggestions. We completely agree that the Diffuse Fertilization Effect (DFE) is fundamentally governed by canopy architecture, which varies immensely across different Plant Functional Types (PFTs). To show the impacts of vegetation type on DFE, we have calculated the PFT-specific sensitivity to

the Clearness Index (CI). (Please see Table S6). We also showed the coefficient of determination (R2) of the multivariate attribution framework in reproducing aerosol-induced GPP anomalies across Earth System Models per Plant Functional Type (PFT). (Please see Table S1).

“Table S6: Sensitivity Coefficients for Clearness Index (β_{CI}) per Plant Functional Type (PFT). ENF, Evergreen Needleleaf Forest; EBF, Evergreen Broadleaf Forest; DBF, Deciduous Broadleaf Forest; MF, Mixed Forest; OSH, Open Shrublands; WSA, Woody Savannas; SAV, Savannas; GRA, Grasslands; WET, Wetlands; CRO, Croplands; BAR, Barren or Sparsely Vegetated.

PFT	BCC-ESM1	IPSL-CM6A-LR	MPI-ESM-1-2-HAM	NorESM2-LM	UKESM1-0-LL
ENF	-0.179400	-0.004691	-0.133819	-0.159882	-0.059526
EBF	-0.034866	-0.037444	0.212178	0.068153	0.255530
DBF	-0.065590	-0.000442	-0.043122	-0.085349	-0.088917
MF	-0.197453	-0.023796	-0.122750	-0.081399	-0.251073
OSH	-0.096439	-0.031949	-0.068272	-0.044959	-0.200439
WSA	-0.131831	0.015233	-0.108264	-0.061041	-0.223069
SAV	-0.128428	-0.013374	-0.133998	0.006582	-0.227113
GRA	-0.058220	0.003497	-0.069130	-0.008668	-0.106475
WET	-0.049906	-0.059406	-0.018018	-0.036812	-0.294887
CRO	-0.074630	0.012429	-0.095520	-0.043673	-0.093012
BAR	0.002708	-0.001309	-0.007610	-0.007820	-0.043406

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Table S1. Coefficient of determination (R^2) of the multivariate attribution framework in reproducing aerosol-induced GPP anomalies across Earth System Models per Plant Functional Type (PFT). ENF, Evergreen Needleleaf Forest; EBF, Evergreen Broadleaf Forest; DBF, Deciduous Broadleaf Forest; MF, Mixed Forest; OSH, Open Shrublands; WSA, Woody Savannas; SAV, Savannas; GRA, Grasslands; WET, Wetlands; CRO, Croplands; BAR, Barren or Sparsely Vegetated.

PFT	BCC-ESM1	IPSL-CM6A-LR	MPI-ESM-1-2-HAM	NorESM2-LM	UKESM1-0-LL
ENF	0.836	0.851	0.743	0.961	0.837
EBF	0.686	0.692	0.887	0.906	0.496
DBF	0.949	0.979	0.989	0.906	0.849
MF	0.660	0.729	0.867	0.901	0.433
OSH	0.880	0.811	0.859	0.764	0.751
WSA	0.779	0.830	0.792	0.870	0.521
SAV	0.807	0.786	0.757	0.787	0.651
GRA	0.682	0.804	0.645	0.814	0.420
WET	0.970	0.985	0.842	0.942	0.973
CRO	0.635	0.832	0.853	0.805	0.496
BAR	0.670	0.925	0.778	0.818	0.611

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2. The paper presents validation results against FLUXNET and FLUXCOM-X, but lacks detailed discussion of these results in the main text. Please add a brief discussion on how model performance affects the reliability of the attribution analysis, particularly noting the systematic underestimation of high GPP values.

Response: Thanks for the suggestions. We agree that the manuscript lacked sufficient discussion regarding the impacts of uncertainties of GPP on the attribution analysis. We have added some sentences to discuss the impacts of systematic underestimation of GPP. (Please see Line 527-534).

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Validation against FLUXNET observations reveals a systemic underestimation of GPP across all five models (Figure S2). However, this underestimation is largely attribute to the scale mismatch between ground-based eddy covariance measurements and model grid pixels. Comparisons of CMIP6 ESMs against the FLUXCOM-X did not show this underestimation (Figure S3). This indicates that ESMs can capture the global GPP magnitudes. Our attribution framework incorporated a systematic bias term to account for the bias of GPP. In addition, our framework was developed to investigate the sources of inter-model spread, rather than to evaluate the accuracy of model simulations. This also mitigates the direct impact of GPP bias on our analysis.

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3. Table 1 indicates that IPSL-CM6A-LR does not consider the DFE, while the Discussion (Section 4.1) mentions that the ORCHIDEE_DF version can simulate DFE. Please clarify which version of IPSL-CM6A-LR was used in this study and explain why the ORCHIDEE_DF version was not included for comparison.

Response: Thanks for the comments. The land component of IPSL-CM6A-LR is ORCHIDEE v2.0, which used a big leaf and did not consider the diffuse fertilization effect (Naudts et al., 2015). In this study, we used the GPP data from CMIP6, which did not use the ORCHIDEE_DF. (Please see Table 1).

“Table 1. CMIP6 Earth system models (ESMs) used in this study. For each model, the land component model and whether the model accounts for the diffuse fertilization effect (DFE) on canopy photosynthesis or not are listed.

Model	Land component	DFE	References
IPSL-CM6A-LR	ORCHIDEE v2.0	NO	(Boucher et al., 2020)
MPI-ESM1-2-HAM	JSBACH 3.20	YES	(Reick et al., 2021; Mauritsen et al., 2019)
NorESM2-LM	CLM	YES	(Lawrence et al., 2011; Lawrence et al., 2019)
BCC-ESM1	BCC_AVIM2	YES	(Li et al., 2019; Wu et al., 2020)
UKESM1-0-LL	JULES-ES-1.0	YES	(Sellar et al., 2019; Clark et al., 2011)

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Specific comments:

1. The abstract does not specify the study period (1850-2014). Please add this information. Additionally, please change "These findings are very important for fully understanding..." to a more objective expression like "These findings provide critical insights into understanding..."

Response: Thanks for the comments and suggestions. We have added the study period in the abstract and modified the sentence. (Please see Line 25 and Line 31-32).

“... the decrease in GPP from 1850 to 2014 ...”

“These findings provide critical insights into understanding the impacts...”

2. The introduction mentions four pathways through which aerosols affect GPP, but the subsequent analysis mainly focuses on radiation and temperature effects, with less

discussion on precipitation effects. Either expand the analysis to include precipitation or adjust the text.

Response: Thanks for the comments. We have added some sentences to show the effects of precipitation changes induced by aerosols on the vegetation photosynthesis. We did discuss the effects of precipitation on photosynthesis because the sensitivity of precipitation from all ESMs are relatively consistent. Therefore, there are little discussion on precipitation effects. (Please see Line 421-425).

“The sensitivity of photosynthesis to precipitation (β_{pr}) links to the soil hydrology schemes and the response of stomatal conductance to water stress. The contribution of precipitation sensitivity to GPP anomalies is generally smaller than that of other environmental factors across most models. This suggests that the response of ESMs to precipitation is relatively consistent.”

3. Figure 2a: The time series shows positive GPP anomalies for some models between 1850 and 1890. Given the extremely low aerosol loadings during this pre-industrial to early-industrial period, discuss whether these fluctuations are driven by internal climate variability rather than actual aerosol forcing.

Response: We sincerely thank the reviewer for the comments. We fully agreed that the fluctuations were driven by internal climate variability in the early-industrial period. We have modified some sentences and discuss the limitations induced by the noise of internal climate variability. (Please see Line 283-288 and Line 549-553).

“From 1850 to 1890, some models show a positive impact of aerosols on GPP. However, the increment in ΔAOD during this period is negligible across all models. This indicates that anthropogenic aerosols have little impacts on the change of GPP from 1850 to 1890. The absence of a consistent directional GPP response suggests that these variations might be related to the internal climate variability noise.”

“Furthermore, it is impossible to fully disentangle internal climate variability by using single ensemble member per model. This limitation mainly occurs during the early

industrial period, when the AOD changes are small and is comparable in magnitude to the internal climate variability induced noise in the GPP difference between historical and hist-piAer simulations.”

4. The terms "diffuse fertilization effect" and "diffuse fertilization effects" are used inconsistently throughout the paper.

Response: We sincerely thank the reviewer for their careful reading and for pointing out this typographical inconsistency. We have adopted the singular form-"diffuse fertilization effect".

5. Please check and ensure consistent formatting of all references, including journal names, volume numbers, page numbers, and DOI formats.

Response: Thanks for the comments. We have checked all references.

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