

Response to reviewers on egusphere-2026-16: Dissimilar Roles of Aerosols, Nitrogen Deposition and Ozone on the Terrestrial Carbon Sink in China during 2010–2020

Nanhong Xie et al.

We sincerely thank the reviewers for their valuable comments and constructive suggestions. These suggestions have greatly improved the quality of our manuscript. In this response document, we detail how we have addressed each of the reviewer's comments. The reviewer's comments are presented in black, **our responses are in blue**, and **the corresponding additions or modifications to the manuscript text are highlighted in red**.

RC1: 'Comment on egusphere-2026-16', Anonymous Referee #1, 07 Mar 2026

The manuscript presents a timely and scientifically significant investigation into how China's "Clean Air Action" has affected the terrestrial carbon cycle. I recommend that this manuscript be accepted subject to minor revisions along the lines below.

Response: Thank you for your positive evaluations. We have carefully considered your insightful comments and revised the paper accordingly.

1. The manuscript reports many national totals to two decimal places, e.g., 17.93 TgC. Please consider rounding key values more appropriately.

Response: We thank the reviewer for this helpful suggestion. We agree that numerical presentation should be handled carefully so as not to imply unjustified precision. In response

to this comment, we re-examined the formatting of all reported carbon-flux-related values throughout the manuscript. Because the study presents a large number of results at multiple levels, including national totals, regional totals, interannual variations, seasonal contributions, and percentage changes, all values were processed and reported using a unified two-decimal-place format in the main text, tables, and supplementary material. We found that rounding only selected national totals would reduce formatting consistency and could introduce discrepancies between the text and tabulated results. In addition, some values are discussed in the context of interannual and seasonal comparisons, where retaining two decimal places helps preserve meaningful differences. Therefore, we retained the two-decimal formatting throughout the manuscript for consistency and comparability, while carefully checking the revised version to ensure internal numerical consistency.

2. The abstract is clear, but the sentence “reversed the dominant atmospheric drivers” is too strong unless supported by a true combined simulation with interactive effects considered. Please reword it.

Response: Thank you for your helpful comment. We agree that the original phrase, “reversed the dominant atmospheric drivers,” was too strong, as this study assessed the independent effects of aerosols, nitrogen deposition, and ozone without explicitly accounting for their potential interactions. In the revised manuscript, we have rephrased this sentence in the Abstract to better reflect the scope of our analysis (Lines 32).

Revised version: “The combined effects indicate that CAA-induced atmospheric chemistry changes led to a shift in the dominant atmospheric drivers of China’s terrestrial carbon sink, from enhancement by aerosols and nitrogen deposition to suppression by ozone.”

3. The meaning of “open” in Table 1 should be replaced by more precise wording, such as “enabled” or “on.”

Response: Thank you for your valuable suggestion. We agree that the term “open” in Table 1 is not sufficiently precise. In the revised manuscript, we have replaced “open” with “on” in Table 1 for greater clarity and consistency.

Revised version: The term “open” in Table 1 has been changed to “on”.

4. For the aerosol run, is only aerosol–radiation interaction active, or are aerosol–meteorology feedbacks also active? Please clarify this in Table 1.

Response: Thank you for this helpful comment. We have clarified the setup of the aerosol experiment in the revised manuscript. In the Ctrl_AOD simulation, aerosols were fully coupled to meteorology, so that the direct aerosol radiative effect and the associated meteorological responses were represented in the simulations, while aerosol indirect effects through cloud processes were not included. We have added a more detailed description of the aerosol experiment in Section 2.3 (Lines 177-180) and revised the corresponding description in Table 1. The uncertainty associated with the exclusion of aerosol indirect effects has already been discussed in the original Discussion section.

Revised version: “.....a baseline simulation without these effects (Base), and three single-factor cases that enabled only aerosol (Ctrl_AOD), O₃-induced vegetation damage (Ctrl_O₃), and nitrogen deposition impacts (Ctrl_Ndep). In the Ctrl_AOD experiment, aerosols were fully coupled to meteorology, so that the direct aerosol radiative effect and the associated meteorological responses were represented in the simulations, while aerosol indirect effects through cloud processes were not included.....”

Table 1. Numerical model experiments.

Simulations	Periods	Aerosol direct radiative effect	O ₃ damage	Atmospheric nitrogen deposition
Base	2010-2020	off	off	off
Ctrl_AOD	2010-2020	on	off	off
Ctrl_O ₃	2010-2020	off	on	off
Ctrl_Ndep	2010-2020	off	off	on

5. Could you describe simply how the carbon-nitrogen cycle is treated in the model? For CLM5, the FUN module is developed to simulate plant nitrogen uptake and nitrogen-carbon interactions. What is the difference between your model and FUN?

Response: Thank you for this helpful comment. We agree that the treatment of nitrogen effects

in the model should be described more clearly. In RegESM, atmospheric nitrogen deposition is calculated online by the chemistry component as dry and wet deposition fluxes of reduced and oxidized nitrogen (NH_x and NO_y), which are then passed to the land component as external nitrogen inputs. These inputs affect soil inorganic nitrogen availability through land biogeochemical processes and thereby influence plant productivity, ecosystem respiration, and terrestrial carbon fluxes. In the revised manuscript, we have added a brief clarification of this treatment in Section 2.1, The RegESM model (Lines 129-137).

Regarding the difference from the FUN module in CLM5, FUN explicitly represents multiple plant nitrogen acquisition pathways and their associated carbon costs, including fixation, retranslocation, and active uptake of NH_4^+ and NO_3^- , and allocates carbon among uptake pathways according to acquisition cost (Fisher et.al, 2010; Brzostek et.al;2014; Shi et.al,2016). In contrast, our model represents nitrogen effects through online atmospheric nitrogen deposition and its propagation through the land biogeochemical processes, rather than through an explicit plant nitrogen acquisition cost framework. The advantage of our current scheme is that atmospheric nitrogen input is calculated online and remains dynamically consistent with regional chemistry and meteorological conditions, which is suitable for examining nitrogen deposition effects under changing air pollution conditions. Its limitation is that it does not explicitly resolve plant nitrogen uptake pathways or their carbon costs in the same way as FUN. By comparison, FUN provides a more process-based description of plant nitrogen acquisition and nitrogen–carbon interactions, but it also requires additional parameterizations and introduces greater process complexity. Model development is a long-term effort, and we are continuing to improve and refine the coupled framework in our ongoing work.

Revised version: “The RegESM framework used in this study integrates RegCM4 as the dynamical core for simulating regional climate processes at a high resolution, the Chem module for interactive gas-phase and aerosol chemistry coupled with radiation and meteorology, and the YIBs land surface model for calculating biophysical processes such as photosynthesis, transpiration, and energy balance, along with biogeochemical cycles of carbon and nitrogen (Giorgi et al., 2012; Shalaby et al., 2012; Xie et al., 2024; Yue and Unger, 2015). **In RegESM, the influence of atmospheric nitrogen deposition on terrestrial carbon fluxes is represented**

through the online coupling between the chemistry and land components. Atmospheric nitrogen deposition is calculated online by the chemistry component as dry and wet deposition fluxes of reduced and oxidized nitrogen (NH_x and NO_y), which are then passed to the land component as external nitrogen inputs. These inputs affect soil inorganic nitrogen availability and subsequently influence plant productivity, ecosystem respiration, and net ecosystem productivity. Therefore, the effect of nitrogen deposition on carbon fluxes is represented as the integrated result of nitrogen input and land biogeochemical processes, rather than as a simple linear fertilization effect. These components are linked through an improved coupling mechanism that

6. Line 596-597, as both scattering and absorbing aerosols were reduced, the clarification of enhanced scattering is required.

Response: Thank you for this helpful comment. We agree that the original wording was not sufficiently precise. Since both scattering and absorbing aerosols declined during the study period, the phrase “enhanced scattering” could be misleading. What we intended to convey is that the aerosol changes during this period were more favorable for diffuse-radiation fertilization, rather than that scattering aerosols increased in an absolute sense. In the revised manuscript, we have rephrased this sentence accordingly (Lines 637-638).

Revised version: The positive effect of aerosols peaked ($+19.22 \text{ TgC yr}^{-1}$), likely because aerosol changes during this period were more favorable for diffuse-radiation fertilization, despite the concurrent declines in both scattering and absorbing aerosols.

7. NEP is a net result of NPP and heterotrophic respiration. How does the heterotrophic respiration respond to these atmospheric drivers?

Response: Thank you for this helpful comment. We agree that the response of heterotrophic respiration (R_h) is important for understanding the NEP changes induced by these atmospheric drivers. In the revised manuscript, we have added a new supplementary figure (Fig. S10) showing the spatial responses of R_h to aerosols, O_3 pollution, and atmospheric nitrogen deposition. We have also added the corresponding discussion in Section 3.2.2, Effects of Aerosols on the Terrestrial Carbon Sink (Lines 349-351 and 358-361), Section 3.3, Effects of

surface ozone on carbon sinks (Lines 507-512), and Section 3.4, Effects of atmospheric nitrogen deposition on carbon sinks (Lines 545-547 and 559-563).

Revised version:

3.2.2 Effects of Aerosols on the Terrestrial Carbon Sink

“During 2010–2020, the aerosol overall enhanced the productivity of China’s terrestrial ecosystems, increasing GPP and NEP by 293.28 TgC yr⁻¹ and 17.93 TgC yr⁻¹, accounting for 3.98% and 4.49% of the national totals, respectively. Aerosols also increased Rh by 182.44 TgC yr⁻¹ over China, indicating that part of the aerosol-induced carbon sink enhancement was offset by enhanced soil carbon decomposition. Meanwhile, the high aerosol loading in these regions ensured sufficient radiative perturbation, amplifying the improvement in canopy light-use efficiency. The spatial pattern of aerosol-induced Rh (Fig. S10a) further shows notable increases in southern China, broadly consistent with the regions of enhanced ecosystem productivity, suggesting that greater carbon input to soils likely stimulated microbial decomposition and partially counteracted the NEP gain. In the Southwest, the response was more complex.”

3.3 Effects of surface ozone on carbon sinks

“.....This bias may stem from the simplified crop representation in the model (Fig. S2). Nationwide, O₃ reduces GPP and NEP by 749.44 TgC yr⁻¹ and 51.33 TgC yr⁻¹, accounting for 10.17 % and 12.9 % of the totals. O₃ also decreased Rh by 288.17 TgC yr⁻¹, with the strongest reductions occurring in eastern and southern China (Fig. S10b). This indicates that the O₃-induced suppression of ecosystem carbon uptake was partly offset by a concurrent decline in heterotrophic respiration. This pattern suggests that reduced photosynthesis and carbon allocation under O₃ stress decreased litter input and belowground carbon supply, thereby limiting microbial substrate availability and weakening soil carbon decomposition. The suppression is attributed to reduced photosynthesis, altered stomatal conductance, and shifts in carbon allocation, which together weaken ecosystem sinks.”

3.4 Effects of atmospheric nitrogen deposition on carbon sinks

“..... These increases account for 9.08% of total GPP and 9.52% of total NEP. Atmospheric nitrogen deposition also increased Rh by 297.26 TgC yr⁻¹ over China, indicating that the nitrogen-induced enhancement of carbon uptake was accompanied by stronger soil

carbon decomposition. The net gains were mainly concentrated in the southeastern, southwestern, and central regions. The spatial pattern of Rh (Fig. S10c) also shows pronounced positive responses in southern China, consistent with the regions of strong nitrogen-induced carbon uptake. This suggests that enhanced plant production and carbon input to soils stimulated microbial decomposition, so that the final NEP gain reflects the balance between increased NPP and increased Rh rather than a simple linear fertilization effect. When stimulation of GPP and NPP outweighed the increase in ER, NEP rose. Warm and humid climates, together with long growing seasons, further amplified these effects.”

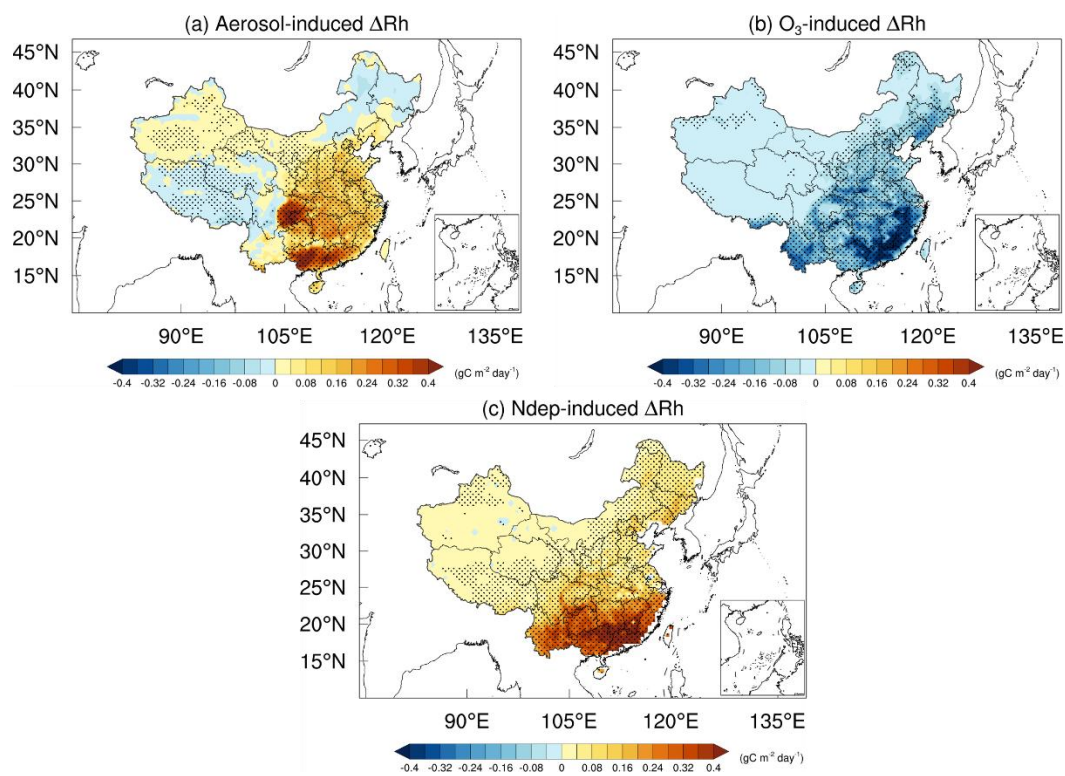


Figure S10. Spatial responses of heterotrophic respiration (Rh) to (a) aerosols, (b) O_3 pollution, and (c) atmospheric nitrogen deposition over China during 2010–2020. Black dots denote significant changes ($p < 0.01$).

Reference

- Fisher, R.A., C.D. Koven, W.R.L. Anderegg, et al., 2018: Vegetation demographics in Earth System Models: A review of progress and priorities. *Glob Change Biol.* 2018;24:35–54. <https://doi.org/10.1111/gcb.13910>
- Brzostek, E. R., J. B. Fisher, and R. P. Phillips, 2014. Modeling the carbon cost of plant nitrogen acquisition: Mycorrhizal trade-offs and multipath resistance uptake improve predictions of retranslocation. *J. Geophys. Res. Biogeosci.*, 119, 1684–1697, doi:10.1002/2014JG002660.
- Shi, M., J. B. Fisher, E. R. Brzostek, and R. P. Phillips, 2016: Carbon cost of plant nitrogen acquisition: global carbon cycle impact from an improved plant nitrogen cycle in the Community Land Model. *Glob. Change Biol.*, 22:1299-1314.