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), O_3-induced vegetation damage (Ctrl_O_3), 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 (NHx and NOy), 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 (NHx and NOy), 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 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 (Rh) 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 Rh 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, O_3 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. O_3 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 O_3-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 O_3 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."

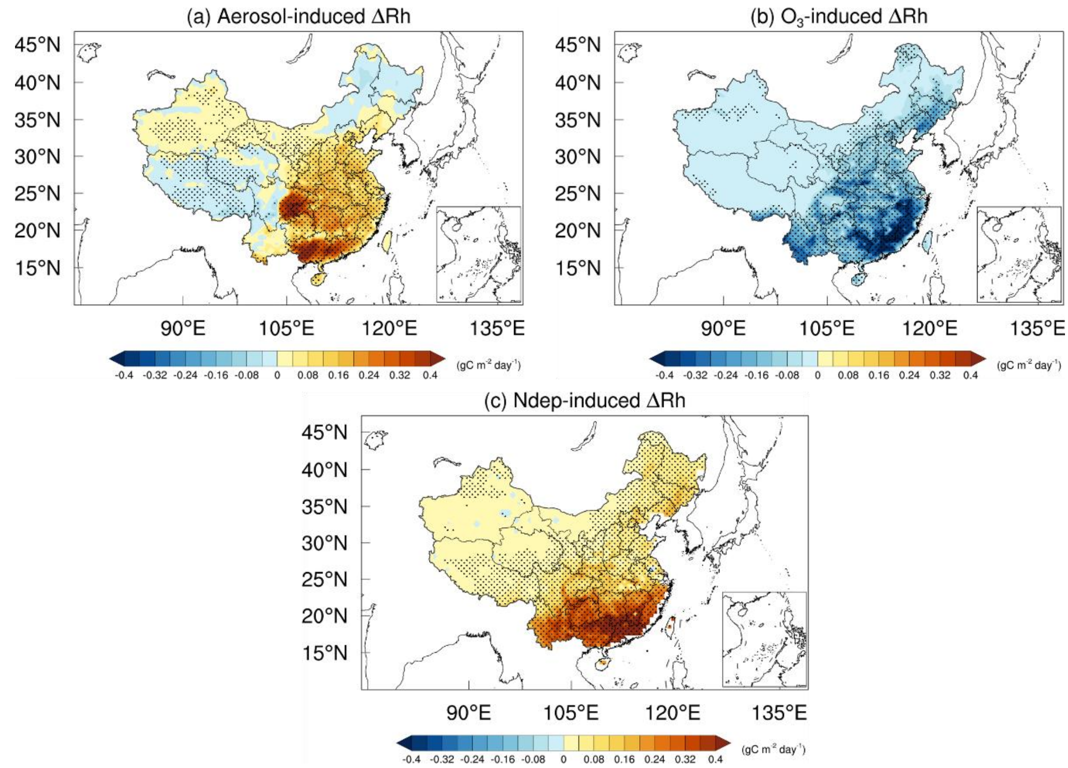

Figure S10. Spatial responses of heterotrophic respiration (Rh) to (a) aerosols, (b) O_3 pollution, and (c) atmospheric nitrogen deposition over China during 2010–2020. Black dots denote significant changes ($p < 0.01$).

==

RC2: 'Comment on egusphere-2026-16', Anonymous Referee #2, 11 Mar 2026

This study employs the advanced regional Earth system model RegESM to systematically evaluate the individual and combined impacts of aerosols, ozone, and nitrogen deposition on China's terrestrial ecosystem carbon sink during 2010-2020. The core scientific value of this work lies in its being the first to quantify, within a fully online-coupled climate-chemistry-ecosystem modeling framework, the dynamic evolution of these three key atmospheric factors and their joint effects on the carbon sink during the implementation of China's Clean Air Action plan. The study finds that the Clean Air Action, by altering atmospheric composition, has shifted the dominant driver of China's terrestrial carbon sink from an "enhancement-type" (aerosols and nitrogen deposition) to an "inhibition-dominated type" (ozone). This conclusion carries significant scientific and policy implications, revealing not only the complex nonlinear relationship between air pollution control and ecosystem carbon sinks but also providing a crucial scientific basis for formulating coordinated multi-pollutant control strategies under the future goal of achieving carbon neutrality. The paper features a cutting-edge topic, advanced methodology, detailed data, and in-depth analysis, making it a high-quality academic manuscript overall. However, before acceptance, the authors need to address and revise the following specific issues.

Response: Thank you for your positive and encouraging comments on our manuscript. We sincerely appreciate your recognition of the novelty, scientific significance, and policy relevance of this study, as well as your positive evaluation of the modeling framework, methodology, and analysis. We have carefully considered all of your comments and revised the manuscript accordingly. Detailed point-by-point responses to the specific issues are provided below.

1. The study isolates three mechanisms to quantify their individual contributions. However, there may be strong interaction effects among them. Could the authors test or reasonably speculate on the impact on gross primary productivity when two or three mechanisms co-exist? Assessing the nature and mechanisms of these interactions is crucial, as they might alter the

core conclusions and our understanding of real-world conditions. While the uncertainty analysis mentions this limitation, I believe this interaction analysis is vital for the paper's final conclusions. The uncertainty section mentions the "need for high-resolution, fully coupled chemistry–ecosystem modeling frameworks to capture the co-evolution of multiple atmospheric processes." I believe your model currently possesses, or partially possesses, such coupling capabilities. Could some tests or inferences be conducted to help us more accurately understand the study's conclusions?

Response:

Thank you for this important and constructive comment. We agree that interaction effects among aerosols, O_3, and atmospheric nitrogen deposition may exist and could lead to non-additive responses of ecosystem carbon fluxes. In the present study, our experimental design was intended to isolate the first-order individual effects of these three atmospheric drivers. A full assessment of their two-way and three-way interactions would require a dedicated factorial experiment framework. Although RegESM includes online coupling among atmosphere, chemistry, and ecosystem processes, the current model configuration used in this study does not yet support a fully consistent interaction analysis among all three factors, particularly for the coupled effects involving nitrogen deposition. Therefore, we did not add new interaction experiments in the revised manuscript.

Nevertheless, following the reviewer's suggestion, we have expanded the Uncertainty section (Lines 703-720 and 724-725) to provide mechanism-based inferences on the possible interactions among these drivers. Specifically, we discuss that aerosol and O_3 effects may be partly antagonistic through changes in diffuse radiation, temperature, and stomatal behavior; that nitrogen deposition may partly offset O_3-induced productivity losses by alleviating nutrient limitation; and that the interaction between aerosols and nitrogen deposition may be region-dependent because nitrogen availability can modulate the ecosystem response to aerosol-induced radiation changes. We also clarify that, although such nonlinear interactions may modify the quantitative magnitudes of the simulated responses, the main conclusion of this study—namely the weakening positive contributions of aerosols and nitrogen deposition and the increasing suppressive role of O_3 during the Clean Air Action period—is expected to remain qualitatively robust.

Revised version:

"Third, nonlinear coupling among aerosols, O_3, and nitrogen deposition introduces systemic uncertainty in estimating their combined effects. Aerosol reduction alters photolysis rates and thereby affects O_3 formation (Tang et al., 2017; Yan et al., 2023; Yang et al., 2022), while O_3 and nitrogen jointly regulate stomatal conductance, photosynthetic efficiency, and water-use dynamics (Sitch et al., 2007; Zhang et al., 2018). In addition, the coexisting effects of these three drivers may not be strictly additive. Aerosol effects and O_3 damage may be partly antagonistic, as aerosol-induced changes in diffuse radiation, temperature, and vapor pressure deficit can modulate stomatal uptake and the physiological stress caused by O_3. Nitrogen deposition may partly offset O_3-induced reductions in plant productivity by alleviating nutrient limitation, whereas the interaction between aerosols and nitrogen deposition may vary regionally because nitrogen availability can influence the extent to which vegetation benefits from aerosol-induced radiation changes. These interactions may amplify or offset each other under changing climatic conditions, and the real-world coexisting effects of these atmospheric drivers may therefore differ from the linear sum of their independently quantified contributions. In the present study, the three factors were quantified separately to isolate their first-order effects, while a full assessment of their two-way and three-way interactions would require a dedicated factorial experimental framework. Therefore, although nonlinear interactions may modify the quantitative magnitudes of the simulated responses, the overall conclusion that the positive contributions of aerosols and nitrogen deposition weakened while the suppressive influence of O_3 became increasingly important during 2010–2020 is expected to remain qualitatively robust. These limitations further emphasize the need for high-resolution, fully coupled chemistry–ecosystem modeling frameworks to capture the co-evolution of multiple atmospheric processes."

"……Future efforts should focus on incorporating aerosol–cloud interactions, expanding field-based O_3 response networks, and improving representation of multi-process coupling and nonlinear interactions to further constrain atmospheric–biosphere feedbacks under China's evolving air quality and carbon neutrality goals."

2. The authors divide China into six subregions (L171-172). However, there appears to be

inconsistency in the naming and boundaries of these regions in the presentation of results (e.g., Figures 4, 5, 6). For instance, how do "South-Central" (L340) and "East China" (L341) correspond to the regional division map (Fig. S2)? Please clarify the correspondence of the regional divisions in the main text or figure captions, ensuring consistency between the region names used throughout the text and those in Fig. S2. It is recommended to add a description of the provinces included in each region in the caption of Fig. S2.

Response: Thank you for this helpful comment. We agree that the naming of the six subregions was not fully consistent among the main text, figures, and Fig. S2. In the revised manuscript, we have standardized the names of the six predefined subregions used for regional statistics as Northeast, North, Northwest, East, South Central, and Southwest throughout the text, figure legends, and supplementary materials. We also distinguish the predefined subregion names used for regional statistics from the general geographic expressions used to describe continuous spatial patterns. Specifically, formal subregion names are used when referring to the six-region statistical analysis, whereas broader geographic expressions (e.g., eastern China or southeastern China) are retained only for describing spatial distribution patterns. In addition, we clarify that the spatial distribution maps are displayed with provincial boundaries to show continuous spatial patterns, whereas the regional statistics are aggregated over the six subregions defined in Fig. S2. We have also updated the caption of Fig. S2 to specify the provinces included in each subregion, and revised the corresponding figure legends and relevant text descriptions throughout the manuscript (Lines 352-354 and 441-454).

Revised version: "…... Spatially, the responses of GPP and NEP to the aerosol radiative effect displayed significant heterogeneity, with the most pronounced enhancements occurring in South Central and East (Fig. 4a, b), where GPP increased by 0.32 gC m^{-2} day^{-1} and 0.31 gC m^{-2} day^{-1}, respectively. These regions are characterized by dense forests and cropland ecosystems with high leaf area index, enabling them to fully exploit the additional diffuse radiation induced by aerosols."

"Regionally, among these factors, diffuse radiation exerted the strongest positive influence on GPP across all regions, particularly in the Southwest (115.92 TgC yr^{-1}), East (67.04 TgC yr^{-1}), and South Central (93.08 TgC yr^{-1}) China (Fig. 5a, b)…….Temperature changes associated with aerosol cooling suppressed GPP nationwide, especially in the

Southwest (-29.07 TgC yr^{-1}) and South Central (-16.19 TgC yr^{-1}), by lowering canopy temperature and reducing evapotranspiration. The contributions of precipitation were minor (-1 to -3 TgC yr^{-1}), while VPD exerted a positive effect, particularly in humid Southwest (55.76 TgC yr^{-1}), suggesting that aerosol-induced cooling and moistening alleviated water stress and indirectly promoted carbon uptake. For NEP, diffuse radiation remained the dominant positive driver, with the largest increases in the Southwest (4.06 TgC yr^{-1}) and South Central (3.35 TgC yr^{-1}) China, while direct radiation continued to exert negative effects..….”

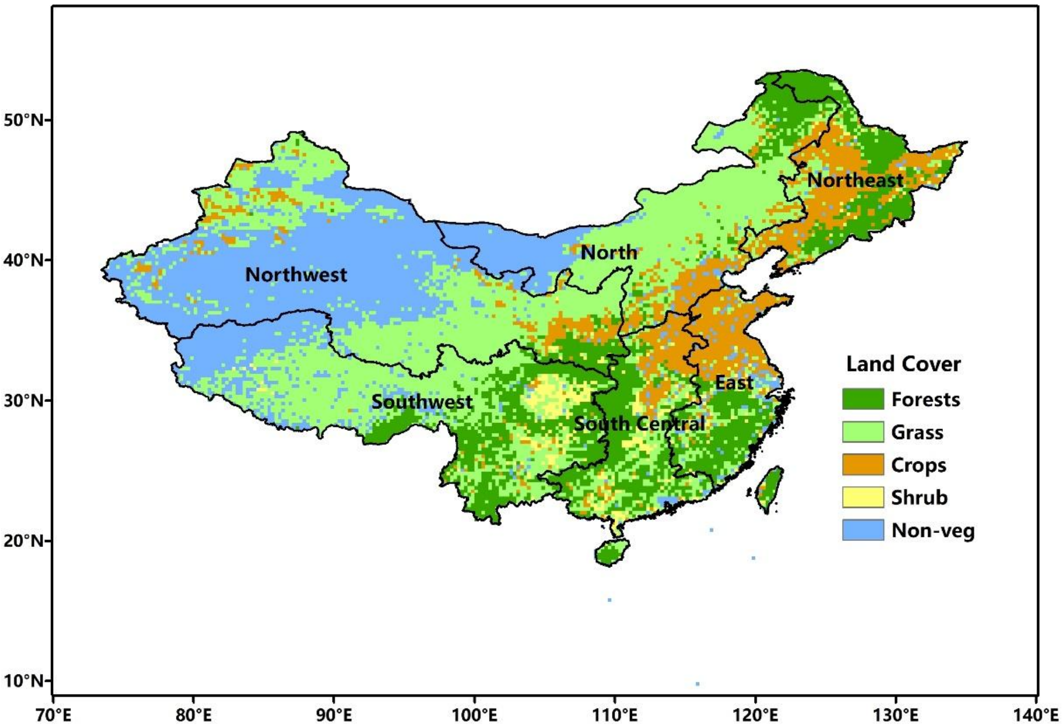

Figure S2. Regional division of China used in this study, including six subregions: Northeast (Heilongjiang, Jilin, and Liaoning), North (Beijing, Tianjin, Hebei, Shanxi, and Inner Mongolia), Northwest (Xinjiang, Gansu, Ningxia, Qinghai, and Shaanxi), East (Shandong, Jiangsu, Anhui, Shanghai, Zhejiang, Fujian, and Jiangxi), South Central (Henan, Hubei, Hunan, Guangxi, Guangdong, and Hainan), and Southwest (Xizang, Sichuan, Yunnan, Chongqing, and Guizhou). The background map shows ecosystem types further categorized based on 2017 MODIS land use types.

3. The statement in L292 that aerosols "increased diffuse radiation" requires clarification. This increase in diffuse radiation also originates from solar radiation and is presumably part of the "reduced downward direct solar radiation" mentioned earlier. The current phrasing of the

relationship between these two terms could be more accurate.

Response: Thank you for this helpful comment. We agree that the original wording was not sufficiently precise. The increase in diffuse radiation does not represent an independent additional radiative source, but rather reflects a redistribution of incoming solar radiation caused by aerosol scattering, accompanied by a reduction in downward direct solar radiation. In the revised manuscript, we have rephrased this sentence to clarify the relationship between direct radiation, diffuse radiation, and total shortwave radiation (Lines 302-304).

Revised version: "Nationally, aerosol scattering reduced downward direct solar radiation by 8.81 W m^{-2} and increased its diffuse component by 3.04 W m^{-2}, resulting in a net decrease of 5.77 W m^{-2} in total downward shortwave radiation at the surface."

4. The seasonal impacts of aerosols and ozone are discussed reasonably (L364-373; L506-511). However, the seasonal analysis for nitrogen deposition (L560-564) is relatively brief, merely stating enhancement in spring/summer and inhibition in autumn/winter. Considering Figure 8 shows the spatial distribution of nitrogen deposition's seasonal impact on NEP, please provide further explanation: Why do areas like the eastern Qinghai-Tibet Plateau and western Sichuan show obvious NEP increases in autumn and winter (Fig. 8c, d), while most other regions show decreases? What are the driving mechanisms for this spatial heterogeneity? Please add an explanation for this spatial pattern after L564.

Response: Thank you for this helpful comment. We agree that the seasonal analysis of nitrogen deposition effects on NEP was too brief in the original manuscript. After re-examining Fig. 8, we found that the positive response is most evident in the eastern Qinghai–Tibet Plateau and western Sichuan in autumn, whereas in winter the positive signal is much weaker and only appears locally. In the revised manuscript, we have added further explanation (Lines 584-586 and 594-605) to clarify the likely mechanisms responsible for this spatial heterogeneity.

Revised version: "The influence of nitrogen deposition on NEP displayed clear seasonality (Fig. 8). Strong positive effects occurred in summer and spring, whereas autumn and winter showed overall suppression at the national scale…… As a result, NEP decreased, and carbon sink strength weakened outside the growing season. However, the negative response in autumn and winter was not spatially uniform. Positive NEP anomalies were still evident in parts of the eastern Qinghai–Tibet Plateau and western Sichuan, especially in autumn (Fig. 8c), whereas in winter this signal became much weaker and more localized (Fig. 8d). This spatial heterogeneity likely reflects the combined effects of persistent nitrogen limitation and weak heterotrophic respiration responses under cold, high-elevation conditions. In these regions, low temperatures constrain soil decomposition more strongly, so the stimulation of heterotrophic respiration by additional nitrogen is limited. Meanwhile, alpine grasslands, shrublands, and montane forests may still maintain some residual photosynthetic activity during the late growing season, allowing deposited nitrogen to support carbon uptake. As a result, nitrogen deposition can still enhance NEP locally in autumn, even though most other regions show seasonal carbon sink weakening."

5. The number of decimal places retained in Table 2 should be unified for consistency.

Response: Thank you for this helpful comment. We agree that the number of decimal places retained in Table 2 should be unified for consistency. In the revised manuscript, we have unified the number of decimal places in Table 2 for consistency (Lines 477-478).

Revised version:

Table 2. Proportion of dominant meteorological factors for GPP and NEP across China (Units: %).

Factors	RadD (%)	RadF (%)	Temp (%)	Precip (%)	VPD(%)
GPP	8.40	77.83	4.45	0.05	9.27
NEP	15.92	72.20	5.64	0.14	6.10

6. The paper begins by mentioning China's Clean Air Action plan, and the study period (2010-2020) spans the pre-CAA, implementation, and later stages. Could the authors more clearly link the temporal evolution of the three factors' impacts on the carbon sink to the specific control measures and emission changes under the CAA? This would allow for a more distinct comparison of the dominant factors and the magnitude of their effects across the pre-CAA, CAA Phase I, and CAA Phase II periods, thereby systematically evaluating the CAA's overall impact on the carbon sink.

Response: Thank you for this insightful comment. We agree that the linkage between the temporal evolution of the three atmospheric drivers and the specific emission-control stages under China’s Clean Air Action (CAA) should be made clearer. In the original manuscript, the interannual responses of aerosols, O_3, and nitrogen deposition were discussed separately in Sections 3.2-3.4. Following your suggestion, we have strengthened this connection in the revised manuscript by adding a more explicit stage-based interpretation in Section 3.5, Integrated Impact Analysis (Lines 632-634,639-644, and 646-653), linking the changes in the carbon sink to the pre-CAA, CAA Phase I, and CAA Phase II periods. In addition, we have added a new supplementary figure (Fig. S11) to show the temporal evolution of relevant emissions during 2010–2020, which helps clarify the correspondence between policy-driven emission changes and the simulated responses of aerosols, O_3, and nitrogen deposition.

Revised version: “……The negative impact of O_3 (-47.33 TgC yr^{-1}) was largely compensated by the two positive drivers, resulting in a pronounced increase in carbon sink strength. This stage corresponded to relatively high emissions of aerosol and nitrogen precursors, which maintained elevated aerosol loading and nitrogen deposition, while O_3 pollution had not yet reached the stronger suppressive level observed in later years. During CAA Phase I (2014–2017), the mean net effect decreased sharply to 3.50 TgC yr^{-1}, marking a transitional stage with competing influences. The positive effect of aerosols peaked (+19.22 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. However, this gain was largely offset by intensified O_3-induced inhibition (-53.80 TgC yr^{-1}). This phase coincided with strong reductions in emissions of SO_2, $PM_{2.5}$ and NOx under the first Clean Air Action (Fig. S11), which substantially altered atmospheric composition. Although declining aerosol loading weakened the total radiative perturbation, the remaining aerosol conditions still supported a strong diffuse-radiation effect. Meanwhile, insufficient VOCs control favored O_3 formation in many regions, thereby amplifying O_3-induced suppression of the carbon sink. In CAA Phase II (2018–2020), the mean net effect further declined to 1.19 TgC yr^{-1}, forming an O_3-dominated pattern. This stage was associated with further declines in aerosol concentrations and nitrogen deposition under continued emission reductions, which weakened their positive contributions to NEP. At the same time, the coordinated control of NOx and VOCs in key regions partly alleviated O_3 pollution, but this improvement was not sufficient to reverse the dominant suppressive role of O_3 at the national scale. Overall, the stage-dependent changes in the net carbon sink effect were broadly consistent with the temporal evolution of anthropogenic emissions during 2010–2020 (Fig. S11), highlighting the strong imprint of CAA-related emission controls on the balance among aerosols, O_3, and nitrogen deposition. With continued emission control, the aerosol-induced enhancement decreased from its peak……"

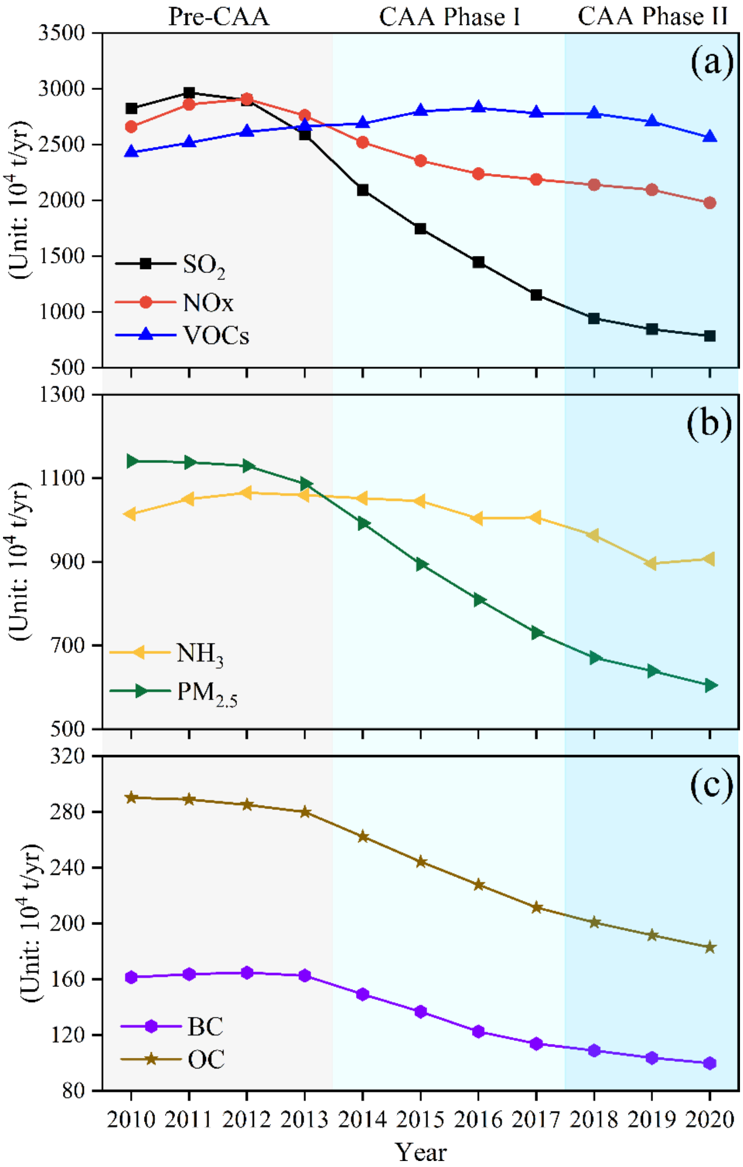

Figure S11. Temporal evolution of major anthropogenic emissions in China during 2010–2020. Panels show grouped annual emissions of (a) SO_2, NOx, and VOCs, (b) NH_3 and $PM_{2.5}$, and (c) BC and OC. Shaded backgrounds indicate Pre-CAA (2010–2013), CAA Phase I (2014–2017), and CAA Phase II (2018–2020).

7. Based on the study's findings, can the authors ultimately propose some scientific strategies or measures to promote the synergistic governance of air pollution and carbon emissions in

China? Specifically, how can we reduce aerosol and ozone pollution while simultaneously enhancing the carbon sink, to better achieve co-control benefits?

Response: Thank you for this insightful comment. We agree that the policy implications of this study should be stated more explicitly. Based on our findings, we have strengthened the final paragraph of the Conclusion (Lines 770-776) to highlight the need for coordinated multi-pollutant control, especially synergistic NOx-VOCs reduction to mitigate O_3-induced carbon sink suppression, and to emphasize the importance of incorporating ecosystem carbon-sink responses into the evaluation of clean-air policies.

Revised version: "……The evolving interplay among these factors illustrates how emission reductions, atmospheric chemistry, and ecosystem feedbacks jointly impact carbon sink dynamics under China's clean-air policies. These findings suggest that future air-quality management should move beyond single-pollutant control and place greater emphasis on coordinated multi-pollutant strategies, particularly the synergistic reduction of NOx and VOCs, to limit O_3-induced carbon sink suppression while sustaining gains in air quality. In addition, ecosystem carbon-sink responses should be incorporated into the evaluation of clean-air policies, especially in ecologically sensitive regions of eastern and southern China, to better achieve co-benefits for air pollution mitigation and carbon neutrality goals."

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.