A letter of Response to Reviewer

Ms. Ref. No.: egusphere-2025-3667
Title: High-resolution Emission Inventory Development and Co-emission Hotspot Identification of Air Pollutants and Greenhouse Gases in Central Plains Region, China

Reviewer #2:

We sincerely appreciate the efforts in reviewing our manuscript and providing valuable suggestions. We are particularly grateful for the recognition of the important of our research region. We have carefully considered all comments and revised the manuscript accordingly. Below are the point-to-point responses to all the comments (The comments are marked in black color and the responses are marked in dark blue color). The changes that have been made according to these responses were marked in yellow color in the highlighted copy of revised version. Note that the following line numbers are shown in the revised version.

Specific details:

1. BC is mentioned in Figure 2, but I do not see any maps of its emissions such as in Figures 4-8. What happened?

Response: Thanks for the constructive comment.
In the previous draft, due to the consideration of the number of complete maps, the BC layout map was initially not included in the main map series. Based on your suggestion, we have added the relevant BC diagram to Figure 4-8 to ensure the completeness of the discussion. The specific revisions are as follows:

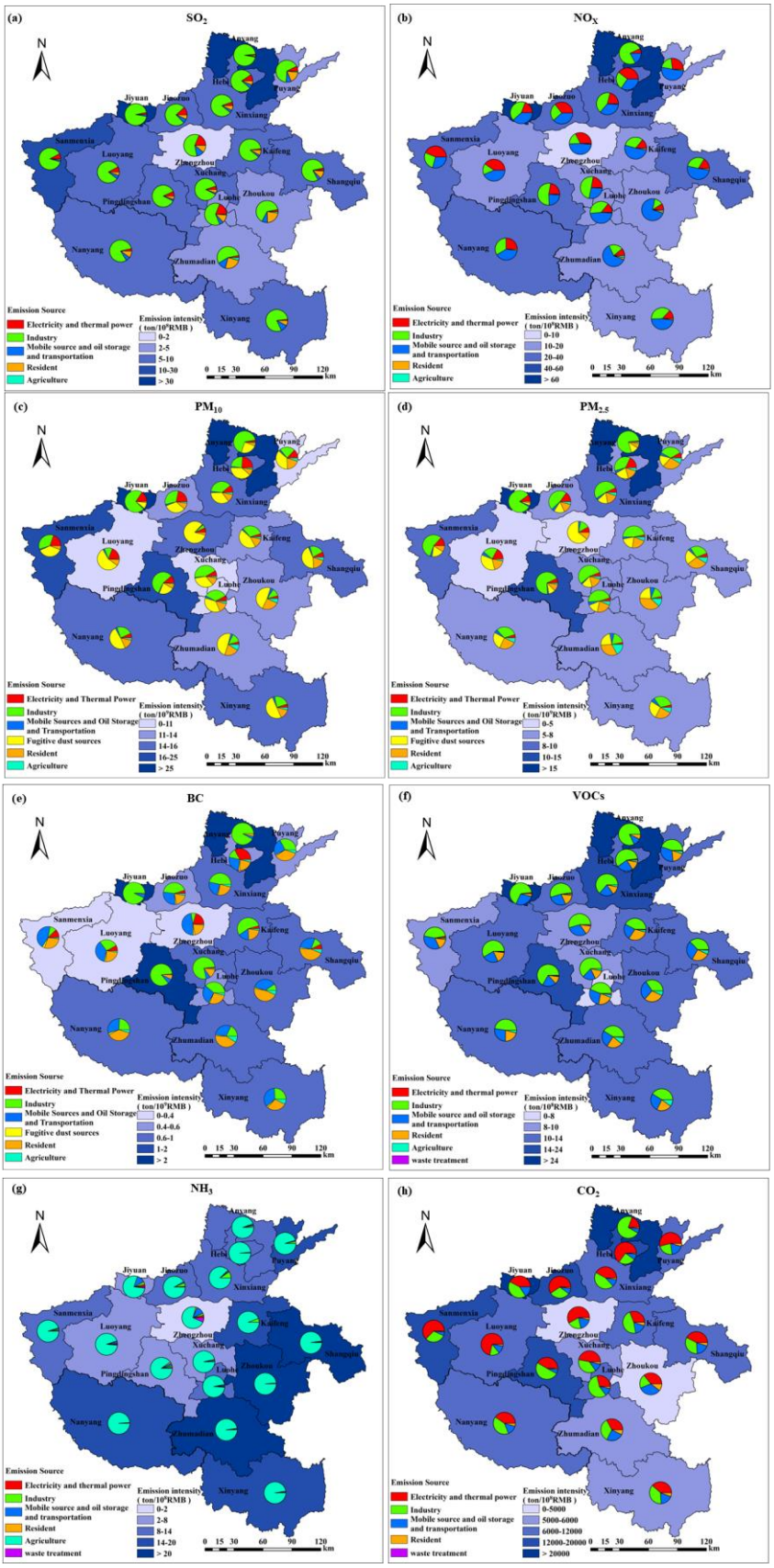


Figure 4. Maps of emission intensity per unit of GDP (ton/10^8 RMB) for (a) SO_2, (b) NOx, (c) $PM_{2.5}$, (d) VOCs, (e) NH_3, and (f) CO_2 across cities. Pie charts in maps indicate the emission source contributions of each city.

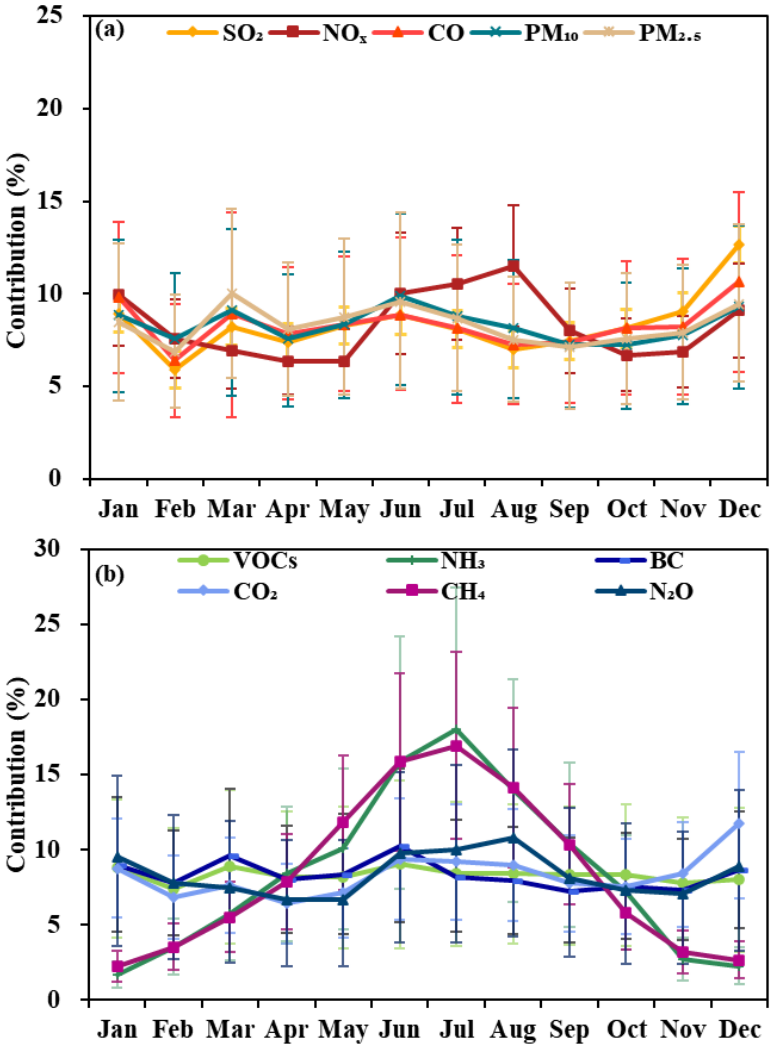


Figure 5. Monthly variation of air pollutants and GHG emissions in 2022 with uncertainty boundary.

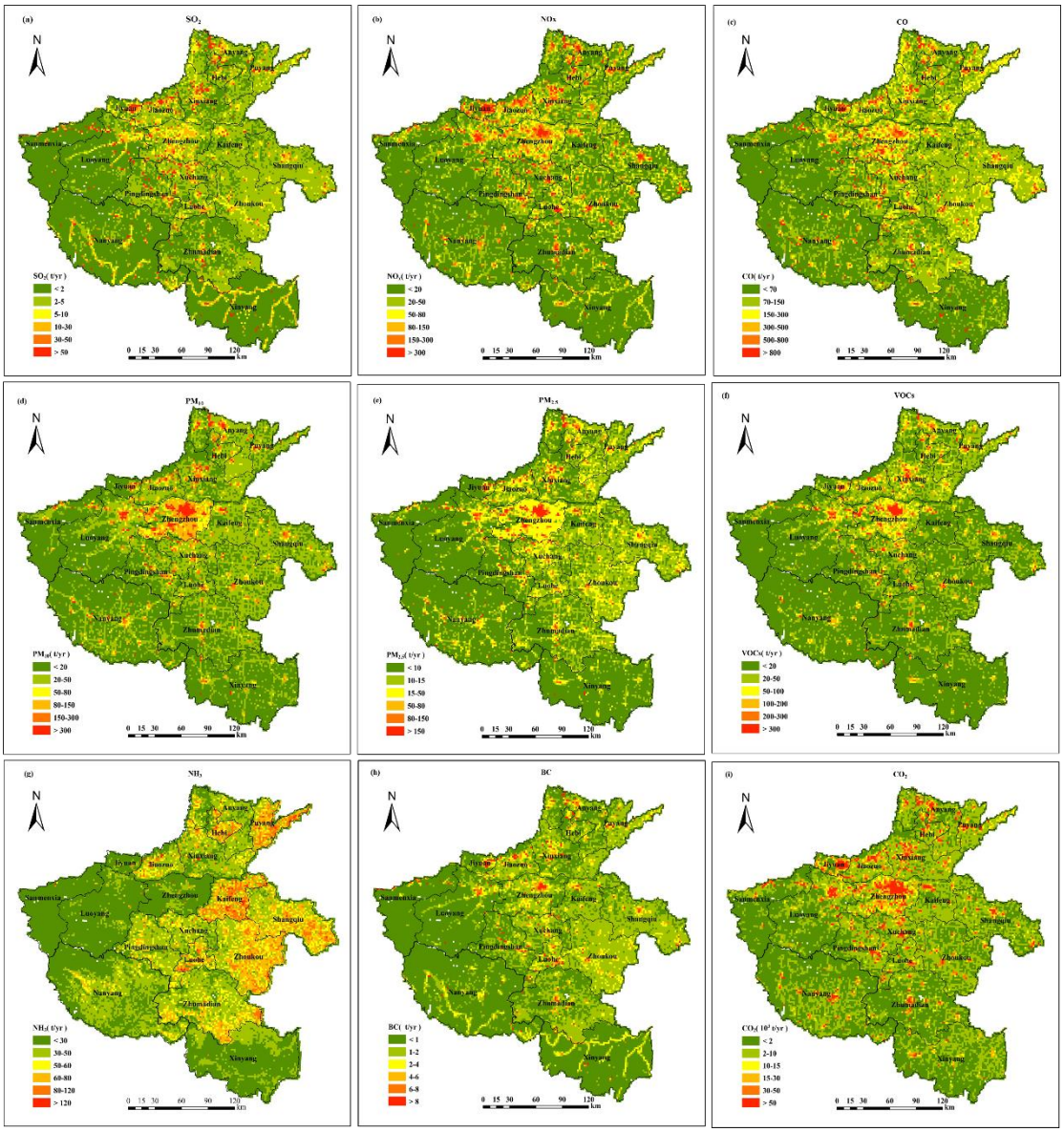


Figure 6. 3 km × 3 km gridded spatial distribution of air pollutants and GHG emissions.

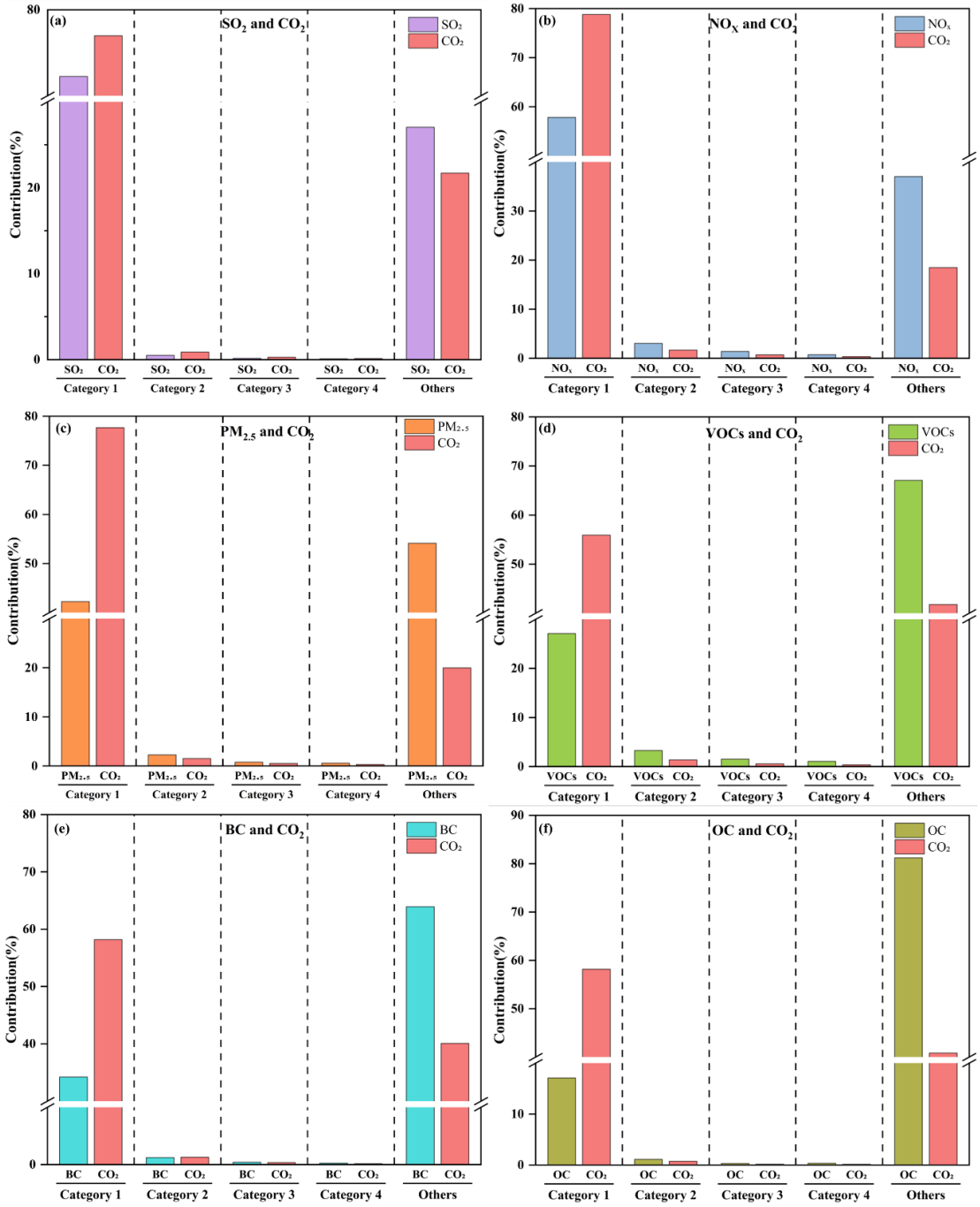


Figure 7. Emission contributions of five categories to different emission co-hotspot. (a) SO_2 and CO_2, (b) NO_X and CO_2, (c) $PM_{2.5}$ and CO_2, (d) VOCs and CO_2, (e) BC and CO_2, (f) OC and CO_2. Categories represent the grad of grid based on descending order of emission: Category 1 (top 5% grids), Category 2 (6-10%), Category 3 (11-15%), Category 4 (16-20%), and Others (bottom 80%).

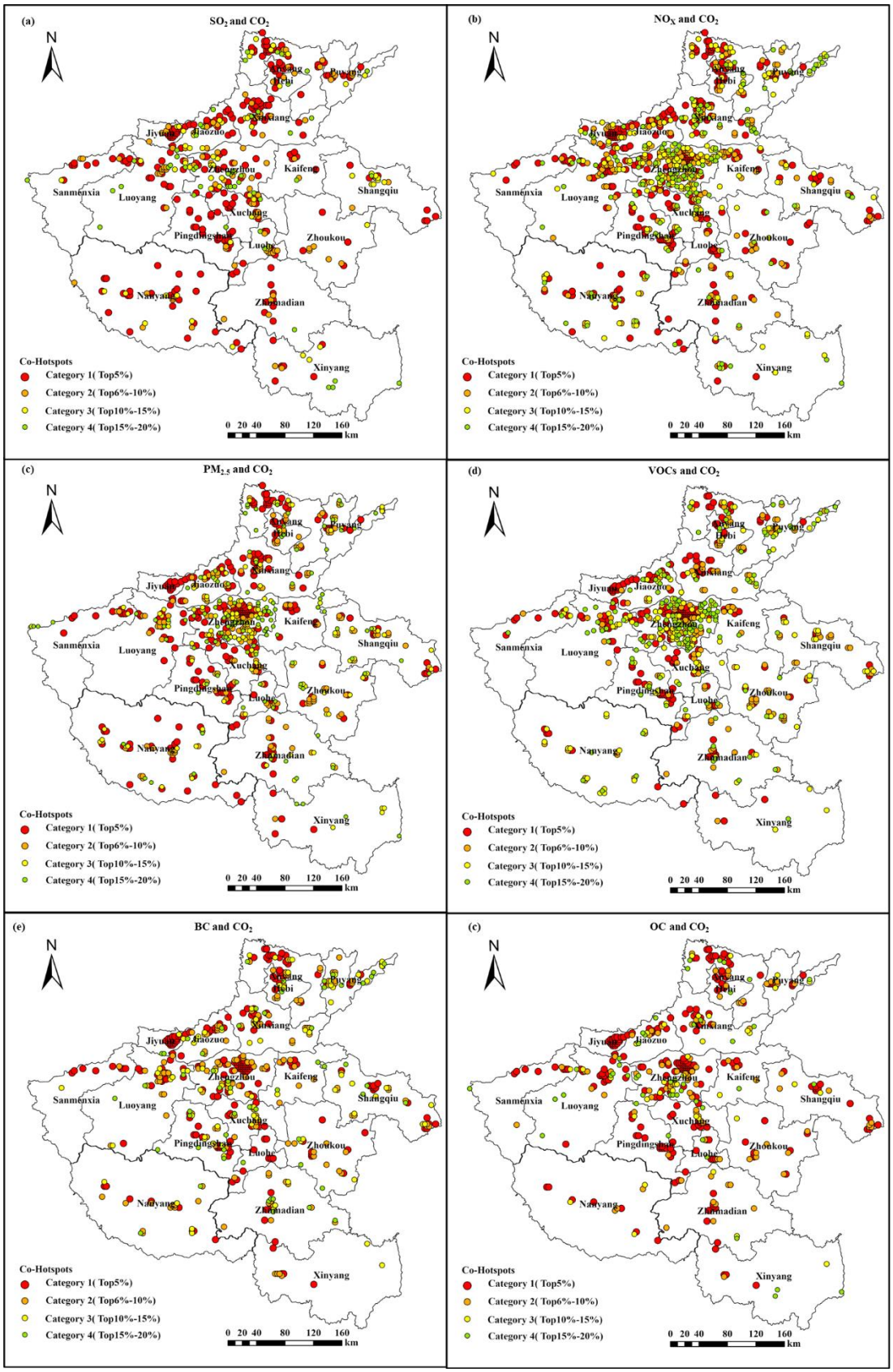


Figure 8. Spatial maps of the co-hotspots of (a) SO_2 and CO_2, (b) NOx and CO_2, (c) $PM_{2.5}$ and CO_2, (d) VOCs and CO_2, (e) BC and CO_2, and (f) OC and CO_2.

2. The equation used in 2.3.1 is not sufficiently robust to predict BC within a reasonable amount of uncertainty, since BC mass is a very small fraction of PM2.5 yet has a substantial impact on the climate system. One such issue has been moving beyond mass-based approaches to include number and particle size-based approaches. Please see work published more than 1 decade ago raising this issue such as https://doi.org/10.1029/2007JD009756 and https://doi.org/10.1002/2013JD019912, as well as more modern work at high spatial resolution which offers solutions to this issue such as https://doi.org/10.1038/s41467-022-35147-y and https://doi.org/10.1021/acs.estlett.5c00340

Response: Thanks for the constructive suggestion.

Thanks for the important information of relevant key literatures. We fully agree that to evaluate the climate effect and environmental concentration of BC in the atmosphere, it is necessary to go beyond the single emission factor method and consider its secondary transport process and microscopic physical properties in the atmosphere. The recommended literature (such as Chen et al., 2022; Liu et al., 2025) and the "top-down" inversion based on satellite remote sensing present in these articles have pointed out a valuable direction for our future work.

However, we would like to take this opportunity to clarify that the core objective in our study is to develop locally integrated air pollutants and co-emitted greenhouse gases emission information first based on unified source classification. There is no consideration of secondary generation at present. Given the multiple number of pollutant species involved and the corresponding requirement for distinct remote-sensing datasets, it is challenged to address all species within a single study by using emission factors and remote sensing retrieval methods both. It is hoped that the first version of integrated emissions can be provided to support subsequent air quality modeling simulations and the most urgent assessment of emission reduction potential. Therefore, based on our understanding of the articles recommended by the reviewer and the comment, we cited these two articles both in the introduction section, where we describe the "advances in high spatiotemporal resolution," and in the conclusion and outlook section, where we discuss the "need to integrate bottom-up and top-down approaches in future work."

The following revisions have been made:

In particular, the development of air pollutant emission inventories has been rapid advancements in spatial resolution and temporal distribution (Chen et al., 2024; Chen et al., 2022; Liu et al., 2025), and some studies have successfully constructed gridded data with a precision of 0.1° × 0.1° or even higher (Zheng et al., 2021). (See Lines 55-58 in the revised version)

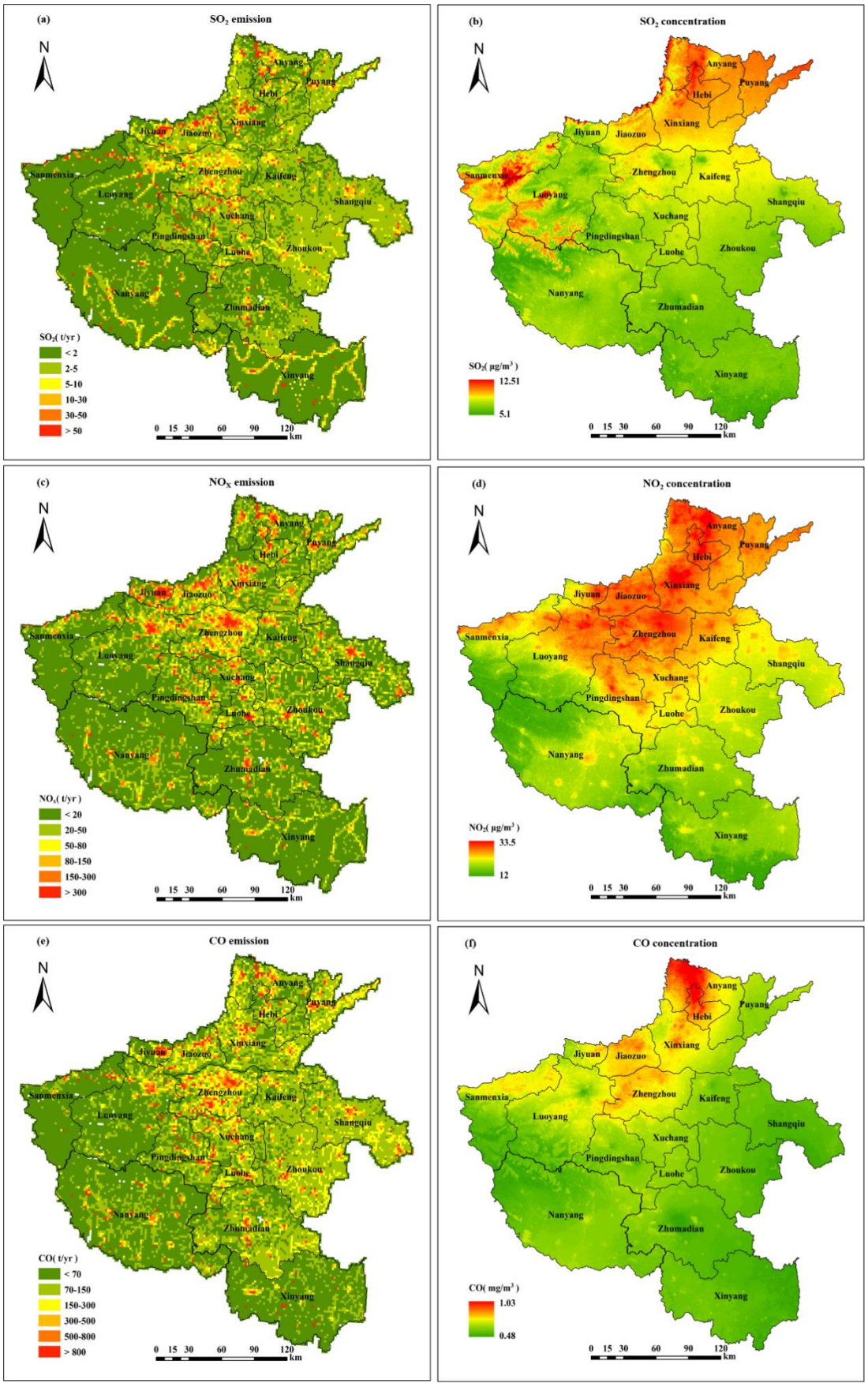
Furthermore, in order to achieve precise quantification of the synergy effect, future research needs to promote the combination of "bottom-up" inventories with "top-down" models and observation methods (such as Chen et al., 2022; Liu et al., 2025), in order to go beyond the limitations of traditional emission accounting. (See Lines 604-607 in the revised version)

References:

Chen, C., Dubovik, O., Schuster, G. L., Chin, M., Henze, D. K., Lapyonok, T., Li, Z. Q., Derimian, Y., and Zhang, Y.: Multi-angular polarimetric remote sensing to pinpoint global aerosol absorption and direct radiative forcing, Nat. Commun., 13, 10.1038/s41467-022-35147-y, 2022.
Chen, T., Xiong, Y. X., Zhao, W. D., Lin, B., He, Z. H., Tao, F. Y., and Hu, X.: Construction of Heavy-Duty Diesel Vehicle Atmospheric Pollutant Emission Inventory Based on Onboard Diagnosis Data, Atmosphere-basel, 15, 10.3390/atmos15121473, 2024.
Liu, J., Cohen, J. B., Feng, Y., Wang, S., and Qin, K.: OMI-Derived Mass- and Number-Conserved Estimation of Black Carbon Emissions, Environ. Sci. Technol. Lett., 12, 731-738, 10.1021/acs.estlett.5c00340, 2025.
Zheng, B., Cheng, J., Geng, G., Wang, X., Li, M., Shi, Q., Qi, J., Lei, Y., Zhang, Q., and He, K.: Mapping anthropogenic emissions in China at 1 km spatial resolution and its application in air quality modeling, Sci Bull, 66, 612-620, 10.1016/j.scib.2020.12.008, 2021.

3. It seems your spatial distributions of sources relating to new industrial growth (Jiaozuo, Sanmenxia, Anyang), new urban growth in in Tier 3 urban areas (i.e., Luoyang, Shangqiu), and biomass burning (many places) do not necessarily match with on-the ground observations of air pollution and multiple recently published top-down studies. Please make such comparisons in general.

Response: Thanks for the comment and this suggestion is highly valuable.
Ground-based observational data on pollutant concentrations integrate the net effects of a suite of atmospheric processes — including transport, dispersion, chemical transformation, and deposition — whereas the emission inventory developed in this study characterizes the spatial distribution of pollutants at their source locations. Consequently, these two datasets provide complementary spatial validation for one another. To further assess the reliability of the spatial distribution in our emission inventory, we conducted a spatial comparison between our 3 km × 3 km gridded emission data and the China High-resolution Air Pollutants (CHAP) concentration dataset for Henan Province in 2022, which features a 1 km × 1 km spatial resolution (Figure S3). The results indicate that, although localized atmospheric processes introduce some regional discrepancies, the high-emission zones identified by our inventory exhibit strong spatial agreement with the high-concentration areas in the CHAP dataset at the regional scale. This consistency is particularly pronounced in key areas such as major industrial zones and urban agglomerations (for additional details, see Supplementary Text 1 and Figure S3).


(a)
SO2 emission
N
Anyang
Puyang
Hebi
Xinxiang
Jiyuan
Jiaozuo
Sanmenxia
Zhengzhou
Kaifeng
Luoyang
Shangqiu
Xuchang
Pingdingshan
Luohe
Zhoukou
Nanyang
Zhumadian
Xinyang
SO2(t/yr)
< 2
2-5
5-10
10-30
30-50
> 50
0 15 30 60 90 120
km
(b)
SO2 concentration
SO2(μg/m3)
12.51
5.1
(c)
NOX emission
NOX(t/yr)
< 20
20-50
50-80
80-150
150-300
> 300
(d)
NO2 concentration
NO2(μg/m3)
33.5
12
(e)
CO emission
CO(t/yr)
< 70
70-150
150-300
300-500
500-800
> 800
(f)
CO concentration
CO(mg/m3)
1.03
0.48

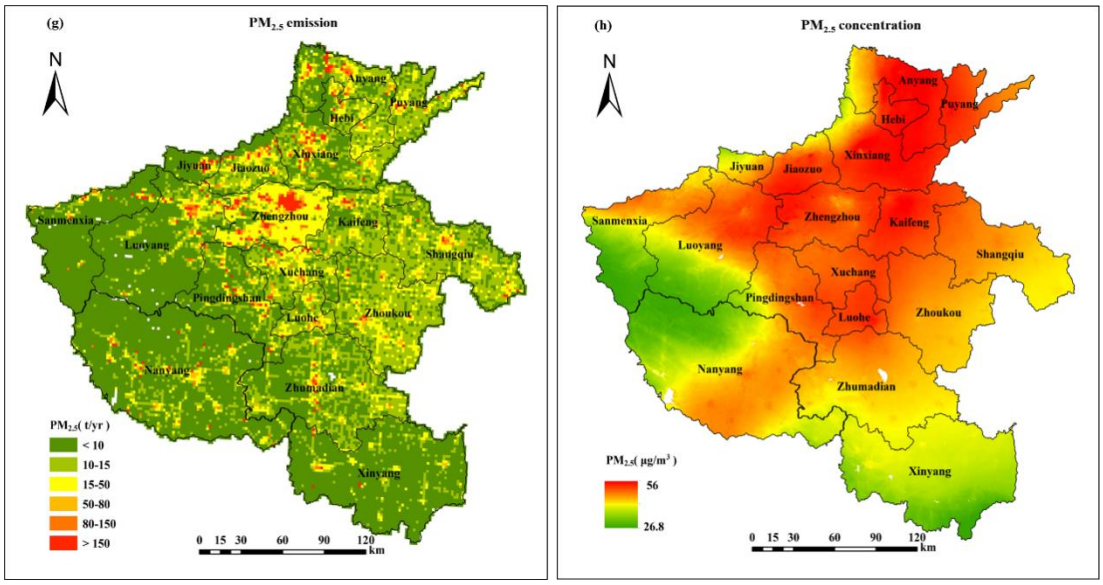


Figure S3. Side-by-side comparison of spatial distributions between 3 km × 3 km gridded emissions inventory (a, c, e, and g) and CHAP-derived (b, d, f, and h) concentrations for SO_2, NO_X, CO, and $PM_{2.5}$ in Henan Province, 2022

4. When making comparisons, it would be best to demonstrate skill of your work on a grid-by-grid and day-by-day basis between your 3km x 3km and similar 5km x 5km gridded datasets. This comparison would ideally be done at high temporal frequency, so that any uncertainties and/or biases can be clearly identified. If there are underlying reasons for these differences, they can be explored in more detail. Adding in this step is critical to demonstrate that the paper is sufficiently innovative and that the results are reasonable.

Response: Thanks for the constructive comment.
We are sorry that the original manuscript provided a 3 km × 3 km grid distribution map, but failed to clearly reflect the changes in spatial patterns over time. Based on the provided suggestions, let's explore this point, which is highly beneficial for the innovative improvement of the entire article. At the same time, in combination with the suggestion of another reviewer, we try to analyze the differences in time changes from the perspective of spatial co-hotspots. We analyzed the spatial co-hotspots for 12 months and selected four representative months - April (spring), July (summer), November (autumn), and January (winter) - to represent the co-hotspots during the seasonal changes. At the same time, during this process, we also optimized the hotspot identification method, eliminating the grids with zero emissions and those located outside the boundary of Henan Province. Some interesting phenomena were indeed discovered. The explanations for these phenomena can be found in the revised manuscript, from lines 526 to 551. Once again, we thank the reviewers for their suggestions. As shown in the figure below:

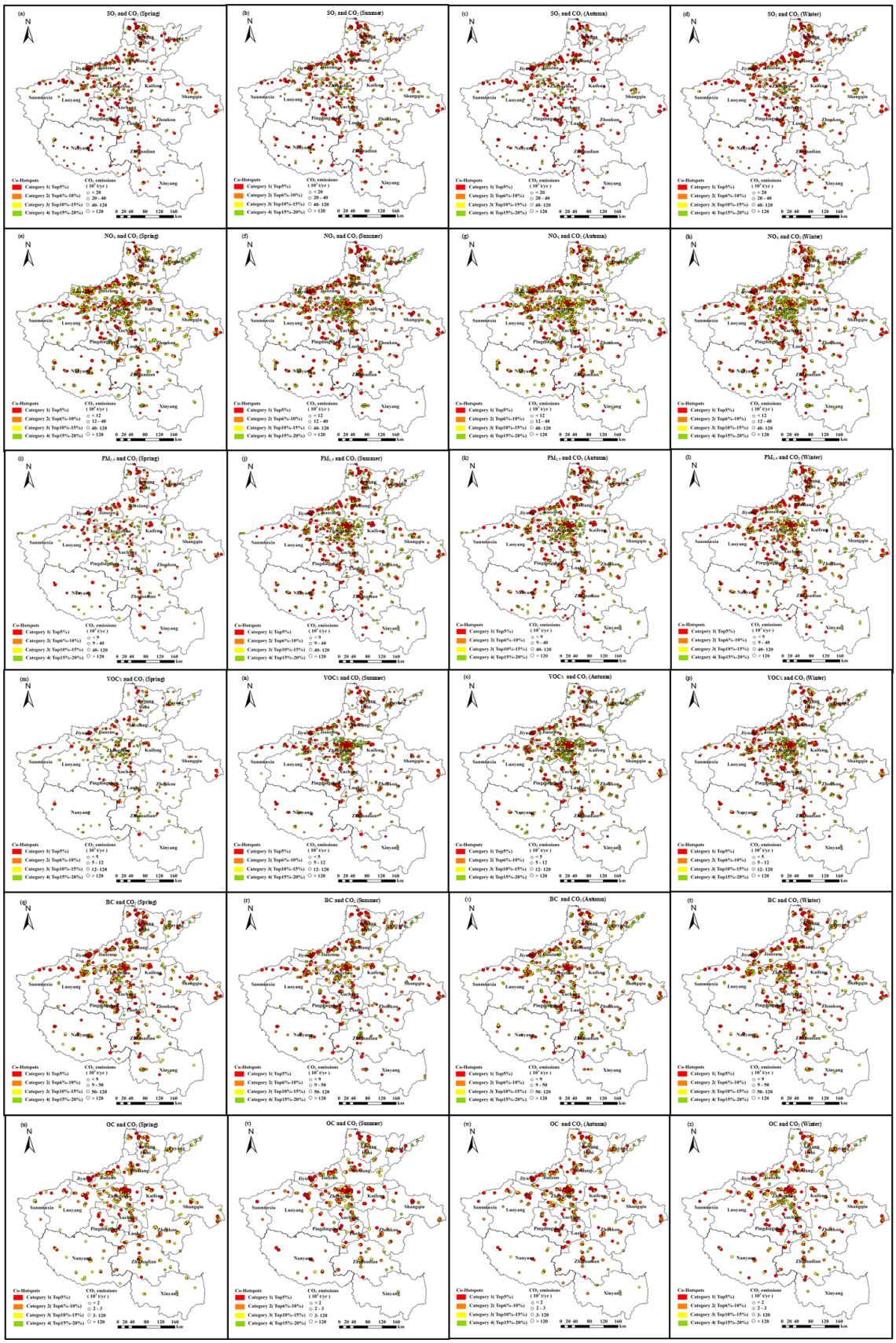


Figure S2. Seasonal spatial maps of the co-hotspots of (a-d) SO_2 and CO_2, (e-h) NO_X and CO_2, (i-l) $PM_{2.5}$ and CO_2, (m-p) VOCs and CO_2, (q-t) BC and CO_2, and (u-x) OC and CO_2 from spring to winter