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Title: Active and Passive Satellite Observations Coupled with Carbon–Nitrogen Synergy for Urban Fossil Fuel CO_2 Emissions Monitoring

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Item-by-item reply to Anonymous Referee

May 18, 2026

Dear Jason Cohen and Reviewers,

We sincerely thank you and the reviewers for your constructive and thoughtful feedback on our manuscript. We have revised the manuscript accordingly and believe the revised version has improved in both clarity and scientific rigor. Please find below a detailed, point-by-point response to each reviewer comment.

1. The reviewers' comments are shown in black.

2. Our responses are also in blue, following each comment.

3. Descriptions of changes made to figures and tables are formatted in bold black text for clarity.

All modifications made to the manuscript are clearly marked in the revised version.

We greatly appreciate the reviewers' careful assessment and your editorial support. We hope the revised manuscript now meets the standards for publication.

Sincerely,

Jinchun Yi

On behalf of all co-authors

Wuhan University

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Reply to Referee # 1

Dear reviewer:

We sincerely thank the reviewer for the positive evaluation of our manuscript and for the constructive suggestions. We greatly appreciate your recognition of the quality of the work and your valuable comments, which have helped us further improve the readability and scientific context of the manuscript.

Sincerely,

Jinchun Yi

On behalf of all co-authors

Wuhan University

Reply to Referee # 2

Dear reviewer,

We sincerely thank the reviewer for the careful review of our manuscript and for the positive evaluation. We greatly appreciate the constructive comments and suggestions provided. We will carefully address all of the reviewer's remarks and further revise the manuscript to improve its clarity and quality.

Sincerely,

Jinchun Yi

On behalf of all co-authors

Wuhan University

Comments:

Line 246–247: "M.2 CO2-to-NOx ratios calculated using sectoral emission factors for CO2 and NOx (Zheng et al., 2020). We derived city-scale ratios by aggregating across all sectors. M.2 used the GEMS sectoral inventory." Zheng et al. (2020) is based on sectoral emission factors, whereas the manuscript appears to use a sectoral inventory. Could the authors briefly clarify whether these two approaches are equivalent, using factors and direct inventories?

ANSWER: This was an error on our part; we are, in fact, using the GEMS sectoral emission factors. We will correct this description in the main text. (Page 11, Line 246–247)

Lines 760–761: "The total uncertainty follows the order Beijing (23.79%) > Paris (18.15%) > Cairo (14.31%)." The reported precision appears excessive; it is recommended to reduce the number of significant digits.

ANSWER: I will revise the description of this section in the main text." Based on the uncertainty calculations, the total uncertainty is on the order of ~24% for Beijing, ~18% for Paris, and ~14% for Cairo." (Page 38, Line 760-761)

The uncertainty analysis (Appendix A5) is a welcome addition, but it currently underestimates the true uncertainty in two important respects. First, the divergence method involves gradient operators that nonlinearly amplify white noise in the original concentration field, leading to structured errors that are not captured by a simple propagation of TROPOMI retrieval uncertainty. Recent work has shown that even after quality filtering, a substantial fraction of calculated emissions is statistically indistinguishable from noise (following REFs, but are not limited to).

https://doi.org/10.5194/acp-25-1949-2025

https://doi.org/10.1038/s41612-025-00977-2

https://doi.org/10.5194/gmd-18-621-2025

https://doi.org/10.5194/acp-25-2291-2025

https://doi.org/10.5194/acp-26-1931-2026

Second, the use of monthly average divergence assumes that the error in daily divergence fields averages to zero, which is not established – the variability around the monthly mean is large and may be systematically biased on days with clouds, high aerosol loading, or strong chemical activity.

I recommend that the authors explicitly discuss these limitations in the revised manuscript, particularly within the section addressing uncertainties and methodological constraints. If feasible, the authors are also encouraged to conduct an additional sensitivity analysis using a range of uncertainty bounds (e.g., ±10-20% in TROPOMI NO2) to illustrate how the emission estimates respond to variations in the input data.

ANSWER: We thank the reviewer for raising this important point. We agree that the uncertainty analysis in Appendix A5 of the original manuscript mainly describes the first-order propagation of TROPOMI NO_2 retrieval errors, wind field errors, NOx/NO_2 conversion errors, and fitting errors related to scale height and chemical lifetime, and therefore does not fully represent the total uncertainty of the divergence method.

In particular, finite-difference gradient operators can amplify high-frequency noise in the NO_2 column field and may introduce structured errors during subsequent processing steps, including non-negative truncation, spatial resampling, monthly averaging, and parameter fitting. Similar issues have also been highlighted in recent studies. The flux divergence approach is highly sensitive to the fine-scale representation of NO_2 vertical profiles, chemical lifetime, and the $NOx:NO_2$ ratio. Direct use of tropospheric NO_2 columns may therefore introduce systematic biases. Zheng et al. also pointed out that the nonlinearity of gradient terms and observational noise may cause part of the inferred emissions to be statistically indistinguishable from noise.

In the revised manuscript, we will redefine the error estimate in Appendix A5 as a "first-order uncertainty estimate" or "lower-bound estimate". We will also clarify in the Methods and Discussion sections that monthly averaged divergence fields can reduce random noise, but do not demonstrate that daily-scale errors have a zero mean. Under conditions such as cloud filtering, high aerosol optical depth (AOD), surface reflectance changes, and strong photochemical activity, daily-scale errors may contain systematic components that can remain in the monthly averaged emissions.

We have added the following statement after Section 2.2.1, "Mass Balance Method": "For boundary grid points, one-sided differences were applied. Although using gradients in multiple directions helps reduce directional dependence, the finite-difference gradient operator can amplify high-frequency retrieval noise in the original NO_2 column field. Therefore, the divergence-derived NOx fluxes should not be interpreted as purely deterministic grid-cell emissions. Instead, they represent monthly aggregated estimates subject to retrieval noise, wind-field uncertainty, chemical-parameter uncertainty, and possible structured errors introduced by gradient operations and gridding. We further evaluate this sensitivity in Appendix A5."

Add "This is an underestimate/lower bound" at the beginning of Appendix A5: "The uncertainty estimated here should be regarded as a first-order propagated uncertainty rather than the full uncertainty of the divergence-derived NOx emissions. In particular, this formulation does not fully capture structured errors arising from finite-difference gradient operators, oversampling from Level-2 observations to Level-3 grids, non-Gaussian retrieval noise, or sampling biases caused by clouds, aerosols, surface reflectance, and photochemical variability."

In addition, we have added the following paragraph to the Summary:" Another limitation concerns the uncertainty of the divergence-derived NOx emissions. Although monthly averaging reduces random noise, it does not guarantee that daily divergence errors average to zero. Sampling biases related to clouds, aerosols, surface reflectance, and photochemical variability may persist in the monthly mean. Moreover, gradient operations can amplify white noise in the NO_2 column field and generate structured artifacts in the derived fluxes. Therefore, the current uncertainty estimates should be interpreted as lower-bound, first-order uncertainty estimates. Future work should include more explicit noise-filtering and detection-limit analyses, ideally using ensemble perturbations of the original Level-2 NO_2 observations and high-resolution chemical transport simulations to better represent NO_2 profile shapes, lifetimes, and NOx:NO_2 conversion factors."