Reply to Referee # 1

Dear reviewer:

Thank you very much for reviewing our manuscript and providing valuable feedback. We sincerely appreciate your patience and detailed comments. Under your guidance, we have carefully addressed each of your comments and made corresponding revisions and additions. All your words are in black and our item-to-item responses are in blue. We have included our revisions for some comments directly for your convenience.

Sincerely,

Jinchun Yi

On behalf of all co-authors

Wuhan University

This study develops a top-down inversion framework to estimate high-resolution, city-scale fossil-fuel CO_2 ($ffCO_2$) emissions by integrating active and passive satellite observations and coupling CO_2 and NO_x emissions through NO_x distributions and CO_2-to-NO_x emission ratios. It further evaluates how different approaches for deriving the CO_2-to-NO_x ratio influence the inferred $ffCO_2$ emissions, showing that optimized ratio estimation enhances emission accuracy and reduces uncertainties in both the ratio and the resulting inversions. The framework is applied to three major metropolitan areas—Beijing, Cairo, and Paris—with comprehensive supporting analyses provided. By improving the estimation of urban carbon emissions at the city scale and lowering associated uncertainties, this work offers valuable contributions to the community for more robust emission quantification and better-informed carbon mitigation strategies.

I recommend this manuscript for publication, with only a few questions and suggestions for consideration.

ANSWER: Thank you for your positive comments. We really appreciate your encouragement and support. To facilitate the readers' understanding of this study, we have carefully revised the whole manuscript according to your comments.

Mandatory changes:

1: Since Aura OMI and OCO-2/3 are not utilized in this study, they should be removed from the figure. In addition, the connections between the different steps of the workflow are not sufficiently clear. The flowchart could be revised to improve clarity and logical progression.

ANSWER: Thank you very much for your comments. We fully agree with your suggestions regarding Fig. 1. In the revised manuscript, we removed Aura OMI and OCO-2/3 and revised the flowchart to improve its clarity and logical consistency.

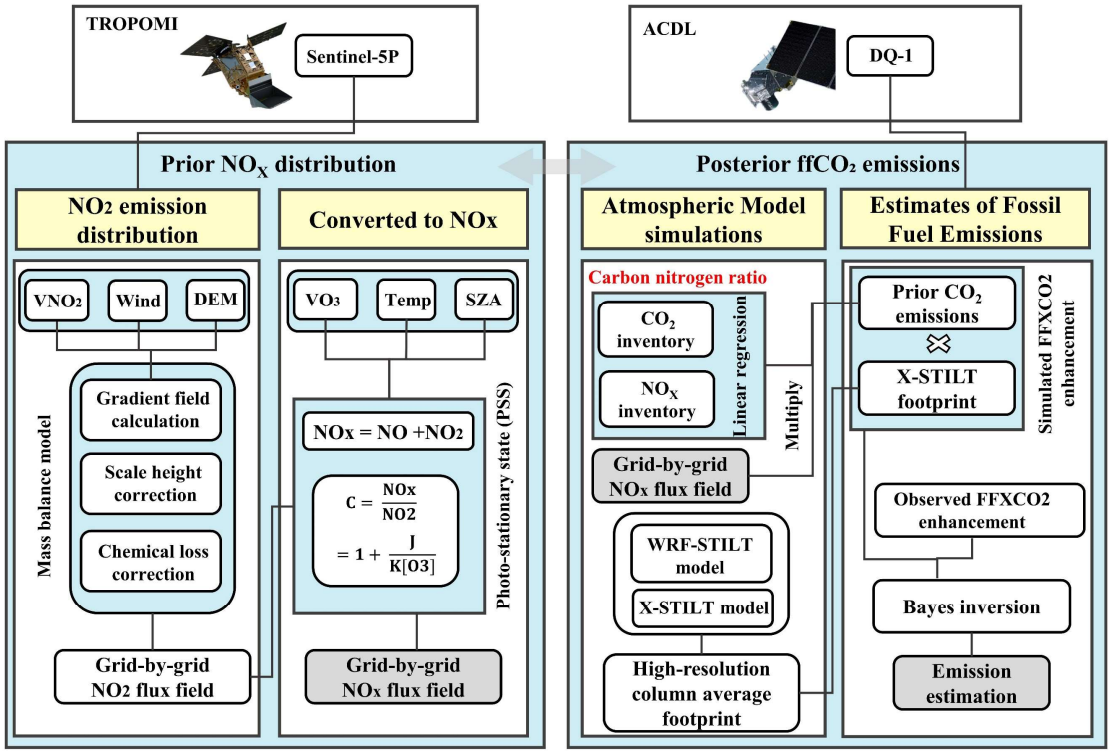

Figure 1 Technical framework diagram

Section 2.1.1 ACDL Products: The statement "which enables direct 'top-down' observations of atmospheric CO_2" is misleading. While the use of an active lidar sensor is indeed a technological breakthrough, it does not inherently enable "direct" top-down emission estimates. This phrasing should be revised for accuracy.

ANSWER: Thank you very much for your comments. We fully agree with your comment. In the revised manuscript, we will refine this description to make it more accurate. Specifically, we will replace “which enables direct 'top-down' observations of atmospheric CO_2” with “which enables active top-down observations of atmospheric CO_2.” (Page 5, Line 105)

P11, Eqs. (4)–(5): Section 2.2.2 (2) is difficult to follow due to insufficient explanation of the parameters in Eqs. (4)–(5). Please revise these equations and clearly describe each variable and its physical meaning.

ANSWER: Thank you very much for your comments. We followed your suggestion and clearly described each variable in Equations (4) and (5) and its physical meaning. (Page 12, Line 272-276, Line 283)

Section 3.2.3: The posterior uncertainties reported in the text do not match the ones stated in table 2. The uncertainties reported in table are significantly larger. What is the reason?

ANSWER: Thank you very much for your comments. This was our oversight. The posterior uncertainty reported in Table 2 is not a percentage uncertainty; however, we mistakenly added the symbol “%” in the column header. We have corrected this issue in the revised manuscript. The uncertainties in the table are calculated as the posterior C/N ratio multiplied by the percentage uncertainty, whereas the values reported in the text represent the percentage uncertainty. Therefore,

the uncertainties listed in the table are significantly larger than the values reported in the text. (Page 24 Table 2)

Recommended minor changes:

P1, L23: XCO_2 should be defined at its first occurrence in this paper.

ANSWER: Revised (Page 1, Line 21)

P2, L49–51: I would recommend adding more references by citing more relevant papers.

ANSWER: Revised (Page 2, Line 50)

P3, L63: Please clarify what specific measurement limitations are being referred to here.

ANSWER: We have replaced "due to the measurement limitations" with "because the CO_2-to-NO_x ratio used in this study is calculated from CO_2 emissions and NO_x emissions, there is currently a lack of accurate top-down measurement methods" (Page 3, Line 65-67)

P5, Fig. 2: It may be more appropriate to relocate this figure to Section A1, where the parameter details are described.

ANSWER: Thank you for your suggestion regarding Fig. 2. We appreciate your comment; however, we prefer to keep the figure in its current location in the main text because it provides important context for the ACDL productions and helps readers follow the analysis more easily. The detailed parameter descriptions are still provided in Section A1 for reference.

P7, L174: Sun et al. (2018) does not appear to be directly relevant to flux estimation. More appropriate references would include Sun et al. (2022; https://doi.org/10.1029/2022GL101102) and Ayazpour et al. (2025; https://doi.org/10.1029/2024JD042817), which focus specifically on flux estimation methodologies.

ANSWER: Revised (Page 7, Line 177-178)

P9, L202-212: It would be helpful to elaborate on how the scale height and chemical lifetime are determined.

ANSWER: Thank you for your comment. This process is already described in the manuscript: "To suppress excessive noise in single-day fits, we perform monthly regressions and adopt the temporal and spatial mean over the month as the final estimate, representing an aggregate over the full spatial domain, the entire month, and the troposphere. The retrieved scale height and first-order chemical lifetime are then applied back into Equations 4 and 6 to obtain the final gridded NO_x vertical fluxes." We believe this description provides sufficient detail on how the scale height and chemical lifetime are determined.

P12, Eq. (11): Please specify the definition of Sobs.

ANSWER: S_{obs} is a diagonal matrix, with the diagonal entries representing the observational error variances ε_{obs}^2 for each orbit. (Page 13, Line 318)

P16, L336 we don't say 'concentration' when we talk about emissions.

ANSWER: Thank you for your comment. We agree that the term "concentration" is not appropriate

when referring to emission. We have revised the manuscript to replace it with “emission” wherever necessary. (Page 17, Line 367)

P16, Table 1: Are the chemical lifetime and scale height values spatially averaged across each city?

ANSWER: Yes

P28, L548: How is the prior uncertainty of the CO_2-to-NO_x ratio treated in experiments M4–M6?

ANSWER: We have stated in the main text that M4 and M6 are the same as M2, and M5 is the same as M1. (Page 11, Line 243-254) Their uncertainty calculation methods are also identical; the only difference lies in the emission inventories used.