Dear editor,

We would like to thank the reviewer for his/her constructive and detailed comments, which have helped us to substantially improve our manuscript. According to the reviewer's comments and suggestions, we have made revision to our manuscript, the main modifications are as follows:

1. Clarification of TROPOMI NO_2 product versions. We have added a detailed description of the differences between the v2.4.0, v2.5.0, and v2.6.0 datasets, and discussed the potential impact on our inversion results.

2. Several other revisions were made to enhance the manuscript's clarity and consistency, including:

1) We supplemented the introduction with background information on the changes in anthropogenic NO_x emissions in Ukraine before the Russia–Ukraine war.

2) All abbreviations are now defined upon first use to avoid ambiguity.

3) References have been added for all datasets used in the study.

4) Wording throughout the manuscript has been refined, and certain sentences have been reorganized to improve logical flow.

5) A disclaimer has been included to emphasize the authors' neutral stance regarding the war and to note that some maps may contain disputed territories.

We believe that these revisions fully address the reviewer's concerns and strengthen the manuscript's overall contribution. For your convenience, we have submitted both a clean revised manuscript and a marked-up version showing the changes, along with a point-by-point response to the reviewers' comments.

We once again thank you and the reviewers for the valuable feedback and guidance. We look forward to your evaluation for our revised submission and hope that it will meet the standards of Atmospheric Chemistry and Physics.

Best regards,

Professor Fei Jiang

Nanjing University

E-mail: jiangf@nju.edu.cn

Dear Reviewer:

We would like to thank the anonymous referee for his/her comprehensive review and valuable suggestions. We have carefully considered each of the comments and suggestions and have revised the manuscript accordingly. In this response, we respond to all of the comments point to point. The referee's comments are listed below in black, our response is given in blue, and the modification to the manuscript is listed in red. The page and line numbers for corrections are referred to the revised manuscript; the page and line numbers of the original review manuscript remain unchanged. References relevant to the response are listed at the end of this document.

Comments:

The revised version of the manuscript by Mao et al. substantially improved, and most of my comments have been satisfactorily addressed. However, before I can recommend publication in ACP, the authors need to address the following aspects:

Major comment:

In the revised methodology, different versions of the TROPOMI NO_2 VCD data are used for different time periods. Rather than using v2.3.1, you use versions v2.4.0, v2.5.0 and v2.6.0 for different time periods. You also highlight that these versions differ substantially from each other, with improvements in the later versions compared to the previous ones. Why don't you use the same version for the entire time period? What uncertainty does this introduce to your methodology? Please provide an overview of the differences between the versions in the SI and include a discussion of the introduced uncertainties in section 4.4.

Response: Thank you for raising this important issue. The reason for using different versions of the TROPOMI NO_2 dataset for different periods is that there is no single version covered the entire study period (2019–2023). For instance, version v2.4.0 only updated to 12 March 2023, while version v2.5.0 only covered the period from 12 March to 26 November 2023 (see https://www.temis.nl/airpollution/no2col/tropomi_no2_data_versions.php). According to the Sentinel-5P TROPOMI NO_2 ATBD (Van Geffen et al., 2024), the differences between these versions (v2.4.0, v2.5.0 and v2.6.0) are relatively minor compared with the substantial changes that occurred between v2.3.1 and v2.4.0.

Compared to v2.3.1, the algorithm in v2.4.0 has introduced an improved treatment of the air mass factor (AMF) calculation, updates in the absorption cross-sections, and improved handling of surface albedo and cloud parameters. These changes led to a better consistency between satellite retrievals and independent validation datasets.

For v2.5.0, the algorithm implemented a correction in the qa_value flagging, especially for snow/ice conditions, thereby slightly increasing the number of valid observations without altering the underlying NO_2 retrieval algorithm.

The algorithm of v2.6.0 incorporated an update in the FRESCO cloud algorithm, improving cloud pressure retrievals used in the AMF calculation. This change may cause small shifts in the tropospheric NO_2 VCD, but validation shows the effect is within a few percent and largely regional.

The uncertainties introduced by these version transitions are therefore limited. The most relevant difference arises between v2.6.0 and the earlier versions because of the cloud-related update, but in our study this version contributes only one month of data (December 2023). Its influence on the overall results is thus negligible.

Following the reviewer's suggestion, we have 1) added explanations for using different data versions, 2) added some discussion for its potential impact on the results, and 3) added a concise overview of these version changes in the Supplementary Information (Table. R1).

1) Explanations for using different data versions (see Lines 146~150):

Different versions of the dataset were used for different time periods because each version only covers a specific time period (see https://www.temis.nl/airpollution/no2col/tropomi_no2_data_versions.php). These products incorporate improved and consistent Level-1b processing and retrieval algorithms, with only minor adjustments between versions (Table S1), representing the most up-to-date and accurate TROPOMI NO_2 dataset available.

2) added some discussion for its potential impact on the results (see Lines 516~521):

In addition, the use of different product versions (i.e., v2.4.0, v2.5.0, and v2.6.0) across the study period may introduce further uncertainties. While these versions are largely consistent with each other and share the same retrieval algorithm framework, minor differences exist due to bug fixes and updates in quality assurance flagging in v2.5.0 and improvements in cloud pressure retrievals affecting air-mass factor calculations in v2.6.0 (Table S1). These differences may lead to small regional or temporal shifts in retrieved NO_2 VCDs, potentially propagating into the inversion results.

3) Added a concise overview of these version changes in the Supplementary Information:

Table. R1. Key updates and their potential impact on NO_2 VCD of versions v2.4.0~v2.6.0 of TROPOMI NO_2 VCDs (Table. S1 in the revised SI)

Version	Time period	Key updates	Potential impact on NO_2 VCDs
v2.4.0	1 May 2018 – 12 Mar. 2023	Improved Air-mass factor (AMF) (surface albedo, clouds), updated cross-sections	Better consistency with validation; no major discontinuity
v2.5.0	13 Mar. – 26 Nov. 2023	Bug fix in quality assurance value (qa_value) (snow/ice handling)	Slightly more valid pixels; minimal effect on mean NO_2
v2.6.0	26 Nov. 2023 – 8 Sep. 2024	Fast Retrieval Scheme for Clouds from the Oxygen A band cloud pressure update affecting AMF	Small regional shifts in VCD (few percent); limited in our study due to short time span

Minor comments:

1. In your manuscript, you focus primarily on relative changes. The introduction would be improved by providing some context on absolute NO_x emissions in Ukraine. Additionally, it would be helpful if you could provide some background information on whether Ukraine was reducing its emissions prior to 2019.

Response: Thank you for this constructive suggestion. We have revised the introduction to include the changes in NO_x emissions in 2015~2019 based on the EDGAR v8.1 inventory. From 2015 to 2019, Ukraine's anthropogenic NO_x emissions were in the range of 504 to 541 kt/yr, indicating that the NO_x emissions were rather stable. This revised description has been added to the introduction (Lines 61~63).

According to the Emissions Database for Global Atmospheric Research (EDGAR) v8.1 (Crippa et al., 2024), the annual NO_x emissions in Ukraine were rather stable before the Russia–Ukraine war, with relative changes in the range of -5% to 3% from 2015 to 2019.

2. Line 58-60: What about particle formation?

Response: Thank you for pointing this out. We have revised the text accordingly, see Lines 57~60 in the revised manuscript and as follows:

As a short-lived gas, directly emitted nitric oxide (NO) can be rapidly oxidized to form nitrogen dioxide (NO_2), which, in the presence of sunlight and volatile organic compounds (VOCs), contributes to net ozone (O_3) generation and secondary particulate matter formation (Roger Atkinson, 2000).

3. Line 107: Please also provide the approximate grid size in km for Ukraine.

Response: Thank you! We have provided the approximate grid size in kilometers. The model resolution of 0.25° × 0.3125° corresponds to about 14.0~20.7 km × 34.8 km over Ukraine (Lines 108~110):

The model was operated at a horizontal resolution of 0.25° (latitude) × 0.3125° (longitude), corresponding to approximately 17 km × 35 km over Ukraine, and a vertical resolution of 47 layers.

4. Line 343: Change to "The war has had and continues to have direct and indirect impacts on [...]"

Response: Thank you! We have revised the sentence to (Lines 350~351):

The war has had and continues to have direct and indirect impacts on industrial production across Ukraine, with the most pronounced damage observed in conflict zones.

5. Line 423: What does "SSCU" stand for? Please introduce all abbreviations properly and provide a reference for the data source.

Response: Thank you for pointing this out. We have clarified the abbreviation in the manuscript. There is a typo here, SSCU should be SSSU, which refers to the State Statistics Service of Ukraine. In addition, we have checked abbreviations throughout the manuscript and added the full name and reference before all the first abbreviation (Lines 434~436).

Further analysis using the data from State Statistics Service of Ukraine (SSSU, 2025) reveals that oil and natural gas consumption in Ukraine decreased by 15% and 34% in 2022, and by 13% and 32% in 2023, respectively (Table 1).

6. Table 1: Please provide a reference for the "SSCU statistics".

Response: Thank you. We have now added the reference for the “SSSU statistics” in Table 1. Specifically, the data are from the State Statistics Service of Ukraine (SSSU), and the official website has been cited in the reference list.

7. Some of the wording needs to be more scientific. For example, the word "fell" (line 22) is ambiguous when describing emission reductions. Please review your manuscript accordingly.

Response: Thank you for this helpful suggestion. We agree that the wording should be more scientific. We have carefully checked the manuscript and replaced ambiguous expressions such as “fell” with more precise terms (e.g., “decreased”, “declined”, or “was reduced”) when referring to changes in emissions. We have also conducted a

thorough review of the entire text, correcting certain verb tenses and sentence structures.

References

Van Geffen, J. H. G. M., Eskes, H. J., Boersma, K. F., and Veefkind, J. P.: TROPOMI ATBD of the total and tropospheric NO_2 data products document number : S5P-KNMI-L2-0005-RP, KNMI, 2024.