

Response to Referee #1:

Thank you very much for your insightful comments and valuable suggestions, which have greatly helped improve this paper. Responses to all your comments are provided below. The authors held extensive discussions on how to revise the content, and this paper is undergoing a major revision to address the concerns of all referees. Therefore, the response was delayed, and we apologize for this.

General Comments

This paper uses the closed-loop integration method, together with OMI and TROPOMI satellite observations and ground-based monitoring data, to systematically analyze the spatiotemporal variations of tropospheric NO₂ column concentrations, surface concentrations, and boundary transport fluxes over the Tibetan Plateau from 2005 to 2024. Given the important role of the Tibetan Plateau in regional and global climate systems, this study focuses on the key issue of transboundary NO₂ transport. A random forest approach is also introduced to assess the relative contributions of the westerlies and the South Asian monsoon at different altitude layers to the transport flux. Overall, the results contribute to a deeper understanding of regional pollutant transport processes and their controlling factors and provide references for studies on cross-regional coordinated emission reductions. This study employs a series of advanced datasets and innovative methods, and the relevant conclusions hold scientific value and provide useful reference. This paper fits the scope of ACP, and I recommend publishing it on ACP after some issues have been addressed.

Some aspects could be further refined to enhance the readability and rigor of the manuscript.

1. I noticed that the authors did not include a section on the validation of the machine learning results in the main text, although I saw it in the appendix. I believe this is a crucial part and the validation parameters (such as R² and RMSE) should be presented in the main text. I recommend including a table in the main text to demonstrate this.

Response: Thank you for your comment. The validation parameters of the model (e.g., R² and RMSE) are now presented in the main text. A detailed summary is provided in Section 2.2.1 (Table 2).

1. There are minor grammatical and expression issues in the manuscript, which are suggested to be revised to improve overall readability.

Response: Thank you for your comment. We have carefully revised the manuscript to improve readability and ensure rigor.

Specific comments:

1. Page 2, Line 25: "...currently operated in TP, Taking Tibet as an example..."

→ “...currently operated in TP. Taking Tibet as an example...”

Response: Corrected as suggested..

1. Page 5, Line 29: “To ensure strict temporal and spatial consistency, ...” should be “To ensure strict spatiotemporal consistency, ...”.

Response: The text has been revised accordingly.

1. Page 6: The formula formatting here is incorrect; the author should adjust it. The same issue appeared in the supplement.

Response: The formula formatting has been corrected in both the main text and the Supplement.

1. Page 7, Line 1: “...some grids in this region that previously exhibited mixed fluxes shift from internal efflux to external influx...” The definition of “mixed fluxes” is not sufficiently clear.

1. Clarify the meaning of “mixed fluxes” in the text, for example, whether it refers to net fluxes close to zero or to spatiotemporal alternation.

Response: Thank you for your comment. The relevant section has been substantially revised. The ambiguous term “mixed fluxes” has been removed and replaced with a clearer description: “some boundary grid cells transition from net efflux in the non-monsoon period to net influx during the monsoon season, thereby forming a more continuous influx structure.”

1. Page 8, Line 2: A large number of references are cited (Guo et al., 2022; Kong et al., 2023; Zheng et al., 2024; Zhang et al., 2025), but the specific phenomena or mechanisms corresponding to each reference are not clearly indicated in the text.

1. Clearly indicate the specific phenomena or conclusions corresponding to each reference when citing, to avoid citation stacking.

Response: Thank you for your comment. The relevant section has been substantially revised. The text has been largely rewritten, and several redundant citations have been removed to avoid citation stacking.

1. Page 8, Lines 16-21: The text repeatedly mentions “high-value” or “high-value source regions” → it is recommended to define it upon first occurrence. Is it referring to PSCF values above a certain threshold? Please clarify.

Response: Thank you for your comment. “High PSCF value regions” are used in this study as a qualitative description of areas with relatively higher PSCF values, indicating locations with stronger potential source contributions. We have standardized the related terminology in the revised manuscript to avoid ambiguity. Please see Lines 12 to 21 on page 8.

1. Page 9, Line 2: "...pivotal role over TP..." → "pivotal role of the TP" is more accurate.
Response: Corrected as suggested.
1. Section 3.3 Local emissions and regional transport of NO₂ over the TP
 1. Page 9, Line 7: "...have exhibited exhibited distinctly different spatiotemporal evolution patterns..." → "...have exhibited distinctly different spatiotemporal evolution patterns...".
Response: The repeated word has been removed, and the sentence has been corrected.
 1. Page 9, Lines 16-17: "...resulting in further spatial expansion of NO₂ hotspots(Choudhary et al., 2021) ..." → "...resulting in further spatial expansion of NO₂ hotspots (Choudhary et al., 2021) ...".
Response: A space has been added before the parenthesis.
 1. Page 9, Line 22: "one of cleanest regions" → "one of the cleanest regions"
Response: Corrected as suggested.
 1. **Page 14, Line 38:** "...pristine background region, the TP is increasingly..." → "...pristine background region, is increasingly..."
Response: Corrected as suggested.

Figure comments

1. Figs. 3–5: The figures and text are a bit small. Making both bigger would improve readability.
Response: Thank you for your comment. We have carefully reviewed all figures in the manuscript and adjusted their size and text formatting to improve readability throughout the paper.