Response to RC1: 'Comment on egusphere-2025-4818', Anonymous Referee #1, 20 Nov 2025

Manuscript: egusphere-2025-4818

Title: Measurement report: Altitudinal Shift of Ozone Regimes in a Mountainous Background Region

Reviewer's Recommendation: Minor Revisions

Overall Evaluation

This manuscript presents a comprehensive and valuable study on the altitudinal distribution of ozone (O_3) and its precursors on Mount Fanjing, a remote background site on the Yunnan-Guizhou Plateau in Southwest China. The research is timely and addresses a critical knowledge gap, as high-altitude observations, particularly in this understudied region, are sparse. The experimental design is robust, incorporating a multi-platform approach with gradient observations, advanced statistical analysis (Random Forest with SHAP), chemical box modeling (OBM-MCM), and Concentration-Weighted Trajectory (CWT) model. The key findings-a positive O_3 gradient with altitude, a shift from net O_3 destruction at the foot to net production aloft, and an altitude-dependent shift in chemical regimes-are well-supported by the data and clearly presented. The study makes a significant contribution to the field of mountain atmospheric chemistry and provides actionable insights for region-specific air quality management. I recommend publication after minor revisions to address the points outlined below.

Response: We sincerely thank Reviewer 1 for their positive and constructive evaluation of our manuscript, "Altitudinal Shift of Ozone Regimes in a Mountainous Background Region" (egusphere-2025-4818). We are grateful for the endorsement of our work's novelty, robust methodology, and significant contribution to the field. We have carefully considered all the specific comments and suggestions provided. Below is our point-by-point response, detailing how we will address each point in the revised manuscript. All suggested revisions were incorporated.

Major Strengths

We are particularly grateful that the Reviewer recognized the following key aspects:

1.This is the first detailed altitudinal gradient study of O_3 and its precursors in the Fanjingshan region. The data provides a crucial benchmark for understanding background pollution in Southwest China.

Response: We agree that this first detailed altitudinal gradient study in the Fanjingshan region provides a crucial benchmark for understanding background pollution in understudied Southwest China.

2.The combination of in-situ measurements, machine learning for driver attribution, and detailed chemical modeling is a powerful and modern approach that strengthens the conclusions significantly.

Response: We appreciate the Reviewer's endorsement of our combined use of in-situ measurements, machine learning (RF-SHAP), and detailed chemical box modeling. We believe this integrated methodology robustly supports our conclusions.

3.The clear demonstration of shifting O_3 regimes with altitude-from NO_x-dominated titration at the foot to VOC-sensitive production influenced by temperature and transport aloft-is a key scientific result. The discussion of the decoupling between VOC concentration and OH reactivity (e.g., isoprene) is particularly insightful.

Response: We are pleased that the clear demonstration of shifting O_3 regimes with altitude—from NO_x-dominated titration to VOC-sensitive production aloft-was effectively communicated. The discussion on the decoupling between VOC concentration and OH reactivity (e.g., isoprene) is indeed a central insight.

4.The conclusion that O_3 control strategies must be altitude-specific is well-argued and has practical implications for regional air quality planning.

Response: We thank the Reviewer for noting that the argument for altitude-specific O_3 control strategies is well-posed and has actionable implications for regional air quality planning.

The Reviewer's supportive comments are greatly encouraging. We have also carefully considered the specific suggestions for revision provided below, which have helped us to further improve the manuscript. Our point-by-point responses follow.

Specific Comments and Suggestions for Revision

1. Methods and Data Presentation:

1)The manuscript mentions 57 VOCs species were measured. It would be highly beneficial to include a table in the supplement listing these species and their average concentrations at each site. This is critical for reproducibility and for readers to assess the VOCs mix.

Response: We agree that providing detailed VOC speciation data is essential for transparency and reproducibility. We have created a new Supplementary Table S1 titled "The correlation coefficients (R^2), relative error and Method detection limit (MDL) of measured VOC compounds and their mixing ratios (mean concentration ± standard deviation) at the mountain foot, mountainside, and mountaintop sites during the observational campaign (March-August 2024)." This table included correlation coefficients (R^2), relative error and Method detection limit (MDL) of measured VOC compounds, and the mean ± standard deviation for each altitude. We have referred to this table in Section 2.2 of the revised manuscript (line 164-166 in the revised manuscript and line 57-60 in the revised Supplementary Material).

2)The 0-D box model (OBM-MCM) is a suitable tool, but its inherent limitation in not accounting for advective transport should be explicitly stated in the methodology or discussion. Acknowledging that the calculated R_trans is a residual helps, but a sentence on the model's limitations would strengthen the manuscript.

Response: We agree with the reviewer's suggestion to explicitly state the model's limitations upfront. We have added a clear statement in the Methods section (line 219-225 in the revised manuscript):

"As a zero-dimensional (0-D) formulation, the model explicitly excluded both vertical and horizontal advective transport processe (Edwards et al., 2013; Lenschow et al., 2016). These physical processes, along with deposition and any chemistry not represented in the mechanism, are collectively reflected in the residual term when comparing modeled chemical production/loss with observed O_3 changes. Although this limits the direct quantification of individual transport pathways, the method remains effective for assessing the relative importance of in situ photochemistry versus the aggregate of physical influences(Liu et al., 2021; Xue et al., 2014). "

Additionally, we have expanded the discussion to acknowledge how this limitation affects interpretation in mountainous terrain (line553-558 in the revised manuscript):

"The 0-D assumption is particularly challenging in mountainous environments, where complex topography drives three-dimensional flows such as valley breezes, slope flows, and mountain venting (Wekker and Kossmann, 2015). Future studies would benefit from coupling detailed chemical mechanisms with mesoscale meteorological models to explicitly resolve transport processes and better partition contributions from local chemistry versus various transport pathways. "

2. Results and Discussion:

1)Global Comparison (Figure 3): The comparison is useful for context. However, to make it more robust, please consider adding the time period (year/season) of the compared data in the figure or its caption, as O_3 levels can have temporal trends.

Response: Thank you for this valuable suggestion. To enhance the robustness and clarity of the comparison, we modified the caption of Figure 3 to specify the season/year of the data for each site, where this information is clearly available from the cited literature. For example: "Data were compiled from published literature (Okamoto and Tanimoto, 2016; Li et al., 2007; Lyu et al., 2021; Xu et al., 2016; Gong et al., 2018; Sun et al., 2016), with most values representing summer or annual averages specific to the periods studied in the respective references." We acknowledge that inter-annual variability exists, but the comparison remains valuable for situating Mt. Fanjing within the global range of high-altitude background O_3 levels (line 882-889 in the revised manuscript).

2)Negative RIR Values: The negative RIR for VOCs at the mountain foot is a critical finding. The explanation is correct (strong NO_x-limited regime where VOC reduction can increase O_3), but this non-intuitive concept could be elaborated upon slightly for clarity, perhaps with a reference to the classical EKMA diagram concept.

Response: We agree that this important finding deserves a clearer explanation. We expanded the discussion around Lines 380-382 in Section 3.3. The revised text more explicitly link the negative RIR to the position on the EKMA diagram: "Negative RIR values for VOCs at the mountain foot (Figure 8A) indicate that O_3 formation is under a strong NO_x-limited regime (Figure 7). In this regime, situated on the right side of the ridge line on a classical EKMA diagram, reducing VOCs can paradoxically increase O_3 production. This occurs because VOC reduction slows the oxidation of NO to NO_2 by peroxy radicals, leading to a higher NO/NO_2 ratio and thus greater O_3 loss via titration (O_3 + NO).” (line 510-514 in the revised manuscript).

This will provide a more mechanistic and conceptual explanation for the non-intuitive result.

3. Language and Presentation:

1)While the figures are informative, some captions are very dense (e.g., Figure 2). Consider streamlining the captions and moving detailed descriptions of plot elements (e.g., the "cloud," "raindrop" components in Figure 2) to the main text or supplement.

Response:We appreciate this suggestion to improve readability. We streamlined the captions for all figures, particularly Figure 2. The detailed technical description of the plotting elements ("raincloud" plot components) was moved to a dedicated section in the Supplementary Information, titled "Description of Graphical Methods." The revised caption was simplified to: “Figure 2. Altitudinal distributions of O_3, its precursors (VOCs, NO_x, CO), and meteorological parameters (temperature, wind speed, relative humidity, pressure) at the mountain foot, mountainside, and mountaintop during the observation period. A detailed description of the plot elements is provided in Supplementary Text S1.” (line 878-881 in the revised manuscript)

2)Some sentences, particularly in the abstract and introduction, are very long and complex. A thorough proofread to break down overly long sentences would improve readability.

Response: We performed a thorough linguistic edit of the manuscript,paying particular attention to the Abstract and Introduction. The goal was to break down complex, multi-clause sentences into clearer, more direct statements while maintaining scientific precision. (line 18-19, 39-53 in the revised manuscript)

3)Check for consistency in reference formatting (e.g., journal name abbreviations, use of "et al.").

Response: We carefully checked the entire reference list to ensure complete consistency with the journal's style guide (e.g., journal name format, correct use of "et al." for multi-author references, formatting of DOIs, etc.). (line 611-863 in the revised manuscript)

Typographical and Minor Errors

1)Page 3, Line 95-100: The transition is slightly abrupt. Consider a smoother link to state the knowledge gap before announcing the study's aim.

Response: We revised the transition in the final paragraph of the Introduction to better flow from the identified knowledge gap to the objective of our study.

Despite the establishment of meteorological networks on Mt. Fanjing, a systematic investigation into the vertical gradient characteristics of O_3 and its precursors has not yet been conducted. To fill this knowledge gap and better understand the driving mechanisms of vertical O_3 distribution in mountainous background regions, this study leverages the three-dimensional meteorological monitoring system of Mt. Fanjing to establish a gradient observation platform for O_3 and its precursors at the mountain foot, mountainside, and mountaintop. The main aim of this study is to better understanding the altitudinal gradient variations of O3 production rates and sensitives. The findings will provide scientific support for the management of regional photochemical pollution and the conservation of ecological integrity in protected areas at the national level. (line 105-112 in the revised manuscript).

2) Page 5, Line 232-235: The ozone concentration at the summit of Fanjing Mountain, which is lower than that of most high mountain sites in the figure, is not included in Figure 3. Please double-check the data.

Response: We appreciate the reviewer's attentive observation. The omission of the Fanjing Mountain data point in Figure 3 was an oversight during figure preparation. In the revised version, we added the measured ozone concentration at the Fanjing summit (40.2 ± 14.7 ppb) to Figure 3 for direct comparison with other global mountain sites, and accordingly update the figure caption and related text in Section 3.1. (line 290-309, 882-889 in the revised manuscript).

Conclusion

This is an excellent piece of work that provides a valuable dataset and insightful analysis of ozone photochemistry in a complex, high-altitude terrain. The minor revisions suggested above will further polish the manuscript and solidify its arguments. I look forward to seeing the publication.

Response: Once again, we thank Reviewer 1 for their insightful and supportive comments, which have helped us identify areas for improvement in the clarity, presentation, and robustness of our manuscript. We are confident that addressing these points will further strengthen the paper. We look forward to the manuscript being considered for publication in EGU sphere.