Reply to Referee #2 Report on "Sources and variability of surface ozone over the Tibetan Plateau revealed by in situ observations and EMAC model simulations" by Zou et al. (egusphere-2026-499)

The referee comments are written in this font style and color.

Our answers are written in this font style and color, with the page and line numbers referring to the track-changes version of the revised manuscript.

Changes in the revised version of the manuscript are written in red.

This manuscript presents a valuable study of surface ozone variability over the Tibetan Plateau using in situ observations from Nam Co (NMC) and Nepal Climate Observatory-Pyramid (PYR), together with EMAC tagging simulations. The study investigates the seasonal and daily variability of surface ozone and attributes it to three broad source regions: the Northern Hemisphere and Tropical Stratospheric Source (NTST), the Northern Hemisphere Mid-High Latitude Tropospheric Source (NHTS), and the Tropical Tropospheric Source (TRTS). The results show that stratospheric influence is strongest in spring, that NHTS transport plays an important role in summer, and that TRTS exerts a particularly strong influence during the pre-monsoon period, especially over the southern and central Tibetan Plateau.
Overall, I find this to be an interesting manuscript that fits well within ACP. The topic is important, the combination of observations and tagged model simulations is appropriate, and the physical interpretation is generally robust. The manuscript is also well organized, and the figures are clear. I therefore think it is suitable for publication after moderate revision.

We sincerely thank the reviewer for the constructive comments and suggestions in the review process. We have fully considered all the comments and suggestions and made modifications in the revised manuscript. The point-by-point responses to the comments and suggestions are given below.

General comment:

1) *My main concern is how to address the relatively large model bias at the PYR station. A mean positive bias of 12.6 ppbv is reported for PYR in the EMAC simulation, which is much larger than that at NMC. This may affect the source-attribution results discussed in Section 4. The authors should clarify which source components may be most strongly overestimated at PYR, for example, NTST, NHTS, and/or TRTS. One possible way to address this issue is to estimate simple scaling factors for NTST, NHTS, and TRTS that reduce the mean model bias while also improving the correlation coefficient and/or minimizing RMSE. Applying such scaling factors* *could provide more robust estimates of the relative source contributions. I therefore strongly encourage the authors to make an effort to correct or at least better constrain the PYR bias.*

We sincerely thank the reviewer for raising this important point and for the constructive suggestions. We agree that the relatively large positive bias at PYR deserves further clarification, as it is critical for the interpretation of the source-attribution results. In the revised manuscript, we have clarified that this bias is most likely related to the limited model resolution in representing the steep, heterogeneous topography at the southern edge of the Tibetan Plateau, together with the associated local meteorology (Page 8, Line 19-25).

The persistent positive bias at PYR indicates that the model tends to overestimate surface O_3 over the southern Tibetan Plateau, particularly during late spring and early summer when stratospheric influence and photochemical O_3 formation are strongest. Because the model performance at NMC is much better, the PYR bias is unlikely to arise from a uniform overestimation across the entire Tibetan Plateau. Instead, it likely reflects the difficulty of representing the complex topography, local wind systems, precipitation, and boundary-layer exchange at PYR, as well as potentially underestimated dry deposition (e.g., due to underestimated vegetated surfaces, also because the bias is largest in the growing season). While the bias affects the absolute magnitudes, the simulated seasonal cycles and relative source contributions remain robust. Consequently, we interpret the PYR source contributions as physically meaningful within the current model configuration, while noting that their absolute magnitudes are subject to local terrain uncertainty.

We compared the nearby candidate grid cells around PYR. As shown in Figure B1, the grid cell ultimately selected for PYR (28.60 °N, 86.63 °E) provides a more realistic representation of the station's terrain than the geometrically nearest grid cell. Figure B2 further demonstrates that the nearest, lower-elevation grid cell yields even higher surface O_3 over the southern Tibetan Plateau than the selected grid cell. Therefore, using that nearest grid cell for the model – observation comparison would further increase the positive bias at PYR rather than reduce it. We have clarified this point in the revised manuscript (Page 6, Line 22-30).

PYR is located on the southern edge of the Tibetan Plateau, where the terrain is steep and highly heterogeneous. At a model resolution of 1.125° × 1.125°, subgrid-scale topographical features and local dynamics cannot be fully resolved. The model grid cell closest to PYR (27.48°N, 86.63°E) has a terrain elevation of only 2307 m, resulting in a discrepancy of 2772 m relative to PYR's actual elevation, and therefore cannot represent PYR. We instead selected the neighboring grid cell at 28.60°N, 86.63°E, whose elevation (4865 m) is much closer to the station altitude and better captures the surrounding topographic setting. A comparison among the nearby candidate grid cells shows that the lower-elevation cell would produce even higher surface O_3, which would further increase the positive bias at PYR. We therefore regard the remaining PYR bias as a consequence of the model's limited ability to represent complex topography and local meteorology, rather than as a problem that can be removed by choosing a different nearby grid cell.

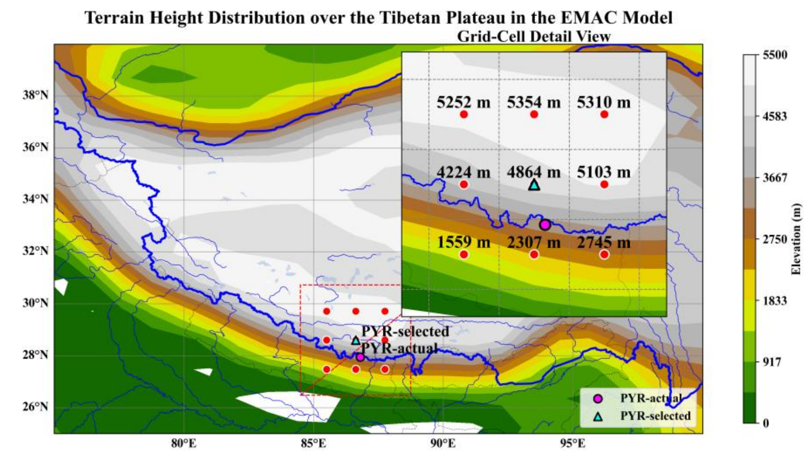

Figure B1 Spatial distribution of model terrain height over the southern Tibetan Plateau and the locations of the PYR station and candidate EMAC grid cells. The actual location of PYR is denoted by the pink dots. The selected grid cell is denoted by blue triangle.

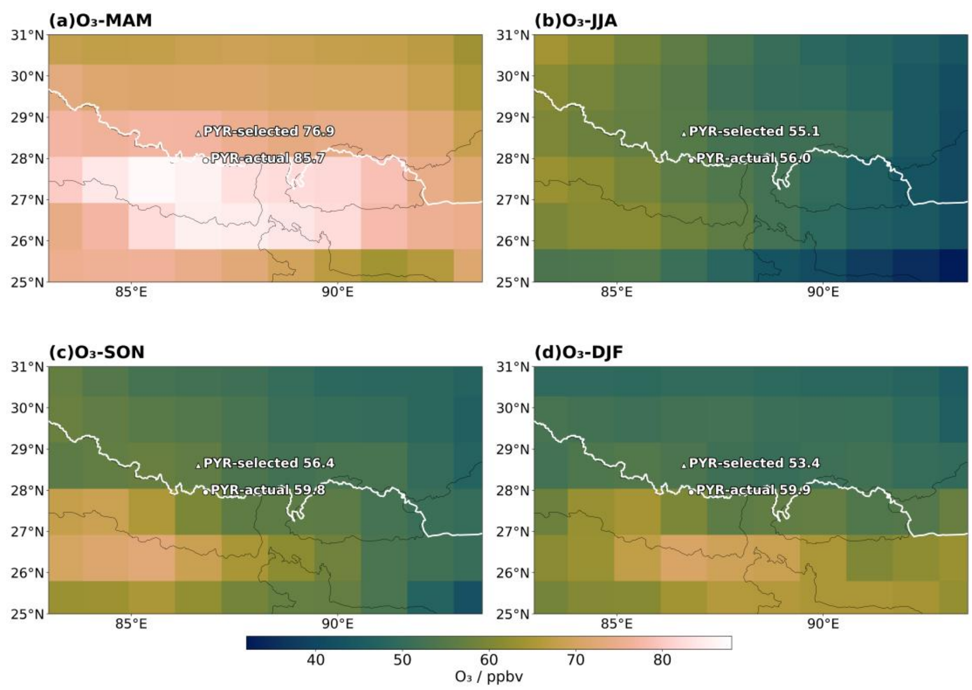

Figure 2 Comparison of simulated seasonal surface ozone concentrations between the selected grid cell and the geometrically nearest grid cell for the PYR station (2010–2012).

Accordingly, we have also revised the corresponding text in the Conclusions in the revised manuscript, so that it is consistent with the above discussion (Page 26, Line 10-21).

This discrepancy mainly reflects the difficulty of representing the steep and highly heterogeneous terrain, the complex underlying surface conditions, and the associated local transport processes over the southern Tibetan Plateau at the current model resolution. The positive bias is most pronounced during late spring and early summer, when stratospheric influence and photochemical O_3 formation are both strong, but this does not necessarily imply a unique overestimation of any single tagged source. Instead, we interpret the PYR bias as a model limitation that affects the absolute magnitudes of surface O_3, while the simulated seasonal cycles and relative source contributions remain physically meaningful and robust within the current model configuration. Therefore, we interpret the source-attribution results at PYR as physically meaningful representations of regional-scale transport within the current model configuration, while noting that their absolute values are subject to local topographical uncertainties.

Regarding which source components may be most strongly overestimated, we cannot robustly assign the PYR bias to a single tagged source only. The bias is present in the total surface O_3 field and therefore affects all tagged components to some extent. However, given the location of PYR on the southern plateau edge and its strong sensitivity to lower-tropospheric transport, local ventilation, and monsoon-related humidity and precipitation, the overestimation is likely more pronounced for the tropospheric contributions, especially TRTS and, to a lesser extent, NHTS, than for NTST. We have accordingly downplayed the interpretation in the revised text and now treat the PYR bias as a model limitation rather than a basis for source-specific correction.

We appreciate the reviewer's suggestion of applying scaling factors to NTST, NHTS, and TRTS. After careful consideration, we decided not to apply such ad hoc station-specific scaling. Because EMAC is a global chemistry-climate model, scaling the tagged contributions to forcibly correct the PYR bias would distort the physical consistency of the source-attribution framework across the Tibetan Plateau. Furthermore, it would degrade the robust agreement already achieved at the NMC station, where the mean bias is much smaller (3.2 ppbv) and the normalized mean bias is only 6.1%. Most importantly, post hoc scaling does not address the underlying physical cause of the PYR overestimation: the limitations in representing complex topography and local dynamic mixing. Therefore, we prefer to retain the physically based model output to ensure regional consistency, while transparently discussing the PYR bias as a limitation of the current model configuration.

Specific comments:

2) *Page 6, line 18*

A nearby grid cell is used for the model comparison at PYR. Please clarify the differences among *the nearby candidate grid cells, and discuss how these differences compare with the reported bias of 12.6 ppbv.*

We thank the reviewer for this helpful suggestion. As detailed in our response to General comment 1), we have clarified the rationale for selecting the PYR grid cell in the revised manuscript.

3) *Page 11, lines 15–17*

For the pre-monsoon, monsoon, and post-monsoon periods, please specify the exact date ranges.

Done. We have specified the exact date ranges for the seasons in the revised manuscript (Page 11, Line 15-18).

Based on monsoon regularity, we divide the calendar year into four phases, the pre-monsoon period (March 1 to June 20), the monsoon period (June 21 to September 10), the post-monsoon period (September 11 to November 30), and the winter period (December to February of the following year).

4) *Page 11, Table 2*

Since the tropospheric sources are analyzed by season in Section 5.2, I suggest that Table 2 also include tropospheric mean values averaged by season for consistency.

Done.

5) *Some grammar edits*

\- *Page 14, line 9: "This background also helps …"*

Corrected.

\- *Page 25, line 5: change to "this study systematically reveals …" for consistency with the tone used in the Conclusions*

Corrected.

Page 25, line 13: "this study has analyzed …"

Corrected.

Many thanks!