Reply to Comments by Anonymous Referee #1 on:

Assessing the relative impacts of satellite ozone and its precursor observations to improve global tropospheric ozone analysis using multiple chemical reanalysis systems

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We would like to thank anonymous referee #1 for their careful reading of our manuscript and for providing valuable comments, which have greatly improved the manuscript. We have revised the manuscript accordingly, and the main changes are summarized below:

1) An analysis was added to highlight the seasonal cycles in the improvements in ozone analysis by data assimilation (Figure 5 in the revised manuscript).
2) A more in-depth discussion was added on the impacts of discontinuity in the current satellite observing system on tropospheric ozone analysis, as well as potential strategies to address this issue after the termination.
3) An analysis was added to the Supplementary material to explain the reasons behind the large differences between TCR-2 and GEOS-Chem adjoint based on only the OMI NO2 assimilation.

Individual comments (in black) and point-by-point replies (in blue) are listed below. Revised text (*italicized font*) from the updated manuscript are in quotes below.

Note that we have added line types in Figure 4 in the revised manuscript to assist readers with color vision deficiencies according to the comments from Editorial Support.

The manuscript assesses the improvement in tropospheric ozone achieved through the assimilation of satellite observations of ozone and some of its precursors (NO2 and CO) in five reanalyses products compared to ozonesonde observations and satellite-based tropospheric ozone estimates. The study also distinguishes between the effects of directly assimilating ozone observations and assimilating only precursor observations. The main conclusion is that assimilation improved the consistency among the reanalyses products, though the impact varies among systems because of differences in the forecast model and assimilation configurations.

The study makes a significant contribution to the field by demonstrating both the capabilities and limitations of the current observing system in constraining the distribution of tropospheric ozone. By examining multiple reanalysis products, it goes beyond most previous studies that have often considered just a single product. The results are presented in a balanced manner, figures and tables are used where necessary, and the text is well-written.

We appreciate your careful review and positive comments.

The following are a few aspects that could be discussed further to help improve the manuscript:
i) It would be helpful to clarify why none of the recently developed satellite-based tropospheric column products (eg. IASI-GOME2 product) were used for evaluation. While these products aren't available for 2010 (the study's evaluation period), the reanalysis datasets extend to more recent years.

The analysis in the present study primarily focuses on 2010. Among the satellite-based tropospheric ozone column (TOC) products, the OMI-MLS TOC product was used because it covers the period (i.e., 2010) when all the reanalysis datasets and control runs, including the experimental reanalysis data, were available.
We have modified the relevant sentence as follows:
(p. 8, lines 222–225)
"*..., we used global distributions of the tropospheric ozone column (TOC) derived from OMI-MLS (Ziemke et al., 2006), which is ... and covers the period when all the reanalysis datasets and control simulations were available.*"

Additionally, three of the five reanalysis datasets were available in 2016. Thus, we compared the available reanalysis datasets with recently developed satellite products (Fig. 1). We used the retrievals of lowermost partial ozone column (0–3 km altitude) derived from the IASI+GOME-2 product (Cuesta et al., 2013), which have enhanced sensitivity in the lowermost troposphere because of the multi-spectral approach using the IASI and GOME-2 measurements in the thermal infrared and ultraviolet spectral domain. The ozone analysis fields were used without application of averaging kernels, as done by Okamoto et al., 2023). Compared to IASI+GOME-2, ozone analyses obtained from

CAMSRA, TCR-2, and GEOS-Chem commonly showed negative biases typically within 3–6 DU. Spatial correlation coefficients between IASI+GOME-2 and reanalysis datasets ranged within 0.53–0.58. The comparisons show commonly systematic bias patterns of all the reanalyses against IASI+GOME-2 products, which were inconsistent with the comparisons against ozonesonde observations. These results suggest a potential issue with the IASI+GOME-2 data or validation approach (e.g., not applying averaging kernels) and indicate that it does not provide helpful validation for this study. While recently developed satellite products from instruments, such as TROPOMI, CrIS, and AIRS-OMI are still under validation, it is meaningful to note the value of incorporating these datasets into future validation studies.

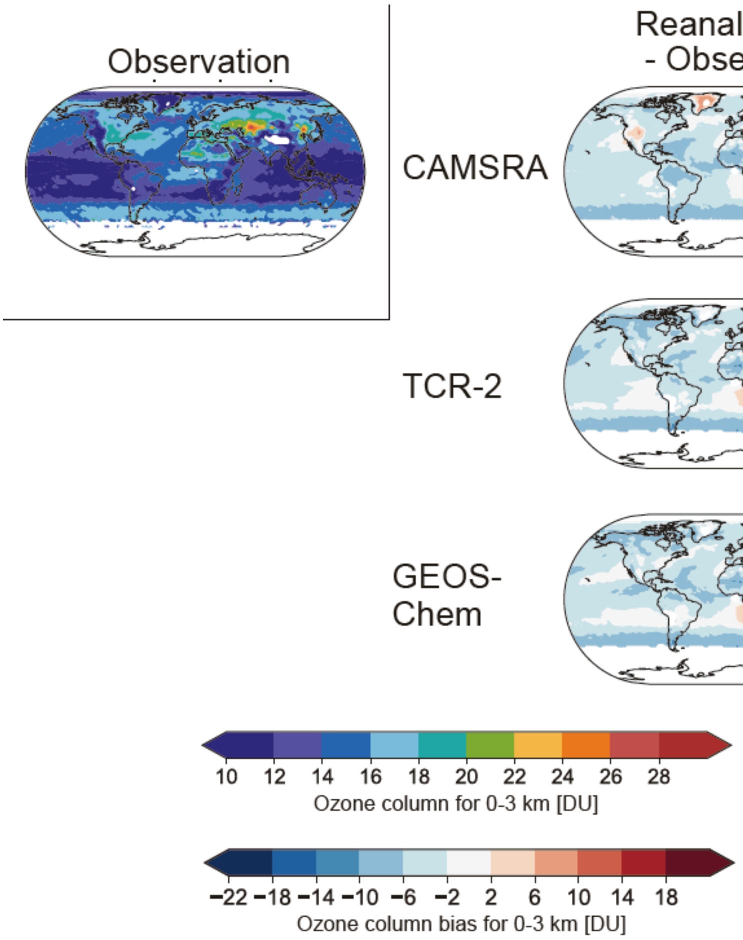

Figure 1. Global distributions of partial ozone column for 0–3 km altitude derived from the IASI+GOME2- observations (first column) and mean bias of the CAMSRA (first row), TCR-2 (second row), and the GEOS-Chem-adjoint (third row) relative to IASI+GOME-2 during June, July, and August 2016. The unit is the Dobson unit (DU).

ii) The analysis of the comparison of the reanalysis products with the OMI-MLS tropospheric column data could be expanded. In particular, it is interesting that assimilation introduces a bias in the models that was absent in the control runs without data assimilation (Figure 3). Also, the high biases seen in the comparison with OMI-MLS are not seen in the comparison with ozonesonde measurements.

We have added a comparison between OMI-MLS and ozonesonde data to Figure 3. This comparison indicates that OMI-MLS presented smaller TOC than ozonesonde observations for many cases, and these findings are consistent with the positive biases observed for the reanalysis relative to OMI-MLS. The following sentence has been added in the revised manuscript:
(p. 10, lines 287–289)
"*After data assimilation, all chemical reanalysis products consistently revealed positive biases of 5–10 DU relative to OMI-MLS from the tropics to the mid-latitudes of both hemispheres. However, this result is inconsistent with the reanalysis comparison results against ozonesonde measurements (see Section 3.2.2). Considering ozonesonde measurements as ground truth, part of the positive bias relative to OMI-MLS can be attributed to smaller TOC in the OMI-MLS data (by 3.7 DU on average) compared to ozonesonde observations, as confirmed in Figure 3 and reported by Gaudel et al. (2024).*"

iii) It would be useful to discuss how the loss of instruments like MLS, OMI, and MOPITT upon decommissioning of Aura and Terra might affect the quality of tropospheric ozone reanalysis datasets in the future.

We have added the discussion on the continuity of constraints on tropospheric ozone by satellite observations after the decommission of current satellites as follows:
(p. 15, line 472–p. 16, line 480)
"*The current satellite observing system provides unique and essential information that are essential for improving ozone analysis throughout the troposphere and stratosphere, as demonstrated in this study. However, the termination or retirement of current instruments such as OMI, MLS, MOPITT, and IASI in the near future may impact the ability to constrain whole troposphere ozone profiles effectively. More recent and future satellite measurements, such as TROPOMI, CrIS, and IASI-New Generation (NG) offer*

the potential to maintain or even improve constraints on tropospheric ozone and its precursors. For instance, advances in TROPOMI NO_2 assimilation compared to OMI NO_2 assimilation, as demonstrated by Sekiya et al. (2022), highlight these capabilities. For UTLS ozone analysis, several measurements, such as OMPS and SAGE III, continue to provide valuable profile measurements."

iv) It would also be useful to discuss whether new types of observations (e.g. profiles in the UTLS) are needed to better constrain tropospheric ozone. Would continuing the current observing system be sufficient, provided that the information from these observations is fully utilized?

The discussion what information will be needed to improve ozone analysis has been added, especially for UTLS ozone profiles, as follows:
(p. 16, lines 480–485)
"*Nevertheless, the uniqueness of MLS to observe through clouds and aerosols and a wide range of trace gases remains powerful in constraining tropospheric ozone profiles and chemistry system. The development of follow-on missions, such as the Atmospheric Limb Tracker for Investigation of the Upcoming Stratosphere (ALTIUS) (Fussen et al., 2019) and the Stratosphere Troposphere Response using Infrared Vertically-Resolved Light Explorer (STRIVE), to fill the gaps is highly desirable for maintaining high-quality tropospheric ozone analysis. Assessing the observational impacts of these instruments through data assimilation is expected to provide critical information for optimizing the observation system.*"

References

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