Please find below a point-by-point response to the two reviews including a list of all relevant changes made in the manuscript.

Response to Referee #1 comments

Boynard et al. present a comprehensive analysis on the quality and reliability of ozone columns observed from IASI, highlighting its consistency with another IR instrument (CrIS) and sonde observations, while pointing out discrepancies from UV instruments in terms of long-term trend analysis. This work includes rigorous validation and comparison by incorporating various datasets which is essential for understanding the spatiotemporal variability of tropospheric ozone, which has been under debate especially regarding recent global/regional trends. The manuscript is overall well written but there are some points to be considered and clarified before publication.

We thank the Referee for taking the time to review the manuscript. The comments have been addressed in the revised manuscript and are described below. We would also like to highlight that, in response to suggestions of CC2 and CC3, Section 4 has been substantially reorganized to improve clarity and coherence, but the results remain unchanged.

1. Section 2.1.1: Can the authors include a brief description on how the IASI-CDR O3 L2 products are retrieved? AK, DOFs, and a priori profiles are discussed as possible contributors to observed discrepancies but readers may not be familiar on how they would affect the retrievals.

The manuscript has been revised as follows:

"This study uses O_3 Level 2 products (vertical profiles) retrieved with the Fast Optimal Retrievals on Layers for IASI (FORLI) software, version v20151001, developed by ULB and LATMOS (Hurtmans et al., 2012). FORLI processes IASI Level 1C radiances together with meteorological Level 2 data to retrieve ozone profiles using an optimal estimation method. This approach combines measured infrared radiances with a priori ozone information to constrain the solution. The a priori profile provides an initial estimate of the atmospheric state and helps stabilize the retrieval in poorly constrained layers, especially when the measurements alone are not sufficient. In FORLI, a single a priori profile is used, based on the global mean McPeters/Labow/Logan climatology (McPeters et al., 2007), along with its associated variance-covariance matrix. The vertical sensitivity of the retrieval is described by the averaging kernels (AKs), which indicate how much the retrieved profile depends on the measurements versus the a priori. The degrees of freedom for signal (DOFs) quantify the amount of independent information extracted from the observations. Variations in the choice of a priori, the shape of AKs, or DOF values can directly influence the retrieval accuracy and vertical resolution, especially in regions where IASI sensitivity is limited. The FORLI software is fully described in Hurtmans et al., (2012)."

2. L123-125: Please clarify what IASI-A/B refer to. Are they the products from Metop-A/B?

It has been clarified as follows:

"The IASI instruments, named IASI-A, IASI-B, and IASI-C, are carried aboard the Metop-A, Metop-B, and Metop-C satellites, launched in 2006, 2012, and 2018, respectively (Clerbaux et al., 2009)."

3. L230-234: Are the differences in tropospheric columns related to uncertainties in the tropopause height?

The discrepancies in the tropospheric columns before 2010 are likely due to uncertainties in the tropopause height, as the IASI-FORLI product used an earlier version of the temperature profiles to determine the thermal tropopause, in contrast to the more recent version used by IASI-CDR. This is further supported by the fact that we do not observe the same pattern in the differences for the total column product, suggesting that the variations in the tropospheric column are linked to the differing temperature profiles used by the two products.

This paragraph has been added to the revised manuscript.

4. L260: O3 -> O_3

Corrected.

5. L338 "IASI pixels have been processed (only 3.5 out of 10)": Can you clarify what this "processed" means?

Only a limited number of stations meet the required criteria, primarily due to the fact that retrievals have been performed for only 3.5 out of 10 IASI pixels.

As this sentence is already provided in Section 2.1.1, it has been removed.

6. L375: a secondary second smaller peak -> a secondary smaller peak

Corrected.

7. L400-402: The two lines look nearly similar at around 200 hPa, they seem to diverge above that altitude. Assuming that IASI is more sensitive to temperature, I'm curious why the smoothed sonde observations (which I understood as to have applied IASI's vertical sensitivity, i.e., AK) show larger discrepancies than the raw sonde?

Thank you for your observation. Around the 200 hPa level, the differences between IASI and both the raw and smoothed sonde profiles are indeed quite similar, as your comment notes. However, above this altitude, particularly in the polar regions, the discrepancy between IASI and the smoothed sonde becomes larger than that with the raw sonde. This behavior arises because IASI has limited vertical sensitivity throughout the profile, which becomes especially consequential in cold polar conditions due to weaker radiance signals caused by low temperatures. Under these circumstances, the retrieval relies more heavily on the a priori. When applying the averaging kernel (AK) to the ozone sonde data, the smoothed sonde reflects IASI vertical resolution but also incorporates the influence of the a priori, particularly where the retrieval is poorly constrained (e.g., above the tropopause). If the a priori is not representative of the true atmosphere, this can cause larger discrepancies between IASI and the smoothed sonde than with the raw sonde, which remains unaffected by retrieval assumptions.

In contrast, in the midlatitudes and tropics, the difference between IASI and the raw sonde is generally larger than with the smoothed sonde, as expected. Additionally, in the tropics, the IASI–raw sonde difference profile shows a vertical shift upward relative to the IASI–smoothed sonde difference. This shift likely results from the combined effects of the AK, which smooths and redistributes vertical information to reflect IASI coarser vertical resolution, and a potentially non-representative a priori for tropical conditions.

The text has been revised as follows:

"In the polar regions, differences between IASI and sonde profiles begin to diverge above 200 hPa, with larger discrepancies between IASI and the smoothed sonde than the raw sonde. This results from IASI's limited vertical sensitivity, which is further reduced in cold conditions due to weaker radiance signals, increasing reliance on the a priori. Applying the averaging kernel (AK) smooths the sonde to IASI's resolution but also incorporates a priori biases, especially where retrievals are poorly constrained, such as above the tropopause. In contrast, in midlatitudes and the tropics, differences between IASI and the raw sonde are generally larger. In the tropics, the IASI–raw sonde difference profile shifts upward relative to the smoothed sonde difference, likely reflecting the AK smoothing and a less representative a priori."

8. L443-445, Figure 12: The difference between the left/right panels over Southeast Asia is surprising. There should be a lot of biomass burning emissions in that region, which wouldn't have been particularly affected by the pandemic. Has the Lanina affected fire frequencies?

The surprising difference between the left and right panels over Southeast Asia likely results from a combination of meteorological, anthropogenic, and pandemic-related influences on fire activity and ozone precursor emissions.

A major factor is the increased frequency and persistence of La Niña events from 2020 to 2023. La Niña typically brings wetter conditions to South and Southeast Asia, which suppress fire incidence by increasing soil moisture and reducing vegetation flammability (Zhu et al., 2021; Yue et al., 2022). This leads to lower emissions of ozone precursors such as CO, NO_x, and VOCs, thereby limiting ozone formation. Concurrently, satellite observations indicate a decline in biomass burning emissions across parts of Asia, supported by decreasing CO trends in regions including China and India (Zheng et al., 2020; Xie et al., 2025). Additionally, stricter environmental regulations and improved land and fire management in countries such as Indonesia and India have contributed to reducing precursor emissions (Zhang et al., 2020; Kashyap et al., 2024). The COVID-19 pandemic also temporarily reduced fire activity by restricting agricultural and land-clearing practices, with reported fire count reductions ranging from 2.9% to 79.4% in South and Southeast Asia relative to pre-pandemic years (Vadrevu et al., 2022).

While the mean tropospheric ozone trend weakened over 2008–2023, quantile regression analysis at the 90th and 95th percentiles reveals increasing trends, suggesting persistent or intensifying extreme ozone episodes. These extremes are potentially linked to episodic fires or favorable meteorological conditions (see Figure 1). This pattern indicates that despite an overall decline in average fire emissions, occasional intense fire events continue to drive elevated ozone levels.

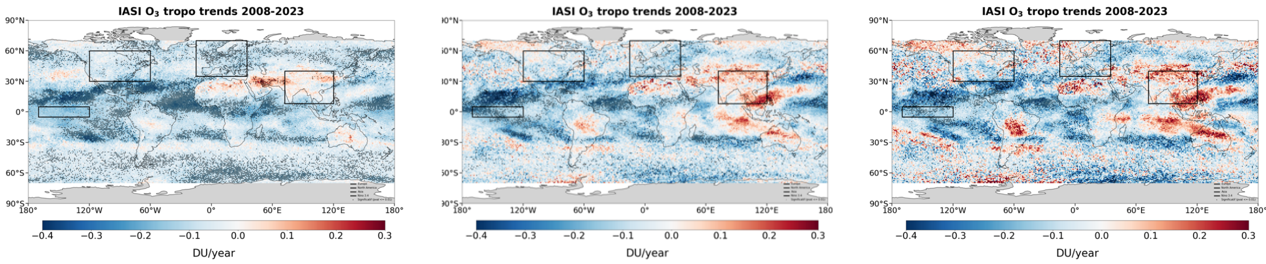

Figure 1: Regional ozone trend estimates at the 50th (left), 90th (middle), and 95th (right) percentiles. Increasing the percentile reveals positive trends mainly in biomass burning regions (South America, South China, Indonesia, Australia), indicating a rise in extreme ozone episodes, while other regions, in particular in the tropical region, consistently show negative trends across all quantiles.

Together, these regulatory, meteorological, and anthropogenic factors likely explain the observed weakening or reversal of tropospheric ozone trends over South Asia between 2008 and 2023.

We have revised the manuscript text accordingly as follows:

“The overall decline in tropospheric ozone between 2008 and 2023 likely reflects a combination of factors, including stricter environmental regulations and improved land and fire management, particularly in parts of Indonesia, India, and China (Zhang et al., 2020; Kashyap et al., 2024), and persistent La Niña conditions from 2020 to 2023 (Zhu et al., 2021; Yue et al., 2022). These La Niña events bring wetter-than-usual conditions to South and Southeast Asia, suppressing fire activity by increasing soil moisture and reducing vegetation flammability, thereby reducing emissions of ozone precursors such as carbon monoxide, NO_x, and VOCs (Zheng et al., 2020; Xie et al., 2025). Additionally, the COVID-19 pandemic temporarily reduced fire activity through restrictions on agricultural and land-clearing practices, with fire count reductions of 2.9% to 79.4% reported in South and Southeast Asia compared to pre-pandemic years (Vadrevu et al., 2022).

Extending the trend analysis using quantile regression at the 90th and 95th percentiles over the same period offers further insight into ozone behavior, especially regarding extreme ozone episodes. As shown in Figure C1 (Appendix C), biomass burning regions such as South America, South Asia, Indonesia, and Australia show near-zero or slightly negative median (50th percentile) ozone trends, but positive trends at higher percentiles, indicating an increased frequency or intensity of extreme events linked to episodic biomass burning. In contrast, other regions generally display consistent negative trends across all quantiles.

These results highlight the complexity of regional ozone dynamics: while average ozone concentrations may decline due to structural changes in emissions and climate variability, extreme ozone events can persist or even intensify in some regions. This underscores the importance of considering both mean and extreme values when assessing tropospheric ozone trends.”

9. Figure 13: How significant was the drop in precursor emissions during the pandemic? It also looks like O_3 is bouncing back up recently. This has been observed in surface concentrations over the US (US EPA). Can the authors briefly comment on observed changes of NOx/VOCs and implications for surface O_3 trends?

During the COVID-19 lockdowns, several studies found that anthropogenic NO_x emissions dropped significantly worldwide. In India, for example, Pakkattil et al. (2021) reported that NO_2 concentrations decreased by about 71.9% compared to pre-lockdown levels, while measurements of VOCs, specifically BTEX compounds, in major metropolitan areas showed reductions of around 82%. These uneven reductions in precursors produced complex effects on surface ozone. In VOC-limited regions, the reduction in NO_x led to less ozone "titration" by NO, which could result in increased ozone concentrations. In contrast, in NO_x-limited areas, simultaneous decreases in both NO_x and VOCs resulted in lower ozone formation (Miyazaki et al., 2021; Nussbaumer et al., 2022). Similarly, Li et al. (2025) documented recent trends and drivers of anthropogenic NO_x emissions in China since 2020, highlighting the rebound in emissions following the initial lockdown reductions.

Recent observations indicate that following the sharp decline during the lockdowns, surface ozone (O_3) concentrations in the United States began to rebound as NO_x emissions recovered. This trend is reported by the U.S. EPA (2024), with the 2023 data showing a pronounced surface-level recovery. Complementary studies further stress that the observed rebound is tightly linked to local precursor dynamics and the prevailing chemical regime (Miyazaki et al., 2021; Keller et al., 2021).

These findings underscore the importance of considering the prevailing chemical regime, whether VOC- or NO_x-limited, when designing emission control strategies to effectively manage surface ozone levels. Our IASI satellite data show that while surface ozone has rebounded following precursor emission recovery, negative anomalies in the free troposphere persist through 2023, highlighting the complex vertical and regional dynamics influencing ozone trends.

The text has been revised as follows:

"The negative ozone anomalies observed since 2020 coincide with substantial reductions in precursor emissions due to COVID-19 lockdowns. Several studies report significant decreases in NO_x and VOC emissions during this period. For example, in Indian cities, NO_2 levels dropped by over 70% and VOC concentrations by more than 80% during the initial lockdowns (Pakkattil et al., 2021). These changes impacted ozone production differently depending on local chemical regimes: in VOC-limited areas, reduced NO_x emissions decreased ozone titration by NO, potentially increasing ozone concentrations, whereas in NO_x-limited regions, simultaneous decreases in NO_x and VOCs led to lower ozone formation (Miyazaki et al., 2021; Nussbaumer et al., 2022). As economic activity resumed, precursor emissions, especially NO_x, rebounded in many regions, resulting in a partial recovery of surface ozone concentrations, particularly over North America (U.S. EPA, 2024). However, IASI data indicate that free tropospheric ozone anomalies remained negative through 2023 across most regions, suggesting a decoupling between surface and free tropospheric ozone behavior, likely influenced by vertical transport and regional dynamics."

10. L474: troposphere (450 hPa to thermal tropopause) troposphere. -> troposphere (450 hPa to thermal tropopause).

Revised to "full (following the WMO thermal definition), lower (surface to 450 hPa) and **upper** (450 hPa to thermal tropopause) troposphere"

11. L479, Figure 14: Does cp450 refer to the lower troposphere? I suggest adjusting the figure labels so that they are consistent with the phrases used in the text.

We confirm that cp450 does indeed refer to the lower troposphere. In response, we have revised the figure labels for consistency: cp450 has been renamed to "lower_tropo", and tropo_upper has been changed to "upper_tropo" to match the terminology used in the manuscript.

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Response to Referee #2 comments

The manuscript “Tropospheric Ozone Assessment Report (TOAR): 16-year ozone trends from the IASI Climate Data Record” presents and validates the IASI-CDR O_3 product, a reprocessed and homogenized version of IASI-FORLI, providing a consistent dataset of tropospheric ozone spanning 2008–2023. The dataset is validated through comparisons with the TROPESS-CrIS product globally and with ozonesonde measurements at selected sites. A comprehensive trend analysis is conducted across multiple vertical layers using 16 years of observations. The manuscript is well-structured, and it is informative, offering a valuable contribution to the understanding of tropospheric ozone dynamics and trends over the past two decades. Below, I provide several comments for the authors to consider before the manuscript can be recommended for publication:

We thank the Referee for taking the time to review the manuscript. The comments have been addressed in the revised manuscript. We would also like to highlight that, in response to suggestions of CC2 and CC3, Section 4 has been substantially reorganized to improve clarity and coherence, but the results remain unchanged. Below is a point-by-point response to each of the Referee comments.

1. The authors employ a 1° × 1° gridded resolution for comparing IASI and CrIS datasets. Given that both instruments have native spatial resolutions on the order of 12–14 km at nadir, it would be helpful for the authors to justify the use of this relatively coarse grid. Was this choice driven by data availability, computational efficiency, or other methodological considerations?

The choice of a 1° × 1° grid is appropriate for global and seasonal-scale validation. Both IASI and CrIS have native footprints of 12–14 km at nadir, but their spatial resolution degrades with increasing scan angle. For example, at 48° off-nadir, IASI expands to about 40 km across-track and 20 km along-track, while CrIS also experiences footprint enlargement at the edges of its swath. Given these variations, a 1° × 1° grid ensures sufficient data density for robust statistical analysis while providing computational efficiency. This grid size is well-suited for comparing seasonal patterns across both instruments at the global scale.

The manuscript has been revised as follows:

“The comparison between IASI and CrIS is carried out for both total and tropospheric columns over the common time period 2016–2022. A spatial grid of 1° × 1° is employed to facilitate this comparison. While this resolution might initially appear coarse, it is well suited for a global and seasonal-scale analysis. Both IASI and CrIS have native spatial resolutions of approximately 12–14 km at nadir. However, the effective resolution degrades at larger scan angles. For instance, at a 48° scan angle, the IASI footprint becomes significantly elongated due to the oblique viewing geometry, reaching up to ~40 km across-track and ~20 km along-track. This spatial degradation supports the use of a coarser aggregation grid. The choice of a 1° × 1° grid is further justified by two main considerations. First, it ensures sufficient spatial sampling within each grid cell, which would not be guaranteed with finer resolutions, especially at global scale. Second, it enables efficient processing of large datasets while preserving the spatial representativeness needed for robust statistical analysis.”

2. Was validation at finer spatial resolutions considered? The authors might comment on whether such an approach was explored and how it might influence the interpretation of inter-satellite differences.

Validation at finer spatial resolutions was not considered, as the validation was performed on a seasonal scale, making the 1° x 1° grid more suitable. A finer resolution would not provide enough pixels within each 1° x 1° grid cell to ensure reliable results, given that the pixel size is 12-14 km.

3. The trend analysis is performed using quantile regression at the 50th percentile (median), which is robust. However, applying the same method to higher percentiles would help assess whether the trends differ when considering extreme ozone events. This would be especially relevant considering the reported decreasing trends in tropical regions, which diverge from findings using UV-based instruments like OMI that often suggest stable or increasing trends in similar regions.

Thank you for the insightful comment. Following your suggestion, we extended our quantile regression analysis to higher percentiles (0.9 and 0.95). The results reveal notable differences compared to the median trends, particularly in regions affected by biomass burning such as South America, South Asia, Indonesia, and Australia. While median trends in these areas are near zero or slightly negative, trends at higher percentiles are clearly positive, suggesting an increase in the frequency or intensity of extreme ozone events likely linked to episodic biomass burning emissions.

Interestingly, the positive trends at higher percentiles observed in South Asia show improved agreement with OMI-MLS observations (Dunn et al., 2024), which report the strongest positive ozone trends above South and East Asia over 2004–2023. This convergence likely occurs because extreme ozone enhancements caused by intense biomass burning events impact both the lower troposphere (captured by IR instruments) and the full column (captured by UV instruments like OMI). Thus, despite differences in vertical sensitivity and retrieval techniques, both instruments detect the influence of extreme events in these regions.

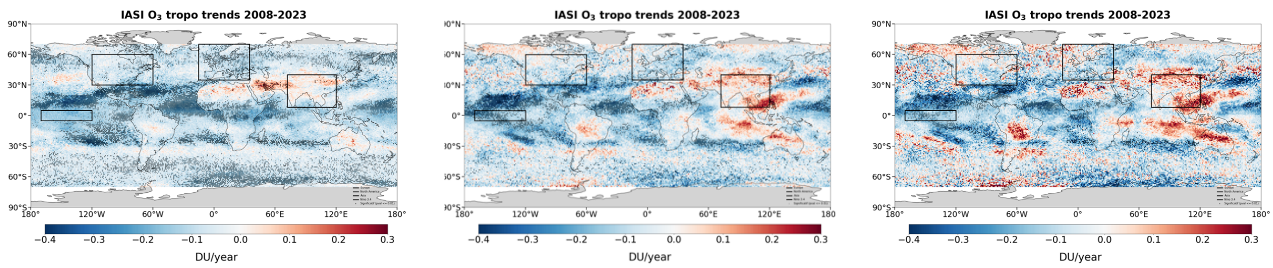

Figure 1: Regional ozone trend estimates at the 50th(left), 90th (middle), and 95th (right) percentiles. Increasing the percentile reveals positive trends mainly in biomass burning regions (South America, South China, Indonesia, Australia), indicating a rise in extreme ozone episodes, while other regions, in particular in the tropical region, consistently show negative trends across all quantiles.

The manuscript has been revised as follows:

"Extending the trend analysis using quantile regression at the 90th and 95th percentiles over the same period offers further insight into ozone behavior, especially regarding extreme ozone episodes. As shown in Figure C1 (Appendix C), biomass burning regions such as South America, South Asia, Indonesia, and Australia show near-zero or slightly negative median (50th percentile) ozone trends, but positive trends at higher percentiles, indicating an increased frequency or intensity of extreme events linked to episodic biomass burning. In contrast, other regions generally display consistent negative trends across all quantiles."

4. The use of 1° × 1° resolution in the trend analysis may mask finer-scale changes, especially in urban regions where surface ozone levels are known to be increasing in many parts of the world. Since urban areas occupy a small fraction of a 1° grid cell, their signal could be diluted by surrounding lower-concentration regions, potentially biasing the trend analysis toward decreases. Could this resolution choice be contributing to the observed negative trends? Discussing this potential limitation would strengthen the interpretation of the trend results.

We thank the reviewer for this thoughtful comment. While it is true that a 1° × 1° resolution may dilute localized signals such as urban ozone enhancements, we emphasize that the primary focus of this study is on global and regional trends, rather than city-scale or local analyses. At these broader spatial scales, the 1° × 1° resolution provides a suitable balance between spatial detail and statistical robustness, especially when working with satellite-based datasets that are inherently limited in their ability to resolve fine-scale features.

Nonetheless, we agree it is helpful to acknowledge that finer-scale trends, particularly in urban areas, may not be fully captured at this resolution, and we have added a sentence in the discussion to that effect.

The manuscript has been revised as follows:

"While the 1° × 1° resolution is appropriate for assessing global and regional trends, it may not fully capture localized changes, particularly in urban areas where surface ozone concentrations can exhibit sharper gradients due to factors such as traffic, industrial emissions, and local meteorological conditions."

5. Lines 360-365. The manuscript notes that differences in tropospheric ozone columns between IASI and CrIS are partly driven by the a priori information used—fixed for IASI and seasonally/latitudinally variable for CrIS. Given the importance of the a priori in shaping retrievals, particularly under conditions of low sensitivity, could the authors comment on what might constitute a more optimal or standardized approach? For example, would using dynamic, seasonally and geographically resolved climatologies for both instruments help reduce inter-product differences?

We thank the reviewer for the insightful comment.

We have conducted an additional analysis to investigate this point more deeply. Specifically, we applied the IASI a priori (fixed in latitude, not seasonally resolved) to the TROPESS retrieval algorithm, which normally uses a spatially and seasonally varying a priori. The results indicate that the choice of a priori profile clearly influences the retrieved ozone profiles. However, the differences observed between the IASI and TROPESS products are smaller than the differences between their respective a priori profiles. This is further illustrated by Figure 1 showing that the difference between the priors (right maps) is larger than the difference between the retrieved TROPESS and IASI columns (left maps). Additionally, the difference between the priors (right maps) is also larger than the difference observed when swapping the priors (middle maps). While the left and middle maps have comparable magnitudes, their spatial distributions differ to some extent. These findings suggest that the a priori alone does not fully explain the discrepancies between the datasets. Moreover, the retrieval process is not strictly linear with respect to the a priori assumptions, indicating that a complete retrieval using the IASI a priori would be necessary to accurately quantify its impact (Kulawik et al., 2008). We will update the manuscript to include this analysis and discussion and emphasize that differences in retrieval methodologies, such as the treatment of prior covariance matrices and the representation of vertical ozone profiles, likely contribute significantly to the observed inconsistencies.

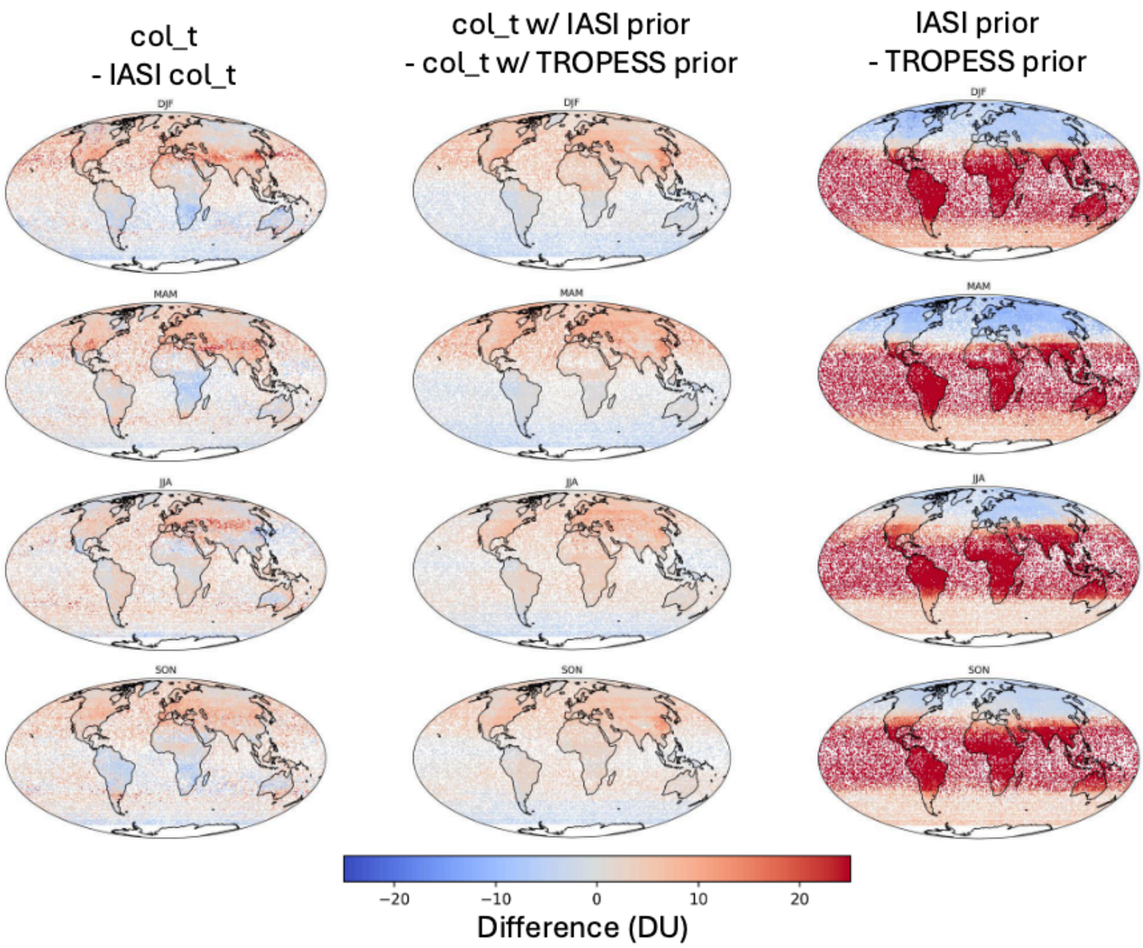

Figure 1. Spatial distribution of tropospheric ozone (Dobson Units) over the period 2016-2022: left: difference between CrIS (TROPESS) and IASI retrievals; middle: difference between CrIS retrievals using the IASI and TROPESS a priori; right: difference between the IASI and TROPESS a priori.

6. In Figure C1, the most pronounced positive trends in lower tropospheric ozone appear in arid regions of Africa and Australia. It would be helpful for the authors to comment on the possible drivers behind these trends briefly. Are they associated with natural emissions (e.g., soil NO_x), biomass burning, or transport processes?

It should be noted that retrievals over arid and desert regions, such as those in parts of Africa and Australia, are subject to well-documented issues related to surface emissivity (Boynard et al., 2018). These limitations can adversely affect the accuracy of lower tropospheric ozone estimates in these areas. Consequently, the observed positive trends are likely biased and should be interpreted with caution. We have clarified this point in the revised manuscript and advise against attributing these trends to physical processes such as soil NO_x emissions, biomass burning, or long-range transport.

The manuscript has been revised as follows:

"Over arid and desert regions, such as parts of Africa and Australia, retrievals may be affected by surface emissivity issues (Boynard et al., 2018), potentially introducing biases in the trend estimates. Therefore, the positive trends observed in these regions should be interpreted with caution."

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