Atmospheric Measurement Techniques Discussions

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Reply on RC1

Prajjwal Rawat et al.

Author comment on "Performance of AIRS ozone retrieval over the central Himalayas: use of ozonesonde and other satellite datasets" by Prajjwal Rawat et al., Atmos. Meas. Tech. Discuss., https://doi.org/10.5194/amt-2022-187-AC1, 2022

We are grateful to both the referees for their useful comments and constructive suggestions, which have improved the MS significantly. The manuscript is suitably revised by incorporating their suggestions and comments. We are also thankful to the editors for their time. We feel that the revised manuscript is suitable for publication in AMT. Please find here our responses in boldface and the referee's comments are in regular font.

Refree#1

This paper assessed AIR ozone profile product against collocated references at the central Himalayas. They performed statistical comparisons with ozonesonde measurements and correlated satellite measurements as well as evaluated the capability of AIRS measurements to capture the atmospheric ozone variabilities inferred from summer monsoon activity, biomass burning, and stratospheric intrusions. The scope of this paper is well within AMT. However, I could not recommend this paper for publication.

We thank you for your detailed comments and suggestions on manuscripts. We have addressed all your comments and we strongly feel that our responses will be in line with your expectations.

Major comments

- Figure 4 and section 3.1: In this section, this author discussed the spatial variation of ozone along with the ozonesonde flight path. However, it is wrong. The associated figure shows the vertical variation of ozone along with the flight path. The spots filled with green to red color represent the stratospheric air masses (o3 > 100 ppb). The horizontal drifting of balloon could be a problem in the polluted boundary layer, but the ozonesonde site used in this study is located in the Himalayan Mountain. The horizontal drifting does not matter with AIRS and ozonesonde comparison.

We are sorry, if there is some confusion with the terminology "spatial distribution". Here we wanted to demonstrate the overall performance of ozonesonde and AIRS over this region and felt that this is the best way to show it. As it gives feeling of spatial and vertical distributions. Our intention was not to claim this as spatial distribution alone, thereby we have clearly mentioned about the altitude in the 4th line onward in the section itself. We have also given

two supplementary figures (S3 and S4) showing altitude variations, along the latitude and longitude. This section's main objective is to show ozone's spatial variation at different altitudes along the balloon track from ozonesonde and AIRS measurements. The ozone values are shown in the logarithmic scale from 10 ppbv to 10^4 ppbv thereby giving a feeling of the stratospheric ozone also. Further, this figure gives both the tropospheric and stratospheric distribution along the balloon track from the two measurements. This figure also gives an overall feeling on the role of winds, its reversal and drift of the balloon during four seasons. Highly polluted IGP region is nearby and biomass burning also influences this site. Additionally, supplementary figures (S3 and S4) are the byproducts of the Figure 4 and we discuss the bias and correlations in terms of "altitude" in addition to the latitude and longitude.

To avoid any confusion, we have changed the title of the section to "Ozone Distribution along Balloon Trajectory" in the revised MS. Further, we have also revised few sentences in this section, making above aspects clearer.

- 428-437 (page 19)

- This author related the positive values of MI with strong monsoon and negative values with weak monsoon. Actually, the monsoon index taken from Wang et al. (2001) represents the strength of the Indian summer monsoon index. The seasonal pattern of MI presented in this paper (large negative values in winter) is not consistent with that shown in Wang et al. (2001) (nearly zero in winter). You should check if there is any bug in calculating monsoon index and need a better understanding on the monsoon index of Wang et al. (2001).

The monsoon index in Wang et al. (2001) is the normalized monsoon index (MI), as mentioned in their caption of figure 3. We have confirmed the robustness of our calculated MI by comparing it with those given by Asia-Pacific Data-Research Center (APDRC) (http://apdrc.soest.hawaii.edu/projects/monsoon/daily-data.html).

APDRC MI data are based on NCAR/NCEP wind and our analysis is based on MERRA-2 reanalysis (M2TMNXSLV v5.12.4) data. In addition, we have also made calculation using ERA-5. As shown in the below figure (Figure 1), our calculated MI (by MERRA-2) are in good agreement with the MI from APDRC and also calculated with ERA-5. Small differences could arise due to the different data source (NCEP/MERRA-2/ERA-5).

Therefore, the mentioned difference is mainly due to display of "normalized monsoon index" in the figure 3 of Wang et al. (2001) and the calculated MI in the present work are correct.

Figure 1. A comparison of calculated MI index in the present study (MERRA-2) with those with MI data from Asia-Pacific Data-Research Center (APDRC) and calculated using ERA-5.

- In Figure 6, the weak summer monsoon could be associated with drier airs, but not for lower cloud cover and higher surface temperature as well as larger ozone amount near surface (larger net ozone production).

Thank you very much. We agree that it cannot be related "directly" with the larger net ozone production and we have removed that part in the revised MS. Nevertheless, model simulations (Lu et al., 2018) have shown that the weak summer monsoon year is associated with higher surface temperature, drier air, and lower cloud cover over India. Now, we have added this (Lu et al., 2018) reference in the revised MS.

- Line 432 "Thereby anti-correlation between ozone and monsoon index". This analysis is wrong. This anti-correlation is not driven from the interannual variations of the summer monsoon strength and its impact on ozone abundance. It is driven from the global seasonality of ozone (low in winter and high in summer) and not understandable monsoon index.

Thank you very much for raising this concern. We would like to add a clarification here that we were not referring to the anti-correlation seen in the monthly variations. It was for annual variations. Monsoon index also refers to the total annual rainfall. Below figure 2 shows the analysis from Lu et al. (2018) in left and our analysis in right. Both show an anti-correlation between MI and the tropospheric ozone (with OMI retrieved ozone in Lu et al., 2018, the correlation was -0.46 over the Indian region). We also observed a significant anti-correlation between MI and annual average ozone mixing ratio in the 300 - 100 hPa region of -0.49 (Below, Figure 2 right), and a similar weaker anti-correlation is also found for other layers. Lu et al. (2018) also defined negative MI as a weaker monsoon year and positive MI as a strong monsoon year. With the help of model simulation, Lu et al. (2018) showed, as mentioned earlier, that the weak summer monsoon year is associated with higher surface temperature, drier air, lower cloud cover over India, and weaker convection, which account for higher ozone than the strong summer monsoon conditions.

Yes, it is correct that there is also a role of large scale ozone variations when showing the monthly data. We have now revised the paragraph accordingly in the revised MS.

Figure 2. Annual variation of Monsoon Index and lower tropospheric ozone over India (Lu et al., 2018) on the left. Right side figure shows analysis made in the present work for 300 - 100 hPa region. The anti-correlation between ozone and monsoon index could be seen in both the analysis.

- Line 435: Secondary ozone peak is a common feature found over the summer monsoon affected area, due to fair weather after termination of summer monsoon rainfall season and before the appearance of winter monsoon. The biomass burning could contribute on the secondary ozone peak, but you need to demonstrate it.

Thanks again. Secondary ozone peak in the post-monsoon period has been extensively studied in surface ozone and balloon-borne observations over the present observation site. Surface ozone observations (Kumar et al., 2011),

observations of its precursors like CO, NOx (Sarangi et al., 2014) and NMHCs (Sarangi et al., 2016) and model simulations (Kumar et al., 2012b) have clearly demonstrated the role of the biomass burning in this secondary peak. Balloon-borne observations have also shown the contribution of biomass burning up to about 6 km (Ojha et al., 2014). We have now briefly added this in the revised MS. Additionally, we have now added a supplementary figure (Figure S7) showing monthly variation in fire counts over northern India during 2011 – 2017 that clearly shows higher fire counts during pre-monsoon (spring) and post-monsoon (autumn) periods.

Sarangi, T., Naja, M., Lal, S., Venkataramani, S., Bhardwaj, P., Ojha, N., Kumar, R. and Chandola, H.C.: First observations of light non-methane hydrocarbons (C2–C5) over a high altitude site in the central Himalayas. Atmospheric Environment, 125, pp.450-460, 2016.

(Here, we have listed additional references only those are used in the response part. References those are available in the MS are not listed here. Similar practice is followed further.)

- Figure 8: I don't think that the comparison results are not inconsistent each other to characterize AIRS ozone profile quality. In manuscript, the author just describes the number of differences/R without "why", mostly.

Thanks, we have added explanation in the revised MS and we feel that the below comment is also related with this comment and we are further responding it below.

- The AIRS-sonde differences are significantly larger at 800 - 600 hPa in summer than other seasons, but the correlation is larger in summer than other season. Please describe "why"

Thanks for pointing this. This is possible when AIRS retrieval are highly influenced by the Apriori. We have made histogram remainder plots with AIRS retrieval and with Apriori in summer-monsoon period that do not show such difference with Apriori (below Figure 3). Additionally, the correlation coefficient is 0.86 with retrieval data (when difference is greater), while correlation is 0.65 with Apriori with negative Biases. Summer-monsoon period experiences cloudy conditions and arrival of moist/cleaner oceanic air and therefore the AIRS retrieval seems to be mostly contributed from the a-priori profile and erroneous due to cloud screening. In the revised MS we have added a sentence regarding the larger correlation of AIRS and ozonesonde (AK) during summer monsoon and possible contribution from Apriori.

Figure 3. Histogram remainder of ozonesonde(AK) with AIRS retrieved ozone and apriori in the 800 - 600 hPa region. The correlation is shown on the right during summer-monsoon.

- For comparison in 300-100 hPa, the differences are much larger in spring and winter than in other season, but the correlation is significantly larger in winter and summer than in others. Please describe “why”

Thank you very much. We feel that AIRS sometimes is unable to capture the prominent dynamical influence like downward transport due to its poorer vertical resolution and limited temporal resolution. Additionally, it is also observed that AIRS is unable to capture several events of the tropopause folding (Figure 3 in MS) those occurs largely in winter and early spring. The larger difference (between AIRS and ozonesonde) during winter and spring is suggested to be due to frequent dynamical events as mentioned. Additionally, such differences are not seen in the apriori as seen in the below figure 4. At the same time a higher correlation during the winter season is mainly due to better retrieval with some biases in compared to apriori. While the summer-monsoon higher correlation is mostly contributed by apriori (below Figure 4).

Figure 4. Histogram remainder of ozonesonde(AK) with AIRS retrieved ozone and apriori in the 300 - 100 hPa region. The correlation is shown on the right during winter, summer-monsoon, and spring.

- Section 3.4 Assessment of AIRS retrieval algorithm with IASI and CrIS radiance.

- line 506: Figure 9.a, the ozone peak layer is not identified.

We agree that it was a general sentence and we wanted to convey that ozone peaks are broadly captured by three sensors. We have now estimated the ozone peak altitude and they are in reasonable agreement (11.35 hPa for ozonesonde, 10 hPa for AIRS, 9.11 hPa for IASI and 7.78 hPa for CrIS). Now we have added this information in the revised MS.

- line 509: You should compare the averaging kernels with AIRS, IASI, and CrIS, to show the impact of different measurement characteristics on ozone profile retrievals.

Here, the IASI and CrIS-based ozone retrievals are research products provided by NOAA, whose retrieval is based on the AIRS retrieval algorithm. Currently, the NOAA IASI and CrIS retrieved ozone product provides no information on the averaging kernels in the level 2 product. Generally, Averaging Kernel (AK), a measure of information contents of retrieval, is calculated using multiplication between error covariance matrics and radiance jacobians, i.e., $[S_x \cdot K_n^T \cdot (K_n \cdot S_x \cdot K_n^T + S_\varepsilon)^{-1} \cdot K_n]$. Both the IASI and CrIS ozone products are based on the AIRS heritage algorithm, which utilizes the same error covariance matrices (S_x) for a-priories and radiance jacobians (K_n) in optimal retrieval; hence we believe their AKs will be more or less similar (only observational error covariance matrics ($S\varepsilon$) will be different as it also depends upon the instruments noise equivalent

differential temperature). Nalli et al. (2017) have provided the AKs information of CrIS NOAA ozone retrieval. The effective AKs of CrIS are similar to AIRS AKs, with higher sensitivity over the stratospheric region in tropical belts (Below Figure 5). Moreover, in the current MS, the differences in vertical sensitivity are not accounted for, as this section's primary aim is to assess how the AIRS retrieval algorithm performs for different IR sensor radiances and channel sets. However, a short discussion about the AKs of these data is added in section 3.4 in the revised MS.

Figure 5. Typical effective averaging kernels (Ae) over different regions for CrIS ozone retrieval (Nalli et al., 2017) on the left and AIRS averaging kernels over Nainital on the right.

- Line 523-528: In this analysis, the number of difference/R is noted, without "why".

We feel that the lower correlation between ozonesonde and the satellite sensors in the lower troposphere could be due to lower sensitivity of satellite sensor and shorter lifetime of ozone. We have added this in the revised MS.

- Figure 10

- This study used OMI L3 total column ozone and OMI/MLS tropospheric column ozone without any citation and acknowledge.

Thank you very much. We have used these data from (https://acd-ext.gsfc.nasa.gov/Data_services/cloud_slice) and have cited Zeimke et al. (2006) for OMI/MLS. In the acknowledgement, we had mentioned about NASA EARTHDATA online portal for this purpose. However, now we have added a specific sentence acknowledging NASA Goddard Space Flight Center Ozone Processing Team in the revised MS.

- This validation study should characterize the errors in AIRS total column during Fall. The bimodal peak is not found in the UTLS and troposphere. In hence, it could be inferred from stratospheric ozone retrievals. Please make a similar plot for the entire/upper/lower stratospheric column ozone and corresponding a priori column. In hence this validation study could recommend the useful vertical range of AIRS ozone profiles.

Thank you very much for the suggestion. To study this aspect, below figure 6 shows the ozone column in four layers (100 - 70 hPa, 70 - 50 hPa, 50 - 20 hPa and 20 – 1 hPa). Bimodal peak is not seen in 100 – 70 hPa and 70 – 50 hPa layer. Two layers, above 50 hPa showed bimodal peak. In-fact, ozone peak in fall becomes more prominent in 20 – 1 hPa layer. Moreover, the AIRS apriori do not have such a bimodal peak.

The original MS already has this information and was mentioned that this bimodal peak is mainly due to contribution from 50 hPa and above. Nevertheless, we have further modified the sentence to make it further clearer.

Figure 6. Monthly variations of AIRS ozone column in four layers of the stratosphere.

- Figure 10.b : MLS is used to evaluate AIRS column ozone integrated between 400 hPa and 70 hPa in spite that MLS is not recommended for use below 216 hPa.

Thank you for pointing this out. The recommended pressure levels for scientific applications of MLS v4 ozone retrieval are 0.0215 to 261 hPa (Livesey et al., 2011; Schwartz et al., 2015). We have now revised the Figure 10b for MLS data, which is starting from 261 hPa to 70 hPa region for UTLS column.

- Line 560: I don’t think that UTLS ozone retrievals could be improved by using more accurate surface emissivity.

Thanks. This was based on other studies (Rodgers et al., 1976, 1990; Dufour et al., 2012; Bai et al., 2014; Boynard et al., 2016, 2018) where biases in satellite retrieval are shown to be influenced by surface emissivity, apart from other factors. Dufour et al., (2012) and Boynard et al. (2018) describe that an inadequate Apriori information including surface emissivity is the most possible factor for the larger UTLS mismatch between ozonesonde and satellite data. Now we have provided these references in the revised MS.

- (Figure 10.c) This paper related the tropospheric ozone peak in spring and fall observed in Himalaya mountain site with the biomass burning in northern India. I am wondering if the burning area is closed to ozonsonde site? It could be helpful to show the MODIS fire count map with ozonesonde site. In addition, please take a look at surface measurements (O3, CO) to see the seasonality caused by the biomass burning.

Long-term variations in the northern Indian biomass burning (Bhardwaj et al., 2016) and its influence on surface based observations of several trace gases (Kumar et al., 2010; Kumar et al., 2011; Kumar et al., 2012b; Sarangi et al., 2014; Sarangi et al., 2016) and aerosols (Sharma et al., 2020; Srivastava et al., 2021; Joshi et al., 2022) and balloon-borne ozone observations (Ojha et al., 2014; Bhardwaj et al., 2018) at the present observational site has been studied very extensively.

It has been shown that the springtime peak in fire activity over the northern Indian regions is dominated by agricultural crop residue burning and forest fires, while the secondary peak observed over the northern region during October–November is associated with crop residue burning (Kumar et al., 2011;

Bhardwaj et al., 2016, 2018). The crop residue burning is a regular land clearing activity practiced in the northern Indian region following wheat and paddy crop harvesting in April–May and October–November, respectively. The spring and autumn seasons account for about 96 % of the total annual fire over the northern Indian region with 75 % in the spring season and remaining in the months of October and November (Bhardwaj et al., 2016). Furthermore, it is also demonstrated during an international field campaign (SUSKAT) that the agricultural crop residue burning in northwestern IGP led to simultaneous increases in surface ozone and CO levels at Nainital, India (present observation site) and Bode, Nepal (Bhardwaj et al., 2018). A biomass-burning-induced increase in ozone and related gases was also confirmed by model simulation and balloon-borne observations over Nainital (Kumar et al., 2011; Ojha et al., 2014; Sinha et al., 2014). In-fact, balloon-borne observations showed enhancements in ozone up to about 6 km (Ojha et al., 2014; Bhardwaj et al., 2018). These findings are also corroborated with the backward air trajectories analysis showing that the enhancement is associated with arrival of the air masses from these burning regions during the spring and autumn (e.g. Kumar et al., 2010; Sarangi et al., 2014; Bhardwaj et al., 2018).

Surface ozone (Kumar et al., 2010), NO, NOy, CO (Sarangi et al., 2014) and light NMHCs (Sarangi et al., 2016) showed spring and autumn peaks, though spring peak is shown to be prominent. Studies on carbonaceous aerosols also showed similar features (e.g. Dumka et al., 2015; Srivastava et al., 2021; Joshi et al., 2022). Role of biomass burning have also been shown in enhancing the regional aerosols radiative forcing (Kumar et al., 2014) and influencing the incoming solar radiation (Dumka et al., 2021).

Considering very extensive studies on biomass burning, with details seasonal cycle and its influence at the present observation site, we did not elaborate much in the present paper and also cited limited references. However, if reviewer feel we can again add figures on MODIS fire count over the observational site.

Kumar, R., Naja, M., Venkataramani, S. and Wild, O.: Variations in surface ozone at Nainital: A high-altitude site in the central Himalayas. Journal of Geophysical Research: Atmospheres, 115(D16), 2010.

Srivastava, P. and Naja, M.: Characteristics of carbonaceous aerosols derived from long-term high-resolution measurements at a high-altitude site in the central Himalayas: radiative forcing estimates and role of meteorology and biomass burning. *Environmental Science and Pollution Research*, *28*(12), pp.14654-14670, 2021.

Joshi, H., Naja, M., Srivastava, P., Gupta, T., Gogoi, M.M. and Suresh Babu, S.: Long-Term Trends in Black Carbon and Aerosol Optical Depth Over the Central Himalayas: Potential Causes and Implications. Frontiers in Earth Science, 10, p.851444, 2022.

Dumka, U.C., Kaskaoutis, D.G., Srivastava, M.K. and Devara, P.C.S.: Scattering

and absorption properties of near-surface aerosol over Gangetic–Himalayan region: the role of boundary-layer dynamics and long-range transport. Atmospheric Chemistry and Physics, 15(3), pp.1555-1572, 2015.

Kumar, R., Barth, M.C., Pfister, G.G., Naja, M. and Brasseur, G.P.: WRF-Chem simulations of a typical pre-monsoon dust storm in northern India: influences on aerosol optical properties and radiation budget. Atmospheric Chemistry and Physics, 14(5), pp.2431-2446, 2014.

Dumka, U.C., Kosmopoulos, P.G., Ningombam, S.S. and Masoom, A.: Impact of aerosol and cloud on the solar energy potential over the central gangetic himalayan region. Remote Sensing, 13(16), p.3248, 2021.

Sharma, S.K., Choudhary, N., Srivastava, P., Naja, M., Vijayan, N., Kotnala, G. and Mandal, T.K.: Variation of carbonaceous species and trace elements in PM10 at a mountain site in the central Himalayan region of India. Journal of Atmospheric Chemistry, 77(3), pp.49-62, 2020.

- Figure 11.

- I am wondering if stratospheric intrusion cases are completely removed for comparing the ozone profiles with and without Biomass burning events (Figure 11.a) and if the burning contaminated measurements are completely removed for comparing the ozone profiles with and without downward transport events. And please specify how to define the cases of downward transport events.

The downward transport events mostly occur during winter (January and February) and early spring (March and early April). Ojha et al., 2016 showed a 15-year (2000–2014) analysis of an EMAC simulation to study the seasonality of ozone downward transport over the Himalayan region and showed that the frequency of downward transport is highest during the early spring pre-monsoon season.

In the present analysis, a total of 10 soundings are classified as downward transport (DT) events using ozonesonde observations. All these events were between January and early April. The dates for DT events are 17 Feb 2011, 01 Feb 2012, 08 Feb 2012, 13 Feb 2013, 06 Mar 2013, 15 Jan 2014, 05 Mar 2014, 06 Apr 2016, 11 Jan 2017, and 12 Apr 2017.

Ozone soundings of 32 days (from mid-April to May) are identified as biomass burning influenced cases in the present analysis. We have now mentioned the period of DT events and biomass burning events in the revised MS.

These DT events are first classified based on an increase in the ozone vertical profile (upper-middle troposphere) and an associated drop in RH values in sonde observations. The final confirmation of DT events is made based on the MERRA-2 reanalysis data of Ertel potential vorticity (EPV), humidity, and ozone as shown in below figure 7. In general, EPV distribution is represented by the potential vorticity unit (PVU) (1 PVU = 1 × 10−6 K m2 Kg−1 s −1). Usually, air masses EPV greater than 1.6 PVU in the troposphere are suggested to be associated with the downward transport of ozone-rich air masses from the stratosphere (Cristofanelli et al., 2006). We have now briefly explained the DT criteria in the revised MS.

Figure 7. Ozonesonde + radiosonde ozone, RH and temperature observation on 08 Feb 2012. High ozone and low RH are observed in the vertical profile, and the MERRA-2 EPV and humidity confirm the downward transport event on the same day.

Cristofanelli, P., Bonasoni, P., Tositti, L., Bonafe, U., Calzolari, F., Evangelisti, F., Sandrini, S., and Stohl, A.: A 6-year analysis of stratospheric intrusions and their influence on ozone at Mt. Cimone (2165 m above sea level), J. Geophys. Res., 111, D03306, https://doi.org/10.1029/2005JD006553, 2006.

6 Figure 12.

Comparing UV radiative forcing (RF) derived from OMI/AIRS/ozonesonde is meaningless in this study for evaluating the AIRS ozone profile product. That is because that Figure 10 already let us know that AIRS total ozone should be not used for scientific analysis.

Thanks. Our main purpose in this section is to demonstrate that how discrepancies in total ozone can induces the difference in the RF values. We have made this RF calculation from ozonesonde and OMI data to give feeling on RF during four seasons over this unexplored Himalayan region. We strongly feel that this section is providing useful information.

Minor comments

- This paper describes that the AIRS/IASI and CrIS data is based on 9.6 um, but also the applied algorithm is based on IR + MW retrievals. Please take care of this inconsistent description.

Thanks. There are a total of 10 quality flags (i.e. 0, 1, 2, 4, 8, 9, 16, 17, 24, 25) in the NUCAPS products, where 0 represents successful infrared (IR) + microwave (MW) NUCAPS retrieval in clear sky condition, 1 represents, failed IR+MW retrieval and successful MW-only retrieval in cloudy condition, and similarly other as discussed in table S2 in the original MS. All the instruments use channels around 9.6 µm for ozone retrieval (Nalli et al., 2017). Furthermore, the AMSU (23 to 90 GHz) in MetOp and ATMS (23.8 GHz to 183.3 GHz) in NPP has no MW channels around 240 GHz, which are used for ozone retrieval in the microwave region; hence even IR+MW channel sets are used in the retrieval ozone information will only come from the 9.6 µm IR region. Nevertheless, to avoid any confusion, we have now changed IR + MW retrievals to IR retrieval in the revised MS.

- 187-188 (8page): It is clear to remove "associated with cloud fraction less than 80 %" in this sentence and adding "The AIRS data is flagged as best quality when cloud fraction is less than 90 % and other criteria (RMS?)".

Thank you very much. We have now revised the sentence as suggested (section 2.1.1).

- 189-191 (8page): that cloud fraction does not exceed -50 +/ 12 %, except in July and Aug when cloud fraction is ~~: In manuscript, the maximum cloud fraction of ~ 65+/-20% % is highlighted. I am confused about the importance/meaning of this maximum value. The maximum value of cloud fraction could be close to 1 over the world.

Please refer to the supplementary Figure S2 (in original MS) that shows monthly variation of the average cloud fraction over the observational site. The maximum cloud fraction of about 65 ± 20% is observed over our location. This shows that the cloud fraction crosses the 80% upper limit rarely. As mentioned above, a quality threshold set to discard the data is 80%. In the present study, only 7% of data during 2011 - 2017 has a cloud fraction of more than 80%. We have modified the sentence in the revised MS to make it clearer.

- 253-259 (11page): This paragraph is out of this 2.1.4 section ozonesonde.

Thanks, we have now included section 2.1.5 as "Other Auxiliary Data" for this paragraph.

- 241-242 (10page): (3-5) % (5-10) % è 3-5 %, 5-10 %

Thank, we have changed it in the revised MS.

- 382 (17 page) : different collocated data sets (~) è ozonesonde and AIRS, respectively. The ozonesonde convolved with AIRS averaging kernels and AIRS a priori are also compared.

Thanks, we have changed it in the revised MS.

- 385 (17 page) : Please replace "mentioned" with better one.

Thanks, we have changed it in the revised MS.

- 440 (19 page) : both ozonesonde and ozonesonde (AK) è ozonesondes with and without smoothing into AIRS vertical grids or original ozonesonde and smoothed ozonesondes.

Thanks, we have now revised the sentence.

- 480(21page) : The histogram remainder between è The histogram of differences between

Thanks, we have changed it in the revised MS.

- 500-502 (22 page): I don't understand why the different number of entire channels between sensors should be related to the ozone retrieval performance. All retrievals use IR near 9.6 nm.

Although all the ozone retrieval is based on Spectroscopic observation of around 9.6 µm, still different satellite instruments have different resolutions for spectral observation. Instruments with a higher number of channels in the same IR region (mostly between 3.7 to 15.4 µm) have the ability to observe and detect smaller thermal contrast from different layers, depending on their weighting function. For all the instruments used in the study, the number of channels (around 9.6 µm) utilized to retrieve ozone is different, and the extra spectral information will have additive ozone information. Because of this, ultra-hyperspectral instruments are being designed for future missions. Hence, we feel that the different number of channels will influence the retrieved ozone or other retrieved parameters.

Please also note the supplement to this comment:
https://amt.copernicus.org/preprints/amt-2022-187/amt-2022-187-AC1-supplement.pdf