Performance of AIRS ozone retrieval over the central Himalayas: Case studies of biomass burning, downward ozone transport and radiative forcing using long-term observations

By Prajjwal Rawat et al., 2022 (AMTD)

We would like to thank the referees for their comments and constructive suggestions. The manuscript is suitably revised by incorporating the reviewer's suggestions and comments. Please find here our responses in boldface and the reviewer's comments are in regular font.

Report #1:

There is no label on the x-axis on Figure 10. My recommendation is to delete information that is widely available from elementary text books, such as the definition of mean, standard deviation, and correlation, or standard physical constants. I have not checked them for accuracy.

Thank you very much and sorry for missing the label on x-axis. We have now revised Figure 10 and given the months name on the x-axis label. About the information/equations on standard deviation and correlation (mentioned in section 2.3), we have now removed equation 6 (standard deviation) and equation 7 (Pearson's correlation coefficient). However, we have kept the information on RMSE and Bias as they are also providing the information on different RTA layers, calculated for satellite and ozonesonde. Here, we have used weighted statistics that are different than the simple statistics, which will be handy to the readers when comparing gaseous profiles in the atmosphere.

Report #2:

Authors sincerely replied to my comments, but I still cannot recommend this paper for publication in AMT, due to the insufficient level of the scientific quality.

Thanks.

We do not agree with the comments on the scientific quality. This is for the first time that vertical ozone profiles from satellites have been compared with ozonesonde observations over the Himalayan region. Due to the complex topography of the Himalayas, various surface characteristics change abruptly over the fixed footprint size of the satellites and make it difficult to retrieve atmospheric parameters and composition from satellite instruments. The AIRS averaging kernel is successfully calculated in all the 100 RTA layers using the trapezoid function and utilized for the first time in the evaluation study. It is important to mention that this exercise has been done using 242 ozone soundings for evaluating satellite ozone profiles and identifying the role of downward transport and biomass burning in influencing the ozone profile. At the same time, larger variations in the tropopause height over this subtropical Himalaya were observed during winter and spring when there are frequent tropopause folding events, higher mean biases (~ 65%) and relative difference (~ 150%) between AIRS and ozonesonde in the UTLS region. Further, the AIRS total ozone showed larger differences with ozonesonde for the autumn season and the UTLS column shows persistent biases but higher correlations throughout the months. In summary, such a large period (2011-2017) of ozonesonde data from South Asia are utilized for the first time to make extensive analysis on comparison with satellite data and variations in different height layers. Hence we feel our manuscript has sufficient scientific quality.

In introduction, this paper emphasized the impatance of evaluating AIRS quality over Himalayas due to its complex topograph. However, I cannot found in section 3 result and discussion where this issue is discussed. They just performed the general comparison, just over the Himalayas.

We disagree with the reviewer. The terrain pressure and other surface parameters are rapidly varying in the mountain regions of the Himalayas and systematic

evaluation/validation of satellite measurements are still lacking here. We have emphasized on the importance of evaluating satellite retrieval over the complex terrain regions, explaining all possible factors influencing the satellite ozone retrieval. Recently Cazorla and Herrera (2022) validated various satellite instruments' ozone retrieval with ozonesonde over the Andes Mountains. This study also explained the need of satellite retrieval in the mountain region and studied the possible differences between ozonesonde and satellite measurements. Such evaluation studies along with ours, offer an opportunity to understand the differences between satellite and truth observations over complex terrains and improve satellite retrievals. The evaluation will be equally important for users to find the retrieval credibility of various space-based ozone observations over such regions for their utilization and for the retrieval developer to mitigate such biases. In addition, our results also discussed the influence of downward ozone transport and biomass burning in influencing ozone profile over the subtropical Himalayan region and their identification from satellite and ozonesonde.

More specifically, the AIRS ozone products are analyzed in terms of retrieval sensitivity, retrieval biases/errors, and ability to retrieve the natural variability of columnar ozone, which has not been done so far from the Himalayan region. Section 3.3 discusses the greater difference between low vertical resolution AIRS ozone with ozonesonde in the UTLS region over the Himalayan region, where the various active dynamical process influences ozone, while the high vertical resolution instrument MLS does relatively well. Section 3.4 shows that not only the AIRS retrieval but other IR satellite instruments (AIRS and CrIS) also shows higher differences in the UTLS region. Furthermore, the columnar ozone evaluation is also presented in section 3.5, which shows AIRS total ozone is highly biased compared to ozonesonde and OMI for autumn seasons, while the UTLS and tropospheric column are in reasonable agreement.

Cazorla, M. and Herrera, E. An ozonesonde evaluation of spaceborne observations in the Andean tropics. Scientific reports, 12(1), pp.1-8, 2022.

From Figure 4/S4, I still think that comparing AIRS and ozonesonde as a function of horizontal drift is not nessarary (wrong). In troposphere, the horizontal drift is insiginficant and the airmass characteristics are not much different in stratosphere within a few degree. Single ozonesonde profiile should be assumed to be meausred at one location espeically in comparison with satellite measurements.

We strongly feel that this is a good figure that gives an overview of the region, with a complete information on balloon drift during four seasons. This figure is not for the direct comparison between ozonesonde and AIRS and the same has not mentioned/discussed in this section. Next section (section3.2) describes and compare the vertical distribution in ozone. Additionally, we do not agree that "In troposphere, the horizontal drift is insignificant". This figure clearly shows that balloon drift is different over the Himalayan terrain during four seasons. It moves rapidly in the East, reaching to Nepal, in winter. It slows down in spring and changes direction completely, to go to the West (IGP region of India) in summer.

Further, below figure 1 shows the methodology for generating the vertical ozone distribution along the balloon track. It gives both the tropospheric and stratospheric distribution along the balloon track from the ozonesonde and AIRS measurements. Figure S3 and S4 (supplementary) showed the longitudinal/latitudinal variation of biases and r^2 among the two measurements, along with the altitude information. We studied bias and r^2 variations with coarser (0.5^o) and high (0.1^o) longitudinal/latitudinal gaps and not much difference in results is observed. This also emphasized the regional distribution of ozone which can be obtained from balloon-borne measurements around the launch site.

About the single profile comparisons without horizontal drifts are discussed in sections 3.2 and shown in Figure 5 (in MS), where the ozonesonde and AIRS ozone profiles are compared from surface to 10 hPa.

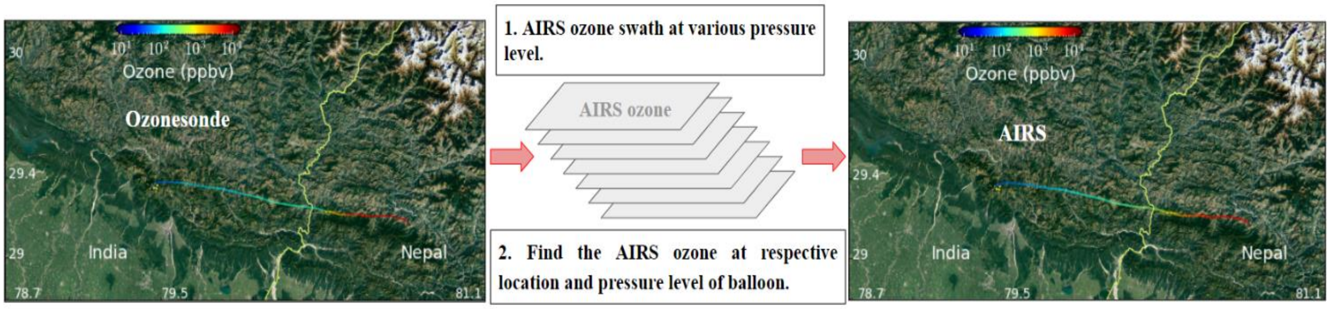

Figure 1. The method to obtain the AIRS ozone along the balloon track.

Comparison between AIRS and ozonesondes (Figure 6) are linked with monsoon index and total water vaopr, without valid scientific connection. In this figure, I don't think that the monsoon index is not the best parameter for describing this time-series. As stated, the correlation is relatively low (~0.2). I don't understand that the AIRS retrieval quality could be lower, depending on the monsoon index.

Thank you. We have not claimed any link, on daily or monthly bases, between the monsoon index and AIRS retrieval quality and not described ozone time series based on monsoon index. Rather, this study was to show that when there are weaker monsoon years, the annual average ozone is generally higher compared to the strong monsoon years. We have not discussed or concluded anything on monthly variations or seasonality. We are confirming the finding of Lu et al., 2018 on relation between the tropospheric ozone and monsoon index over the Indian region. To make this further clearer, we have now revised Figure 6 and showed (left lower most corner) annual average values of ozone and monsoon index from year 2011 to 2017.

I found a lot of cases that the references this paper cited are either "out of date" or "inadequate". It makes me think that the author did not investiate preminary studies well and the credibility of reserach results is low.

We have now added more references. Below are the clarifications on some confusion on the cited references. We have also revised the sentences accordingly.

e.g) on page 5, the Himalayas ~~ impacts global/regional radiative budgets and climate pervasively (e.g, Lawrence and Leieveld, 2010; Lelieveld et al. 2018). The cited two papers are about the pollutant outflow from southern Asia and impact of air pollutants on health.

Thanks, first reference is a kind of review paper for the South Asia that covers all aspects. Nevertheless, we have now added the specific references (Cristofanelli et al., 2014; Zhang et al., 2015) in the revised MS.

e.g) on page 6, V4 used regression retrieval as the first guess in physical retrieval while later version used a cliamtology based first guess fro the physical retrieval (McPeters et al., 2007).

The cited paper is about an ozone profile cliamtology, not for either the related retrieval algorithm.

We are sorry for the confusion. The cited reference (McPeters et al., 2007) was not for the retrieval algorithms. This reference was used to refer that the climatology-based first guess is used as a-priori in the satellite retrieval. Now, we have modified this sentence.

e.g.) Smith et al. 2007 is wrongly cited in this paper for comparing two datasets with different vertical resolutions.

Thank you for pointing this out. Nevertheless, Smit et al., 2007 was used as this work utilizes ozone data from three different sensors (SPC-5A (EC), SPC-6A (FZJ), and ENSCI-Z (NOAA)) and raw data has different vertical resolutions. We have now added two references (Verstraeten et al., 2013; Boynard et al., 2016) in the section 2.2 that emphasize the need to account vertical sensitivity of two sensors when comparing the ozone profiles.

In addition, this manuscript should be thoughly revised to correct English usage and many typped errors.

Thank you. We have revised the MS as much as possible for correct English and for typos.