Review of Smit et al., *Intercomparison of IAGOS-CORE, IAGOS-CARIBIC and WMO/GAW-WCCOS Ozone Instruments at the Environmental Simulation Facility at Julich, Germany*

Reply to referee #2

We thank referee #2 for the complete and thoughtful review of our manuscript and providing thoughtful comments and suggestions that have helped us improve this manuscript. We also thank Editor Troy Thornberry for handling our paper and coordinating the reviews. Our responses to reviewer comments are provided below in red italic text.

Anonymous Referee #2, 08 May 2025

As mentioned, several times in the text this intercomparison study is a first step of the long-term goal to get the global ozone sonde data and IAGOS-O3 data sets traceable to one common reference. This long-term goal is extremely important for the ozone research community and therefore this study is very welcome! Accordingly, I recommend publication after addressing two major and the minor comments below.

Major

1. As mentioned in the text twice there is no ozone reference instrument running at reduced pressures at any National Metrological Institute in the world. The OPM at Julich acts as a workaround to this situation. However, we need such a reference in addition to studies like this one. Although this gap in the whole concept is mentioned in the manuscript, I recommend to address it even more prominent and pronounced eg. in the abstract. This would enable relevant persons better to ask for closing this gap.

>>> Thanks for the suggestion and recommendation.

We added an extra sentence at the end of the abstract and a similar sentence at the end of the second paragraph of Chapter 4:

“An important existing gap in doing intercomparison studies like this is that no ozone reference instrument is running at reduced pressures at any National Metrological Institute in the world. For the global observation networks of measuring free atmospheric ozone, it is essential to close this gap to enable the traceability of ozone measurements from different platforms to one standard reference, which is crucial to harmonize long-term ozone records to detect long term-changes of ozone in the free atmosphere.”

2. The display and description of the figures can be crucially improved. Each single issue is a minor one (and are listed in the minor section below). However, overall, these issues make it sometimes hard to follow the arguments of the manuscript.

>>> Thank you very much for the many suggestions you did to revise the figures. Thereby, it has been attempted that all figures are more harmonized by following same standards. The changes are a substantial improvement to read and understand the figures better and more easily.

Minor and typos

Figure 2:

There is no temperature data and the y-axis "Temperature" text can be omitted. Please arrange the figure similar to Figs. 4b, 6, 7b, 9, and 11, ie. separate upper and lower panel. Here and in other figures, please use lower case letters for ppbv. There is no need to write VMR in addition to "Volume Mixing Ratio" at the y-axis. For this type of figure, it would be nice to use both sides of the frame for y-axes descriptions instead of an additional y-axis on the left side.

>>> The figures have been revised following your suggestions.

Figure 3:

Some blue dots are masked by color descriptions. Please avoid that. Less cryptic axes descriptions would be welcome, eg. "reference pressure" instead of "p-ref.", "pressure difference" instead of "Delta p". At least explain abbreviations if used in the plots, eg. "Delta p", "cuv.", "ref.", in the caption.

>>> Exchange by a new figure of higher resolution.

Figure 4 (& 7):

Panel letter descriptions, a b c, should be inside the plots. 4a and 4c: Separation into two parts like in 4b with help lines at -5, 0, and 5% would be helpful.

>>> The figure has been changed following your suggestions.

Line 38: Please add a comma "... of the atmosphere, and its impact ..."

>>> The last part of the sentence has been omitted on suggestion by referee#1

Line 69: The information in the two brackets can be combined.

>>> Done.

Line 148: "... to prove that the linearity of the instrument is within 1%."

>>> The sentence has been slightly revised following your suggestion and that from referee#1

Line 151: Unsure, what the word "above" should tell.

>>> Revised the sentence for better understanding.

Line 152: Is the "s" in "P1s" correct?

>>> Changed by “Each flown P1-Package”

Line 287-292: In the description of what can be seen in this figure, please add a comment on missing data, ie. absence of CAR-O3 measurements during about 30 min, partly during descent. Any additional comment, what had happened at 14:40 UTC?

>>> Incidentally the temperature controller of the UV-LED was not working properly, thus the measured O3 values were flagged as potentially erratic and removed from the final data. We add an extra sentence at L292: “The three missing data intervals of the CAR-O3 instrument were caused by a malfunction of its temperature controller for the UV-LED light source such that the measured O3 values were rejected, not shown in the graph and excluded from further analysis”.

Line 304: My understanding of the following text is, that the issue found with the electronic analog-digital converter was systematic present in all CAR-O3 instruments and not only in the instrument used in this study. Please mention that explicitly here.

>>> An extra sentence to explain the issue in more detail is included at end of the paragraph at L312. "For the two similar CAR-O3 type instruments (FAIRO-1 and FAIRO-2) flown primarily on the German research aircraft HALO (HALO (High Altitude and Long-Range Research Aircraft), the ADC modules were investigated and found to be configured correctly, such that no correction is needed".

Line 320-321: The statement "... occurs identically during ascent and descent and no indication for any hysteresis effects could be observe" is hard to verify with the current set of figures. I miss an additional corresponding figure overlaying ascent and descent branches with eg. different colors.

>>> We fully agree. We dropped here the statement of the hysteresis, but investigated the behaviour of P1-O3 and CAR-O3 relative to the OPM in more detail in Fig. 10 by breaking down the slopes of the scatter fits for the corresponding instruments and pressure levels into the upward and downward parts of the ozone step levels, once for the full ozone range and once for the lower ozone range. The corresponding scatter graphs are shown in Fig. S1 and S2 in the Supplement, and the results of the slopes of the linear fits are summarized in Table 3.

Line 420-424: Please swap the sequence of both sentences.

>>> Done

Line 421-422: The relative differences for larger parts, eg. zero ozone periods, are not shown in the upper panel of figure 9. Why?

>>> At lower ozone concentrations even small differences between the instruments can easily produce large relative differences. We revised the sentence into:

"Here only relative differences for the higher ozone levels are shown in Fig. 9 to avoid that at lower ozone concentrations even small differences between the instruments can easily produce large relative values."

Line 421/422 & 431/432: The figure numbering seems to be odd. The referenced figure 8 deals with experiment 4 and not with experiment 7. A corresponding figure for experiment 7 is missing. Please add such a figure. Instead figure 9 figure 10 should be referenced.

>>> The figure number referencing has been corrected: Fig.9 for offsets and Fig.10 for the slopes at the three different pressure levels (950, 600 and 400 hPa). Because we only have results at three discrete pressure levels we dispensed for an additional figure such as Fig.8 but to summarize in Table 3 the results of the derived offsets and slopes at the three different pressure levels and low and high ozone values. The obtained results are at ozone values larger in agreement with the previous experiments #3 (Fig. 5) and #4 (Fig. 8): see also the paragraph L426-429 in the reviewed manuscript (Jan.2025)

Line 427: Small differences of -(1-2) % for the P1-O3/OPM are mentioned. I see values between -7 % and +3 %. Have I misunderstood something?

>>> There is indeed a misunderstanding - to avoid this, the paragraph (L426-429) has been rewritten. Please also see our reply on your next comment on Table 3.

"Table 3 shows that the behaviour of the three instruments observed at ozone levels larger than about 100 ppbv is consistent with the results obtained from the Exp. #3 and Exp. #4. At lower ozone values below 100 ppbv, however, the slopes for P1-O3/OPM differ slightly by -(1-2) % compared to their corresponding slopes of P1-O3/OPM derived for higher ozone values, respectively. Breaking down the slopes into the upward and downward part of the ozone step levels, P1-O3/OPM reveals a small hysteresis effect of about a 2 % which is most pronounced in the lower range of ozone levels. CAR-O3 shows no hysteresis, neither at the higher nor at the lower ozone levels (Table 3 and Figs. S1 and S2 in the supplement). The observed differences are of unknown origin but still within the experimental reproducibility of about ±1 % as mentioned in Section 3.2.2."

Table 3: In figure 10 one can see only the fits per instrument for the upper O3-ranges but not for the lower O3-ranges. Another figure filling that gap would be helpful to verify such values like 0.942 for the P1-O3/OPM at 400 hPa / 0-200 ppbv.

>>> Thanks for the suggestion, we added to the figure also graphs for the lower ozone ranges.

>>> In addition, we have changed the approach of Fig.10 and Table 3. As before the offsets of the three instruments have been determined during the periods of zero ozone exposure, while the slopes were obtained from linear fits of the scatter plots in Fig.10-a., b., c. respectively but not forced through the origin. In addition, similar graphs are shown for the lower ozone ranges for the corresponding three pressure levels (Fig.10-d., e., f.). For the 6 graphs in Fig.10 we also determined the slopes for the periods of upward and downward ozone step levels. The corresponding scatter plots and linear fits are displayed in Fig. S1 and S2 of the Supplement for the P1-O3/ OPM and CAR-O3/OPM, respectively. All results are summarized in Table and discussed in the new manuscript in paragraph:

"From Table 3 the behaviour between the three instruments observed at ozone levels larger than about 100 ppbv is consistent with the results obtained from the Exp. #3 and Exp. #4. At lower ozone values below 100 ppbv, however, the corresponding slopes for P1-O3/OPM differ slightly by -(1-2) % compared to their corresponding slopes derived at higher ozone values, respectively. Breaking down the slopes into the upward and downward part of the ozone step levels it show that P1-O3 reveals a small hysteresis effect of about a 2 % which is most pronounced in the lower range of ozone levels, while CAR-O3 shows no hysteresis, neither in the higher nor in the lower ozone levels (Table 3 and Figs. S1 and S2 in the supplement). The observed differences are not really understood but are still within the experimental reproducibility of about ±1 % as mentioned in Section 3.2.2. "

Line 448: malfunction

>>> Done.

List of Acronyms: Please add RAM.

>>> RAM is not an acronym but ram air pressure is only another expression for dynamic air pressure. In L251 we revised the sentence by

"……thus use the dynamic (ram) air pressure generated by the high speed of the aircraft……".

Line 583: Staehelin

>>> Done.

General: It would be nice to have somewhere an exact definition of the relative difference used, eg. = (O3_IAGOS - O3_OPM) / O3_OPM

>>> We add at L292 the exact definitions of the relative differences:

The relative differences in % of the μ_{O3} (VMR) readings of P1-O3 and CAR-O3, respectively, shown in this study are consequently defined regarding the μ_{O3} readings of the OPM-O3 instrument acting as the reference as follows:

$$Rel.DifferenceofP1O3 = \frac{(\mu_{O3,P1O3} - \mu_{O3,OPMO3})}{\mu_{O3,OPMO3}} \quad (3)$$

$$Rel.DifferenceofCARO3 = \frac{(\mu_{O3,CARO3} - \mu_{O3,OPMO3})}{\mu_{O3,OPMO3}} \quad (4)$$