Answer to RC2:

Reviewer comments are given in black and author answers are in blue. Changes in the revised manuscript are marked in red.

This manuscript describes comparisons between satellite-derived and ground-based observations of OClO. The manuscript is generally well written and presents important validation for the GOME-2 (A and B) satellite data records. The manuscript is well within the scope of AMT and with revision should be acceptable for publication. There are two areas in which the article should be clarified:

1) While the comparison is reported as a bias (offset between satellite observation and ground-based observation), the data appear to fit a model where the satellite observations have a lower slope and relatively small intercept. Potential reasons for this behavior should be discussed.

2) Some of the airmass factor analysis was not clear and needed further explanation.

Answer: *We thank the reviewer for his useful comments and suggestions. The main comments and specific issues are addressed point by point below.*

Concerning the remaining differences between satellite and ground-based, we agree that it can be fitted by a slope smaller than unity, with a relatively small intercept. The term “bias” to express the remaining satellite minus ground-based differences is thus maybe not the most appropriate, as the intercept is generally also referred as additive bias, compared to the multiplicative bias coming from the slope. We however do not agree that the comparison is only discussed in term of a bias. In Sect. 4.3 and Table 4 the results are discussed both as a bias/offset (fig. 16) and as slope and intercept (fig 17). We changed the term bias to “SAT-GB offset” at the end of the abstract (lines 11-13) to minimize the confusion. The small intercept can potentially be explained by the GOME-2 normalization correction (see Sect. 2, lines 88-93), that subtracts any remaining positive OClO SCD in region where no OClO is expected. The slope smaller than one can potentially be explained by the differences between the GOME-2 and ground-based DOAS settings and the corresponding SCD uncertainties. For GOME-2 there is e.g. the impact of the mean residual or the scan angle empirical correction functions, see Sect. 2 lines 84 to 88, while the uncertainties from the ground-based data is estimated to be between 26% to 33%, which is close to the remaining multiplicative bias from the slope (0.64 and 0.72 for GOME-2A and GOME-2B, respectively). This discussion has been further extended in Sect. 4.3 (details below, in the comment about Table 4).

Concerning the airmass factor analysis, we have redone Fig. 8 with the same convention than in Fig. 6 for the sake of consistency and clarity of the discussion (see further explanations below).

Specific issues (listed by line number) are below:

Abstract, line 10: Are these slopes compared to ground-based observations?
Yes, these are slopes compared to the ground-based observations. This has been specified in the abstract

now. This has been clarified as in the text (line 11) as follows:
" with slopes of 0.64 and 0.72 with respect to the ground-based data ensemble, respectively."

Line 78: This appears to be an anonymous FTP server. Many of these servers will transition to other more secure means. Is this transition envisioned? How will data be accessed in the future?
Besides sftp and ftps, anonymous FTP is also a relative secure (and user friendly) option, and there are no short term plans to change it.

Line 84: Is "Eta" explained in some citable source (e.g. the ATBD?). If so, please cite it.
The citation to the ATBD has been added.

Line 90: This "normalization" seems more like a "bias" correction for the orbit based upon a region where OClO is not expected. Should this be called a bias correction?
We agree with the reviewer that this normalization is a sort of bias correction. But the term "normalization" is used in the algorithm ATBD (Valks et al., 2019), so we would like to keep the same naming convention.

Line 116: is "Annex A1" the right name? Appendix?
We agree "Appendix" is more appropriate. This has been changed here, and in other places of the manuscript (e.g. in Section 3.1.1, line 171)

Line 153: I am unclear on how the errors are being represented. If I understand right, you are expressing a percentage of 15 x 10^13molec/cm^2. Doesn't that mean you are really talking about a SCD error (say 10% of this "reference" would mean 1.5 x 10^13 molec/cm^2.). I think that if the primary values are SCD errors, they should be expressed that way, and you can then give the percentage of this reference as secondary. Note that the 15+/-2 is quite confusing in this context. Are you dividing by a number with error and also propagating this error?
We reported SCD errors as the median value of the DOAS fit errors for SCD values in the 13 to 17x 10^13 molec/cm^2 range (i.e., 15 plus or minus 2 x 10^13molec/cm^2). This is done because some stations have much higher or lower SCD values range, and we wanted to report the error using a "common baseline". We then report the random error as a percentage value of 15x10^13 molec/cm^2 to be coherent with the systematic uncertainty estimates, provided as a percentage.
Also, to address a comment from reviewer 1, the absolute values of the SCD errors are now also given in Sect 1.1.3 and in the abstract.

Line 171: Typically bias is an offset in intercept, and slope error is a multiplicative error. I think you mean that the intercepts are small, so the differences between the measurements are mostly in the slope.
This is indeed what we meant. The sentence has been partly revised to clarify:
All intercepts except for IUPH are small (smaller than $1x10^{13}$molec/cm^2 (see Fig. A2)), and the differences between the measurements reside mostly in the slope, meaning that those differences are mostly multiplicative.

Line 178-185: I don't understand this; it is exploring the different cross sections? How is this done?
The third test is performed with a similar methodology than the second one, ie performing regression analyses of OClO SCD retrieved with different settings (different y-values, see the last line of table 3)

with respect to one set of OClO SCD (x-values). In this case, the x-values in figure A3, are the SCDs obtained from the ground-based Ny-Alesund spectra using the GOME-2 settings instead of the median OClO SCD values (as in fig. A2). As for the second case, the effect of the possible different OClO cross-sections is further added as a separate step in table 3.
The first sentence in the paragraph has been revised to:
"The expected systematic bias due to differences between each group's analysis and the GOME-2 OClO retrieval settings is investigated in a third test. This test (presented in Figure A3) uses a similar methodology than the second test presented above, but we now compare the SCDs obtained by applying to the Ny-Alesund spectra the DOAS settings from the different groups and the GOME-2 settings defined in Table 1. "

Table 3: What is "-" and are "n.a." in this table? If the "-" means no error, why not say 0? Ny-Alesund seems to also use the 213K OClO cross section, wouldn't that lead to no error, but 2.5 is listed.
"-" means indeed zero. This has been changed in Table3 for the revised manuscript. "n.a" means non applicable. This is the case for the Arrival Height NIWA measurements which have a specific wavelength range (in the visible) outside the range of the Ny-Alesund spectra. Therefore, this case could not be tested, as explained in the text.
The Ny-Alesund test case is a bit peculiar regarding the OClO cross-section. The Kromminga et al. cross-section at 213K was used, but it is an older reference (from 1999 instead of 2003, see line 134) and tests have shown that there is a bias between both cross section sources of about 2.5%. The "b" footnote of Table 2 has been put in bold, as done for other information, when being different than the OClO cross-section baseline.

Line 200-202: How does this AMF relate to "photochemical AMFs"? It seems like Figure 7 lower panel indicates that the OClO SCD is within noise of zero at 70 degrees? Can this be explained further?
In Figure 7, the whole time-series is presented (irrespective of whether chlorine activation takes place or not), so, on average over all the years, the OClO SCD is indeed around zero at 70°. The correction itself is calculated and applied to each individual day. On activated days, such as illustrated in Fig. 5, the OClO SCD is non zero at 70° SZA. In such conditions, measured SCDs follow the same behavior as the photochemical AMF (as demonstrated by the linearity of the Langley plot in Fig. 5). Note that the OClO AMF used in Fig. 5 corresponds to the median photochemical AMF displayed in red in Fig. 7.

Figure 7 caption typo -- it says "offsset" --> corrected, thanks.

Figure 8 shows AMFs that are quite different from the AMFs shown in Figure 6. Can it be explained why these two AMFs are so different and how both are used?
The AMFs in both figures are defined differently. In figure 6, the AMF is defined with respect to the vertical column at 70° SZA, while in figure 8 the AMF is defined relative to the VCD at each SZA (i.e. a different VCD value for each angle). In the first case (Fig. 6), the AMF is proportional to the measured SCDs and therefore easier to interpret. To avoid any confusion, we decided to redo figure 8 using the same definition as in figure 6. We had to change date and latitude as on the 10th of February at 65°N, the minimum SZA of the day is of about 77°, and therefore 70° is not reached. The new day (01/03/2000) corresponds to the high activation case (blue line) of figure 6.
Note that the AMF of Figure 8 is not used in the calculation and its purpose is to provide an illustration of the difference between the AMF in both satellite nadir and ground-based zenith geometries.

The previous figure 8 is thus replaced in the manuscript by the following one:

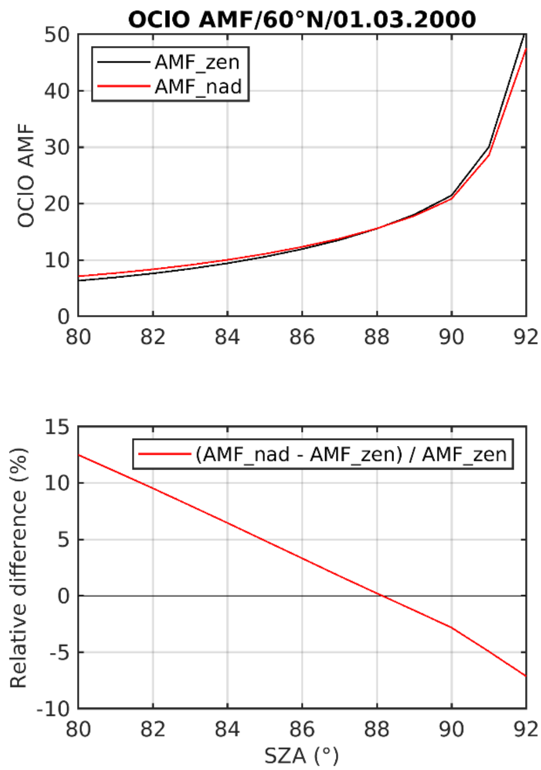


Figure 8. OClO AMF calculations for 60°N from ground-based zenith and satellite nadir geometries

On Figure 9, some points seem to go below the lowest values plotted on the plot. This seems particularly true of the Neumayer data.

This is indeed true, mostly for Neumayer, where there are several points down to -3.5e14 molec/cm². There are about 27 points smaller than -1e14 molec/cm² over 1536 total GOME-2A satellite comparison points (and 5 over 633 for GOME-2B), see figure below with time-series and scatter plot.

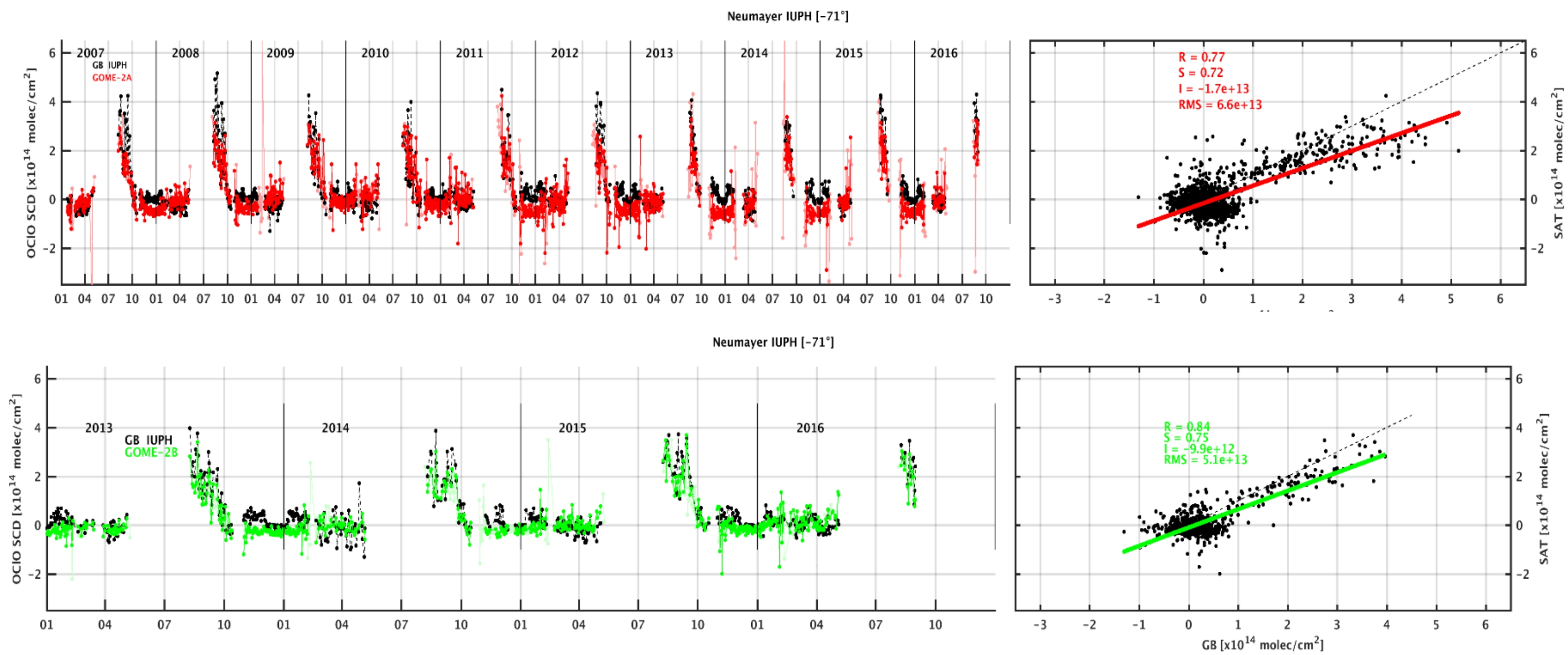
However, we think that in the interest of displaying (1) as many details as possible and (2) maintaining a coherence between both hemispheres and between GOME-2A and GOME-2B, it is better not to redo all plots of figures 9 to 14 with a smaller limit on the x-axis.

We have added a warning in the caption on figure 9 :

"Please note that in some cases, some GOME-2A points lie below the x-axis limit of -1e14, down to -3.5e 14 molec/cm², especially from 2011 onward (e.g., in the case of Neumayer, this represents 27 data points over a total of 1536)."

and in the text:

"It can be noted that in the case of GOME-2A, some daily mean points are negative and smaller than the lower x-axis limit in Fig. 9. This is especially the case from 2011 on, when data are more negative, as also seen in Fig. 2 and discussed at the end of Sect. 2."



Neumayer IUPH [-71°]
GB IUPH
GOME-2A
OClO SCD [x10^{14} molec/cm^2]
SAT [x10^{14} molec/cm^2]
R = 0.77
S = 0.72
I = -1.7e+13
RMS = 6.6e+13
Neumayer IUPH [-71°]
GB IUPH
GOME-2B
R = 0.84
S = 0.75
I = -9.9e+12
RMS = 5.1e+13
GB [x10^{14} molec/cm^2]

Line 298-299: Can the authors explain the sentence "Unfortunately the gap in ..." I don't understand the information in the parentheses about "...pixels SZA..." or the "...prevents to detect the..." phrases.
Actually, the GOME-2 instruments only retrieve valid OClO SCDs in a SZA range between 85° and 92°, as explained in lines 99-101 and 228 and this has an impact on the possible GOME-2 OClO measurements (see lines 232-235). Between February and May, the SZA around some of the northern hemispheric sites is systematically smaller than 85°, and thus no valid OClO SCD can be retrieved, while ground-based instruments continue to measure OClO at twilight. An illustration of the GOME-2A SZA variability around two illustrative sites is given in the figure below, where the reduction of the number of measurement points after July 2013 and the change in swath configuration, are also seen.

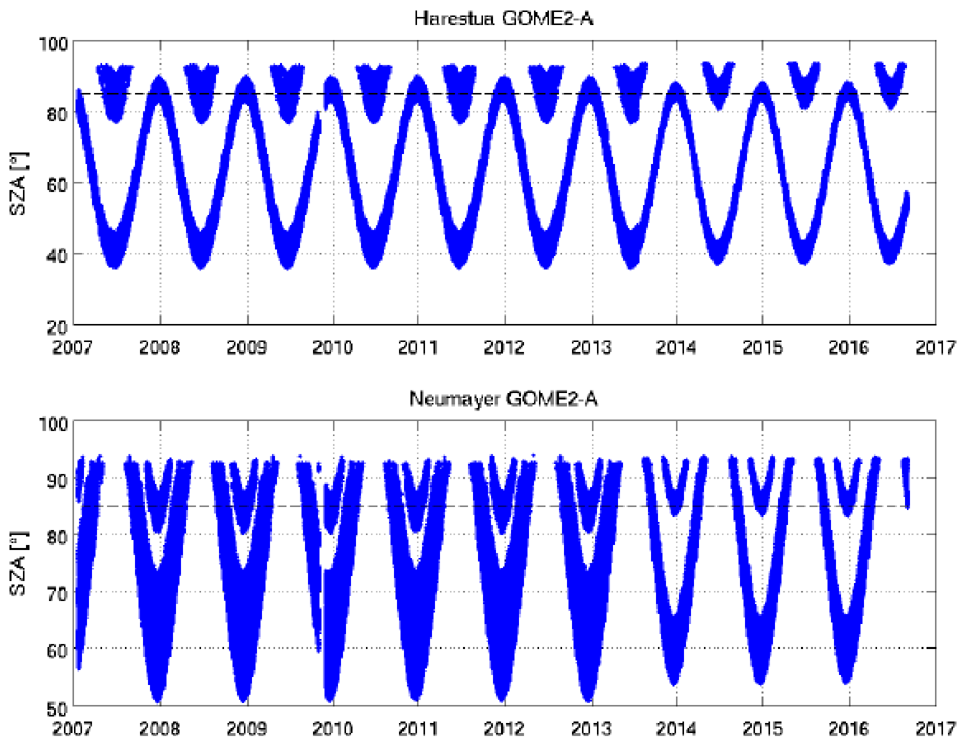


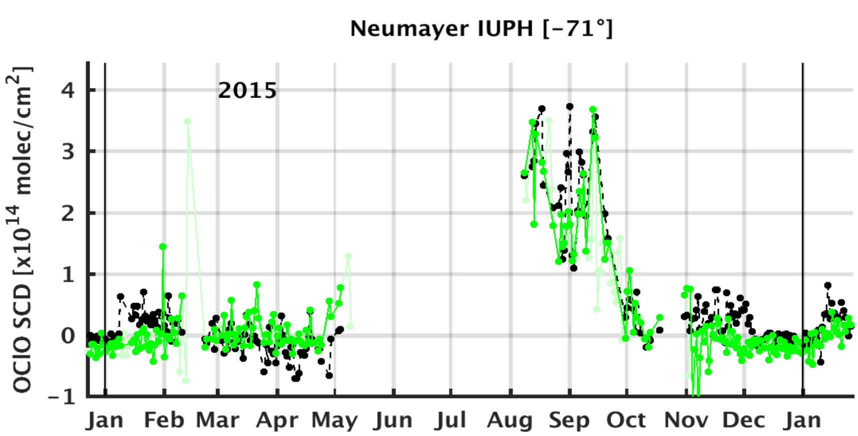
Illustration of the SZA time evolution for all the pixels within a radius of 200 km around the station. In July 2013 GOME-2A swath is reduced to half of his nominal length, which impacts the coverage around the stations. The black dotted line corresponds to 85° SZA.

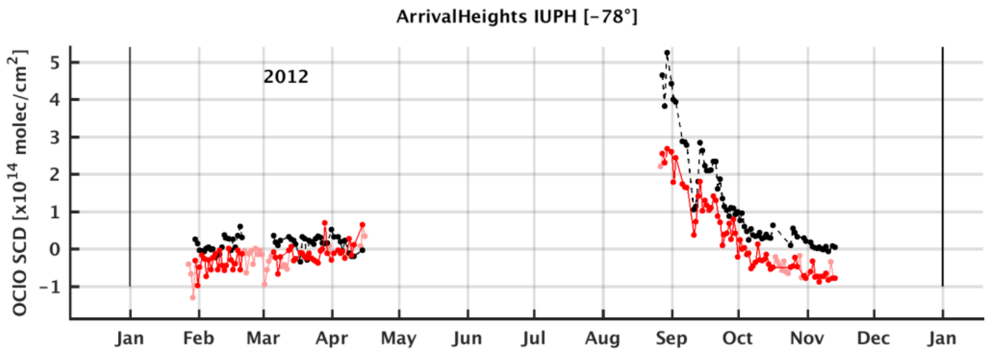
The sentence has been revised to "Due to the low SZA values (systematically smaller than 85°SZA) around the sites between February and May, no valid OClO SCDs could be retrieved by GOME-2, while some OClO activation peaks are detected during this period by the ground-based instruments measuring at twilight."

Table 4 and discussion of Table 4: Although there is a low bias, it appears that the intercepts are a lot smaller than the bias, indicating that the slope being under unity is the largest contributor to the negative bias.
We agree with the reviewer, and some more discussion in this sense is added in Section 4.3:

"The small intercepts are representative of small additive biases, while the slopes smaller than unity are the largest contributors to the negative multiplicative bias. The small intercept can potentially be explained by the GOME-2 normalization correction (see Sect. 2), that subtracts any remaining positive OClO SCD in region where no OClO is expected. The slope can potentially be explained by the different GOME-2 and ground-based DOAS fit settings and the corresponding SCD uncertainties (see Sect. 3.1.1). For GOME-2 there is e.g. the impact of the mean residual or the scan angle empirical correction functions (see Sect.2). The impact of the AMF differences highlighted in Fig. 8 has also a multiplicative effect. The smaller satellite SCDs for valid flags (ie >85°SZA) found here compared to the ground-based ones, could be potentially compensated in the VCD by the AMF. Fig. 8 shows that AMF_sat is smaller than AMF_gb, only for SZA>88°."
and
"due to their DOAS settings choices, and in general, there is a total uncertainty within the ground-based datasets of about 26 to 33%, which is close to the remaining 36 and 28% multiplicative biases from the slope (slope values of 0.64 and 0.72 for GOME-2A and GOME-2B respectively). "

Line 350: Day-to-day variations are mentioned in OClO, but it is a bit hard to see on the plots that the data follow on these timescales. It appears from the data that many of the variations are on a slower than day-to-day timescale, so it seems like the agreement is more in the longer term behavior.
We partially agree that it is hard to see on those figures the day-to-day variability since OClO variations are usually on a longer time scale. There are however, some short-time changes (day-to-day), and these are usually seen by both ground-based and satellite measurements. This is why we used the 'day-to-day variation' formulation. The number of comparison data points per month oscillates between zero to around a dozen on average and can reach up to almost 30 on some months. Two examples of short-term variations (zooms of Fig. 9 and 10) observed at Arrival Height and Neumayer are presented in the figure below. The numbers in the table below correspond to the number of comparison data points for the selected months at both stations.





Neumayer, 2015 1: 25 points	ArrivalHeights, 2012 1: 1
Neumayer, 2015 2: 14	ArrivalHeights, 2012 2: 20
Neumayer, 2015 3: 25	ArrivalHeights, 2012 3: 21
Neumayer, 2015 4: 25	ArrivalHeights, 2012 4: 9
Neumayer, 2015 5: 2	ArrivalHeights, 2012 5: 0
Neumayer, 2015 6: 0	ArrivalHeights, 2012 6: 0
Neumayer, 2015 7: 0	ArrivalHeights, 2012 7: 0
Neumayer, 2015 8: 12	ArrivalHeights, 2012 8: 3
Neumayer, 2015 9: 13	ArrivalHeights, 2012 9: 26
Neumayer, 2015 10: 11	ArrivalHeights, 2012 10: 21
Neumayer, 2015 11: 29	ArrivalHeights, 2012 11: 11
Neumayer, 2015 12: 30	ArrivalHeights, 2012 12: 0

In a number of places near Figure A.3 caption, "Ny-Alesund" is misspelled. --> corrected, thanks.