

We would like to thank the reviewer for his/her constructive comments and the time dedicated to reviewing our manuscript. We agree that the suggested changes, particularly regarding the readability of the text and the presentation of the figures, significantly improve the clarity of the study.

Below, we provide a point-by-point response to the specific comments. The reviewer's original comments are shown in black, and our responses are provided in blue:

The paper of Gomez-Martin et al. addresses the calculation of Air Mass Factors (AMFs) for ground-based zenith DOAS observations at twilight for two Antarctic stations. The subject is complicated in particular due to the need to account for the earth sphericity and photochemical variations of several of the measured species. The authors use the models SLIMCAT (CTM) to derive effective concentration profiles along the light path, and MYSTIC (RTM) to calculate corresponding AMFs. They then compare these calculations with DOAS measurements of NO₂, O₃, BrO, and OCIO, finding a good agreement except for BrO, which is explained by tropospheric contributions not considered in the model.

This study is important for the community, the method is new and robust and the results consistent so I have only minor comments on the content. However some work could be useful to improve the presentation before publication.

General Comments (GC):

GC.1: In several sections (2.2 and especially 4.1) the text should be split in paragraphs to make it digestible. For instance, when they introduce a new figure, it is normal to start a new paragraph. Same for a new line of reasoning.

We agree with this suggestion. The text in the aforementioned sections has been restructured into a larger number of paragraphs to improve the flow and logical separation of ideas.

GC.2: Carefully using a LLM could improve the text readability as several sentences are hard to read, with for instance the subject too far away from the verb. Exemples of complicated sentence which could be improved in my opinión:

For a nicer reading we have changed the sentences as follows:

L. 248 'To check the validity of these approximations, SCDs of the four target species obtained using AURA in 2-D mode and considering the photochemical model concentration profiles (different for each SZA), have been compared with the SCDs obtained with AURA in 1-D mode, using a single averaged concentration profile (eq. 12)'

"To check the validity of these approximations, a comparison between two sets of data has been performed: (1) the SCDs of the four target species obtained using AURA in 2-D mode and considering the photochemical model concentration profiles (different for each SZA), (2) SCDs obtained with AURA in 1-D mode, using a single averaged concentration profile (eq. 12) for the whole atmosphere"

L. 165 Thus, the concentration of a given gas in a given atmospheric layer encountered by the sunlight reaching an instrument at the surface, for SZA = θ (c ,), is actually an average of the

concentrations corresponding to all values of the SZAs encountered by all the beams passing through this layer along their optical paths (see Fig. 3).

“Let $(c_{\theta}(l, \vartheta))$ be defined as the concentration of a specific gas observed by a ground-based instrument within an atmospheric layer and for a given SZA = ϑ . This concentration is represented as an average of the concentrations associated with all SZA values encountered by the various beams as they are passed through the layer along their respective optical paths (see Fig. 3).”

GC.3: Regarding the figures: the texts are often too small, especially in the legend. It s partly due to the fact that they are loaded.

We have increased the font size of all figure legends to ensure better legibility.

GC.4: Some of the figures could be split in two or more, e.g. figure 7 (we dont see the value for ozone AMF relative difference due to the scale defined by OCLO). In Figure 8, some material could go the supplement. Do we need all the months in the main text?

The size of Figure 7 has been increased for better clarity.

Regarding Figure 8, we believe including all months is valuable as it illustrates the seasonal variations between them. We have noted that Figures 8 and 9 are the only ones displaying the full annual cycle, while others focus on specific months for clarity.

However, to facilitate visualization, we have split the previous Figures 8 and 9 into separate plots for visible and UV absorbing gases. Consequently, the original Figure 8 is now Figures 8 and 9, and the original Figure 9 has become Figures 10 and 11.

GC.5: Figure 5: There is nothing to see for 80° because the average profile perfectly matches the model. So showing 80° is not that useful. It would be interesting on the other hand to plot the ratio of the maximum average concentration with respect to the model, to see at which SZA the averaging starts to matter.

While the average does not change the profile appreciably at SZA = 80°, we agree it is useful to demonstrate at which point the averaging becomes significant. We have updated the figure to include profiles for SZA = 80°, 85°, 90°, and 94° to better illustrate this transition.

GC.6: AMF calculation: it would be useful for readability to have a table for the inputs and algorithms used in p. 15.

We have added Table 1 to the manuscript, which details the inputs and algorithms used in the AMF calculations.

GC.7: L 428 'Figure 10' seems to relate to figure 11. I missed where the true figure 10 was presented in the text.

We thank the reviewer for identifying this error. The numbering has been corrected, and Figure 10 (now Figure 12) is correctly cited in the text.

Specific Comments (SC):

SC.1: L.54 Since 2012, the ground-based DOAS community working on stratospheric research [e.g. Adams et al., 2012]. If it s the DOAS community, there should be one more than one paper to refer to?

We have updated the citations to better reflect the work of the community: [e.g., Hendrick et al., 2011; Adams et al., 2012; Yela et al., 2017]

SC.2: L 77 reads contradictory with L 81. Can you please explain or reformulate?

L. 77 'To our knowledge, the only publication showing OCIO AMFs for SZA up to 95° is Pinardi et al. [2023].'... "

L. 81 'Finally, in Kühl et al. [2004], OCIO AMFs are estimated with the AMFTRAN radiative transfer model [Marquard et al., 2000] for different Gaussian vertical profiles and for SZAs between 40 and 95.'

We have reformulated the sentence for clarity: "*To our knowledge, the only publication providing explicit OCIO AMFs values for SZA up to 95° obtained from measurements is Pinardi et al. [2022]*"

SC.3: Figure 1: SLIMCAT should be in the figure?

SLIMCAT has been added to Figure 1.

SC.4: L 130: I think a_l is the box-AMF? but it s not explained in the text, could you add that in the text?

This is explicitly stated in the revised manuscript (L131): "*For each of those SZA above the station, box-AMFs (a_l) relate the optical path followed by sunlight at each atmospheric layer (ds_l) with the vertical layer thickness (dz_l)*"

SC.5: Equation (2) to (6) Do I understand correctly that this calculation is for one SZA at the station? If so, it would be pedagogical to explicitly state that VCD_{total_ph} depends on this SZA.

We have explicitly stated in the text that calculations are performed for each SZA above the station (θ in Fig. 3). We have also modified the description to clarify that VCD_{total_ph} is calculated from vertical profiles not averaged and just above the station:

“we use the VCD_(total_ph) (eq. 6) calculated from the vertical profiles obtained with the 1-D photochemical model, i.e. calculated from the vertical profiles not averaged and just above the station.”

SC.6: L.151-152: 'In addition to gas phase chemistry ...' -> I assume you do not use this PSC module? If not, please indicate or remove this sentence, if yes, please give more details

Yes, the model uses the PSC module. It is essential for the long-term (decadal) 3-D model simulation that provides the output for the ground-based stations. The module is kept switched on for the 1-D diurnal photochemical sampling to avoid any spurious chemical trends (e.g. if an air parcel within the PSC regime of the 3D model suddenly appears to no longer contain PSCs). A reference for the model scheme and a sentence on the importance of including this chemistry has been added.

SC.7: L.162: 'The concentration ... representative for ... 2.8° -> In Chipperfield (2006), I read that the model grid is variable. So it s the model runs that you have that were calculated at 2.8°, not the model itself. If this it true, can you please reformulate?

The sentence has been reformulated:

“The concentration profiles used in this work and provided by the photochemical model are representative for a horizontal resolution of 2.8°”

SC.8: l.172 takes chemistry into account -> photochemistry would be clearer

This change has been made.

SC.9: L.177: 'single scattering is already a good approximation' -> can you be quantitative on that?

A detailed study is provided in Perliski and Solomon [1993]. While we do not provide a single numerical value, the differences between approximations are visually evident in Figures 2 and 3 of that reference.

SC.10: Figure 4 y label should be 'scattering altitude' for clarity

Since the scattered intensity (x-axis) is a function of altitude (y-axis), we believe that using "scattering altitude" might be redundant or confusing. We have elected to keep the current labelling.

SC.11: L.303 'daily or even more resolved sampling is recommended for OCIO' -> what would it mean, more resolved than daily? Two AMFs for the two twilights a day?

We agree that "more resolved than daily" is unclear in this context. We have revised the sentence to:

"However, taking into account that for individual measurements these differences are expected to increase, for the study of specific episodes (a few days), daily sampling is recommended especially for OCIO"

SC.12: L.460 'source of error for all modelled SCDs could be the estimation of the reference ' -> measured instead of modelled?

This correction has been made.