Response to comments on egusphere-2025-4942 Submitted 06 Oct 2025

Anonymous Referee #1

Referee comment on "**Cross-calibration of GOME and SCIAMACHY Spectrometers Enhanced by Polarization Monitoring Devices Data**" by Owda, A., Coldewey-Egbers, M., Slijkhuis, S., Lichtenberg, G., and Aberle, B., https://doi.org/10.5194/egusphere-2025-4942, 2025.

We are grateful to the anonymous referee for taking the time to review our manuscript and provide us with constructive comments. We have carefully considered all comments and suggestions and thoroughly revised the manuscript.

In this response letter, we intend to address all comments, concerns, and suggestions point by point. The response will be highlighted in blue and the corresponding modification in the revised manuscript in orange. The original comment from the anonymous referee will be in black.

General comments:

"The paper is in general written in a clear and succinct manner and the reasoning is good to follow. The subject is highly relevant for long term atmospheric data records and this pre-study shows how the PMDs could be used to improve the cross-calibration between GOME and SCIAMACHY. However there are some points where the paper could be improved: Table 1 does not list the differences between GOME and SCIAMACHY; this is probably not intentional and should be corrected. Furthermore some of the information on the instruments should be given earlier in the text and not only in the discussion. The fact that the PMDs can be used to extend the cross calibration beyond the PICS can be emphasized even more in the abstract. If the paper is framed as a pre-study for future work, the low number of pixels used to derive the transfer functions is explainable. You have chosen a structure where the paper is divided in methods, results and discussion. It might improve the overall readability of the paper and avoid lengthy repetitions if you outline the different steps in a few bullets and discuss each step in detail including the used method, result and discussion. And of course summarize in the conclusion"

Response: Thank you very much for the general comments and the positive impression about our paper.

Regarding Table 1, it was not intentionally duplicated with Table 2. Table 1, which compares the differences between GOME and SCIAMACHY, has been added to the revised manuscript. [Fixed]

Additionally, we agree that further details on the instruments, particularly the PMDs, should be addressed in the beginning. The changes to the manuscript regarding these comments will be addressed within the specific comments section. [Fixed]

We agreed that further emphasis should be placed on extending the cross calibration beyond the PICS; therefore, the abstract was modified. [Fixed]

Lines 9-10 (Abstract)

"Sub-pixel variability analysis, based on Polarization Monitoring Devices (PMD) data, enabled the evaluation of the homogeneity and similarity of the scene as observed by GOME and SCIAMACHY, thereby reducing the uncertainty in the cross-calibration process."

Lines 25-27 (Abstract)

"This work highlights the potential for extending the cross-calibration beyond traditional PICS and ideally suited scenes, increasing robustness across varied surfaces and atmospheric conditions."

We stick with our chosen structure of the research paper. We have removed many repetitions. For some sections, such as 2.3, 4.2.1, and 6.1, we outlined the discussion in bullets.

Specific comments

Response: Thank you very much for the specific comments. We believe that your comments were very useful, and fixing these comments helps to improve the readability of the paper.

We have dealt with your comments one by one as follows:

SC1 0 14 Please add "from GOME and SCIAMACHY." It's otherwise not clear that both instruments had PMDs on board.

[Fixed]

In line 17 in the abstract, "... from both GOME and SCIAMACHY …."

SC2 1 60 "is has been assumed", can this point not be proven or confirmed? I would rephrase and include a reference where it has been shown.

[Fixed]

The sentence has been paraphrased, and the same reference is still there.

Line 64: Many studies assumed that the PICS remain temporally invariant

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SC4 2 103 "four channels"—which ones? You only name 3 (UV, VIS, NIR)

[Fixed]

The sentence has been modified and clarified. The four refers to the number of detectors the GOME had, which is 4.

Line 109: "... and four detectors (1A, 1BA, 3, and 4)"

SC5 2 104 Spectral resolution in NIR is missing.

[Fixed]

The spectral resolution of NIR is added

Line 109: "... and 0.4 nm in the VIS and NIR ".

SC3 2 115 Table 1 and it's caption are identical to Table 2. The listed differences between the instruments should include the LTAN, size and spectral resolution of the PMDs, the spectral resolution and range of both instruments, spatial resolution,…

[Fixed]

Table 1 and Table 2 are different now. Table 1, which shows the differences between GOME and SCIAMACHY, is provided in the revised manuscript. Table 2 in the original manuscript becomes Table 4 in the revised manuscript.

See Table 1

SC6 2 119 You refer that you use SCIAMACHY L1c data, but then you mention the preprocessing from L1b to L1c, please correct. Either L1c is input and you can discard the discussion on the cluster concept and refer instead to the specification of the tool or you start from L1b data and then do the pre-processing.

[Fixed]

We decided to remove the text regarding L1b SCIAMACHY and the tool we used to convert L1b to L1C. The process will start with the input of L1b GOME and L1c SCIAMACHY.

Line 123: "The fully calibrated Level 1 products from GOME (Level 1b) and SCIAMACHY (Level 1c) are used as input for the cross-calibration method."

SC7 2 133 Please explain why you use reflectance (most instrument effects divide out)

[Fixed]

Further explanation is added for the reason for using the reflectance in:

Lines 130-134:

“Reflectance is used because instrumental effects common to both Earth and Sun observation light paths, such as etalon interference, are largely canceled through the ratioing process. Furthermore, the retrieval of most atmospheric parameters is based on the reflectance. Reflectance served as a key parameter for the derivation of the transfer functions (TFs), which were used to update the GOME observations based on SCIAMACHY observations, as defined in Section 4.1.4.

Lines 172-174:

“GOME measured radiance, but it was affected by a randomly varying residual etalon, which is effectively removed when converting to reflectances. Therefore, using reflectances as the basis for the harmonization is advantageous.”

SC8 2 140 What is the spatial resolution of the PMDs? Please be specific.

[Fixed]

The spatial resolution of the GOME and SCIAMACHY PMDs are given in Table 1. Further details on PMD from both sensors are provided in the same table as well.

See Table 1

SC9 4 188 What is the Akima interpolation scheme? Please explain or give a reference.

[Fixed]

We added the reference for the Akima interpolation.

Line 216. “….Akima interpolation scheme, which is a method for smoothly interpolating data points using piecewise cubic polynomial (Akima, 1970).”

SC11 4 204 Why do you use a 3rd-degree polynomial? Have you done any over- and underfitting tests? The UV and VIS still show some features which are not

fitted but consistent for all cases, what is the reasoning to not fitting them? Please explain this in the paper. (I assume you will to keep spectral features)

[Fixed]

Yes, we have tested based on which function will preserve the structure of the spectrum and avoid overfitting. It found out that the third-degree polynomial function is more suitable to use.

Yes, we agree that there might be some consistent spectral deviation from a polynomial. However, these remain within the uncertainties. It was decided to use a polynomial on ratios since that is “fitted away” when performing a Differential Optical Absorption Spectroscopy (DOAS) fit to retrieve trace gases. Thus, DOAS fits on the FDR4ATMOS would remain fully consistent with previously obtained and validated trace gases.

See Lines: 231-237

“Among the tested polynomial degrees, a third-degree function was selected, as it adequately represents the spectral behavior while preventing overfitting and suppressing artificial artifacts and spurious high-frequency details. Although small systematic deviations from a purely polynomial behavior may exist, these remain within the measurement uncertainties. The use of a polynomial is justified because broadband spectral structures are removed in the Differential Optical Absorption Spectroscopy (DOAS) retrieval by polynomial fitting. Consequently, this approach ensures that DOAS analyses performed on the FDR4ATMOS data remain fully consistent with previously retrieved and validated trace-gas products.”

SC12 4 213 higher temporal resolution: the specifics could be added to the updated Table 1 and referred to here.

[Fixed]

It was meant to be the frequency of the PMD's measurements, not the temporal resolution. Therefore, the phrase “temporal resolution” is replaced with the frequency of the PMDs. The information about the PMD frequency is given in Table 1.

See Table 1

SC13 4 244 threshold T (T is not defined in Eq.(10))

[Fixed]

Equation 10 is updated by adding the threshold term and more explanation in terms of the equation.

See Equation 10 and Lines (264-266)

SC14 4 Table 1 You could add in the caption 757-773nm for the O2 A-band

[Fixed]

Table 1 is now Table 4 after adding some tables based on feedback from other reviewers. The caption is updated. The caption of Table 4 contains the exclusion wavelength ranges of the O_2 A-band.

See Table 4

SC15 5 255 The number of 151 is quite low, this is for one year of data? It might be good to repeat that here.

[Fixed]

Line 195 "... for one year of data"

SC16 5 258 "all scanlines" what do you mean by all scanlines? Over different regions? Far away from the PICS. Or do you mean the groundpixels close to but not overlapping with the PICS?

[Fixed]

All scanlines mean all ground pixels that can exist with the whole scan, regardless of whether they intersect with PICS or not.

Line 198: "...since some ground pixels are close to the PICS but do not overlap with it"

SC17 5 268 Are the differences between Nadir, East and West not present for VIS and NIR? Please add this in the text or show the different directions for VIS and NIR in a plot.

We have also tested and found there is no differences when we consider VZA for Bands 3 and 4. Therefore, we keep only plots of ratios of Band-2B based on VZA.

SC18 5 279 "nearly constant value", please be more specific, the fit is close to 0.94 and you then chose this value? Or did you average the value left & right of the O2 A-band?

[Fixed]

It has been clarified how the transfer function for Band 4 is derived. We have taken the average of the ratios beside the O_2 A-band (the left and the right side of the O_2 A-band). The derived TFs for Band 4 (including the O_2 A-band) are constant functions with a value of 0.94.

Line 308-309: For Band 4, the TF was obtained by averaging the ratios on the left and right sides of the O2 A-band, yielding a constant value of 0.94, which represents the TF for Band 4, including the O2 A-band (blue dashed line in Fig. 7c)

SC19 5 283 Why are the uncertainties larger? Is that because you combined all views? Would it improve if you distinguish East, West and Nadir?

[Fixed]

No, it is not about combining all views. As we mentioned in the previous comment, there is no dependence on VZA for Bands 3 and 4.

In the UV, a significant part of the signal comes from scattering by the atmosphere. The contribution of surface reflection strongly increases with increasing wavelength. Thus, inhomogeneity of the scene due to surface

inhomogeneity is expected to increase with wavelength. Since we don't have an exact match of GOME and SCIA ground pixels, surface inhomogeneity may cause a difference in TFs for different satellite overpasses, hence a larger scattering in derived TFs around the "true TFs".

The large uncertainties in Bands 3 and 4 compared with Band 2B are explained in Section 5.3, based on the sub-pixel variability of the pixels used in the cross-calibration in the same section from the PMD analysis (see Fig. 8). The values of standard deviation and coefficient variation are high for Bands 3-4. Therefore, the homogeneity of pixels used in the cross-calibration is less than for Band 2B; this leads to higher uncertainties.

Lines 326-331.

"The σ values of PMD measurements for Band 2B from both GOME and SCIAMACHY (Fig. 8d) are relatively low, indicating more spatially uniform and homogeneous pixels. In contrast, for Bands 3 (Fig. 8e) and 4 (Fig. 8f), the σ values of GOME PMDs are higher than those of SCIAMACHY, suggesting that less homogeneous pixels are involved in the cross-calibration for these bands. A similar trend is observed in CV : lower variability is seen in Band 2B (Fig. 8g) compared to Bands 3 (Fig. 8h) and 4 (Fig. 8i). Furthermore, the PMD measurements of GOME pixels exhibit higher variability than those of SCIAMACHY."

SC20 5 286 Some more instrument details would be useful (add in Section 2). Are the PMD matched to the spectral channels in wavelength? Earlier in the text you write they are broadband. Is the field of view the same as for the spectrometer views?

[Fixed]

More instrumental details about PMD are added to the revised manuscript. Additionally, a new table (Table 2) is added, which shows the ranges of the PMD for GOME and SCIAMACHY.

See Table 2 and

Lines 150-153. The wavelength ranges covered by the PMDs are chosen to overlap with the corresponding spectral channels. For instance, the wavelength ranges of the PMD-1 for both GOME and SCIAMACHY (Table 2) align with the

wavelength range in the UV band used for the cross-calibration in the FDR4ATMOS (Table 3).

SC21 5 300 PMD variability GOME & SCIAMACHY: do you have an explanation why the variability.

[Fixed]

It is expected to have different PMD values due to the broader range of the PMD wavelength of the GOME compared with SCIAMACHY. We have added Table 2, which gives more information about the wavelength ranges of the PMD channels.

Lines: 153-154 “The wavelength ranges of the PMDs in GOME were broader than those of the corresponding PMDs in SCIAMACHY; hence, different PMD measurement values are expected for SCIAMACHY and GOME.”

SC22 5 306 Only 39 pixels left over? The seems rather little.

I agree that 39 pixels are rather few. We believe that 39 GOME pixels overlapped with hundreds of SCIAMACHY pixels can be used to derive the TFs.

Fig. 10 shows the differences in TFs when 151 and 39 pixels were used. It shows that the values of TFs have not changed by more than 1.2%. But the significant changes were for the standard deviation.

SC23 5 Fig. 4 (c) Sudan 1 -> Libya 4?

[Fixed]

It has been corrected

Figure 4 caption

SC24 6 328 "higher spatial sampling frequency" , how much higher the sampling is should be included in Section 2

[Fixed]

The frequencies of the PMDs are provided in Table 1.

Table 1

SC25 6 347 This may be attributed… Please be specific; is it a guess, or do you have any evidence for this statement?

We have evidence from the PMD analysis performed for GOME and SCIAMACHY. Figures 8(d–i) show that both the standard deviation and the coefficient of variation are more widely spread for GOME than for SCIAMACHY. The scatter points are more dispersed along the x-axis than along the y-axis, indicating that the cross-calibrated pixels are not identical and exhibit a low level of homogeneity.

SC26 6 350 It is a bit late to provide all this PMD and instrument information only in the discussion. Please move all this information to Section 2.

[Fixed]

The information about PMDs are provided in Table 1 and Table 2. Further information about PMDs are provided in the manuscript.

Table 1, Table 2, and lines 144-149.

SC27 6 358- 362 This part has already been discussed in the results section. It does not need to be repeated here. And as in line 347, can you show that the sites are less homogenous in these wavelengths than in others (maybe from other instruments?)

[Fixed]

The repeated part is removed. For the sites are less homogeneous; it was a part of the first paper we submitted to AMT. We have presented a methodology to rank the stability of the PICS based on a group of statistical parameters. Further details on the ranking of the sites can be found in our under-review paper:

https://egusphere.copernicus.org/preprints/2025/egusphere-2025-4639/.

SC28 6 all For the discussion, apart from extending the scenes to derive TFs, what is the wider implication? Can this method also be used to cross-calibrate other instruments? Could this also be used to cross-calibrate to instruments without PMD but also with a higher spatial sampling for certain wavelengths (small pixel columns in OMI, for example)? It is a good point to close the loop with the abstract where the need to cross calibrate instruments over many decades is described.

[Fixed]

The presented method will be used for cross-calibration of further missions in FDR4ATMOS. We have mentioned in the conclusion the missions we planned to cross-calibrated such as GOME-2A/B/C.

Line 450-452: "The proposed method can be applied in principle whenever higher spatial resolution data are available, to produce a long and continuous observational record spanning multiple decades."

SC29 7 397 "spectral channels with strong absorption" : this suggests more than the O2 A-band was excluded, is this correct? Then this should be mentioned already much earlier. If not just refer to the O2 Aband.

[Fixed]

We excluded only the O_2 A-band from the derivation of TFs.

Caption of Table 4

SC30 7 417 Please call it cross calibration; the absolute calibration of both sensors has not been investigated.

[Fixed]

We did only cross-calibration and did not perform any absolute calibration investigation.

Technical comments/typos

Response: Thank you very much for the technical comments/typos. We appreciate your language check and apologize for the typos. We have checked the revised manuscript several times to avoid the typos as much as we can.

We have dealt with your comments one by one as follows:

TC1 0 5 was --> is

[Fixed]

Line 5

TC2 0 14 presented-->presents

[Fixed]

Line 8

TC3 1 30 The focus arises -> this sentence does not read well, please rephrase

[Fixed]

The sentence has been paraphrased

Lines 34-36: This leads to a focus on the urgent need to address atmospheric change and its impacts

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TC4 1 47 is one of the well-known methods -> is a well-known method, the "one of" implies that you should also mention other methods

[Fixed]

The sentence has been paraphrased

Line 51

TC5 1 49 ". Many other man-made" implies that deserts or

[Fixed]

The sentence has been paraphrased

TC6 2 Fig 1 Please increase the size of axis and text labels

[Fixed]

Fig 1 has been updated by increasing the size of axis and labels in the revised manuscript.

TC7 3 Fig 2 Caption: "except" -> excluding. Figure: please make sure the steps in the figure have the same name as in the text.

[Fixed]

Fig. 2 has been updated by using the same variables as used in the text.

TC8 4 Fig 3 Please increase the size of the axis and legend and make it colorblind-proof. The degree sign is missing for the numbers

Fig 3 has been updated by increasing the size of the axis and labels and adding a degree sign in the revised manuscript.

[Fixed]

TC9 4 175 is the pseudo

[Fixed]

Line 186

TC10 4 185 The sentence reads difficult, there seems to be a word missing. Consider to rephrase: "C1 and C2 are the correction factor and offset for scene dependent effects"

[Fixed]

C1 and C2 are the correction factors for scene-dependent effects and offsets, respectively

Lines 206-207

TC11 4 203 represented ->represent

[Fixed]

Line 220

TC12 4 206 1nm-width wave -> 1nm wide wavelength intervals

[Fixed]

Line 223

TC13 5 276 indicating a ____ across (word missing).

[Fixed]

TC14 5 Fig. 6- 10 Figures 6, 8, 9 and 10 should have less white around them and the text should be larger. If you change the aspect ratio and scale to the actual data points, it would be easier to read.

[Fixed]

The figures have been updated in the revised manuscript. Further checks for the colorblind effects have been applied to all figures.

TC15 5 315))_ and (space missing)

[Fixed]

TC16 5 Fig 10 Caption: panels g to i are not described

[Fixed]

The caption is updated by adding details for the missing subplots (g-i)

TC17 6 328 of the TF

[Fixed]

TC18 All All Please reconsider when you use the past tense, for example cross calibration is (not was) important.

[Fixed]

The manuscript will be revised several times to check for further typos and grammatical issues.

TC19 Fig 6/10 When plotting the NIR data vs wavelength, please consider a interrupted scale and focus the plot more on where you do use data

[Fixed]

We have clarified the way we derive the TFs for Band 4 (NIR). To avoid the misunderstanding, we present the TFs of Band 4 for the whole spectrum range. This is what we have made exactly. Therefore, we have also clarified and differentiated between the derived TFs of Band 2B and 3 vs. Band 4.

Response to comments on egusphere-2025-4942 Submitted 06 Oct 2025

Anonymous Referee #2

Referee comment on "**Cross-calibration of GOME and SCIAMACHY Spectrometers Enhanced by Polarization Monitoring Devices Data**" by Owda, A., Coldewey-Egbers, M., Slijkhuis, S., Lichtenberg, G., and Aberle, B., https://doi.org/10.5194/egusphere-2025-4942, 2025.

We are grateful to the anonymous referee for taking the time to review our manuscript and provide us with constructive comments. We have carefully considered all comments and suggestions and thoroughly revised the manuscript.

In this response letter, we intend to address all comments, concerns, and suggestions point by point. The response will be highlighted in blue and the corresponding modification in the revised manuscript in orange. The original comment from the anonymous referee will be in black.

General comments:

Owda et.al. describe a method to harmonize the reflectances of the spectrometers GOME and SCIAMACHY. Goal is a harmonized time-series of both instruments for reflectances. The authors uses measurements over PICS sites with co-located reflectance measurements from both instruments. The method includes utilizing the spatially higher resolved measuerments of the PMDs of both instrument to ensure homogenous scenes used for the harmonization.

In general, the paper is well written. The ideas behind the method are well described.

Long term data records are an important topic in atmospheric science. Harmonizing the data from different instrument is especially an issue for satellite based measurements. Harmonizing reflectances is a new approach to harmonize the measurements on the spectrometer level.

This paper describes a method to harmonize the reflectances of the satellite instruments GOME and SCIAMACHY. A method to harmonize the irradiance is not covered. This is not clearly stated in the abstract (according the the abstract, the FDR4ATMOS project aims to provide also irradiance). Please clarify this in the abstract, for example in line 7: This paper presents, for the first time, the cross-calibration methodology for *the reflectance of t*he spectrometers used in the FDR4ATMOS project. You might also consider adding the term *reflectance* to the title of the paper.`

Response: Thank you very much for the general comments and the positive impression about the paper. We agree that we should highlight clearly the harmonized parameter in the manuscript. We presented only reflectance in the manuscript; therefore, we have added that clearly in the title of the paper and in the abstract as well. [Fixed]

See Title "Reflectance-Based Cross-calibration…."

See Line 8, "across-calibration methodology for the top-of-atmosphere (TOA) reflectance of the spectrometers."

In the introduction, I miss the motivation for the selected spectral windows. This is driven by the common spectral windows, which contain spectral absorbtions of important trace gases. I suggest adding the relavant trace gases for each band also in Table 2. [Fixed]

Response: The motivation for the selection of these ranges of spectral bands is added to the introduction. The relevant trace gases for each band are added in Table 4

See Table 4 and

Lines 82-84. "The FDR4ATMOS focused on three spectral windows in the ultraviolet, visible, and near-infrared (UV/VIS/NIR), as these regions contain well-characterized absorption features of many key atmospheric trace gases (see Table 4)."

In Figure 7, transfer functions (TFs) for the whole band 4 (including O2A) are shown (dashed line). In Figure 10, only the two separate TFs outside the absorption are shown. The TF for band 4 needs some clarification:

How is the TF for the whole channel build? [Fixed]

We agree with your point of view that further clarification is needed.

We considered only the ratios from the wavelength intervals to the left and to the right of the O_2 A-band. The O_2 A-band was excluded from the derivation process of TF of Band 4 (NIR). The TF of band 4 is the average of the ratios from the left and right

sides of the O_2 A-band. Fig 6(g- i) shows the left and right sides of the ratio of the O_2 A-band.

Which TF will be used for the harmonization? This is finally stated in the conclusion: `constant value for the whole band`. This needs to be clarified already here. Therefore, the whole channel 4 TFs need to be added to Figure 10, because that is the used one. [Fixed]

That is correct; we agree on that. The manuscript is modified as well.

The TF is a constant value that is used to update the whole band (including the O2 A-band). Figure 10 is corrected.

Lines 308-310. For Band 4, the TF was obtained by averaging the ratios on the left and right sides of the O_2 A-band, yielding a constant value of 0.93, which represents the TF for Band 4, including the O_2 A-band (blue dashed line in Fig. 7c).

Related to this: In Table 1, for the NIR the wavelength intervalls are given as 756–757 & 773–774 nm. These are the intervall used for the TF calculation, but the FDR4ATMOS product will contain the intervall 756-774nm including the O2A Band. Here you need to distinguish between the spectral window in the harmonized product and the windows used in your calculations. You also need to descripe the calculation of the final TF for band 4. [Fixed]

We agree. We distinguish between the spectral ranges used to derive the TFs and the harmonized ranges.

This note was added to the caption of Table 4

See Line 239-143

For the derivation of the TF of the NIR spectral window, the O_2 A-band is excluded due to its high atmospheric sensitivity and the resulting strong variability in the observed reflectance. Instead, the two wavelength intervals of 1 nm width located immediately to the left and right of the O_2 A-band were used to compute the TFs. The ratio measurements obtained in these adjacent intervals were averaged to derive a single wavelength-independent TF, which is then applied to the entire spectral window, including the O_2 A-band.

Specific and technical comments

Response: Thank you very much for the specific comments. We believe that your comments were very useful, and fixing these comments helps to improve the readability of the paper.

We have dealt with your comments one by one as follows:

1. **p5, l120:**

   The SCIAMACHY Level1 product does not contain cloud information. Probably, your cloud information comes from the corresponding Level 2 products. Please clarify.

   [Fixed]

   Line 125-126. "For SCIAMACHY, cloud information from Level 2 was added to the standard Level 1c products, whereas GOME Level 1b products already contained cloud information."

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2. **p5, 122:**

   The cluster concept refers to a subdivision of a channel containing a specific wavelength region and detector exposure time, aiming to identify certain important spectral windows in the data.

   The goal is not to identify important windows. The goal is to optimize the data rate towards the important spectral windows:

   ..., aiming to optimize the data rate towards important spectral windows in the data.

   We have decided to take this part of the information out of the manuscript. The revised manuscript will not have any description of the cluster concept. The conversion process of Level 1b -> Level 1c was disregarded. The input for the harmonization starts with SCIAMACHY data, which is at Level 1c.

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3. **p5, l127:**

   with the scial1c tool developed by DLR (the link to the tool is under Section 8).

   I suggest to change this to a normal reference and add the URL to the references, something like: with the scial1c tool developed by DLR (ESA, 2025c).

   [Fixed]

   We have followed your suggestion by putting the links under the references.

   See Section 8 "Data availability and tools"

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4. **p7, Fig. 2:**

   Add to the text in the building blocks the variable names used in text/formulas, just as in the first block with (R_g) and (R_s)

   - SCIA2GOME Pseudo reflectance -> SCIA2GOME Pseudo reflectance ($R_{SCIA2GOME}$)

   - Ratio of refectance (SCIAMACHY/GOME) -> Ratio of refectances (Ratio)

   - Transfer functions ... -> Transfer functions (TF) ...

   I suggest to add a block for "Outlier removal", that step is missing in the sketch.

   [Fixed]

   Fig.2 has been updated in the revised manuscript based on reviewers' and your feedback.

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5. **p7, eq(1):**

   Please use a proper multiplication sign in equation (1), this seem to be a simple dot (.).

   Should be *\cdot* in Latex math mode. Same for all further equations.

[Fixed]

See equation 1

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6. p7, Figure 3:

   There is a gap between subsequent SCIAMACHY scanlines. This is not expected; there is (almost) no gap between the scanlines (similar to the two GOME ground pixels in the plot). Please check your figure.

   This gap refers to considering only forward scanning in the cross-calibration. The backscan is not considered in the cross-calibration, therefore, there is a gap between the forward scanning of SCIAMACHY.

   We have updated the caption with this piece of information.

   See caption of Fig 3

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7. p9, Table2:

   This table is a duplication of Table 1, only provide and refer to Table 1.

   [Fixed]

   There was a duplicate. Tables 1 and 2 were the same. In the revised manuscript, there are no more duplicated tables.

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8. p 24, l397:

   the spectral channels with strong absorption features: Only the O2A absorbtion band is excluded, so I suggest to clarify here, that the O2A window is the one excluded.

   [Fixed]

   O_2 A-band was the only window excluded from the derivation of TFs.

   See Line 435-436 “Furthermore, the O_2 A-band with strong absorption features was excluded from the derivation of TFs”

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9. **p 24, l401:**

   It found that... -> It has been found that...

   [Fixed]

   See Line 415

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10. **25, Section 8:**

    Instead of a list of links (with wrong indentations, use the `itemize` environment for lists), make a short text and move the links to the references. Something like:

    ***SCIAMACHY and GOME Level-1 data are available from ESA (ESA, 2025c; ESA, 2025d),* etc.**

    [Fixed]

    Instead of using links. We moved all links to the reference and cited them as you suggested.

    Section 8

Response to comments on egusphere-2025-4942 Submitted 06 Oct 2025

Anonymous Referee #3

Referee comment on "**Cross-calibration of GOME and SCIAMACHY Spectrometers Enhanced by Polarization Monitoring Devices Data**" by Owda, A., Coldewey-Egbers, M., Slijkhuis, S., Lichtenberg, G., and Aberle, B., https://doi.org/10.5194/egusphere-2025-4942, 2025.

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General comments:

Major comments

This paper presents the post-calibration method of GOME reflectance through cross-calibration with SCIAMACHY data. However, I believe that additional analyses are required to enhance the scientific significance of the study.

1. **This paper cites a reference for the long-term degradation of GOME in contrast to the radiometric stability of SCIAMACHY. The authors should perform and present their own evaluation results. This would also help establish a more robust calibration strategy.**

First, this research paper is the second part of a series of proceedings papers on spectrometer cross-calibration and extends calibration beyond specific sites and scenes. In the first research paper, we build on our analysis of a decade of GOME and SCIAMACHY observations.

The first part has been submitted to *AMT* and is currently available as a preprint: https://egusphere.copernicus.org/preprints/2025/egusphere-2025-4639/

Our comparison between GOME-1 and SCIAMACHY shows that SCIAMACHY exhibits greater stability than GOME-1. In addition, we identified the degradation patterns in GOME-1, while SCIAMACHY observations displayed comparatively less degradation. Our own analysis is presented under Figs 3-6 in the first research paper. The reference cited in the research paper refers to our own work and analysis.

2. **The paper emphasizes the necessity of correcting GOME degradation but presents transfer function (TF) results only for the year 2003. The authors should include year-by-year results at least, and clearly specify whether and how this methodology is applied on an annual or monthly basis.**

This paper is designed to present a new method for cross-calibration (methodology paper). We have chosen the year 2003 due to the relatively low degradation of GOME and SCIAMACHY as well. Our decades of analysis of GOME and SCIAMACHY reflectance (given in the first paper) confirm that. By the selection of the year 2003, we disregard the influence of degradation.

However, we agree that degradation can influence the TFs. In our paper, we have written a complete section under "6.5 Limitations of the derived TFs". Furthermore, we have pointed that out clearly, and there will be further work on this matter. We will use the same method but with different years to check the annual variation of TFs.

Line 409-412: "Since the TFs are expected to be influenced by degradation, especially in the UV, it is recommended to apply the reflectance degradation to the GOME data before deriving TFs to ensure their long-term consistency. This is envisaged for the next version of TFs of the FDR4ATMOS project."

3. **This paper also addresses how to deal with the post-calibration for GOME 1995-2022.**

The main goal of this paper is to present a methodology for the cross-calibration of spectrometers. GOME-1 and SCIAMACHY have an overlapping operational period of nearly 10 years. By leveraging the stability of SCIAMACHY, we can use it to calibrate GOME-1 and thereby create long-term, consistent observational records from both sensors.

4. **They should provide the validation results of the L2 product with and without TF-based correction.**

This paper aims to present a new cross-calibration method for spectrometers at Level1, as the main aim of the FDR4ATMOS project. Additionally, it presents how we leverage the characteristics of PMDs for further improvement of TFs by reducing the error bars (uncertainties).

5. **The manuscript requires careful proofreading. I have indicated only a few of the total typos in the technical correction section.**

Yes, we agree that the manuscript needs further grammatical and typo checks. The manuscript will be revised several times.

Specific comments

Response: Thank you very much for the specific comments. We believe that your comments were very useful, and fixing these comments helps to improve the readability of the paper.

We have dealt with your comments one by one as follows:

Section 1.3

#Line 82 the necessity to preserve the spectral structure of the observations

->Please clarify. This say that "the spectral resolution of the two datasets needs to be matched." ?

[Fixed]

Yes, you are right that the sentence needs further clarification and paraphrasing. We have not matched the spectral resolution, and we do not need an exact match in the spectral resolution. Therefore, we have dropped the spectral resolution from the challenges.

We have clarified the sentence as follows:

Lines 85-90: "This cross-calibration between the satellite spectrometers GOME and SCIAMACHY presents several unique challenges. Despite the significant temporal overlap of the two missions, there were no simultaneous observations at the same locations. Additionally, differences in spatial resolution further complicate the cross-calibration process."

#Line 83-84: These challenges distinguish spectrometer cross-calibration from that of imaging satellite instruments, which typically do not face such constraints.

-> The meaning of this statement is unclear to me.

#Imaging sensors generally have much higher spatial resolution and do not require strict preservation of spectral structure

-> The comparison implied in this statement is unclear. Limb? It is hard to agree with "high spatial resolution measurements do not require strict preservation of spectral structure."

We agree that this statement might be confusing. We wanted to point out the differences between the cross-calibration of imagers and spectral imagers with a high spectral resolution of 0.5 nm or better. The main application of spectral imagers is the retrieval of trace gases. The retrieval of trace gases depends on the spectral structure of the top-of-atmosphere reflectance. For example, DOAS retrievals typically require a relative point-to-point accuracy of 10^-4. This means that we have to be very careful about the harmonization: In order not to negatively impact trace gas retrievals, we have to preserve the point-to-point structure and should only correct the broadband difference between instruments. Imagers are not that sensitive to fine-scale changes of the spectrum that are important for atmospheric applications because of their comparatively coarser spectral resolution.

Another difference is that imaging spectrometers have launched since the early 1970s, and missions overlapped in time and have many collocations (and co-temporal observations). One example is the Landsat series, with 8 satellites in orbit since 1972. Spectral imagers covering a large part of the spectrum with high spectral resolution were only launched in the 1990s. For GOME-1 and SCIAMACHY, we have no spatio-temporal collocations because of their different orbits. Thus, the cross-calibration of GOME-1 and SCIAMACHY faced other challenges than the cross-calibrations of imagers, meaning that we could not use cross-calibration methods for imagers and had to develop our own methodology.

See Lines 89-93

"Cross-calibration of imaging sensors does not require the stringent point-to-point accuracy needed for spectroscopic trace-gas retrievals, as imaging applications are less sensitive to small radiometric inconsistencies than Differential Optical Absorption Spectroscopy (DOAS)-based retrievals, which typically demand relative accuracy on the orderof 10−4. In contrast, trace gas retrievals from GOME data require specialized approaches that preserve spectral integrity throughout the calibration process."

Section 2.1

 # The PMDsare broadband detectors specifically designed to capture polarization information with high temporal resolution

-> High temporal resolution or spatial resolution? Line 140 highlights the spatial resolution of PMD.

[Fixed]

It has been corrected. It meant the high frequency of the PMD observations compared with the spectral channels. The temporal resolution is removed and replaced with spatial resolution.

Line 144. "The higher spatial resolution of PMDs ….."

5.2 Transfer functions

 # The ratios were higher for the overlapping pixels with eastward VZA compared to those with nadir and westward VZA

-> Interpreting the results solely based on the magnitude of the ratio is not appropriate. A ratio close to unity indicates consistency between the two satellite reflectances, whereas deviations above or below 1 should be interpreted as discrepancies rather than simply as "higher" or "lower" values.

[Fixed]

Yes, it is not appropriate to rely solely on the magnitude of the ratios when interpreting the results. The sentence is used to describe the situation and not for a judgment about what is better or worse!. It is important to consider both the mean values and the standard deviations in the judgment.

I agree that the ratios for the East VZA were close to 1, indicating that the reflectance values from both sensors were relatively close to each other. However, the standard deviation values were relatively higher than for the Nadir and West VZA, meaning that the ratios of the East VZA values were more widely dispersed.

Based on this understanding, we have revised the description of these ratios to make it clearer.

See Lines 304. "The TF of eastward VZA is closer to 1 than those for nadir and westward VZA (Fig. 5b), indicating that the reflectance values for East VZA are, on average, similar between the two sensors. However, the standard deviation for East VZA is relatively higher than for Nadir and West VZA, indicating a wider spread of reflectance values in the East direction compared with the other viewing angles."

For further details on the reasons why the error bars of East VZA are larger than those of Nadir and West VZA.

[Fixed]

Lines 373-378. It is found that the TFs for the East VZA exhibit larger uncertainties compared with those for the West and Nadir VZAs. The PMD measurements of GOME and SCIAMACHY in Band 2B show a dependence on the VZA, which is consistent with the derived TFs for the same band (see Fig. \ref{fig_8}a). As shown in the figure, the PMDs for the East VZA are less correlated than those for the West and Nadir VZAs, indicating less homogeneous pixels in the East viewing direction. Consequently, the uncertainties associated with the East VZA are higher than those for the Nadir and West VZAs.

#. On average, the uncertainties in Bands 3 and 4 were about 4 times greater than the uncertainties in the Band 2B nadir TFs

-> Please provide deeper insight. Why do bands 3/4 have more SDs than band 2B? GOME/SCIAMACHY spectral-dependent SNR information could be sourced.

The PMD analysis of the cross-calibrated pixels helps us to understand the reason for larger uncertainties for the longer wavelength. Fig. 8 shows the statistics of the PMD analysis, including mean, standard deviation, and coefficient of variation (CV). For Bands 3 and 4, the standard deviation and CV were more widely spread than those for Band 2B, indicating lower homogeneity of the pixels used in the cross-calibration for Bands 3 and 4 compared with Band 2B. Therefore, the uncertainties in Bands 3 and 4 were higher compared with Band 2B.

See the following texts in the manuscript:

Lines 398-400. "The PMD analysis revealed that the degree of spatial uniformity is wavelength-dependent. A broader range of σ and CV values is found for Bands 3 and 4 compared to Band 2B (see Fig. 8 (g-i)), suggesting reduced pixel homogeneity at longer wavelengths. This reduction in homogeneity contributes to higher uncertainties in the TFs derived for Bands 3 and 4."

Also in the conclusion:

Lines 443-445. "The PMD analysis demonstrated a correlation between measurements of PMDs of GOME and SCIAMACHY. The homogeneity of pixels is wavelength-dependent. The spatial uniformity of overlapped pixels of Band 2B is higher than Bands 3 and 4, which impacts the uncertainty of TFs among the bands."

 # Section 6.1: "Third, the PMD-based analysis approach was applied as an indicator of pixel homogeneity in the cross-calibration. This approach helped exclude non-homogeneous pixels and ensured more uniform pixel textures, thereby reducing the uncertainty of TF. This was possible thanks to the higher sampling frequency of PMD measurements compared to the main spectral channels."

-> This does not appear to be consistent with the analysis results presented in Section 5.5. Section 5.5 shows no significant difference in the transfer functions (TFs) with and without PMD-based filtering. The impact of the filtering is instead reflected in the standard deviations (SDs). However, the correction factor used for cross-calibration depends only on the TFs. Therefore, I believe that the PMD-based filtering should be removed in order to enhance the sampling. Moreover, this study already selects analysis regions where spatial homogeneity is ensured.

It is not ensured that the spatial homogeneity is ensured for the data we used in the cross-calibration because we were using areas larger than the PICS itself. The footprint of the GOME pixel is bigger than the dimension of PICS. Additionally, our analysis for spatial homogeneity of PICS was performed as a part of our first research paper, and we have selected the most stable sites for the cross-calibration.

We agree that there were no significant changes in the magnitude of the TFs with or without PMD, which reflects the fact that highly homogeneous PICS scenes were used. This outcome was expected and is also favorable, as it indicates that the PMD analysis did not introduce any bias.

Furthermore, we believe that it is preferable to obtain TFs with reduced standard deviations. The approach presented here helps to improve the uncertainty, as evidenced by the smaller error bars. This methodology will also be applied in the

next paper, which aims to expand the analysis to datasets from other sites beyond PICS.

Based on these considerations, we have decided to retain the PMD analysis in its current form in the revised manuscript.

We emphasized using PMD for further cross-calibration studies beyond using only PICS

Lines 26-27 in the abstract.

"This work highlights the potential for extending the cross-calibration beyond traditional PICS and ideally suited scenes, increasing robustness across the varied surface and atmospheric conditions."

#Section 6.3 GOME PMDs had roughly double the spectral bandwidth compared to SCIAMACHY, and the optics are different, (ii) the GOME measurements at the equatorial crossing time of 10:30 against SCIAMACHY at 10:00, hence, the GOME PMDs would receive larger signals, (iii) PMD data on Level 1b were not corrected with the cos (phi) factor (as the reflectance was), (iv) the larger values in PMDs

-> It should be described in data description first, not in discussion section.

[Fixed]

Yes, we agree.

Additional details and information about PMD were added in a new table in the revised manuscript. The details will be presented in Table 2.

See Lines 142-154

"Information from PMDs: PMDs offer a higher spatial resolution compared to the measurements from the main channels. The higher spatial resolution of PMDs compared with the main channels' resolution (see Table 1) allows multiple PMD measurements to be captured within a single GOME or SCIAMACHY ground pixel. This enables the investigation of variation at the sub-pixel scale. For GOME, the PMDs were read out sequentially every 93.75 ms, which means for a nominal East-West scan (4.5 s), 45 PMD measurements were collocated. For a possible scan width of 960 km, each PMD could cover an area of 40 × 20 km² (Table 1). As a result, PMDs are utilized to assess the homogeneity of the overlapping pixels from GOME and SCIAMACHY. The PMD measurements used in this study are normalized with the

PMD measurements of the sun. The wavelength ranges covered by the PMDs are consistent with those of the corresponding spectral channels. For instance, the wavelength ranges of the PMD-1 for both GOME and SCIAMACHY (Table 2) align with the wavelength range in the UV150 band used for the cross-calibration in the FDR4ATMOS (Table 3). The wavelength ranges of the PMDs in GOME were broader than those of the corresponding PMDs in SCIAMACHY; hence, different PMD measurement values are expected for SCIAMACHY and GOME."

Technical comments/typos

Response: Thank you very much for the specific comments. We believe that your comments were very useful, and fixing these comments helps to improve the readability of the paper.

We have dealt with your comments one by one as follows:

Line 54 (Cosnefroy et al., 1996) è Cosnefroy et al. (1996)

[Fixed]

Line 57. "Cosnefroy et al. (1996) proposed…"

Line 55 km2 à km_2

[Fixed]

Line 58. 100 × 100 km^2

Line 66 remove "two spectrometers"

[Fixed]

Line 69 (Owda and Lichtenberg, 2025) -> Owda and Lichtenberg, (2025)

[Fixed]

Line 70. Owda and Lichtenberg (2025) compared the life mission reflectance data of GOME and SCIAMACHY

Line 66 (Coldewey-Egbers et al., 2018) -> Coldewey-Egbers et al. (2018).

[Fixed]

Line 73. in agreement with Coldewey-Egbers et al. (2018).

Line 77 have recently been è have been or was recently

[Fixed]

Line 80. GOME and SCIAMACHY have been cross-calibrated…

Line 78 please add a reference for FDR4ATMOS and introduce any related outcomes from companion papers.

[Fixed]

Yes, we referenced the FDR4ATMOS. For companion papers for the FDR4ATMOS, only 1 paper is still under review by AMT. Part 1, which shows the comparison between GOME-1 and SCIAMACHY, was added.

Line 79 the: ultra-violet è theultra-violet

[Fixed]

Line 82

Line 80 The cross-calibration between the satellite spectrometers GOME and SCIAMACHY è This cross-calibration

[Fixed]

Line 84

Line 98 scattered in the Earth's atmosphere è scattered by the Earth's atmosphere

[Fixed]

Line 103

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131 remove “(“, “)

[Fixed]

Section 3 is better to be placed in Section 4.

We would prefer to keep it in a separate section

Line 155 cross-calibration on Rs and Rg è cross-calibration between Rs and Rg,

[Fixed]

Line 163

Line 160-164. The information is correct, but need to be revised. For example, from “Learth is the calibration radiance as measured by the instrument.”, “as measured by the instrument” is unnecessary.

[Fixed]

We have paraphrased it.

Lines 171-172 ”GOME measured radiance, but it was affected by a randomly varying residual etalon, which is effectively removed when converting to reflectances. Therefore, using reflectances as the basis for the harmonization is advantageous.”

Line 167: Figure 4 or Figure 3

[Fixed]

Figure 4 is correct

Line 179: difference in è difference between

[Fixed]

Lines 178. The time difference between GOME and SCIAMACHY

Line 183: need to be revised for FDR4ATMOS manual (2024)

[Fixed]

Why both table 1 and table 2 are provided ?

[Fixed]

It was a mistake. Tables should be different. Table 1 will show the differences between GOME and SCIAMACHY. Table 2 (now Table 4 in the revised manuscript) shows the instrumental bands and the spectral ranges of the harmonized FDR products.

See Table 1 and Table 4

5.1 is better to be placed in section 4.

[Fixed]

We agreed and moved Section 5.1 to the Method section, under Section 4.1.3.

See Section 4.1.3

---

need to be revised for Band 2B (Fig. (8a),

[Fixed]

The figure will be updated in the revised manuscript.

The correlation between PMD measurements from GOME and SCIAMACHY è the correlation of PMD measurements between GOME and SCIAMACHY

[Fixed]

Line 319. The correlation of PMD measurements between GOME and SCIAMACHY.