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Atmospheric Measurement Techniques Discussions

Interactive comment on "The effect of horizontal gradients and spatial measurement resolution on the retrieval of global vertical NO_2 distributions from SCIAMACHY measurements in limb only mode" *by* J. Puķīte et al.

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Response to Referee #1

Here are the comments/remarks that came to my mind while reading this paper. First, I should say that the overall quality of this article is excellent: it is well structured, sentences and explanations are precise, figures helpful and one can feel that large efforts and carefull analysis have been deployed to reach these very interesting and useful results. I hope the following comments are not too naive and will help to make

some points more clear. I list them below following the structure of the paper.

We want to thank Referee #1 for reviewing the manuscript and his/her very positive response and helpful comments. Please find our reply point by point below.

- General comment : bias (between 1D and 2D, 1D and true, 2D and true) is widely used for adressing the accuracy of the technique, but it is almost never mentioned what is the impact of the random error of the retrievals. If this component is large (larger than the difference between 1D and 2D retrievals), what would be the consequence on the conclusions of this study? (I absolutely don't want to say that tomography is not improving, it is definitely! But I would like to balance the results regarding the random error of these retrievals) Especially for the Fig 4 and 5 for which you say in the 3rd paragraph of the page 9 that "this retrieval error is on the order of the correction due to the gradient effect [...]. [...] the retrieval error [...] and the difference between the 1D and 2D retrieval are compared in Figs 4 and 5 [...]." But I don't see any "retrieval error" in these figures...

In Figs. 4 and 5, areas for which the difference between 1D and 2D retrieval is larger than the retrieval error are indicated by a shading. This is done in order to highlight those areas for which the gradient effect (the difference between the 1D and 2D retrieval) is significant. For the shaded areas the difference between the 1D and 2D retrieval is not necessarily due to the effect of the horizontal gradient but may be caused by the statistical error. Therefore we wrote in the article: "Note that also the statistical component of the retrieval error might cause part of the variations in the differences between 1-D and 2-D retrieval." We now add to this sentence: "therefore the retrieval must have a certain precision in order to obtain a significant improvement by the 2D approach."

Regarding the last part of the comment, we think that this is a misunderstanding: Although we do not plot the retrieval error in Figs. 4 and 5, the comparison is still provided in these figures, i.e. we added a shaded area if the difference between the 1-D and 2-D retrieval is smaller than the retrieval error (see text and captions of the figures). We think that such a comparison is more illustrative as just a plot of the retrieval error for the context of this study. Therefore the wish of the reviewer to balance the results regarding the random error of the retrievals was also our intention and we think that this balance is given by Figs. 4 and 5 (i.e. by the shading of the areas for which the gradient effect is not necessarily the cause of the differences between 1D and 2D retrieval.)

- p.10, 2nd paragraph : in averaging the orbits, you explain the smaller difference between 1D and 2D by the "improved statistics"... but I don't understand this argument...

For those areas where the retrieval error is larger than the difference between the 1D and 2D retrieval, averaging of the orbits leads to smaller differences due to the statistical (or random) component of the retrieval error. We clarify this by saying "... (1) the improved statistics *because statistical retrieval errors of single orbits are (partly) averaged out ...*"

- In the same section, you say that there are large differences of gradients from an orbit to another. Would it be possible/useful to use the data from the adjacent orbit and use the gradient information to improve the results in a 3D model?

If we understand it correctly, this comment suggests to consider also horizontal gradients across track in the tomographic retrieval approach by combining the retrievals from different orbits. We think that this is an interesting idea and will investigate its feasibility in future studies.

- Last paragraph of section 4.1 : you compare the results of the fig.12 and the fig.9 despite the fact that they don't show exactly the same thing : fig.9 shows the diference between 1D and 2D retrievals of real measurements fig.12 shows the difference between 1D and true values (of simulated measurements) Moreover, in the fig.12, I don't understand very well how you can have such a strong and steep correlation between for instance a gradient at 20km and the bias at 30km...? (even with small gradients)

We selected as a reference always the best available 'truth'. Of course, for real measurements, we do not know the true distributions. In order to justify the usage of the 2D retrieval as a reference, we performed simulation studies where we compared also

the 2D retrieval with the truth (see Fig. 13) for some simple linear gradient cases and as well also did simulations for chemical model scenarios.

Regarding the correlation coefficient (left plot): The value is large because the gradient at any altitude is assumed to be linear. Thus it correlates by 100% to the gradient at any other altitude. Thus, although logics would say that the difference between 1D and true values at 30 km altitude would come from the gradient at altitudes that are above 30 km, nearly the same correlation is obtained also with respect to the gradient at 20 km (the retrieval noise is only slowly degrading the correlation at higher altitudes.).

The same explanation is also valid with respect to the right plot: Although in reality a gradient at 20 km altitude does not affect the difference at 30 km, the good fit between this gradient and this difference occurs because the gradient at an altitude of for example 33 km correlates by 100% with the gradient at 20 km (due to the linear gradient at all altitudes).

- In the 2nd paragraph of p.17, you say (and it seems convincing regarding the results of the fig.13) that there must be a better latitudinal sampling than 3.3°. But in section 4.1.3 at the end of p.18, you say that it can't be improved... To me it looks like a small contradiction, but still, there must be a way to get rid of the gradient effect on the 2D retrievals...

In the 2nd paragraph of p.17 we say that the distance of 3.3 deg may still be a bit too coarse as optimal distance because of the systematic error at 16.5 km. Later, in Sect. 4.1.3 at the end of p.18, we do not want to say that it is not improving for smaller distances w.r.t. systematic error. In fact we say here "that a distance in the interval between 3.3 deg and 1.7 deg (i.e. $\sim$3 deg) allows to correct for the horizontal gradient effect". In fact, the systematic error is corrected also for very small spacing like 1.7 deg. However we point also out that random retrieval noise increases.

We clarify the respective text. We mention that "for very small distances, like 1.7 deg, a smoothing constraint could be introduced to reduce this noise, but then the retrieval resolution will be downgraded". But the conclusion remains the same, i.e. that a too fine measurement resolution does not improve the retrieval resolution anymore.

- Section 4.2.1 : It seems that you can't retrieve correctly when the gradient isn't smooth enough... Is this a consequence of your 100% a priori covariance matrix which is constraining too large variations? And by the way, are there any off-diagonal elements in this matrix?... The retrieval procedure is not that detailed. (but I know that it was not the point of this paper)

With respect to the interpolation approach, we say that "such a good agreement may however not be obtained, if the gradient is not so smooth and varies more strongly along the orbit". We say this because the nominal limb mode has a poor spatial sampling that exceeds the horizontal sensitivity area of limb measurements. If there are larger horizontal variabilities in the atmosphere than the spatial sampling and the horizontal resolution of the limb measurements, the retrieval still could have some errors because the information content is complete to extract this variability.

To clarify this, we rephrase the statement as: "such a good agreement may, however, not be obtained, if the gradient is not so smooth and varies more *significantly within sensitivity areas of limb measurements and between scanning sequences because the coarser sampling cannot resolve the finer variations*."

Therefore the answer to the question regarding 100% a-priori covariance matrix is: No, this is a consequence of spatial undersampling, i.e. the information about the distribution within and between the sensitivity areas of limb measurements is missing (as just explained). Also stronger a-priori settings would not necessarily improve the retrieval, it could e.g. introduce a systematic offset.

No off-diagonal elements larger than zero in the covariance matrix were used (as described in Kühl et al., 2008), the only constraint for the interpolation approach is given in Eq. (4) in Sect. 2.3, but it does not cause an additional impact from a-priori. In order to clarify this at the end of Sect. 2.3 in the algorithm description we add: "... Thus no additional a-priori smoothing constraints like off-diagonal elements for the a-priori covariance matrix are necessary."

We agree that the retrieval description is not very detailed and besides the point mentioned by the Referee that "it was not the point of this paper" we hope that the relevant description sustaining the arguments and conclusions of the article are given in Sect. 2 and in the provided references.

- Small question : Would a finer sampling grid allowing for correlation between 3 limb scans at least help improving bias errors?

Yes, it would (see also second comment above). One can see this for example, when the distance between the scans is 1.7 degrees where at least 3 scanning sequences overlap. We comment this in Sect. 4.1.3 rewriting the last sentence on page 18 as follows: "However, as can be seen for the case with a distance of 1.7 deg, further reducing the distance, also increases the retrieval noise, thus showing limited improvement for this gradient strength w.r.t. the distance of 3.3 deg *(although it improves the overlapping of consecutive scanning sequences and corrects well for the systematic discrepancies)*."

Typo:

- caption of the Fig 8 : double "the".

- p.13 2nd paragraph : "Relative values for the analyzed orbits are indicated in the left panel of fig 10". I think it is the right one.

We correct for the typos as suggested and thank again the referee for his/her comments.

Interactive comment on Atmos. Meas. Tech. Discuss., 3, 2055, 2010.