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Interactive comment on "Carbon monoxide column retrieval for clear-sky and cloudy atmospheres: a full-mission data set from SCIAMACHY 2.3 µm reflectance measurements" *by* Tobias Borsdorff et al.

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The paper by Borsdorff et al. presents results of CO retrievals from the SCIAMACHY short-wave infra-red channel (SWIR) around 2.32 micron. The paper focuses on results from retrievals for cloudy scenes and contrasts them with results achieved previously by Borsdorff et al. (2016) for clear-sky retrievals. Both results are based on the same inversions scheme called the Shortwave Infrared CO retrieval (SICOR) developed by Vidot et al. (2012) and Landgraf et al. (2016b). SICOR can treat clouds as a homogeneous scattering layer providing knowledge of their height and optical thickness

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(assuming a triangular height profile). Height and optical thickness are retrieved in a first step from a retrieval of methane column under a clear-sky assumption and the subsequent comparison of this results to TM5 model based CH4 profile estimates.

The paper demonstrates that cloudy-sky retrievals overcame the significant previous deficiencies of SCIAMACHY CO clear-sky retrievals, i.e. the high CO noise errors for measurements over dark surfaces and low instrumental SNR, and the limited amount of retrieval data due to cloud masking. The validity of SCIAMACHY CO cloudy-sky retrievals have been demonstrated by comparison to ground based CO measurements (after applying the SCIAMACHY cloudy-sky retrieved averaging kernels to them).

The validation results presented in this paper also demonstrate that there are measurement conditions which principally favour situations where the impact of cloud shielding is negligible with respect to limitations of SCIAMACHY clear-sky CO retrievals.

The authors conclude that all-sky retrievals lead to an overall data-set with much better spatial coverage (including water surfaces) and better quality due to improved average retrieval performance of these all-sky measurements.

The paper is well written. The results are reported in a clear and structured manner and I can recommend the paper for publication in AMT providing the authors have considered the following general and specific remarks:

General comment:

Retrievals involving the knowledge of certain above-ground mean-scattering heights with negligible information retrieved from below the scattering layer require special precautionary measures taken by the producer to avoid mixing of total and partial column information. The authors mention in Section 2.3 on page 6 the potential of providing complementary information due to this mixing, but do not go in any detail how this complementary information (what is meant is probably profile information) can be retrieved or is used.

I find the way the retrieved column is interpreted relative to the true profile in equation 4 quite misleading with respect to the formulation in the conclusion saying: “Generally for clear-sky observations the null-space error is small, but for cloudy conditions it can easily exceed 30 percent. Here, clouds shield the atmosphere below and the a priori CO profile shape is used to add the lacking information.” Here it is formulated as if “ghost column” information from the scaled a-priori profile is added to complement the lacking information of the retrieved column above the scattering layer, while in Equation 4 it looks like the profile information is over-weighted with an averaging kernel above the cloud, therefore using only (or predominantly) a priori profile information from above the scattering layer in the retrieval. What is true?

In addition, the potential draw-backs of providing this mix of effective and total column information is not discussed in much detail in the paper. While this type of data-set can potentially be used relatively safely in model assimilation, where the use of the averaging kernels is an integral part of the assimilation process, it is less clear how such a data-set can or should, if at all, be used in the way it is displayed in Figure 10. This does not render the data-set useless of course. However it requires a discussion on the purpose of the data-set presented here. From my point of view, such a SWIR CO SCIAMACHY data-set is only complete once the results presented have been assimilated in a model, i.e. as a level-3 or 4 products, and model information has been added to the part of the profile not visible to the retrieval. From this perspective the scope of this paper would then be the presentation of a major step towards such a final level-4 data-set.

I therefore suggest to add a discussion of this aspect (maybe even consider to change the title to sub-column retrievals) and consider to add an outline on how to complete the task, in a next step. E.g. by providing a final SCIA CO SWIR data-set by adding missing sub-column information for individual cloudy-sky retrievals involving a model or other means (i.e. reducing the null-space error). We should not forget that there are currently many atmospheric composition and other retrieval methods available which potentially can provide an-above-cloud-column (e.g. water vapour retrievals from the same type of instrumentation) but choose instead to provide data-gaps in order to avoid confusion and biases, even though averaging kernels are available as well for these retrievals. While overcoming instrument SN deficiencies are the means to an end it cannot be the end for the means.

Specific comment:

Abstract: line 10: “low bias...”: Some SCIAMACHY CO retrievals apply a bias correction to the CO product, e.g. to agree with MOPITT at source free locations (Pacific) or with trusty ground stations. Is any bias correction applied prior to this comparison?

Abstract: line 20: “overall the cloudy-sky...” Considering the improvements exposed above, would not cloudy-sky measurements be something more than simply a "valuable addition"?

Introduction: line 7: “two stream radiative transfer solver..” Are two streams sufficient to accurately simulate observed radiances at top of the atmosphere? This simplification could lead to observation geometry dependant biases. Are sphericity effects taken into account?

Section 2.1, line 23: Are the SCIAMACHY operational L1 noise values reliable? Otherwise - although formally correct - the consideration of the measurement noise could worsen the CO estimates. Or is the CO product derived from a different SCIAMACHY L1 product?

Section 2.2, page 5, 1st paragraph: A short motivation for increasing or choosing this spectral window would be helpful (like for the reduction of noise. information content, type of absorbers, ice layer contamination etc...).

Section 2.2, page 5, line18: If the used cloud model has a fixed half-width of 1.5km, the lowest possible cloud top height in the forward model is 3km. Does this not constrain the retrieval in an unnecessary way?

General: I find the term "physics-based" retrieval bit problematic. It suggests that you may do certain things somewhere else, which are not physics based. Do you? I hope not! Full-physics would be also problematic, since many effects have not been considered in the retrieval, e.g. horizontal variability inside the spatial pixels.

Section 2.2, page 5 last paragraph: The cloud optical properties depend on the micro-physical ones. Accordingly, the retrieval results depend on the assumed cloud micro-physics. Could you be more specific on the cloud microphysical model which has been used?

Section 2.3, page 6: After 2005, SCIAMACHY channel 8 detector suffered irreversible damage decreasing the quality of the spectra. Do the FRESCO and SICOR cloud heights also correlate that good for other years after 2005?

Section 2.3, page 6, line 14ff: “In case of an optically thick cloud...” It is not clear from this formulation whether scaling of the profile in a retrieval under cloudy conditions is performed differently or in the same way as in the clear sky case. When it is stated that "... using only the measurement sensitivity above the cloud", does it mean that "the atmosphere bellow the cloud is neglected and not taken into account during the fitting process" or that "the forward model, which includes a cloud layer, is practically insensitive to CO bellow the cloud and mainly fit the CO information above the cloud"? Please clarify.

Section 2.3, I am missing a discussion of the fact that you expect/want the cloud parameters to be different from the FRESCO once retrieved in the NIR in first place. Since otherwise you could simply use the latter to at least adjust your h_cld. I think you should mention here the reasons why and how you expect them to be different in the SWIR. For sure one expects them to be higher in the SWIR, which is what one can see.

Section 2.3, page 6, line 27: “Also for the validation...”. Strictly speaking the data-use is limited. Since its limited to the profile part where the null-space is small. While the sentence is correct in principle it paints a too broad picture of data use.

Section 2.3, page 6, line 32: “CO retrievals for cloudy conditions...” Is the complementary use of CO columns with different averaging kernels to retrieve vertical profile information demonstrated somewhere in the paper (see general remark)? In contrast, the reduction of the S/N and the consequent reduction on the retrieval noise is clearly demonstrated and should function as the key-motivation to use cloudy scene retrievals.

Section 2.3, page 7 last paragraph, last sentence: “...and in addition has the potential to improve the CO product over land.” -> In cases where the true and the a-priori CO profile are similar, and where no significant deviations in CO concentration (true vs. a-priori) below the cloud layer occur.

Section 3: retrieval conditions: SN>20: This condition will change the CO retrieval densities favouring Earth location with high surface albedos. Have you notice any data gaps in dark surface locations?

Section 3: retrieval conditions number 3): The quality of the SCIA channel 8 spectra and, consequently, also the CO data record, gets worse after the end of 2005. Accordingly one could think in time variable noise thresholds to select for useful CO retrievals. Are the given noise thresholds constant over the whole mission? \varepsilon_CO $\sim$ 1x10ˆ19 represents roughly a relative noise error of some hundreds of percent. Please justify this quality criterion.

Section 3.1, page 8, line 5: “Furthermore, towards...” Whereas this is an acceptable assumption for unpolluted regions, I would expect that CO concentrations increase towards the surface in polluted areas, since CO emissions happens at surface (vehicle and industrial emissions, biomass burning, etc). Maybe the assumption is backed by transport over the selected circular area of 850km?

Section 3.1, page 8, line 9: “...chosen dynamically...”: Can you provide the maximum and minimum temporal difference considered in the collocation?

Section 3.1, page 9, line 3 and 4: Considering a collocation area higher than 2x10ˆ6 kmˆ2, the difference in city areas of about ∼1000kmˆ2 do not a play a role explaining the CO results.

Section 3.1, page 9, 1st Paragraph and Figure 6: How does the here presented reasoning explain the fact that cloudy sky retrievals compare so much better to MOZAIC measurements with averaging kernel applied than the corresponding clear-sky retrievals. Is the above cloud column more representative to the above cloud in-situ measurement? Or what is going on here. Especially given the fact that the cloudy and clear sky columns by Mozaic are not so different in first place.

Section 3.1, page 9, Last Paragraph: An additional reason for the good agreement is also the better SNR at Windhoek due to higher surface reflectivity

Section 3.2, page 9, line 23 and 24: "Becasue of lack of..." Is the collocation area in this case also a circle of 850km radius? How does the criterion of 30-day window compare with the dynamically chosen time window allowing an error of the mean of < 1x10ˆ17?

Section 3.2, page 10, line 6: ">17 ppb": According the the Mauna Loa and Reunion plots, the \varepsilon_S amounts to values larger than 100 ppb. How is this number here then to be interpreted according to the plots?

Section 3 generally: Wouldn't it be an option the application of the AK to TM5 profiles? Of course, the null space error would remain.

Conclusion, page 11, line 31: on biases: Are these biases shown in Fig. 6?

Figure 4, Caption: If clouds are thick and high enough, the cases compared here represent basically the CO column from ToA down to the upper troposphere. Considering that the MOZAIC/IAGOS CO profiles are extended to ToA using TM5 data, in how far do the comparison shown here for thick high cloud cases - and after applying the SCIA AK – really refer to a comparison between SCIA vs. MOZAIC/IAGOS and not SCIA vs TM5?

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Figure 10: To which extend is this plot dominated by the data of the "good SCIA SWIR years" 2003, 2004, 2005? Is the CO product displayed here considering only data from 2006 up to 2012 maintain the smoothness and the coverage properties of the given plot?

Editorials:

Abstract: line 9: “This improves...” -> The situation improves...

Section 2.1 line 7: C = (1, . . . , 1)T -> I would suggest to describe it in the form of: “the transpose of the column vector” or similar.

Section 2.1, line 12: Define gain matrix G for completeness and readability (all other quantities have been defined).

Section 2.1 line19: “an” -> a

p.9, line 1: "...a larger representation errors..."

Section 2.2, page 5, line 9: “clouds” -> aerosol and clouds

Section 2.2, page 5 line 10: “Moreover”? I think this is the purpose in first place...

Section 2.2, page 5, line 16 and 17: “To establish ...”. This sentence should probably go in the previous paragraph, since it is relevant for the retrieval of h_cld and tau_cld. But I guess the CH4 profile is also fixed for the "physics-based" retrieval. Is it?

Section 3.1, page.8, line 30: "Thus confirms that...";

Section 3.1, page.9, line 1: "...a larger representation errors..."

Section 3.2, page 9, line 20: “air column” -> dray-air column?

Figure 2, Caption: “cloud at...” -> cloud center height? cloud top height? Please specify.

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