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Atmospheric Measurement Techniques Discussions

Interactive comment on "Aerosol profile information from high resolution oxygen A-Band measurements from space" *by* A. Geddes and H. Bösch

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We would like to thank he reviewer for the helpful and detailed comments. We have revised the manuscript according to the suggestions and we address the reviewers comment with a point-by-point response below. Changes in the manuscript as per your comments are highlighted in magenta in the supplement.

The paper presents results of theoretical estimations of the retrieval accuracy of tropospheric and boundary layer aerosols from space-borne instruments. Although the paper contains some information which can be useful for future investigations its scien-

tific content is rather low. In its present form the paper is more suitable to be published as a technical report. The investigations of the retrieval precision under assumption of the planned SNR values are of very low importance as it is widely known that most of the instruments never reach the technical SNR performance because of unpredictable instrumental issues. In this respect I am wondering why the authors haven't made any attempt to look in the real measurements, e.g. from GOSAT or from older instruments like GOME/SCIAMACHY/GOME-2. This is actually the only way to convince the reader that the retrieval algorithm is working properly and all necessary parameters are taken into account. Furthermore, looking at the real measurements, e.g. from GOSAT, one can analyze if the obtained residuals are really on the level of the SNR defined by the technical requirements. If not, theoretical investigations with an unreachable SNR have very low value. I am sure the authors know that a reliable estimation of the surface uncertainty is crucial when retrieving real measurements. However, the authors completely ignore this issue just saying that a good estimation of the surface albedo increases the retrieval accuracy. No discussion on the methods to do it and eventually needed addition parameters is presented. Even the theoretical study analyzing the influence of atmospheric parameters is done in a quite simplified manner. Authors assume aerosol layers of a Gaussian shape with a fixed width and make no efforts to investigate what happens if the real width of the layer is different or if the vertical distribution of the aerosol is continuous. The paper contains no plot comparing the true, a priori, and retrieved LAOD profiles although providing these kind of plots is usual for sensitivity studies. To my opinion the only scientific goal of the paper is the conclusion that the aerosol in the lower atmosphere can theoretically be retrieved with the accuracy mostly lower than 30

- This manuscript presents an investigation in (theoretical) capabilities of upcoming (and existing) sensors for the retrieval of vertical aerosol profile information. We appreciate that the manuscript does not cover all potential aspects but we strongly believe (in accordance with other reviewers) that the presented manuscript gives results of interest to the readers of AMT. To analyze existing spectra (which would only be possible

for GOSAT and not for the other sensors of interest) from space-based instruments or large-scale full end-to-end retrievals would certainly be an interesting project but this would be a completely different study and could be covered in a follow-on publication. For the analysis of 'real' space-based spectra, imperfect knowledge of spectroscopy or uncertainties in the instrument calibration will lead to additional contributions in the residual of a spectral fit. The need for good calibration and improvements to the spectroscopy of O2 is widely recognized and efforts are underway that will lead to further improved spectroscopic data. We include this point in the summary of the manuscript We also like to point out that the retrieval method throughout the manuscript is based on a simultaneous retrieval of surface albedo and aerosols with the only assumption being that of a Lambertian reflector. Throughout the manuscript we use a very weak constraint on surface albedo so that no a priori knowledge is assumed. However, we provide an assessment of the impact of better priori knowledge on surface albedo on the aerosol retrieval (section 5.2) . We appreciated that the potential parameter space for aerosols is very large and some assumption have to be made to reduce it. We would like to clarify that our study includes full profile retrievals as well as retrievals of parameterized profile (where the width is kept constant) and for the latter one we assess the impact of this assumptions by allowing the presence of multiple aerosol layers (Fig. 10).

Detailed comments The title of the paper is misleading as it does not contain information on the vertical range. One might think e.g. stratospheric aerosols are meant.

- We have changed the title and included 'tropospheric'

Abstract: "retrieval errors typically exceed a value of 0.05" - please clarify if you mean relative or absolute error. In the latter case some information on the typical value of AOD in the lower atmosphere is needed.

- The error is absolute and a typical value for the AOD in the 0-2 km range has been included to make this clearer

Page 6028, lines 11 - 15: Where these dependencies of SNR come from? What are the reasons for this behavior. Is this assumption for GOSAT confirmed by real measurements?

-The SNR properties of the four instruments are based upon mission requirements for CarbonSat and S-5P, from calibration data for OCO-2 and from real spectra for GOSAT

Page 6029, lines 13 - 15: "An aerosol extinction profile with a Gaussian-shaped vertical distribution has been assumed for all scenarios." - a justification for this choice is needed. Furthermore, more work needs to be done to investigate what happens with the results if the "true" profile has a different width or shape. In any case, a continuously decreasing aerosol amount with the altitude is of interest.

- As already mentioned above, this manuscript is about the theoretical capability for the aerosol retrieval and the first part of the manuscript is for a profile retrieval which allows adjusting the profile shape itself. However, for all instruments, the vertical resolution of the retrieval is relatively low and thus the retrieval and especially the estimated errors and degrees of freedom (studied in this manuscript) are not too sensitive to the details of the profile shape. We investigate the retrieval performance based on a number of scenarios that include different aerosol heights to represent different regimes that allow comparing the performance of the different instruments. However, we already include studies of the expected retrieval error when changing the AOD amount and heights over a large range (AOD ranging from 0.1 to 1 and height ranging from 1 to 8 km, Figures 8 and 9)

Page 6029, lines 16 -19: "All simulations use the same aerosol optical properties as described in Cogan (2012) for type 2b aerosol from Kahn et al. (2001)" - as the aerosol is in the focus of the paper it is inappropriate to skip a detailed description of aerosol parameters used for the investigation.

- We have include more detail on the aerosol single scattering properties of aerosols (see also responses to reviewer 3)

Page 6030: the averaging kernels for all considered instruments have to be plotted and discussed. - We have changed figures 4 and 5 and included the averaging kernels for OCO-2 and S-5 P to represent the two instruments with the most different performance.

Page 6030: the inclusion of the intensity offset to account for the fluorescence effect is fine for estimations of the a posteriori covariance and DoF but questionable for the rest of the study. To do it correctly one has to simulate measurements including the fluorescence contribution and perform the retrieval excluding the fluorescence from the forward model. However, from the description in the paper it looks like the author completely neglect the fluorescence in the modeling. Furthermore, the fits with the intensity offset might be affected by the noise. To account for this all simulations/retrievals need to be done including a random noise added to spectra. As I can judge from the text this was not the case in the presented study.

- This is correct. Fluorescence is not added to the simulations as we are primarily interested in the coupling with the a posteriori covariance and DoF (See also response to reviewer 4).

Page 6030, line 14: “For the 4 top-most levels ...” - it would be useful if you provided the pressures/altitudes for this layers.

-DONE. We have included this information directly after this quote.

Section 2: As shown in Figs. 6 an 7 DoF values for the total vertical range are somewhere between 5 and 6. Does it make any sense to use the retrieval grid with 39 layers?

- Using a number of vertical layers much larger than the degrees of freedom is very common in optimal estimation and the number of retrieval layers can be much larger than the degrees of freedom as the a priori constraint is used to regularize the retrieval problem. Using a grid with few layers (or alternatively a parameterization as is shown in the manuscript) can be more practical and can lead to more robust retrievals but it

tends to lead to biases from the hard constraint (either low resolution retrieval grid or parameterization of the shape)

It would be nice it you listed the layers of the vertical grid both in mb and km in text.

- Instead of giving the height of all 39 pressure levels which is unpractical, we have given the surface pressure and elevation and the pressure spacing of the levels and where needed we have included a conversion between pressure and approximate altitudes. We also included a new km scale in figures 4 and 5.

Section 4.1: In the beginning of the section a trivial fact is reported that the retrieval precision increases with increasing SNR and DoF increases with the increasing resolution. Everybody who has ever done a retrieval knows it already. The only thing which deserves a short discussion here is the influence of the intensity offset. However, since the authors come to the conclusion that its role is rather minor, the Fig. 3 and the discussion around it is actually unnecessary. The concluding paragraph starting at line 5 of page 6033 is totally sufficient.

- Figure 3 is of importance as it shows the impact of SNR and spectral resolution on AOD error and DOF and thus it puts the results for the specific instruments into perspective. It is true that it can be expected that AOD error tends to improves with SNR and DOF tends to increase with spectral resolution but the detailed trend of AOD error and DOF in the full 2-DIM space is not trivial.

Section 4.1: More complicated scenarios with continuous aerosol distributions and layers with different widths need to be investigated.

- This comment is already addressed above

Section 4.1: Some plots showing the true, a priori, and retrieved profiles have to be shown.

- As discussed already above, the method used in this manuscript is based on linear analysis instead of large-scale end-to-end retrievals (where the above separation of a

priori, true and retrieved profiles would be relevant)

Influence of the temperature has to be analyzed A scaling factor for a correction of the atmospheric temperature is included in the retrieval statevector so that the impact of temperature on the retrieval will be small.

- We have included an assessment of the effect of a systematic difference in the shape of the temperature profile (by perturbing the temperature in 0-1 km range) in section 6.1.

Investigations for higher surface albedo e.g. 0.7, 0.9 need to be done

- The cases shown in the manuscript reflect a typical low albedo case and a high albedo case that represents heavily vegetated land. Cases with even higher albedo (representing ice and snow surfaces) would indeed lead to somewhat smaller errors (see response to reviewer 4, Figure 2) but the differences are small and thus we do not believe that such an additional 'very high' albedo case would add much additional information

Section 4.2: It is unclear how the a priori information is given in that case. Some plots with true, a priori, and retrieved profiles are needed. - As has been discussed already above, section 4.2 does not deal with full end-to-end retrievals but with an assessment of the a posteriori errors and DOFs (see also the response above)

Sections 4.1 and 4.2: The presented results do not contain any information about dependence of the retrieval results on the a priori information.

- We have included an assessment of smoothing errors for the aerosol profile retrieval which represents the contribution of the assumed a priori constraint via the a priori covariance matrix (combined with assumed variations of atmospheric aerosols) on the estimated AOD errors.

Section 5.1: It is questionable if the representation of the aerosol vertical distribution with a fixed-width Gaussian shape is useful. Clearly, large error can be expected if

the real shape is different. To my opinion one can only justify this approximation by a statistical analysis of real distributions.

- We agree that the use of parameterized shapes can introduce biases in the retrieval and this is why we include the profile retrieval as well as a retrieval using parameterized shapes in this manuscript. The impact of the the presence of an aerosol distribution that differs significantly from the chosen shape is shown in Figure 10 of section 5.1. However, since the vertical resolution is relativity low in all cases, small variations in the aerosol profile will have a low impact.

Section 5.2: What happens in a case of a partial cloudiness?

- This is a complex topic and certainly much outside of the scope of this study (Studies in this direction are underway by the OCO-2 team). Typically, partial cloudy scenes will be removed, e.g. from collocated imager data, otherwise it will bias the results.

Section 5.2: Where the information to constrain the surface albedo should come from? As far as I know this is one of the most crucial issues when working with the real data. The authors have to pay more attention at this issue taking into account the fact that the need for a proper estimation of the surface reflectivity may result in a completely new retrieval making all previous estimations useless.

- Throughout the manuscript we use a retrieval approach that retrieves surface albedo together with aerosols as we indeed do not believe that information on surface albedo representing the observation can be acquired with sufficient accuracy from external datasets. To investigate this in more detail, we have assessed the level of knowledge needed on surface albedo to improve the aerosol retrieval (see section 5.2).

Section 6.2: Details on aerosol types have to be summarized in the paper. Providing a reference is not sufficient.

- We have included more details in the manuscript (see also response to reviewer 3)

Section 6.2: Uncertainties of AOD are given in percent while they were given in AOD

units everywhere above. Percentage errors for the height make no sense.

- We have changed table 4 and given absolute errors for both height and AOD.

Conclusions: “Although this retrieval does not result in a more precise AOD retrieval if the aerosol is in the boundary layer, it allows very precise retrievals of AOD and height for elevated aerosol layers.” - the latter statement is only true if the real aerosol layer has a similar shape and width as the assumed one. Otherwise large errors might occur. In general, I do not agree that the parametrized retrieval is more advantageous as it has much higher uncertainty when applied to an unknown aerosol distribution in the real atmosphere.

- We have included this point in the ‘summary and conclusion’ section.

Figures 4 and 5 are hardly readable. They have to be made larger. Please provide second y-axis in km. Include additional plots showing the measurement response.

-Km-scale has been added and we the figures are larger now. Note that we have replaced the averaging kernels from CarbonSat with those from OCO-2 and S -5 P now in both figures to illustrate the differences between the higher and lower resolution instrument.

Legend in Figs. 6 and 7 is difficult to understand.

- The legend has been re-worded.

Real measurements have to be analyzed to convince the reader that the presented algorithm is usable for the aerosol retrieval in a presence of real measurement uncertainties

- This point is already addressed above.

Please also note the supplement to this comment:
http://www.atmos-meas-tech-discuss.net/7/C2825/2014/amtd-7-C2825-2014-

supplement.pdf

Interactive comment on Atmos. Meas. Tech. Discuss., 7, 6021, 2014.