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Atmospheric Measurement Techniques
Discussions

Interactive comment on "A MAX-DOAS aerosol profile retrieval algorithm for high altitude measurements: application to measurements at Schneefernerhaus (UFS), Germany" *by* Zhuoru Wang et al.

Anonymous Referee #2

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General comments

Wang et al. introduce a new MAX-DOAS aerosol profiling algorithm for high altitude sites. The algorithm itself is based on a parameterized approach using a pre-calculated look-up table and is optimized to retrieve profiles from data measured at high altitudes. The authors include an extensive sensitivity study and discuss the most important errors thoroughly. Furthermore, an attempt to validate the performance of the algorithm with ancillary measurements is shown. The AMTD version of this manuscript was also

added with one retrieval example of synthetic data and the comparison with an OEM algorithm.

First of all, I would like to comment that the manuscript has improved considerably since the first submission. Unfortunately, my main concern from the first manuscript assessment is still valid. The validation part and the retrieval of synthetic data is not enough to show that this algorithm is not only capable of retrieving accurate profiles but performs better than state-of-the-art OEM algorithms at high altitudes (as the authors claim). In order to solve this issue, I suggest to extend the corresponding sections with the following tests:

1. The retrieval test of synthetic data (Section 4.3) should be complemented with further examples (different exponential profiles and elevated profiles).
2. Comparisons of retrieved profiles with Ceilometer profiles should be added as well. This could be done in an additional section or with similarly averaged Ceilometer profiles in Fig. 10.
3. Fig. 3, 6 and 7 are shown for one example only. It would be interesting to see how the depicted parameters look like for a not so ideal profile retrieval (e.g. smaller (larger) RAA (SZA) or different profile shapes).

Specific comments

P1, L4-5 and P3, L20-23 and P28, L22-23: The authors claim that commonly used MAX-DOAS algorithms are not suitable for profile retrievals at high altitudes. Since this is neither shown properly in this manuscript nor do the authors cite a publication which addresses this issue, I think that these sentences should be reworded or removed (see also comment to **Section 4.3**).

P3, L29: area → areas?

P4, L15-16: "The exposure time and number of scans of each measurement are adjusted automatically (...)." Could you please explain what the automatic adjustment of

the number of scans of each measurement means?
P5, L5-6: "(...) the derivation of Angström exponents is critical and thus omitted." If this is critical, why is it omitted? In Section 4.5, you derive Angström exponents from MAX-DOAS results. It appears inconsistent to me that Angström exponents are only discussed from MAX-DOAS alone without validating with sun photometer results. This is even more problematic as you found that the MAX-DOAS AODs are much smaller than the sun photometer results (when the AOD lower 0.02 is the main reason for the omission). You could also compare with AERONET data in case the derivation from the available sun photometer is problematic.
P5, L13: preformed → performed
P7, L19-20: Which phase function and SSA values were used for the simulations? Which climatology was used?
Section 3.5: Which climatology was used for the LUT creation? Are different pressure and temperature conditions/profiles are taken into account (in addition to the cross section temperature discussion)?
P10, L6: A fixed median phase function was used for the LUT but Fig. 3 and Section B3 tell me that it is quite important to use a proper phase function (especially for small RAA). Do you plan to add more dimensions to the LUT for different phase functions or how do you deal with this problem?
P11, L22: ceiometer → ceilometer
P13, L11-12: "(...) we found that O_4 DSCD at 5° is almost negatively correlated with AOD." This is new for me. Could you please show this in a plot (maybe in the appendix)? Something only valid for high altitude sites?
Fig. 3: Please add SZA and RAA values to the description of your example cycle as it is used throughout the manuscript.
P16, L14-15: "This is because the a priori profile is not needed in our retrieval algorithm". To be more accurate, you include a priori assumptions of aerosols above retrieval height in your total uncertainty. Furthermore, since your layer σ_3 and σ_2 depend on σ_1 you have another constrain for your solution which could be understood as

a priori information. The question is how do you account for this kind of uncertainty?
P16, L17: In $\chi^2 \leq 1.5M$, is M the number of LOS? From an OEM point of view, more LOS mean usually a higher information content. But for your approach, more LOS mean a larger χ^2 criterium and therefore more possible profiles in your weighted mean calculation. Could you please explain this issue?
Section 4.3: Please add information on the used OEM algorithm and the RTM including parametrization of the OEM retrieval (e.g the definition of a priori and measurement covariance matrices, climatology, vertical grid...). Maybe in a table? The OEM solutions do not seem to be constrained enough (too many oscillations).
Furthermore, box-like true profiles would also be problematic for lower altitude sites and higher AODs due to the a priori smoothing. Please add also a retrieval for an exponential true profile (an elevated true profile would also be interesting). One problem arises by saying that the shown true profile (nearly box-like) is representative for UFS but you use an exponential a priori profile for the OEM. Since the a priori profile is the best (first) guess of the true atmosphere, an exponential profile is insufficient here (in contrast to typical retrievals in the PBL). A better a priori would be a Boltzman distribution or maybe an exponential profile with an even larger scaling height.
Additionally, please add a graph showing the simulated and retrieved DSCD including an RMS value of the difference between both DSCD as I don't think that the noise-free OEM solutions are that bad but might describe the measurement well.
Section 4.4 and Fig. 9: The reason for such a large difference between sun photometer and MAX-DOAS AOD is still unclear to me. I agree that aerosols in higher altitudes might be responsible for a difference but this is true as well for measurements in the PBL. But here, the introduction of a scaling factor leads to a much better agreement. The relative amount of aerosols in altitudes higher than 2km might be responsible but this is just a guess without prove. Could the authors please take a look at the Ceilometer profiles to solve this issue (see also the following comment for Fig. 10)? Furthermore, which kind of scaling factor (SF) is needed to bring the MAX-DOAS AOD to the sun photometer level and how large is the difference to the actually applied

SF? Is there also a clear seasonal pattern in your SF? If yes, maybe your way of how to retrieve LOS depending SF is not optimal?

Fig. 10: Please add also similarly averaged Ceilometer profiles and an error range for your profiles. Since a validation instrument is available, a comparison should be shown. The ceilometer backscattering signal could be scaled with the sun photometer AOD (see e.g. Wagner et al. 2019 for details). With this kind of comparison you could also assess how much aerosol is located at even higher altitudes than 2km.

Section 4.5: See comment to **P5, L5-6**.

P29, L6: profile → profiles

Appendix B: Here, important information are missing. For example, when you use aerosols in B1, which SSA and phase function is used? In B3 which SSA? In general, which climatology.

P34, L8-9: "using phase functions from Hohenpreißenberg should not have a significant impact on the aerosol retrieval". But the results are only shown for RAA = SZA = 60°. For other geometries it might be important to have an accurate phase function. Especially since you show in Figure 3 that the phase function is one of the largest error sources.

P35, L5-6: the averaging kernels (...) are all close to zero at the altitudes above 2km. That is correct but OEM based aerosol retrievals are iterative approaches which might still get an elevated layer more or less correct even though the kernels look like that. The sensitivity in these altitudes is lower for sure but if there is a dominant elevated aerosol layer, your retrieval is not capable of retrieving it accurately due to the dependencies of the individual layers while OEM algorithms might find an accurate solution (see also comment to **Section 4.3** for a test of an elevated layer).

References

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