We would like to thank the reviewers for their valuable comments and suggestions. It took more time than expected to go through all of the individual points, in particular as some of them required a significant extension of our original investigations. E.g., we included additional evaluations of ceilometer data to provide consistency checks for the MAX-DOAS retrievals, as well as additional examples of synthetic data retrieval. As a consequence we want to apologize for the delay of our point to point responses.

Reply to RC1

We thank reviewer #1 for the quick response and the detailed comments. We appreciate the comments and we understand that these comments have a positive effect on the scientific content of the manuscript while improvement of the descriptions and further clarifications are necessary. We have further clarified the retrieval procedure and improved the description of the look-up table parameterization. A point to point basis response to the reviewer's comments is provided in the following for consideration. Our answers are presented in blue texts. Please note that all the page and line numbers mentioned below refer to the pages and lines in the manuscript with revision marks.

Anonymous Referee #1

Received and published: 4 September 2019

The manuscript entitled "A MAX-DOAS aerosol profile retrieval algorithm for high altitude measurements: application to measurements at Schneefernerhaus (UFS), Germany" by Wang et al. presented a new look-up table based aerosol extinction profile retrieval algorithm for MAX-DOAS observations at Schneefernerhaus (UFS), Germany. Details of the parameterization of the look-up table, retrieval procedure and error analysis are presented. In addition, the authors also investigated the sensitivity of different input parameters to the retrieval results. The new retrieval technique is applied to synthetic data for validation. The long term observations of aerosol optical depth are also validated by comparing to sun-photometer measurements. The validated MAX-DOAS measurements are then used to investigate the temporal variation of aerosol at UFS. The manuscript is in general well organized and scientifically interesting for the community. Therefore, I recommend publishing the manuscript after addressed the following comments.

Sect.1 para 2: the authors summarize the main methodologies for aerosol monitoring, however, these mentioned AERONET, Lidar and MAX-DOAS are very different in the measured parameters, detection range, etc. I suggest the authors could introduce a little bit about the measured aerosol parameters of these methods, and their advantages and disadvantages for aerosol monitoring.

Response: We have added brief comments to these measurement instruments in Sect. 1 Para. 2 (see Page 2, Lines 25-30).

Sect. 2.2: the sun-photometer measured AOD were interpolated to obtain the AOD at 360 nm and 477 nm. Which kind of the interpolate method? Linear or non-linear? Any large difference due to different interpolate method?

Response: The data were interpolated following the Angström exponent method. As the AODs at 360 and 477 nm were both interpolated from the data at two nearby wavelengths (340 & 380 nm and 440 & 500 nm, respectively), the difference due to different interpolation method is expected to be small. We have compared our results with the data derived using linear interpolation. For most of the data, the difference is less than 1%. We have supplemented the information about data interpolation in Sect. 2.2 (see Page 5, Line 20).

Why only time period between10:00-14:00 UTC and stable aerosol abundance were considered?

Response: It is because the calibration uncertainty is very high under low SZA. This has been further clarified in the text (see Page 5, Line 21).

What does the intensity means in P.5 L.2?

Response: It means (spectral) radiances. This has been clarified in the text (see Page 5, Line 23).

The aerosol optical properties required for MAX-DOAS inversion were collected from the AERONET site at Hohenpeißenberg. It is located at an altitude of 980 m and approximately 43 km north of the UFS. As the authors introduced, the aerosol vary strongly with time and location. How to estimate the uncertainties on the retrieved results due to the difference of aerosol optical properties between Hohenpeißenberg and UFS site?

Response: We realize the different aerosol optical properties between UFS and Hohenpeißenberg. Therefore, we examined the sensitivity of O_4 DSCD to aerosol optical properties, and the influence was estimated to be less than 3%. Some other studies also showed that aerosol optical properties only show a small (1.5-4%) impact on the retrieval of aerosol extinction profiles (e.g. Chan et al., 2019). We have supplemented this information to Sect 2.2 Para. 2 (see Page 5, Line 34 to Pate 6, Line 3).

Sect. 3.1: How the DOAS fit windows were determined? Are they based on sensitivity analysis? Please clarify.

Response: The fit windows were determined according to both the absorption signal of O_4 and the SNR of our spectrometers. We have added some explanations in Sect 3.1 (see Page 8, Lines 4-11).

How about the performance of spectral analysis? The levels of RMS and SCD errors? Any filtering for O_4 DSCDs was applied before being introduced to the retrieval scheme?

Response: We have added further descriptions about the performance of spectral analysis in Sect 3.1 (see Page 8, Lines 20-23). The results with residual RMS larger than 10^{-3} are filtered out. This is also supplemented in Sect. 3.1 (see Page 8, Lines 19-20).

Please add a reference to QDOAS: http://uvvis.aeronomie.be/software/QDOAS/

Response: The reference has been supplemented in Sect 3.1 Para. 1 (see Page 7, Line 33).

Sect. 3.3: How did the authors obtain the topography? And how did the authors distinguish snow or rock and vegetation? Is it taken from a digital elevation map (DEM) and albedo map? Please clarify.

Response: Both the altitude data and surface type are obtained from Google Earth. This has been clarified in the caption of Fig. 2 and Sect. 3.3 (see Page 10, Fig. 2 and Line 9).

How to define the pseudo-reality topography usingTRACY-2?

Response: This is described in Sect. 3.3 Para. 4 (see Page 10, Lines 8-14).

What's kind of the parameters were included in the pseudo-reality topography?

Response: These are described in Sect. 3.3 Para. 5 (see Page 10, Line 19 to Page 11, Line 1).

It would be useful to compare radiative transfer simulation results from the two radiative transfer models with the same setting to quantify the differences between the two models.

Response: We have supplemented the comparison result in Sect. 3.3 Para. 3 (see Page 10, Lines 5-7).

Sect. 3.5: It is difficult to understand the parameterization of aerosol extinction coefficient in Table 3. Please clarify.

Response: The description of the parameterization has been refined (see Pages 14-15).

I also think the vertical resolution of retrieval is very coarse in the design of the look-up table, in particularly compared with other ground based MAX-DOAS studies.

Response: The parameterization is based on the measurement sensitivity. Because the information content of the measurements is rather limited, a finer vertical grid would not really improve the accuracy of the retrieval, but would greatly increase the complexity as well as computational effort. In most of the OEM-based MAX-DOAS studies, although their vertical resolution is higher (usually 200 m per layer), the degree of freedom of the signal (DFS) is usually around 2. In addition, the vertical variation of the aerosol extinction at the UFS is expected to be low. Therefore, a coarse resolution setting would be sufficient. This information is supplemented in Sect. 3.5 (see Page 14, Lines 12-15).

Btw, there is only one sub-section of 3.5, I do not suggest to use the title of 3.5.1.

Response: These two sections have been rearranged as Sect. 3.5 and 3.6 (see Pages 14-17).

Sect. 3.6: What's the DOAS fitting error? How to evaluate it? There are so many sub-titles. In my opinion, 3.6.1 and 3.6.2 can be grouped as the errors on measured O_4 DSCDs, while 3.6.3-3.6.6 can be regarded as the errors on simulated O_4 DSCDs. So I suggest to re-organized this part.

Response: We have clarified the definition of the DOAS fitting error in the text. This section (now Sect. 3.7) has been rearranged following the reviewer's suggestion (see Pages 17-20).

Sect. 4.4, p. 26, l. 5-6: Any explanation about the seasonal pattern of AOD that higher in summer and lower in winter?

Response: This is explained in Sect 4.5 Para. 1 (see Page 36, Lines 15-16). It can be explained by the higher biogenic emissions in summer, as well as the stronger vertical transport of aerosols.

Also the systematic underestimation of MAX-DOAS AOD? Could the authors can present the co-located ceilometer observations or lidar measurements nearby to certificate the vertical structure of aerosol extinction?

Response: We have supplemented the ceilometer results in Sect. 2.3 (see Page 6, Fig. 1 and Page 7, Lines 13-16). The results indicate that the aerosols above 2 km contribute 30-50% to the total AOD. As the MAX-DOAS reports AOD only up to 2 km, an underestimation of total AOD is expected.

Please also discuss the possible reason for the high ratio of aerosol extinction coefficient between 360 and 477 nm in summer than in the other seasons.

Response: This is explained in Sect. 4.5 Para. 2-3 (see Page 36, Line 21 to Page 38, Line 7). It indicates that the particle size is smaller in summer.

Sect. 5: The conclusion is mostly repeating the results, please consider shorten the entire summary and conclusion section.

Response: We have shortened this section (see Page 38, Line 9 to Page 40, Line 3).

Minor comments: p. 6, l. 2-3: Did the authors observe any seasonal pattern of cloud cover? It might be important for the later analysis of aerosol temporal variation.

Response: We have supplemented a summary of the cloud screening results in Sect. 3.2 (see Page 8, Lines 31-34 and Page 9, Table 2). The percentage of cloudy measurements is highest in summer (67%) and lowest in winter (54%).

p. 7, l. 6: Which radiative transfer model the authors are referring to? Please clarify.

Response: It refers to LIDORT. This has been clarified in the text (see Page 9, Lines 8-9).

p. 9, l. 11: Please define all the terms in the equation.

Response: The missing definition of ΔS_s has been supplemented (see Page 15, Line 29).

p. 13, l. 10: I don’t understand why should the surface albedo error dependent on aerosol profile?

Response: Maybe the previous description was a bit misleading. We have revised the description of Sect. 3.7.2 to avoid confusion (see Page 18, Line 31 to Page 19, Line 4).

p. 14, l. 9-13: If the authors already consider the error caused by aerosol above the retrieval height, then why the error bar of Fig. 9 still do not overlap with the sun-photometer observations most of the time?

Response: This is only a source of error that we consider in the retrieval, but the MAX-DOAS AOD in Fig. 9 only represents the AOD under 2 km. We have further clarified this issue in the text (see Page 17, Lines 3-4).

p. 17, l. 4-10: Radiative transfer model error also play a role in the discrepancy between measurement and simulation. Please revise the statement.

Response: We have revised the description (see Page 24, Line 1).

The elevation dependent O4 scaling factor also introduced in other studies, e.g. Irie et al., 2015; Zhang et al., 2019. Please review and cite.

Response: We have supplemented the two references (see Page 24, Lines 5-7).

p. 25, fig. 9: The error bars do not overlap with the sun-photometer measurements most of the time indicated that there are some significant error sources are not consider in the error analysis. Please clarify.

Response: The main reason is that the MAX-DOAS AOD only represents the AOD under 2 km. This has been further clarified in the text (see Page 34, Line 33 to Page 35, Line 2).

p. 27, fig. 11: As mentioned before, cloud screening also play a role in the analysis, it is important to indicate the number of valid measurement used in the calculation.

Response: We have supplemented a summary of the cloud screening results in Sect. 3.2. The numbers of valid measurements are listed in Table 2 (see Page 9).

Reference:

Chan, K. L., Wang, Z., Ding, A., Heue, K.-P., Shen, Y., Wang, J., Zhang, F., Shi, Y., Hao, N., and Wenig, M.: MAX-DOAS measurements of tropospheric NO2 and HCHO in Nanjing and a comparison to ozone monitoring instrument observations, Atmospheric Chemistry and Physics, 19, 10 051–10 071, https://doi.org/10.5194/acp-19-10051-2019, https://www.atmos-chem-phys.net/19/10051/2019/, 2019.