Anonymous Referee #2

We would like to thank the reviewer for his / her useful comments.

GENERAL COMMENTS

The manuscript entitled "Evaluation of UV-visible MAX-DOAS aerosol profiling products by comparison with ceilometer, sun photometer, and in situ observations in Vienna, Austria" by Schreier et al. presents vertical profiles of aerosols retrieved from Multi-Axis DOAS. The MAX- DOAS observations are compared to co-located measurements of particulate matter, AOD from sun photometer, and backscatter profiles from a ceilometer.

Aerosols play a crucial role in the atmospheric system. They affect air quality, have an impact on radiative transfer, and provide surface areas for chemical reactions. Aerosol vertical profiles from MAX-DOAS provide a valuable contribution to the understanding of the role of aerosols in the boundary layer. Therefore, this manuscript fits well into the scope of AMT.

In general, the manuscript is well written. However, some aspects of the methodology are unclear and important information is missing. In particular, the discussion mainly focuses on regression coefficients between MAX-DOAS and co-located data, but it is not always clear which quantities are actually compared in the regression analysis (see Specific Comments). While regression coefficients provide information only on the precision of the measurements, there could be more emphasis on the discussion of slope and intercept of the linear regression analysis in order to assess the overall accuracy.

We agree that the sole use of regression coefficients is not optimal for the comparison of vertical profiles. We have therefore added a discussion of slopes (see Page 17, Line 28-29 and Page 18, Line 1-5) of the linear regression analysis and moreover calculated absolute and relative differences (see answers to specific comments for more details).

Smaller correlation coefficients between surface extinction/AOD from MAX-DOAS and co-located instruments are found during summer. The authors conclude that this is due to a poorer performance of MAX-DOAS during this season. I cannot really see any reason for this. Are the DSCD errors higher or is the information content lower in summer (this would require a discussion of the averaging kernels, see my comment below)? When looking at the right panels of Fig. 2 and 3, the smaller correlation coefficients instead seem to be caused by aerosols being less abundant during summer than in other seasons, leading to poor statistics. Furthermore, there is a single outlier in the Vis data (lower-right panel of Fig. 3) that is likely to have a strong impact on the slope of the regression line.

We fully agree with the comment that aerosols are less abundant in summer than in other seasons and thus, poor statistics with respect to correlation coefficients are expected for summer. We have now introduced averaging kernels (see answer to the comment below). After convolution of ceilometer data with BOREAS AVKs, the extreme single outlier in the Vis summer data disappears and the slope is higher than before (see Fig. 6).

Apart from some general remarks on the vertical range of the retrieved profiles, a discussion on the vertical sensitivity based on averaging kernels is missing. At least some examples of averaging kernels for different atmospheric scenarios should be presented and discussed. Due to the limited vertical resolution of the MAX-DOAS extinction profiles, a quantitative comparison between MAX-DOAS and Ceilometer profiles requires the convolution of the high-resolution Ceilometer profiles with the MAX-DOAS averaging kernel according to Rodgers and Connor (2003) (see, e.g., Frieß et al., 2016 and Tirpitz et al., 2021). This is of particular importance because the vertical sensitivity of the aerosol profiles retrieved by the BOREAS algorithm appears to be limited to the lowermost 500 m (Fig. 9 in Bösch et al., 2018), which means that large fractions of the aerosol column are invisible for the MAX-DOAS instrument.

We have now introduced averaging kernels. We now present three examples of AVKs (morning, noon, and afternoon) for the UV and Vis channel for one exemplary day (10 October 2018) with changing aerosol load throughout the day (see Fig. 2 and 3 as well as Page 8, Line 16-27 and Page 9, Line 1-21). The quantitative comparison between MAX-DOAS and ceilometer vertical AE profiles is now more representative as we have now convoluted the high-resolution ceilometer profiles with the BOREAS averaging kernels according to Rodgers and Connor (2003) (see Fig. 5 and 6 as well as section 3.1.1).

Furthermore, we would like to emphasize that the sensitivity of MAX-DOAS profiling algorithm is not limited to the lowermost altitudes but it is the highest here. The sensitivity is good enough to retrieve elevated layers in synthetic data if the layer dominates the aerosol profile (see Bösch, 2019).

SPECIFIC COMMENTS

Abstract L20-23: It is not correct that coincident measurements of temperature and pressure profiles were used here for the first time for profile inversion, see e.g. Friedrich et al. (2019), who used daily radiosondes.

We have now deleted "For the first time," in the abstract (see Page 1, Line 20-22).

P6, L15: Do you use the 0° elevation measurements for the profile retrieval? I could imagine that this leads to difficulties in the inversion, either due to blocking by surrounding buildings or trees, or due to the fact that the field of view includes both atmosphere and surface.

The 0 degree elevation measurements are not used in the retrieval in our study. We have now added a sentence in the text to clarifying that measurements taken at 0° elevation angles are not used for the profile retrieval (see Page 6, Line 19-20).

P8, L12: Mean vertical profiles of which quantities are used as input parameters for the RTM?

We have now added a sentence to clarify, which quantities are used (see Page 13, Line 11-15).

I suggest to structure the sub-sections of Section 2.2 in the order of their importance, starting with the MAX-DOAS profile retrieval, and to move Section 2.2.1 on cloud flagging to the end of section 2.2.

We have now re-structured the sub-sections of Section 2.2 accordingly.

P8, L16: It is not clear to me what the term 'Hence' refers to. The term 'Differential slant column' is not defined yet and should either be explained here, or replaced by 'measurements'.

We have now deleted the term 'Hence' and replaced 'DSCDs' with 'measurements' (see Page 13, Line 16-17). The term DSCD is explained for the first time at Page 10, Line 27-29.

P8, L19-24: The technical description of the pyranometer should be moved to section 2.1.

We have now moved the technical description of the pyranometer to section 2.1 (see Page 8, Line 7-12).

P9, L4: What do you mean with 'daily total second-order difference'? Is this the mean of the second-order differences? Please clarify.

We have now introduced the term 'daily sum of the second-order differences', this should be more clear (see Page 13, Line 25-28).

P9, L25: The term 'oxygen dimer' should be avoided; O4 represents the O2 collision complex.

We have now avoided the term 'oxygen dimer' (see Page 10, Line 15-17).

P10, L7: Again, this is not the first time that measured atmospheric profiles of pressure and temperature from a co-located site are used for MAX-DOAS profile retrieval, see general comments.

We have now deleted "for the first time" (see Page 10, Line 28-29).

Section 2.2.2: An error discussion regarding the retrieved aerosol profiles is completely missing. Retrieval errors and vertical resolution based on averaging kernels, as well as information content should be discussed here. A discussion of averaging kernels is particular importance because the lack of sensitivity for aerosols at high altitude might explain parts of the discrepancies between MAX-DOAS and ceilometer, and because the ceilometer profiles should be convoluted with the MAX-DOAS averaging kernels in order to perform a quantitative intercomparison between both data sets (see general comments).

We have now introduced and discussed vertical sensitivity, averaging kernels as well as retrieval errors in our manuscript (see section 2.2.1 as well as Fig. 2 and 3). The ceilometer profiles have now been convoluted with the MAX-DOAS averaging kernels to perform a more quantitative comparison between MAX-DOAS and ceilometer (see section 3.1.1 as well as Fig. 5 and 6).

P11, L7: In which way has time been extracted from the backscatter profiles? Do you mean the time stamp of the profiles? This would not really be worth mentioning.

Yes, with time we mean the time stamp of the profiles. We have now deleted the term 'time' (see Page 12, Line 3-4).

P11, L13,19 and 22: I think the term 'assimilation' is inappropriate here because it has a well-defined meaning in atmospheric science, namely to adapt a modelled atmospheric state to observational data in a statistically optimal way. Maybe gridding the data (in time and space) would be a more appropriate term.

We have changed the text as suggested (see Page 12, Line 7-8 and Page 12, Line 16).

P11, L15-19: Please add a sentence motivating why the temporal averaging has been done in such a quite complicated way, instead of just averaging over the duration of a MAX-DOAS scan.

The motivation behind our temporal averaging is the fact that we wanted to achieve a slightly higher number of ceilometer data (a couple of measurements before and after the MAX-DOAS elevation scan) for averaging than only the duration of the MAX-DOAS vertical scan. We have now changed the respective sentence in the manuscript (see Page 12, Line 12-15).

Please describe how you are dealing with the missing aerosol information from the Ceilometer in the lowermost 50 m, where MAX-DOAS is most sensitive and variability in aerosol extinction is probably highest. What kind of extrapolation did you apply for the calculation of the extinction in the lowermost retrieval layer and for the determination of the AOD?

It should be noted here that the location of the ceilometer (198 m a.s.l.) is about 70 meters lower than the one of the BOKU MAX-DOAS (267 m a.s.l.) because of local topography. This information is also given in the manuscript (see Sect. 2.1). In order to make the lowermost 100 meters of MAX-DOAS (station level, e.g. 260±50 m) comparable with the lowermost available ceilometer measurement, we have used the lowermost measurement of the ceilometer as a single value. We therefore did not perform any extrapolation for the layers below 50 m above the ceilometer and just assume that the single value of 50 meters above ground represents the average of the lowermost 100 meters value of MAX-DOAS, which of course is a simplification. We have added this information in the text (see Page 12, Line 18-24). AOD is only determined from MAX-DOAS measurements in our study and not from ceilometer measurements. For the scaling of ceilometer measurements, AOD from AERONET is used (see Page 12, Line 26-31 and Page 13, Line 1).

P12, L25: It is not clear what kind of data has been used for the calculation of the correlation coefficients. Did you correlate extinction at all heights, or just at the surface? Seasonally averaged or individual profiles?

In our study, we have defined the correlation coefficient for vertical profiles with respect to the seasonally averaged MAX-DOAS/ceilometer profiles for the different time intervals (e.g. 6-8 UTC, 8-10 UTC, …), where all altitudes have equal weight (see Page 15, Line 18-21).

P14, L11: Here it is stated that there is limited sensitivity of MAX-DOAS aerosol profiles above 4 km. When looking at Fig. 9 in Bösch et al. (2018), the sensitivity rather seems to be restricted to the lowermost 500 m only. Again, this means that a convolution of the Ceilometer profiles prior to the comparison is crucial – see general comments.

The sensitivity is not 'restricted' to the lowermost 500 m only. It rather is stronger below 500 m and lower above 500 m. A convolution of ceilometer profiles with the averaging kernels has now been performed (see answer to the comment above).

P16, L3: Here you distinguish between the availability of total columns and surface values. Shouldn't the total column always be available if the surface value is available and vice versa, since both are derived from the according vertical profile?

Yes, if the surface value is available then also the total column value is available and vice versa. We have now changed in the text accordingly (see Page 19, Line 15).

TECHNICAL CORRECTIONS

Title of 2.1.4: 'In situ' -> 'In situ aerosol measurements'

Has been changed as suggested (see Page 7, Line 23).

P9, L23: Remove 'Briefly' from the beginning of the sentence.

We have removed 'Briefly' (see Page 10, Line 14).

P9, L26: Remove comma after 'thus'.

We have removed the comma after 'thus' (see Page 10, Line 16).

P12, L8: A threshold in difference between modelled and measured O4 DSCD of 1000 molec2/cm5 is extremely small, given that typical O4 DSCDs are in the order of 1043 molec2/cm5. Is this a typo?

Yes, this was a typo. We have changed the text as suggested (see Page 14, Line 21).

REFERENCES

Rodgers, C. D. and Connor, B. J.: Intercomparison of remote sounding instruments, J. Geophys. Res, 108(D3), 4116–4229, doi:10.1029/2002JD002299, 2003.

We have added the reference (see Page 27, Line 7-8).