Anonymous Referee #3

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

GENERAL COMMENTS

In this paper, aerosol extinction (AE) profiles, aerosol optical depth (AOD), and near-surface AE are retrieved from MAX-DOAS measurements acquired on cloud-free days during the September 201-August 2019 period at two stations in the vicinity of the Vienna (Austria) city centre. These retrievals are performed using the Bremen Optimal estimation REtrieval for Aerosols and trace gaseS (BOREAS) algorithm and are evaluated against co-located ceilometer, sun photometer, and in situ instrument observations covering all four seasons. The retrieved AE profiles are found to agree well with those from the co-located ceilometer in fall, winter, and spring, with correlation coefficients ranging between 0.85 and 0.99. During those seasons, a good agreement is also obtained with the ceilometer for the near-surface AE and between the MAX-DOAS and sun photometer AODs. The MAX-DOAS retrieval results appear to be less reliable in summer and the possible origins of the lower performance of BOREAS in those conditions are discussed. Finally, the spatial variability of AOD and near-surface AE over Vienna is assessed by analyzing the retrieved BOREAS aerosol profiling products in the different azimuthal pointing directions of the two MAX-DOAS instruments and for the different seasons.

This paper is well written and clearly structured and presents interesting results which fit well with the scope of AMT. I recommend the final publication of the manuscript after addressing the following major and specific comments:

Major comment: To my opinion, the present study suffers from two weaknesses: no uncertainty budget is presented for any of the MAX-DOAS retrieved quantities (AE profile, near-surface AE, and AOD) and there is no estimation and characterisation of the vertical sensitivity of the MAX-DOAS AE profile retrievals through the calculation and examination of the averaging kernels and corresponding DOFS. The uncertainties on the Ceilometer AE profiles and other ancillary data deserve also to be discussed. Both aspects (uncertainty and vertical sensitivity) of this major comment should be addressed in the revised manuscript.

In the revised manuscript, we have introduced BOREAS averaging kernels, presented and discussed examples of those and furthermore used AVKs for smoothing the ceilometer AE profiles to make them more comparable in a quantitative way (see Sect. 2.2.1). In addition to the characterization of MAX-DOAS vertical sensitivity through AVKs, we now report on errors of BOREAS retrievals, ceilometer, and sun photometer measurements (see Sect. 2.2.1).

SPECIFIC COMMENTS:

Page 3, lines 11-13: I think here it is worth explicitly mentioning that a large part of the sun photometer measurements effort is endorsed by the AERONET network. The AERONET http link could be also added. Then, no need to add the http link again on page 7, lines 7-8.

We fully agree with this comment and have changed the text accordingly (see Page 3, Line 13-15).

Page 10, line 20: the choice of the a priori scaling height (1.25km) should be justified here. Is it based on a sensitivity study using different a priori scaling height values?

This value was determined from preliminary tests performed on measurements taken from the IUP Bremen MAX-DOAS instrument. We have now added a sentence with this piece of information (see Page 11, Line 14-16).

Page 12, lines 7-9: The level of agreement between measured and simulated O4 DSCDs is used to select valid MAX-DOAS AE profile retrievals. I guess that the criteria used (absolute and relative difference smaller than 1000 molec2 cm-5 and less than 10%, respectively) is applied individually to all the elevation angles. I think this should be explicitly mentioned in the text.

Yes, the criteria used is individually applied to all elevation angles. We have now added a corresponding sentence in the text (see Page 14, Line 19-21).

Page 12, lines 13-14: It is said that temporal changes in pressure and temperature can affect the BOREAS retrieval. This general statement requires some explanation: how large can be this effect on a daily basis since daily atmospheric temperature and pressure profiles are used as input for the AE profile retrievals?

In the PhD thesis of Tim Bösch it was estimated that on a daily basis, the near-surface AE can be up to 12% larger when pressure/temperature is taken from sondes instead of using pressure/temperature profiles from the US standard atmosphere (Bösch, 2019, https://media.suub.uni-bremen.de/handle/elib/1572?locale=de). We have now added this information in the manuscript (see Page 14, Line 27-29 and Page 15, Line 1-6).

Page 13, lines 13-16: the higher correlation coefficient values between MAX-DOAS UV and ceilometer AE profiles is explained by the fact that in the UV, the MAX-DOAS instrument probes air masses closer to the ceilometer which is located at 2.25km from the MAX-DOAS. Is it a valid argument since the effective horizontal distance representative of the MAX-DOAS measurements of O4 in the UV can be as large as 10-15km or even more under clear-sky conditions? Was there any attempt to estimate the effective horizontal distances for both the UV and VIS channels?

The effective horizontal distances for the UV and Vis channels have been estimated in a recent study (Schreier et al., 2020, https://doi.org/10.1016/j.aeaoa.2019.100059) for the Vienna MAX-DOAS instruments. For measurements taken at 1° (UV) and 3° (Vis) elevation angles, mean effective horizontal distances were estimated at about 6-12 km and about 7-18 km for the UV and Vis channels, respectively.

As we have now convoluted ceilometer AE profiles with BOREAS AVKs, the statement that UV MAX-DOAS profiles are better correlated with ceilometer profiles than the Vis ones is no longer correct. It is now rather the other way round. As both UV and Vis effective horizontal distances are larger than 2.5 km, we reject our argument. We have now changed the statement in the text accordingly (see Page 15, Line 21-25).

Page 13, lines 25-29: According to the authors, BOREAS has difficulty in retrieving AE profiles and near-surface AE during summer. One possible reason is that during that season, AE profiles have a box-like shape and are therefore not well retrieved with the exponential a priori used. Did the authors make a sensitivity test using a priori profiles with box-like shape in order to see whether it improves the AE profile retrievals in summer? If it significantly improves their retrievals but also the agreement with the ceilometer and the sun photometer, I think the authors should consider to include such a sensitivity test in their manuscript.

Box-like profile shapes are problematic for MAX-DOAS inversion algorithms relying on Bayesian approaches like optimal estimation or iterative approaches as Levenberg-Marquardt (LM) and Newton-Gauß (NG) with Tikhonov terms for several reasons. 1. For most algorithms, the a priori covariance matrix is calculated as deviation from an a priori state. This means that the covariance matrix has "Zero-elements" in altitudes where the box profile is zero, which will lead to an instability during inversion. 2. Even if these covariance values are set to finite values, large changes from this box-shape are not possible within one inversion (OEM) or small numbers of iterations for LM and NG as changes are done relative to the a priori state. 3. This means that especially the box width/height needs to be known well because large deviations from this shape are not possible.

However, box-like profiles can in principle be retrieved with exponential a priori profiles resulting in oscillating features around the true box shape, with smaller AOD in layers with true finite aerosol concentration due to the a priori based additional aerosol abundance for altitudes above the true box.

Page 14, lines 9-17: According to the authors, lower BOREAS AODs are expected because of the limited sensitivity of MAX-DOAS profiling for higher altitudes, while AERONET AODs better represent elevated aerosol in the free troposphere (and stratosphere). The authors then argue that in Spring, Saharan dust events over Austria could potentially explained higher AERONET AOD, mentioning the detection of such events in the Austrian Central Alps. I think this explanation is very speculative and requires further investigation: for instance, have such events been detected during the period where the MAX-DOAS measurements presented in this study were performed? If yes, is it statistically significant, i.e. during how many days Saharan dusts stayed above the Vienna area?

We agree that this explanation is speculative. As we are focusing on vertical AE profiles below 4 km in this study, and because Saharan dust events are not the focus of this study, we decided to remove the discussion of 'Saharan dust' events from our study.

We have now added a discussion of slopes of the linear relationship between UV/Vis BOREAS retrieved and AERONET AODs (see Page 17, Line 28-29 and Page 18, Line 1-5).

TECHNICAL CORRECTIONS:

Page 12, line 27: 'intervalls' -> 'intervals'

Has been changed as suggested (see Page 15, Line 20).

Page 14, line 12: 'tropsphere' -> 'troposphere'

Has been changed as suggested (see Page 17, Line 28).