

Reply to comments from Referee #2

We would like to thank Referee #2 for the thorough review of our manuscript and valuable feedback. Below we reply to the raised issues one by one.

This paper reports a new MAX-DOAS profiling algorithm detailedly. The algorithm is based on a scientific and reasonable method. The results have good correlation with the results from the other instruments. In general the scientific topic is meaningful.

Specific comments:

1, The title of this paper is about a NEW algorithm, so you should highlight what is really NEW and innovative in your algorithm, and what are the advantages comparing to the other MAX-DOAS profiling algorithms. These points should also be included in the Abstracts.

In fact the title does not claim that the paper is about a NEW algorithm. But we understand that it is not fully clear from the current manuscript what is actually new of the described MAPA algorithm. In order to clarify this issue, we extended the abstract and methods respectively:

Revised abstract:

Abstract. The Mainz profile algorithm MAPA derives vertical profiles of aerosol extinction and trace gas concentrations from MAX-DOAS measurements of slant column densities under multiple elevation angles. This manuscript presents (a) a detailed description of the MAPA algorithm (v0.98), (b) results for the CINDI-2 campaign, and (c) sensitivity studies on the impact of a-priori assumptions such as flag thresholds.

Like previous profile retrieval schemes developed at MPIC, MAPA is based on a profile parameterization combining box profiles, which also might be lifted, and exponential profiles. But in contrast to previous inversion schemes based on least-square fits, MAPA follows a Monte Carlo approach for deriving those profile parameters yielding best match to the MAX-DOAS observations. This is much faster, and directly provides physically meaningful distributions of profile parameters. In addition, MAPA includes an elaborated flagging scheme for the identification of questionable or dubious results.

The AODs derived with MAPA for the CINDI-2 campaign show good agreement to AERONET if a scaling factor of 0.8 is applied for O_4 , and the respective NO_2 and HCHO surface mixing ratios match those derived from coincident long-path DOAS measurements. MAPA results are robust **with respect** to modifications of the a-priori MAPA settings within plausible limits.

New section:

2.1 Heritage and advancements

MAPA founds on the parameterized profile inversion approach described in Li et al. (2010) or Wagner et al. (2011). It uses similar profile parameter definitions as Wagner et al. (2011) and forward models linking those parameters to dSCD sequences.

Main advancements of MAPA as compared to Wagner et al. (2011) are:

- MAPA is completely rewritten from the scratch in Python.
- All settings are easily adjustable by separate configuration files.
- MAPA provides the option of a variable scaling factor for O_4 (see section 2.7)
- MAPA uses a Monte-Carlo approach for the profile inversion (see section 2.6), while Wagner et al. (2011) used a least-squares algorithm.
The MC approach is faster and provides physically meaningful uncertainty information.
- MAPA provides an elaborated flagging scheme for the identification of questionable results (section 2.8).

In the sections below we provide a full description of the MAPA profile inversion algorithm, including also parts which have been described before (like the profile parameterization) for sake of clarity and completeness.

2, In the chapter about CINDI-2 campaign, the results are compared with the results from other instruments. However, it is also important to compare with the MAX-DOAS result from the same instrument but retrieved with the other algorithms.

We fully agree that comparisons with other inversion algorithms is essential. However, within this study, we focus on the description of the MAPA algorithm itself and selected results.

Within the ESA FRM4DOAS project (<http://frm4doas.aeronomie.be/>), extensive comparisons of different inversion schemes (both OE and parameter based) have been performed for both synthetic as well as measured dSCD sequences. The results of these studies are or will be published in near future:

- Frieß et al., Intercomparison of MAX-DOAS Vertical Profile Retrieval Algorithms: Studies using Synthetic Data, Atmos. Meas. Tech. Discuss., <https://doi.org/10.5194/amt-2018-423>, in review, 2018.
- Tirpitz et al., MAX-DOAS profiles for CINDI-2, in preparation.
- Richter et al., FRM4DOAS verification report, in preparation.

We have added the following sentence to the conclusions:

Within the FRM4DOAS project, different parameter-based as well as OE-based profile inversion algorithms have been compared extensively for synthetic dSCDs (Frieß et al., 2018) as well as real measurements (Tirpitz et al., in prep.; Richter et al., in prep.).

3, In the description of the algorithm, it is better to use the symbols that are commonly used in the related papers. For example, in Equation (1), it is better to use “AMF” instead of “A”, “SCD” instead of “S”, and “VCD” instead of “V”. In other equations, they have the same problem.

We understand that abbreviations like AMF and VCD would be easier to digest. Still, we prefer single letters as symbols for variables in all equations (as recommended by NIST: <https://www.nist.gov/pml/nist-guide-si-chapter-10-more-printing-and-using-symbols-and-numbers-scientific-and-technical>), whereas AMF within an equation might be read as $AxMxF$.

Table 2 helps the reader to quickly understand the meaning of symbols/variables used in the equations throughout the document.

4, How accurate is the retrieval results when the distribution of aerosol and trace gases is high (i.e. 3km).

The profile parameterization used in MAPA includes the height parameter h . We have investigated the dependency of the ratio of AOD from MAPA versus AERONET on h :

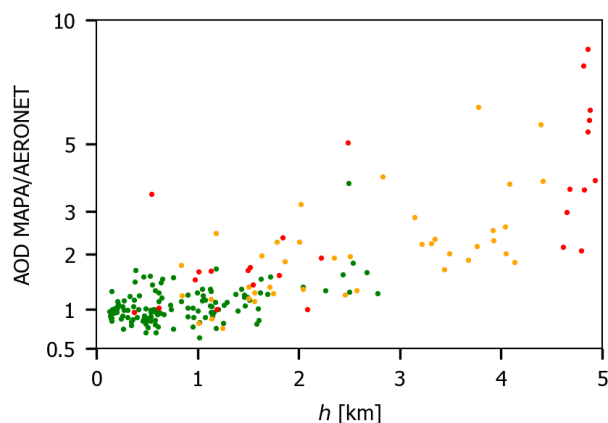


Figure R2-1: Dependency of the AOD from MAPA vs. AERONET as function of the height parameter h .

This clearly demonstrates that MAPA results are not at all trustable for high h (interestingly, MAPA AOD is always higher than AERONET for these cases). Thus, the height parameter is used for defining the height flag, and to discard all measurements with $h > 3$ km. From the figure above, this criterion might even be chosen more strictly in the future.

We have included this figure to the revised manuscript in order to support the discussion of the threshold for the height flag.

In addition, it will be better if the aerosol and trace gases profiles retrieved using MAPA are validated by corresponding profiles measured using other instruments (i.e. air balloon).

We fully agree that accurate independent profile measurements are desirable for validation of MAX-DOAS inversion schemes. Within CINDI-2, some NO_2 sonde measurements have been performed by KNMI, generally revealing polluted boundary layers of about 500m altitude, in agreement with the MAPA profiles. These sonde measurements are included in the extensive CINDI-2 profiling intercomparison by Tirpitz et al. (in preparation).

Minor comments:

1, In Figure 7 and 8, “mixing ratio [ppb]” => “Mixing ratio [ppb]”

Done.

2, page 4 line 1, “to be retrieved first as prerequisite for trace gas inversions” => “to be retrieved first as a prerequisite for trace gas inversions”

Fixed.

3, page 5 line 6, “increase from ground to h” => “increase from the ground to h”

Fixed.

4, Page 5 Line 21, “aerosol profiles, and trace gases”, “comma” and “and” can't be used together. Delete comma.

We have modified the sentence to

Below, the forward models will be described for both O₄ (which is the basis for retrieving aerosol profiles) and trace gases.

5, Page 18 Line 19, “cloud, and no sequence”, “comma” and “and” can't be used together. Delete comma. Correct this mistake throughout your manuscript

5 We are not aware of a general rule that prohibits the usage of "and" after a comma. On the contrary, according to <https://www.grammarly.com/blog/comma-before-and/>, the usage of a comma before "and" is needed when joining two independent clauses.

We will ask the Copernicus copyeditor for guidance for the respective sentence.

6, Page 7 Line 25, “if lowest R is” to “if the lowest R is”

We have modified the sentence to

“if lowest RMS values are always found for ...”.

7, Page 15 Line 12, “we focus of variations of” to “we focus on variations of”

Fixed.

8, Page 18 Line 30, “cloud scenes still remains” to “cloud scenes still remain”

Fixed.

9, Page 19 Line 21, “Currently, an MAX-DOAS” to “Currently, a MAX-DOAS”

Fixed.