Interactive comment on “Differential optical absorption spectroscopy (DOAS) and air mass factor concept for a multiply scattering vertically inhomogeneous medium: theoretical consideration” by V. V. Rozanov and A. V. Rozanov

Anonymous Referee #1

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1 General Comments

The paper is generally well written and addresses an important discussion with respect to the applicability of different DOAS variants in weak and strong absorption strength regimes. It introduces DOAS and intercompares four commonly known variants and the associated air mass factor concepts within a single mathematical framework. This consistent approach allows for a sensitive judgement of the different assumptions and simplifications made.

There are however the following points of criticism, which are specified in more detail in the specific comments that follow.

a) The paper focusses especially on the DOAS analysis of spectra of multiply scattered (MS) Sun light. Contrastingly, the authors relate the DOAS variants applied to these spectra to the direct light (DL) experiment. Whereas for the DL experiment the Beer-Lambert law can be exploited to linearly relate the trace gas number densities to the logarithmic Sun normalised radiance even for the case of strong absorption, this approach is not valid for multiply scattered light in the case of strong absorption. The functional dependence between the radiance logarithm and the number density is therefore not equation (49) but the solution of the RTE in terms of the radiance as a function of the trace gas number density profile. A suitable representation can be obtained e.g. from the Neumann series Marchuk et al. (1976); Marshak and Davis (2005) or employing the equivalence theorem van de Hulst (1980).

b) Another striking difference between DL and MSL measurements is the wavelength independence of the slant column density. The reason is, that the light path is the same for all wavelengths in DL measurements, whereas it is different for different wavelengths in MSL spectra. The authors try to relate the MSL DOAS SCD to DL DOAS SCD by compelling the wavelength independence. The suggested SCD resp. AMF definition is unprecise and related to a certain setup of DOAS (especially a certain number of fit coefficients) in a certain wavelength window. It may be different for a slightly different fit window.

c) The paper focusses on satellite DOAS, but this is not properly reflected by the title. The difference becomes evident when analysing MDOAS UV box air mass factors for the retrieval of tropospheric ozone using DSCDs obtained from ground based measurements. Furthermore there is a lack of description of other features of the DOAS method, potentially interfering with the SCD retrieval as these are for instance de-
scribed in Wenig et al. (2005). The paper can therefore not be termed a review. I encourage the authors to explicitly write more about the separability of DOAS and RTM, since it is a key issue in your paper.

d) The paper is too long and has too many formulas. It is suggested to merge parts of the text as for example equations (9) and (10) in order to increase the readability.

2 Specific Comments

page 703
Equation (2): you should define $l_1$ and $l_2$ although it might be clear.

line 21: Why does the atmosphere need to be cloud free? I guess due to an increased scattered light contribution.

Equation (12): Does this definition require a constant absorption cross section?

lines 4 to 7: The wavelength dependence might formally be neglected but it will propagate into the lowermost polynomial coefficients, won’t it? Please discuss how “greedy” the polynomial is, and how far a wavelength independent SCD definition will be related to the polynomial coefficients. (as for example stated in line 6, on page 740). However I can not clearly see a benefit of this SCD definition, because the $\beta_k$ in equation (103) can only be obtained through computionally expensive calculations.

page 716
lines 1 to 3: Please discuss differences between tropospheric ozone UV box air mass factors calculated according to definitions (32) and (57) in combination with (87). What are the implications for retrievals of profiles of strongly absorbing trace gases especially using DSCDs obtained from ground based measurements?

Equation (49): This is not the functional relationship between the number density profile of a gaseous absorber and the logarithmic Sun normalised radiance in a MS atmosphere. The correct relationship can be obtained e.g. through the Neumann series or approximately through the equivalence theorem.

Equation (59): If think instead of $k$ and $\bar{k}$ you wanted to write $p$ and $\bar{p}$. The expression is generally interesting for other Jacobians as for example derivatives of the logarithmic radiance w.r. to aerosol properties.
Equation (75): right side of 3rd equation symbol: I think it has to be $d \ln (I(\lambda))$.

lines 11 to 13: The sentence is problematic and has to be clarified, since the $S_\lambda$ can be obtained through DOAS, but when obtaining it by RTM the light path information is contained in the $w_k(\lambda, z)$.

3 Technical Corrections

page 699

line 7: "applied DOAS" → applied the DOAS
line 21+22: "extention" → extension

page 701

line 1: "This" → These

page 705

line 3: "are unknown at this point polynomial coefficients" → are polynomial coefficients, which are unknown at this point
line 4: "Clearly, this" → This

C220

lines 10 to 11: "the rapidly [...] is usually" → $\sigma_\lambda^d(l)$ is usually

page 706

line 5: "As clearly seen," → As can be seen on the right side of equation (10)
line 10: "trough" → through

page 707

line 18: "coarse" → course

page 709

line 16: "is so-called" → is the so-called

page 713

line 9: "one have to" → one has to
line 11: "necassary" → necessarily, "of the scattered" → of scattered
line 18: "in course" → in the course

page 714

line 1: "who have introduced" → who introduced
As clearly seen, therewith.

As a sum of two components, respectively varying slowly and rapidly with the wavelength.

arbitrary differentiable → arbitrary but differentiable

As formulated in (49), the intensity logarithm.

Regarding can also be obtained.

previous

of second

extinction

This means that $S_{\lambda}$ is equivalent to

is a Fredholm

associated with the
altitude layer \([z_{i-1}, z_i]\)

page 735

line 4: "As clearly seen, " → As can be seen here,

page 738

line 14: "rewritten" → rewritten

page 739

line 1: "As clearly seen, Eq." → Eq.
line 16: "covert" → convert

page 740

lines 3 to 4: "Replacing \([\ldots]\), we have:" → Replacing in this equation the wavelength dependent air mass factor \(A_j(\lambda)\) by an constant value \(A_j\), which is currently unknown, we have:
line 15: "spectral window that is in line" → spectral window. This is in line
line 17: "A more convenient for a practical use equation" → A practically more convenient equation

page 741

lines 10 to 11: "Thus, \([\ldots]\) of equations:" → Thus, the complete DOAS procedure to retrieve the vertical column is represented by the following system of equations:
line 21: "is clearly seen" → has been revealed

page 742

line 12: "summarize" → summarizes

page 744

line 2: "under assumption of a" → assuming

page 745

line 6: "where the \([\ldots]\) given by" → where the weighting function for the entire atmosphere \(W_j(\lambda)\) is given by
line 19: "in 425" → in the 425

page 746

line 16: "derivative" → the derivative
calculated assuming the absorption cross section to be $\sigma_c^\lambda$ instead of $\sigma^\lambda$.

its smoothly $\sigma_c^\lambda$ → $\sigma_c^\lambda$

Here, $W(\lambda)$ is the variational derivative of the intensity with respect to the gaseous absorber number density integrated over the entire atmosphere and is given by

for an a priori ozone

for an a priori ozone

error canceling occurs

A similiar behavior

resulting in the retrieved vertical

which

References


