Atmos. Meas. Tech. Discuss., 3, C216–C227, 2010
www.atmos-meas-tech-discuss.net/3/C216/2010/

Atmospheric Measurement Techniques Discussions

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

Received and published: 19 April 2010

1 General Comments

The paper is generally well written and adresses 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.

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Interactive Discussion

Discussion Paper

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 interferring with the SCD retrieval as these are for instance described 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

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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.

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page 707
Equation (12): Does this definition require a constant absorption cross section?

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page 713
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 β_k in equation (103) can only be obtained through computionally expensive calculations.

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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?

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page 719

line 6: After introducing $L_{\lambda,j}$ you use it only on the next three pages.

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page 720

line 1: What exactly is the slant optical thickness when regarding scattered Sun light? If one uses box air mass factors to calculate it in a case of strong absorption, how does it differ from $-L_{\lambda,j}(k)$? Of course it is a problem to use the same terms for direct light and scattered Sun light measurements, or not?

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page 722

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.

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page 725

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.

page 732

Equation (75): right side of 3^{rd} 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_λ can be obtained through DOAS, but when obtaining it by RTM the light path information is contained in the $w_{\bar{k}}(\lambda, z)$.

3 Technical Corrections

page 699

line 7: *"applied DOAS"* $\rightarrow$ applied the DOAS

line 21+22: *"extention"* $\rightarrow$ extension

page 701

line 1: *"This"* $\rightarrow$ These

page 705

line 3: *"are unknown at this point polynomial coefficients"* $\rightarrow$ are polynomial coefficients, which are unknown at this point

line 4: *"Clearly, this"* $\rightarrow$ This

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Interactive Comment

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

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page 706

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

line 10: *"trough"* → through

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page 707

line 18: *"coarse"* → course

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page 709

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

---

page 713

line 9: *"one have to"* → one has to

line 11: *"necessary"* → necessarily, *"of the scattered"* → of scattered

line 18: *"in course"* → in the course

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page 714

line 1: *"who have introduced"* → who introduced

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page 716

line 9: *"As clearly seen,"* $\rightarrow$ Therewith

page 719

lines 18 to 19: *"as a sum of slowly and rapidly varying with the wavelength components"* $\rightarrow$ as a sum of two components, respectively varying slowly and rapidly with the wavelength

page 721

line 17: *"arbitrary differentiable"* $\rightarrow$ arbitrary but differentiable

page 722

lines 10 to 11: *"As clearly seen, at each wavelength, λ, the intensity logarithm"* $\rightarrow$ As formulated in (49), the intensity logarithm at each wavelength λ

line 16: *"Considering"* $\rightarrow$ Regarding

lines 16 to 17: *"can be also obtained"* $\rightarrow$ can also be obtained

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page 726

line 18: *"previos"* $\rightarrow$ previous

page 727

line 18: *"of the second"* $\rightarrow$ of second

line 21: *"extention"* $\rightarrow$ extinction

page 732

line 11: *"As clearly seen, S_λ coincides with"* $\rightarrow$ This means that S_λ is equivalent to

lines 11 to 13: A major [. . .] without a knowledge of photon paths. I believe that this sentence does not make sense, since the knowledge about the photon paths is included in $w_{\bar{k}}(\lambda, z)$.

page 732

line 16: *"is the Fredholm"* $\rightarrow$ is a Fredholm

page 733

lines 1 to 2: *"for the i-th layer bordered by altitudes z_{i-1} and z_i"* $\rightarrow$ associated with the

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altitude layer $[z_{i-1}, z_i]$

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page 735

line 4: *"As clearly seen, "* $\rightarrow$ As can be seen here,

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page 738

line 14: *"rewitten"* $\rightarrow$ rewritten

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page 739

line 1: *"As clearly seen, Eq."* $\rightarrow$ Eq.

line 16: *"covert"* $\rightarrow$ convert

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page 740

lines 3 to 4: *"Replacing [. . .] , we have:"* $\rightarrow$ 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"* $\rightarrow$ spectral window. This is in line

line 17: *"A more convenient for a practical use equation"* $\rightarrow$ A practically more convenient equation

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page 741

lines 10 to 11: *"Thus, [. . .] 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

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page 742

line 12: *"summarize"* → summarizes

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page 744

line 2: *"under assumption of a"* → assuming

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page 745

line 6: *"where the [. . .] given by"* → where the weighting function for the entire atmosphere $W_j(\lambda)$ is given by

line 19: *"in 425"* → in the 425

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page 746

line 16: *"derivative"* → the derivative

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page 748

lines 20 to 21: *"calculated [. . .] "* $\rightarrow$ calculated assuming the absorption cross section to be σ_λ^c instead of σ_λ.

lines 25 to 26: *"its smoothly [. . .] ,σ_λ^c"* $\rightarrow$ σ_λ^c

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page 750

lines 8 to 9: *"Here, [. . .] given by"* $\rightarrow$ Here, $\mathcal{W}(\lambda)$ is the variational derivative of the intensity with respect to the gaseous absorber number density integrated over the entire atmosphere and is given by

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page 752

line 12: *"for a priori ozone"* $\rightarrow$ for an a priori ozone

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page 753

line 7: *"For a sake of"* $\rightarrow$ For the sake of

lines 13 to 14: *"an error canceling is occurred"* $\rightarrow$ error canceling occurs

lines 16 to 18: *"The similar behavior"* $\rightarrow$ A similiar behavior

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page 754

line 2: *"resulted"* → resulting

line 3: *"in retrieved vertical"* → in the retrieved vertical

line 6: *"that"* → which

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