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Atmospheric Measurement Techniques Discussions

Interactive comment on "Determination of aerosol properties from satellite observations of the Ring effect" *by* T. Wagner et al.

T. Wagner et al.

thomas.wagner@mpic.de

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Anonymous Referee #2

General comments The manuscript presents results of a study of the aerosol effects on atmospheric Raman scattering and oxygen absorption in the UV and Vis. The study is based on both radiative transfer simulations using a Monte-Carlo model and satellite observations by SCIAMACHY. The subject of the manuscript is appropriate to AMT. The paper contains original material that has not been published. Earlier work is adequately recognized and credited. The paper is well organized and clearly written. However, the paper needs major revisions. The paper can be recommended for final publication provided the authors are able to address to all the following specific comments.

Author comment: First we want to thank this reviewer for the positive assessment and the comments and suggestions, which we found very constructive and helpful to improve our manuscript.

Compared to the original versions several major changes have been performed. Before the reviewers comments are answered in detail (see below), a short summary about these changes is given:

A) According to the suggestions of both reviewers, the title is changed to: 'On the potential of determining aerosol properties from satellite observations of the Ring effect'

B) The number of figures was reduced and several figures were shifted into the appendix. The Figures which remained in the main part of the manuscript concentrate on the following aspects: - general description of the effects of aerosols on the Ring effect and O2 and O4 absorptions -comparison of measurement data with model simulations -model data illustrating the main effects of aerosols on the Ring effect and O2 and O4 absorptions The number of Figures in the main part was reduced from 25 to 18. The number of figures in the appendix was increased from 6 to 8. The total number of figures is reduced from 31 to 26. In most figures the font size of the labels and legends were increased.

C) Additional radiative transfer simulations are performed for the oxygen A band and the results are included in the revised version.

D) The discussion of the albedo effect is revised

E) A new table was added for the conversion of the Raman scattering probability into other measures for the strength of the Ring effect.

F) The conclusions are largely changed

G) In the original version some radiative transfer simulations at 630 nm were performed

AMTD

3, C1974–C1982, 2010

for an albedo of 10% and others for an albedo of 15%. We replaced the latter simulation results by the results for 10% to make our results more consistent.

Specific comments

(1) The title does not properly represent the content of the paper. The paper deals mostly with studying the aerosol effects on Raman scattering and oxygen absorption for different geometries and geophysical conditions. The paper has a little with actual retrieving aerosol properties (i.e. aerosol height, aerosol optical thickness, and single scattering albedo) from satellite observations. The retrieval of aerosol optical properties implies the use of an inverse model. This study uses forward modeling only.

Author comment: We agree that our manuscript presents a sensitivity study (and not an aerosol inversion algorithm). We changed the title as suggested by this reviewer and also reformulated the conclusions.

(2) The choice of SCIAMACHY for analyzing the satellite observations is quite questionable. The authors correctly mention that "the probability for cloud contamination is rather high" due to coarse spatial resolution of SCIAMACHY and "OMI would be the most suitable for the analysis of the Ring effect". According to the title, the oxygen absorption is not a focus of the paper. Therefore, the analysis of the O2 absorption band can be easily dropped out and the use of OMI will provide more appropriate data for the analysis. An additional argument for the use of OMI data is that the SCIAMACHY instrument is sensitive to polarization. This hampers the Ring effect analysis as the authors state in Conclusions.

Author comment: We agree that OMI would be a better suited instrument for Ring effect retrievals. This was also clearly stated in the manuscript. Nevertheless, we are still convinced that SCIAMACHY observations are well suited to test the basic dependencies of Ring effect observations on aerosol parameters. SCIAMACHY observations also allow the direct comparison of Ring effect observations with O2 absorptions, which provides interesting additional results (and potential synergy). To repeat our study with

AMTD

3, C1974–C1982, 2010

OMI data is beyond the scope of this study. But we want to encourage the OMI retrieval teams to implement similar Ring analysis retrievals in their processors. We added this suggestion to the conclusions.

(3) The aerosol effects on Raman scattering are computed in terms of Raman scattering probability. The existing Raman codes provide the spectral dependence of elastic and total radiances. It is not straightforward to compare the authors' results with other Raman codes. Moreover, the paper lacks any comparison with literature results. That is why the authors should provide information that facilitates the reproducibility of their results with other Raman codes.

Author comment: Detailed comparison of our model results with results from existing models were performed in Wagner et al. (2009) and good quantitative agreement was found. In the same study, also a detailed conversion recipe is presented, which allow an easy conversion of the Raman scattering probability (RSP) into other definitions of the filling in. The advantage of using the RSP as measure for the strength of the Ring effect compared to other definitions (see e.g. Joiner et al., 1995a,b; deBeek et al., 2001; Langford et al., 2007) is that it is independent on the specific choice of a Fraunhofer line and in particular also on the spectral resolution of the instrument. The RSP is directly proportional to the filling-in calculated from other definitions of the filling in and can be easily converted into these definitions (for details see Wagner et al., 2009a). We added this information (section 2.2.1) and a new table with selected conversion factors to the revised version of our manuscript.

(4) Section 2.2.4. The normalized radiance in Eq. 2 is defined without the cosine of the solar zenith angle. In this case, authors' statement of Section 2.2.4 that says "for a perfectly scattering atmosphere and reflecting earth surface the normalized radiance is unity" is incorrect.

Author comment: Many thanks for this hint. We removed that statement and added short information why we did not include the cosine of the SZA in equation 2.

(5) Section 4.3. The explanation of the dependence of Raman scattering on surface albedo is unclear, particularly the statement “with increasing surface albedo the probability of the observed photons to be scattered by molecules slightly decreases”. In reality, the dependence of Raman scattering on surface albedo has a minimum at some value of surface albedo. This value depends on wavelength. For instance, this value is about 0.2 for wavelength of 335 nm (it can be seen in Fig.14). For longer wavelengths, the minimum occurs at higher values of surface albedo. This can be seen by plotting the data for higher albedos.

Author comment: The reviewer is right. We modified and extended the discussion of the albedo dependence. In the Figure (new Fig. 10) we extended the range of the surface albedo (to 0-1).

(6) Section 4.4. Extrapolation of aerosol optical depth into the UV using measurements in the Vis is quite unreliable [Krotkov et al., Opt. Engineering, 2005] particularly for the AERONET station ‘Beijing” where the presence of UV-absorbing aerosols is common.

Author comment: We added a statement (and the reference) about the uncertainties of the extrapolation to short wavelengths to the text (section 4.4).

(7) Section 4.4. I did not find information about aerosol height used in the simulations which data are presented in Fig. 15 and Fig.16. This is important for absorbing aerosol because TOA radiance noticeably depends on the aerosol height in this case.

Author comment: The aerosol height was given in the figure legends, but was probably hard to read. We enlarged the legends to make this information more clear.

(8) Section 4.5. There is a strong need of an explanation of the result shown in Fig. 17 for 335 nm that the Ring effect is larger for non-absorbing aerosol with optical thickness of 4 than for the same aerosol with optical thickness of 1. For this wavelength band the dependence of the Ring effect on surface albedo is quite weak (see Fig. 14), so the aerosol albedo effect on Raman scattering can be considered to be negligible. This

leads to a question: why the aerosol shielding effect is not seen.

Author comment: This is an interesting question, which can be explained by the effect of aerosols on multiple molecular scattering. At short wavelengths the observed photons usually undergo more than one molecular scattering event (even without aerosols). If scattering aerosols are added, they partly scatter the incident photons directly back (shielding effect) and thus decrease the fraction of observed photons which have undergone a Raman scattering event. The major part of the photons, however, is scattered in forward directions and these photons have a high chance to be Raman scattered. For high aerosol loads multiple scattering on aerosols can even lead to a slight increase of the Raman scattering probability compared to the aerosol free case. Since with increasing aerosol layer height, the shielding effect becomes more effective, the RSP decreases slightly with aerosol layer height. These effects explain the height dependence for scattering aerosols. If absorbing aerosols are present, also part of the incident photons are directly scattered back to the satellite instrument (but less compared to the purely scattering case). The most important difference to the purely scattering aerosols is that for the absorbing aerosols also a substantial fraction of the photons from inside the aerosol layer are absorbed before they reach the satellite instrument. Especially for high aerosol optical depth this effect becomes increasingly important because of the increased probability for multiple scattering. Thus the RSP is smaller compared to the case with purely scattering aerosols with the same optical depth. We did not add this explanation to the manuscript, because we think it goes too much into detail. If the reviewer and/or the editor thinks we should add it to the manuscript, we will or course follow their recommendation.

(9) Section 4.6. Figure 22 (O_2 AMF at 630 nm panel) shows a strange result that the oxygen AMF does not depend on aerosol optical depth and aerosol height in the case of non-absorbing aerosol. The result should be explained. Also, information about surface albedo used in computations is missing.

Author comment: This finding is indeed surprising, but is probably a coincidence. For

AMTD

3, C1974–C1982, 2010

purely scattering aerosols, shielding effect, albedo effect (and for large aerosol optical depth also multiple scattering) almost cancel each other. As can be seen in the revised figure (new Fig. 17), which was calculated for surface albedo of 10% (630nm) and 20% (758nm), the results for the different AODs and layer heights are more different than those of the original figure (albedo 15%). These results indicate that the almost same results in the original figure were just a coincidence.

(10) Section 4.7. Figure 24 shows a relatively strong dependence of the O4 AMF on the aerosol asymmetry parameter that is qualitatively different from the O2 AMF dependence on the asymmetry parameter. Please provide an explanation.

Author comment: The differences must be related to at least one of the three systematic differences between both simulations: different wavelength, different albedo or different profile shape. To answer this question we performed additional simulations, where we varied one of the above mentioned parameters. It turned out that the wavelength dependence had the strongest influence on the observed differences. This can be understood by the wavelength dependence of Rayleigh scattering: For short wavelengths multiple scattering is more important than for large wavelengths. Since aerosols with smaller g scatter less photons in forward direction they lead to a stronger increase of multiple scattering and thus to larger absorption paths. We added this information to section 4.7.

(11) Section 5. Conclusions listed in this section should be substantially revised.

-second main conclusion. I did not find any discussion in the text that would support the conclusion of the dependence of the Ring effect mainly on aerosol height and single scattering albedo at shorter wavelengths and mainly on aerosol optical depth at longer wavelengths. Please remove the conclusion if you are unable to support it quantitatively.

Author comment: Maybe there is a misunderstanding here? The different dependencies were already well illustrated and discussed in the original version of our

AMTD

3, C1974–C1982, 2010

manuscript:

In section 4.4 it was shown (and discussed) that the dependence of the Ring effect on the aerosol OD increases towards longer wavelengths.

In section 4.5 it was shown (and discussed) that the dependence of the Ring effect on the aerosol layer height increases towards shorter wavelengths.

In section 4.6 it was shown (and discussed) that the dependence of the Ring effect on the single scattering albedo increases towards shorter wavelengths.

We think that this part of our conclusions is well justified and we left it mainly unchanged (we reworded it slightly).

- third main conclusion. The conclusion of the weak dependence of the Ring effect on surface albedo is questionable. It is well known that surface albedo is low in the UV and blue Vis [see e.g. Herman and Celarier, JGR, 1997; Kleipool et al., JGR, 2008]. For low values of surface albedo (A<0.1), the Ring effect significantly depends on surface albedo, except for shortest wavelengths (< 340 nm) where the Ring effect varies with surface albedo less than 10% in the range A=0-0.1.

Author comment: We agree that the dependence of the Ring effect is not necessarily smaller than for the O2 and O4 absorptions. We revised the discussion on the effects of the surface albedo in section 4.3 and in the conclusions.

- fourth main conclusion. I agree that the SCIAMACHY data are not appropriate for the Ring analysis because of the instrument polarization sensitivity (see also comment 2). However, this statement cannot serve as a conclusion.

Author comment: We changed the section title into ‘conclusions and outlook’. We think that it is important to note the polarisation sensitivity of the SCIAMACHY instrument in this section, because it implies important consequences for future instruments.

- fifth main conclusion. I disagree that the interpretation of oxygen absorption obser-

AMTD

3, C1974–C1982, 2010

vations for aerosol retrieval “is rather ambiguous” as compared with the interpretation of the Ring effect. For instance, Dubuisson et al. [Remote Sens. Environ, 2009] have successfully demonstrated estimating the aerosol altitude from satellite measurements in the oxygen A-band. The interpretation of the Ring effect may also show possible ambiguity from albedo and shielding effects (see Fig. 17 data for 335 nm).

Author comment: We agree that our discussion was too simplified and our wording not fully appropriate. We changed this part of the conclusions to clarify the different dependencies. We also included a discussion on the aerosol retrievals using the O2 A band in section 2.2.3 and added the respective references. Nevertheless, we still think that at long wavelengths, and especially for the O2 A band, the uncertainties of the actual surface albedo cause more problems compared to short wavelengths. In addition, the seasonal variation of vegetation causes further uncertainties. We added this information to section 4.3 and to the conclusions.

(12) The authors show their results in 31 figures, most of them have 6 to 12 panels. Too many illustrations may distract a potential reader from main findings of the paper. I recommend reducing the number of figures and leaving those which illustrate and highlight the main findings. For instance, I do not see much added value in 6 figures of Appendices A and B. They can be eliminated without losing significant information.

Author comment: We agree and reduced the number of figures (see also point B above)

(13) The quality of some figures should be improved by increasing the size of characters. For instance, it is hard to see the legends in Fig. 15 and 16.

Author comment: We increased the axis labels and legends of most figures.

Interactive comment on Atmos. Meas. Tech. Discuss., 3, 3535, 2010.