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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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Title: Determination of aerosol properties from satellite observations of the Ring effect Author(s): T. Wagner et al. MS No.: amt-2010-105 MS Type: Research Article Overall Rating: Scientific Significance: Fair Scientific Quality: Fair Presentation Quality: Fair

Recommendation: Significant revisions needed. In this manuscript the Ring effect (filling-in of Solar Fraunhofer lines by Raman scattering) is studied and compared to the depth of O2 and O4 absorptions. The authors claim that the Ring effect has potential for the retrieval of aerosol properties from satellite spectrometers.

Author comment: First we want to thank this reviewer for the comments and sugges-

tions, 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 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.

My main concern about this manuscript is that it presents only a sensitivity study based on simulations and some selected observational cases. Although there is a claim (also in the title of the manuscript) that aerosol properties can be derived from the Ring effect measurements, I find no direct evidence in the manuscript. Showing that the spectrum is sensitive to aerosols is not the same as being able to derive quantities on aerosols from the spectrum. This manuscript is only a sensitivity study and no other claims can be made. The manuscript has not convinced me that aerosol retrieval using the Ring is feasible.

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. With respect to the statement of this reviewer that 'The manuscript has not convinced me that aerosol retrieval using the Ring is feasible.' we want to give the following reply: To our knowledge, no comparable study on the influence of aerosols on satellite observations of the Ring effect has been performed so far. Many of the observed findings could be well reproduced by our model simulations, and good quantitative agreement was found for retrievals at four different wavelengths. Besides observations with substantial aerosol load, also good agreement was in general found for cloud-free observations and low aerosol load. Here in particular the influence of the viewing angle was investigated and found to be important. The ability to correctly model the aerosol- and cloud-free case is an important prerequisite to correctly retrieve the changes caused by the presence of aerosols. Of particular importance is the correct simulation of the effect of the viewing geometry. To our knowledge, such studies have never been performed before. The results of our study show a clear effect of aerosols on the SCIAMACHY measurements, which are in general in good quantitative agreement with model simulations. In our opinion our study provides clear evidence for the potential of the retrieval of aerosol properties from Ring effect observations.

For the O2 analysis the relative weak band at 630 nm is used. From many studies it is concluded that the O2 A band contains much more information on aerosol and

their vertical distribution. The choice of the O2 band at 630 nm is not motivated in the manuscript. Given the importance of the O2 A band for current and future mission, the analysis shall also include this band.

Author comment: The O2 band at 630nm was chosen because it is relatively weak. On the one hand this band is sufficiently strong to ensure its analysed with high accuracy. On the other hand it is weak enough to allow a substantial fraction of the observed photons to have seen the surface. This is a prerequisite to have sensitivity to near-surface aerosols. Another advantage is that it also can be analysed by a simple DOAS analysis. Nevertheless, also observations of the O2 A band have their specific advantages. We are thankful for this and a second reviewer to draw our attention to the potentials of O2 A band observations (and relevant publications). The reviewer is right in mentioning the specific potential to retrieve information on the aerosol vertical distribution. We added this information to the manuscript (in section 2.2.3). We also added model simulations for the O2 A band to our manuscript. However, these simulations are only representative for the weaker parts of the O2 A band (OD«1). The simulation results for the weaker parts of the O2 A band are similar to those for the O2 absorption at 630 nm indicating the fact that for both wavelengths Rayleigh scattering plays a minor role. However, it should be noted that (in contrast to 630nm) for the O2 A band the surface albedo is more variable (mainly because of the high reflectivity of vegetation). This variability complicates the interpretation of the measured absorption with respect to the retrieval of aerosol properties. We added a discussion on the variability of the surface albedo in section 4.3.

The manuscript contains too many figures. Some of these figures are trivial and should be removed. For other figures the information should be condensed. Rethink of each figure its purpose for the manuscript and if it can be removed or placed in an appendix. Given the large number of figures and sub-figures compared to the text, I get the impression that the reader is doing the analysis instead of that the authors explain there analysis in the manuscript. To give an example, to explain the variation with solar and viewing angle 9 plots are used, included many subplots. I strongly recommend to bring this back to at most 5 plots, with only a few subplots.

We agree with this comment and reduced the number of figures (see point B above). However, we kept several figures in the appendix, which contain rather trivial information, because this information could be helpful to comprehensively assess the influence of aerosols (and the viewing geometry) on several measured parameters. To our knowledge no such detailed quantitative comparison between SCIAMACHY observations and simulation results has been presented before.

One of the reasons that Raman scattering has not been used for the retrieval of aerosol properties is because the forward modeling is very complex. Especially the interaction with the surface, for example of water, is difficult to model and depends on the optical properties of the water body. The authors briefly touch upon this on page 3541 line 25. This shall also be discussed as part of the conclusions.

Author comment: We agree with this comment and we added additional discussion in section 4.3 and in the conclusions.

The manuscript focusses on extreme aerosol events. In the sensitivity analyses aerosol optical depth of 1 and 4 are used. Explain why these values were chosen. Does this imply that the potential of the Ring effect for aerosol retrieval only holds for large plumes?

Author comment: Strong aerosol events were chosen because their effects can be best 'seen' in the measured data. Of course, Ring effect observations (and also O2 absorptions) are sensitive also to smaller aerosol loads, because they can be analysed with high accuracy (relative error of only a few percent or below). We added a discussion on the achievable accuracy for Ring effect observations in section 2.2.1 and in the conclusions.

In the simulations an unphysical aerosol model is used. Fo an aerosol size distribution

with a size parameter of 0.68 the AOD will decrease as a function of wavelength. This is not accounted for in the simulations. Therefore there is no aerosol size distribution that has these optical properties. Discuss the aerosol model and its limitations in the manuscript.

Author comment: We assumed an asymmetry parameter of 0.68 because it is a good approximation for urban aerosols (e.g. Dubovik et al., 2002). For the cases where only model simulations were performed (dependence on SCA and AP), no explicit wavelength dependence of the AOD was assumed, because the purpose of these simulations was to illustrate the general dependence of the observed quantities on the aerosol properties. For the comparison between observations and model simulations, the decrease of the AOD with wavelength was considered (see e.g. (new) Figs. 16, 20 and 21): for the simulations at 630nm systematically smaller AOD was assumed. In the revised version of the manuscript we added more discussion of the choice of aerosol properties in section 3.

Specific points: The title of the paper is not appropriate. In the paper no aerosol properties are derived from Ring satellite observations. At most the title good be "On the potential of determination ...."

Author comment: We changed the title to: 'On the potential of determining aerosol properties from satellite observations of the Ring effect'

page 3538 line 25. An important difference between clouds and aerosols in the shortwave part of the spectrum is that aerosols can significantly absorb part of the Solar radiation. This is missing in the discussion on the two effects.

Author comment: We added this information to the text (Introduction).

Section 2.2.4. Mix-up of symbols and terminology. The radiance is normally denoted by I and the Solar irradiance by F. On line 7 of 2.2.4 a statement is made on the reflectivity. However the statement is only true when the cosine of the solar zenith angle is in the denominator of equation 2.

Author comment: We replaced the symbols as suggested and added a short discussion why the cosine of the SZA is not used in equation 2.

From section 3 it is unclear if polarization is taken into account in the radiative transfer model. If not how provide argumentation why the results are representative.

Author comment: Polarisation was not included in the radiative transfer model. However, as shown by Landgraf et al. 2004 (see also discussion in Spurr et al. 2008) in contrast to the modelled radiance, the strength of the filling-in is only weakly affected by the neglect of polarisation. Although in our model instead of the Raman scattered radiance, the probability of an observed photon to have been Raman scattered is modelled, the same arguments hold: the probability for Rayleigh scattering and that for Raman scattering are affected in the same way by the neglect of polarisation; thus for the calculation of the Raman scattering probability these errors almost cancel out. This rationale is supported by the good quantitative agreement of our model results with results of other models (see Wagner et al., 2009a). We added this information to section 3.

Figure 4. Why does the y-axis for O4 start a -1 ?

Author comment: Many thanks for this hint! We corrected the figure.

What is the point of showing Figure 6. The fact that the normalized radiance decrease with SZA seems rather trivial because the TOA irradiance decreases with the cosine of the SZA. I recommend to remove this figure from the manuscript.

Author comment: We agree and removed this figure

Page 3546 line 26. Describe in the manuscript the procedure to ensure that only cloudfree sciamachy observations are used?

Author comment: In the MODIS images it was checked if the location of the SCIA-

MACHY observation was cloud-free. If any clouds or cloud fragments were observed at the location of the SCIAMACHY observations, these observation was classified as cloud-contaminated. We added this information to the text.

In section 4.3 the point is made that the O2 and O4 absorption depend more on the surface albedo than Ring effect. However, looking a figure 15 this is arguable. The O2 at 630 nm doesn't vary more with wavelength compared to the 380 and 630 nm Ring. Here also the argument on the complex modeling of water surfaces should be included; now the manuscript oversimplifies on the surface reflectance discussion.

Author comment: We agree that our simplified discussion should be improved. We thus completely modified the discussion of the influence of Ring effect and gas absorptions on surface albedo. We also changed (new) Fig. 10, which now presents the full range of possible albedo values (0-1). We discuss the complex dependence of the Ring effect on surface albedo in detail and point out that for the relevant albedo values the Ring effect decreases with increasing surface albedo, while the O2 and O4 absorption increase. We also included in section 4.3 a discussion of the effect of vibrational Raman scattering on the Ring effect retrieval.

Section 4.4. The stronges and most direct effect that the AOD increases have is on the radiance itself. Therefore this section should start with a discussion on figure 16, followed by a discussion on figure 15, which is much more complex.

Author comment: We followed the suggestion of the reviewer.

Section 4.5, figure 17. The dependence on the aerosol height for the ring effects seems very small considering the very large AOD of 1 and 4. Discuss how these numbers of about 0.001 RSP /km compare to measurement errors

Author comment: We added information on the achievable accuracy for the Ring effect retrieval in section 2.2.1 and in the conclusions. Expressed as Raman scattering probability (RSP) the accuracy of Ring effect analyses ranges between about 0.0003 for

430nm and 0.001 for 335nm. This corresponds to an uncertainty in the height determination at 350nm between about 200m and 1000m for the different assumed aerosol properties (the Ring effect retrieval at 350nm is probably best suited for the height determination, because at this wavelength the retrieval uncertainties are especially low and the altitude sensitivity is relatively high.

Section 4.5, page 3556, line 1. The MODIS images shows that underneath the aerosol layer there are significant amount of clouds. The claim that this is mostly cloud-free is not convincing.

Author comment: The reviewer is correct. However, it should be noted that the probability of cloud contamination was already stated in the manuscript (end of section 4.5). In the revised version we state more clearly that these measurements might be contaminated by clouds.

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