AMTD, 2, 379-438, 2009
Reply to the referee # 1
Cloud sensitivity studies for stratospheric and lower mesospheric ozone profile retrievals from measurements of limb scattered solar radiation

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June 6, 2009

1 General comments

1. This paper addresses a relevant scientific question within the scope of AMT. The question is the sensitivity of retrieved ozone profiles to incorrect cloud information (input to forward RT model during inversion).

2. This is novel work for ozone profiles, although Sioris et al. (JGR, 2003) have studied the sensitivity of retrieved NO_2 profiles to various clouds and this work should probably be recognized (one sentence).
⇒ A reference to Sioris et al. [2003] has been included in the introduction.

3. Substantial conclusions are reached on the sensitivity of retrieved O_3 profiles to clouds, especially with respect to the dependence on solar zenith angle and cloud optical thickness (COT). Although, the discussion of the SZA dependence is not very insightful, nor is the discussion on the COT dependence for small COT.
⇒ See replies to specific comments below.

4. The assumptions and methods are clearly outlined but some of the assumptions are not valid (see below).
⇒ See replies to specific comments below.

5. The results are sufficient to support the interpretations and conclusions.
⇒ Thank you.

6. The description of experiments and calculations are sufficiently complete and precise to allow their reproduction by fellow scientists (traceability of results).
⇒ Thank you.

7. The authors do not give proper credit to related work (see above) but they do clearly indicate their own new/original contribution.
⇒ See reply to point 2 above.

8. The title clearly reflects the contents of the paper.
⇒ Thank you.

9. The abstract provides a concise and complete summary.
⇒ Thank you.

10. The overall presentation is well structured and clear.
⇒ Thank you.

11. The language is fluent and precise.
⇒ Thank you.

12. Mathematical formulae, symbols, abbreviations, and units are correctly defined and used. However, the symbol l used as a line-of-sight coordinate strongly resembles I used for intensity. This may cause confusion and may be resolved by the use of a font which improves the distinction between these letters.
⇒ We fully agree with the reviewer that the variables for intensity and distance along the line of sight are difficult to distinguish in the online AMTD version. We just checked what the letters look like using the times font used for the production of the final paper. With this font the letters look quite different, and will not be confused.

13. Page 387 of the paper should be eliminated. The derivative with respect to ozone number density is not relevant. Also, additional effort is encouraged to reduce the length of this paper. The paper is too theoretical, at times distracting from the main message.
⇒ The discussion in page 387 defines the weighting function of ozone which is used then to explain the obtained results. This is why this page can not be eliminated. According to our opinion, some theoretical background is essential to understand the obtained dependencies. Here, we would like to point out that the main objective of the paper is not only to quantify the retrieval errors arising when neglecting the clouds but also to discuss the nature of these errors and their transformations when using different combinations of the measured data.

14. The reference to Roebeling et al. is unnecessary. Also, there is a reference to previous work by one of the co-authors (Rozanov and Kokhanovsky, 2008) when earlier work by others could have been cited instead. This comes across as egocentric. Also, the comparison with nadir geometry is admittedly not apples–to–apples (since the triplet is not used) and thus is not very relevant.
⇒ The reference to Rozanov and Kokhanovsky (2008) was used because this is the only study we know which discusses the influence of the cloud geometrical thinkness on the total columns of ozone retrieved from statellite measurements in nadir viewing geometry. We would be grateful if the reviewer could provide us with some references which can be cited instead.

Concerning the comparison to the nadir geometry, we would like to point out the paper discusses the influence of clouds on the limb radiance, normalized limb radiance, and on the Chappuis triplet. Thus, we do not understand the argumentation that the nadir geometry is not the "apple" because it does not use the triplet. There are also limb retrieval methods which do not use the triplet to obtain the ozone profiles. Furthermore, there is no common scientific definition whether certain types of atmospheric observations should be compared or not. Thus, the definition of the "apple" is just a personal view which can differ from reader to reader.

2 Macroscopic comments

Referee: In the conclusions section, it would be nice if the authors suggested how this study will impact their retrieval algorithm, i.e. will any of the lessons learned be applied? Perhaps this is

beyond the scope of this paper.
Author: One aspect which will be included in the future version of the ozone retrieval algorithm is the significant reduction in the cloud impact if only tangent heights above the cloud top are used. As shown in Fig. 6 the maximum errors are reduced from 15% to 3% if this approach is taken. Tropospheric clouds are also detected (and cloud top heights determined) from the SCIAMACHY limb measurements themselves, and this cloud data base will be used here. Note, that the operational version of the limb ozone profile retrieval operated by DLR already includes this cloud information and restricts the tangent height range used accordingly.

Referee: The paper focuses on the sensitivity to clouds below the FOV. Perhaps, a sentence could be written (providing a reference) about what is done to determine whether clouds are in the FOV in analyzing real SCIAMACHY data. High clouds clearly are observed by SCIAMACHY in the tropics and as shown in this paper, the effect is larger than the effect of extremely thick clouds below the field of view.
Author: As already mentioned above, a tropospheric cloud data base derived from SCIAMACHY limb observations is already available for the entire mission period, and this information will be used for future ozone profile retrievals as described above. We added a short paragraph on this in section 8.

Referee: Also, there is not much insight as to why the sensitivity to clouds below the FOV increases with decreasing altitude. Some discussion of this is presented in Sioris et al. (JGR, 2003) and Sioriss PhD thesis. In spite of the 49 equations and 30 pages, this paper is lacking in terms of discussion, and explanation with words of how the relevant radiative transfer processes produce the observed sensitivities.
Author: Instead of words, in our discussion we have used an approximative formulation of the radiative transfer equation which is according to our opinion much more convincing. If any explanations are really missing we would be gratefull if the reviewer could make suggestions what exactly should be explaned in more detail.

Referee: For the discussion of why the Chappuis triplet and the radiance have a direct relationship, it appears to be based on an assumption that is not valid.
Author: See our answer to your comment "P414L2-5" below.

Referee: The use of the term "radiation" in several instances in the appendix is not appropriate. The appropriate term for this quantity should have units that match the units on the right-hand side of the equations (e.g. A7, A13). Conventional notation is recommended.
Author: The notations are corrected.

3 Microscopic science comments

P380L2 "affecting trace gas retrievals." $->$ e.g. "and thus affect trace gas retrievals".
Author: Changed.

P381L2 Instantaneous cloud coverage is not 60%. Please provide a peer-reviewed reference for this. The Pruppacher and Jaenicke (1995) reference states that, over land, the coverage is 52.4%. Using Cloudsat observations, Mace et al. (Geophys. Res. Lett., 2007) found 50.6% and this value is an overestimate because of the finite size of the Cloudsat footprint (1.4 x 2.5 km) and no ability to resolve sub-pixel cloud fraction.
Author: We changed the value to "about 50%" and included the references suggested by the referee.

P381L17 The reason provided for why limb scattering radiative transfer is complex is not correct. This source of complexity (i.e. multiple scattering) is true for other geometries. What makes the radiative transfer complex in limb geometry is that planeparallel assumptions are no longer valid.
Author: We partly agree with the referee. The fact that the sphericity of the atmosphere has to be considered in some way is of course also a major complication. Still, compared to remote sensing applications in the SWIR, where multiple scattering is not that important any more, the treatment in the UV/visible spectral range is difficult because of the presence of a often strong multiple scattering component. We changed the sentence to: "The limb-scatter geometry is characterized by a complex radiative transfer, because the multiple scattering or diffuse radiation contribution to the observed limb radiances can be significant (Oikarinen et al., 1999), and because the sphericity of the atmosphere cannot be neglected. Furthermore, the underlying surface, which may contribute significantly to the diffuse illumination of the sensed air volumes, is not observed directly."

P386L19 It is interesting that the authors find 307 and 310 nm substantially affected by multiple scattering and surface reflection. It is good to see this discussed.
Author: Thanks for pointing this out.

P390 The following is not likely to be valid: "Assuming the relative error of the ozone profile retrieval to be independent of altitude"
Author: Since the relative error of the ozone profile retrieval as defined by Eq. 14 is used to analyze the dependencies only qualitatively, the absolute value of the error are not essential and this assumption is sufficient.

P396L20-22 The authors make a good point regarding the importance of removing information going into the retrieval from tangent heights for which clouds are in the field of view.
Author: Thank you

P396L26-28 The authors do a good job of studying a wide range of COT values and closely examining the sign of the sensitivity.
Author: Thank you

P403L6-25 This explanation is very weak. Ideally, there would be an explanation why the sensitivity decreases as SZA increases above 80 degress and a second explanation why the sensitivity increases for increasing SZA at small SZA.
Author: We partly agree with the referee in that we don't provide a really comprehensive bottom-up explanation of the observed dependencies. We would be glad if we were able to provide it, but we feel that our investigations do not provide enough insight to fully understand the underlying physics.

P407L17-18 I entered some reasonable values for the quantities in Eq. A2 and Eq. A5 and find 7% differences for I_N. Perhaps higher order terms of series need to be considered?
Author: Please bear in mind that we analyze the dependencies only qualitatively and we are not interested in the absolute values. For this purpose the approximation is sufficient.

P414L2-5 The assumption is not valid for ozone in the Chappuis band e.g. at mid-latitude tropopause tangent heights.
Author: Although the derivative of the triplet with respect to the cloud parameters has shown the same sign as the derivative of the solar radiation reflected by clouds in all test scenarios we have considered, it can be mathematically proven only if the above mentioned assumtion holds. For very large ozone concentrations the signs of the derivatives can be different and the sensitivity of the triplet to clouds can not be explained considering the intensity of the reflected solar radiation anymore. This is also added to the text.

4 Technical comments

Thanks, all comments included.