Authors' reply to comment of Omar Torres

We thank Omar for his interest in our manuscript, and for his useful comments.

Before we address the individual comments, we give a brief introduction on the most important changes compared to the original version.

1) MLER UVAI

Only recently we found out (initiated by the referee comments) that the so-called MLER cloud description, described in Ahmad et al. (2004), was used to improve the NASA's UVAI algorithm of TOMS in the update to version 7 (besides many other changes). Unfortunately, this information is not available from existing algorithm description documents and caused us to believe that the TOMS UVAI were still based on the LER assumption (like the operational UVAI from GOME, SCIAMACHY, and GOME-2). The application of the MLER concept for the calculation of UVAI constitutes an important improvement, especially for measurements in the presence of clouds: cloud effects on the UVAI are largely reduced. In the revised manuscript we include MLER UVAI and discuss the differences to the LER UVAI. One interesting finding is that although the cloud effects are reduced using the MLER concept, they are still not sufficiently corrected: in the presence of clouds (and absence of aerosols), MLER UVAI can still substantially deviate from zero. Also, like for LER UVAI, the MLER UVAI determined in the presence of clouds cannot be interpreted in a quantitative way, because they are not representative for the respective UVAI without the cloud influence.

2) Cloud correction for UVAI

As suggested by one of the reviewers, we investigated whether the effects of clouds and aerosols on the UVAI were additive. This was a very valuable suggestion, because it turned out that this is generally not the case! This finding had two important consequences:

a) cloudUVAI cannot be used to correct the cloud effect for satellite measurements also affected by aerosols. But it can still be used to test whether a measured UVAI in the presence of a cloud is caused by the cloud alone, or if there may be an additional effect from aerosols.

b) we developed a scheme for the quantitative correction of the measured UVAI in the presence of clouds, taking into account the simultaneously measured cloud properties (mainly the effective cloud fraction). Although this correction scheme is not perfect, we were able to derive more realistic UVAI for measurements with small effective cloud fraction than without that correction.

3) Simulations with a Mie model

In addition to Lambertian and Henyey-Greenstein (HG) cloud models, we also simulated cloud effects based on more realistic Mie models. While in general the results are similar to the results of the HG model, in specific cases substantial differences between Mie and HG cloud models occur caused by the different phase functions. These effects are systematically investigated and described in the revised version.

Detailed comments

The Henvey and Greenstain approximation is not an adequate model to represent scattering properties of clouds. The authors are aware of the inadequacy of the H-G phase function. In several parts of the manuscript the authors blame this deficiency as the possible reason why the obtained results are not as expected. Yet, in the manuscript they offer no justification for its use. The analysis presented here would more valuable if realistic representation of cloud microphysics was used for the radiative transfer analysis.

Author reply:
We agree with this comment. We have repeated the model calculations using more accurate phase functions from Mie calculations. We found that the differences between UVAI modelled using Mie or Henyey-Greenstein phase functions were not very large for nadir viewing geometry and small solar zenith angles, and our general conclusions were not affected. The results from the comparison of simulations with Henyey-Greenstein or Mie phase functions are presented and discussed in Section 3 of the revised manuscript.

The authors use the term 'CloudUVAI' to refer to the residue associated with the presence of clouds when the LER is used to explain the satellite-observed spectral spectral dependence of UV reflectance. CloudUVAI is a misnomer. Clouds are not aerosols. What the authors refer to as CloudUVAI is simply a residual quantity used as a measure of the success of the LER approximation to predict the observed spectral dependence using a simple approximation of the surface-atmosphere column[Torres et al, 1998; Herman et al., 1997]. The residue is zero when the LER adequately explain the observation. The term UVAI should only be used when the source of non-zero residues is the presence of aerosols. In all other instances the term 'residue' should be used.

Author reply:
We agree that the term "cloudUVAI" is strictly not correct, and we now mention this in the introduction. We nevertheless chose to stick with the term for lack of an alternative: we feel that using "UVAI" in some cases and "residue" in others will lead to confusion.

The theoretical definition of the AI in equations 2a and 2b ignores the fact that there is a level of noise associated with the measurements. In practice the rigid cutoff at zero does not apply. In fact most of the residue values the authors try to explain as physically meaningful fall in the range of the noise. The noise level depends on the presence of other geophysical non-aerosol-related sources of error as well as sensor calibration. Known calibrations issues of the SCIAMACHY sensor contribute to a larger noise level. The authors should clearly establish what the expected AI uncertainty associated with the sensor is. Based on calibration problems discussed elsewhere the quoted 0.2-0.3 range is not realistic.

Author reply:

Unfortunately, it is not possible to establish a fixed threshold above which UVAI values are significantly different from zero. The threshold not only depends on the measurement conditions (e.g. ocean colour or degree of polarisation) but also on instrumental or calibration uncertainties. However, for most measurement conditions, the measurement noise is not the limiting factor. We recognize the fact that UVAI, in particular the negative UVAI, can be biased by artifacts from various sources, such as the "geophysical non-aerosol-related sources" you mention. However, many of the effects we present are on the order of 1 UVAI unit, which is significantly larger than any such artifacts.
The given uncertainty range of 0.2-0.3 UVAI units is based on the effects of SCIAMACHY's calibration errors on UVAI. Its derivation is given in detail in (Penning de Vries et al., 2009).

When discussing the results in figure 1 (H-G phase function) to those of figure 2 (LER approximation) which shows the performance of the two approaches in predicting the observed spectral dependence, the authors conclude that the H-G parameterization is better. I do not understand the basis of their conclusion. The comparison of simulated residue shows that the LER approximation explains better the spectral dependence of the 'observations' (in this case the synthetic data). The LER yields lower residues and shows less angular dependence than the H-G. It also converges quickly to zero with cloud fraction. The H-G based calculations, on the other hand, show larger dependence to viewing geometry as well and dependence on the assumed asymmetry parameter. Thus, in the context of the residue concept, the LER is a better model than the H-G parameterization. Fig 1b also shows significant effect of g on thin clouds. The authors should refer to the work of Ahmad et al [2004, JGR] who evaluated the LER approximation. Ahmad et al [2004] used accurate Me calculations to compare the performance of the more rigorous model representation of cloud scattering effects in explaining the 340/380 ratio a parameter directly related to the residual quantity. They showed (by comparing to actual measurements) that the modified LER approximation (MLER, an approximation that represents the reflectance of clouds as the combination of two LER surfaces of low and high reflectivity), explained the TOMS observations under a variety of conditions. The more rigorous Mie-theory based approach was not better than the LER method in explaining the observations.

Author reply:
Thank you for this comment. It helped us to improve the manuscript by including a comparison of UVAI calculated using the MLER algorithm, and UVAI from our LER algorithm. As you say, MLER UVAI are generally less affected by small to moderate-sized clouds (in absence of aerosols). However, we did find significant deviations from 0 for large clouds (CF_{eff} > 0.7) on the order of 1 UVAI unit or more. Also, the effects of clouds on MLER UVAI in scenes containing aerosols are similar, if not identical, to those for LER UVAI. In conclusion, clouds should also be taken into account when MLER UVAI are studied.

In their literature review of AI applications the authors missed the most comprehensive use of near-UV observations for global aerosol characterization in terms of AOD and SSA derived based on the AI's information content [Torres et al, 2002, 2005, 2007].

Author reply:
We have added references to the literature you mention and to (Veihelmann et al., 2007) in the introduction.