Authors’ reply to comment of Anonymous Referee #2

We thank the referee for the constructive review of our paper.

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

1) MLER UVAI

The comments of this referee gave us the hint 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 this reviewer, 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) Símulations 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.

In setting this goal [to improve the observed AIs so that they can be used for more quantitative analysis and for extending the range of AI applications to the study of 'scattering' (weakly or non-absorbing) aerosols], the authors have made an implicit assumption: UV AI can be decomposed into cloud and aerosol components, and the sum of the two is equal to the total. But its validity has not been discussed or illustrated thus far. It is recommended that the authors to describe the physical basis for this assumption, and/or to provide case studies to illustrate its validity under various observing conditions, since it is not obvious that when both cloud and scattering aerosol are in the same IFOV, the observed AI would always become more negative comparing to cloud or aerosol alone.

Author reply:
This is an excellent and crucial observation that led to a complete re-writing of the part of the manuscript dealing with the correction of UVAI for the effects of clouds. As suspected by the referee, the effects of aerosols and clouds on UVAI are not independent and subtraction of cloudUVAI from UVAI of a scene containing aerosols and clouds does not yield the UVAI corresponding to the same aerosol scene in absence of clouds. In the new Section 5 of the revised manuscript we introduce a different method to correct UVAI for the effects of clouds, in which cloud parameters (mainly CF_{eff}) as well as aerosol properties (UVAI) are used as input. The physical basis for this measurement is given by model simulations with 640 different aerosol scenarios (new Figs. 11-12). Application of the new cloud-correction method to three months of SCIAMACHY data shows that the method works reasonably for pixels with small to moderate cloud fractions ($CF_{eff} < 0.25$).

Furthermore, even for the cases when UV AI is additive (i.e., the sum of the components equals to the whole), it is not clear that in practice the aerosol contribution can be separated from that of the clouds, in part because cloud parameters (especially the effective cloud fraction) used by the simplified cloud model for cloud AI calculation are likely affected by the presence of aerosols.

Author reply:
The quality of the cloud correction certainly depends on the quality of the input data, i.e., the measured cloud fraction. The cloud fraction is, however, not strongly influenced by the presence of aerosols, because it is determined in the red wavelength range (for HICRU) where the contribution of aerosols is generally small due to the spectral dependence of aerosol optical thickness. This is not the case for large particles (e.g., mineral dust) and for aerosol layers with very high optical thickness. We feel that such exceptional cases do not fall within the scope of the paper, and do not discuss them further here.

The bulk of the work presented in this paper is the comparison of modeled cloudUVAIs and those observed by SCIAMACHY. While the authors see agreements (in Figure 7) between modeled and measured AIs, this figure also reveals large biases (as large as half an AI unit even when effective cloud fraction is small) between the averages of measured *and two modeled AIs for the full range of effective cloud fractions and for the three solar zenith angle bins, implying that biases will be introduced into the AIs when correction is performed. This problem is likely due to unrealistic cloud model employed in this study. This observation is based on the conclusions reached in a previous work by Ahmad, Z., P. K. Bhartia, and N. Krotkov (2004) (Spectral properties of backscattered UV radiation in cloudy atmospheres, J. Geophys. Res., 109, D01201, doi:10.1029/2003JD003395), which has shown that the spectral dependence of cloudy observations can be very well modeled with Mie scattering clouds. In other words, the cloudUVAI can be modeled more accurately (with less bias) with a more realistic cloud model.*

Author reply:
In re-writing the manuscript, we have included simulations performed with Mie phase functions and compared them with simulations where Henyey-Greenstein phase functions were assumed. The differences were, however, found not to be very large for nadir viewing geometry and small solar zenith angles, and our general conclusions were not affected.
The results from simulations with various cloud models are presented and compared in Section 3 of the revised manuscript.

Another issue with this paper is the use of Lambert Equivalent Reflectivity (LER) model in deriving the observed AIs. The work by Ahmad et al. [2004] has shown that LER model in general could not reproduce the spectral dependence of UV radiances. This is the reason why large negative AIs are derived for cloudy observations using the LER model, as seen in the results presented in this paper. Correcting a large negative measured AI with a large negative modeled AI to extract a small signal of scattering aerosols does not seem to be an optimal approach to achieve the objective of this paper. I would recommend that the authors to look at a new scheme for cloudAI correction.
Specifically, Ahmad et al's work has also shown that the Mixed LER (MLER) model does a pretty decent job in reproducing the spectral dependence of cloudy observations, implying that using MLER model for AI computation would reduce the magnitude of the negative AI values associated with clouds. Note that NASA's AI products are computed using the MLER model, and the negative AI values associated with clouds are generally smaller than those presented in this paper. Therefore it may be worthwhile to derive the observed AIs using the MLER model, and to develop a scheme to correct the smaller negative AIs based on the derived effective cloud fraction.

Author reply:
The referee is thanked for this comment – it was not known to us that the NASA's UVAI algorithm differs from the LER algorithm, as this is not mentioned in the literature. In the revised manuscript we have included a comparison between the MLER and LER UVAI algorithms. We indeed found that MLER UVAI are generally less affected by small to moderate-sized clouds (in absence of aerosols). However, we also found significant deviations from 0 for large clouds ($CF_{eff} > 0.7$) on the order of 1 UVAI unit or more. In addition, the effects of clouds on MLER UVAI in scenes containing aerosols are similar, if not identical, to those for LER UVAI. In conclusion, clouds need also be taken into account when MLER UVAI are studied.

In summary, providing the physical basis for AI corrections and demonstrate that it can be achieved with limited cloud information, as well as improving the cloud model and investigating the merit of alternative AI computation scheme are recommended.

Author reply:
All these changes were implemented, as detailed above.